Abstract

This dissertation deals with the role of phonemic contrast in determining the featural content of phonological relations, and with the relation between phonemic and phonetic contrasts. Chapter one provides an introduction to the contrastivist hypothesis, which holds that phonological computation operates only on those features necessary to distinguish the phonemes of a language from one another, and argues that the Continuous Dichotomy Hypothesis of Dresher, Piggott, and Rice (1994) provides the best means of identifying features as contrastive or redundant. The next two chapters analyze data on voicing assimilation in Czech, Slovak, Polish, and Russian (chapter 2), and on vowel harmony in Yowlumne and Pulaar (chapter 3) that present particular challenges to the contrastivist hypothesis; here it is argued that although redundant features are sometimes crucially present in phonological representations, they do not need to be phonologically active. The data are analyzed using contrastive specifications supplemented by the novel device of prophylactic features, which are redundant features carrying information that is necessary for the Phonetic realization of segments, but not for the phonological computation itself. Along the way, comparisons are drawn with analyses that incorporate more detailed Phonetic information into the phonological representations, and the advantages of the underspecification approach are revealed. Chapter 4 considers the interaction
between phonemic contrast and phonetic distinctness in determining the shapes of phonological inventories. It offers a critical view of some phonetically-oriented approaches, and presents as an alternative a view in which abstract and minimal phonological representations of phonemic contrasts lead to phonetically distinct surface realizations through the synchronic mechanism of phonetic enhancement and the diachronic influence of the acquisition procedure. Finally, chapter 5 explores the degree to which contrastive specification is compatible with Optimality Theory (Prince and Smolensky 1993). Some of the insights of the contrastivist hypothesis can be maintained in Optimality Theory through the translation of a contrastive feature hierarchy into a constraint ranking, but contrastive specification is ultimately at odds with the Optimality Theoretic principle of Richness of the Base and the assumptions that underlie it. The main points of the dissertation are summarized in chapter 6.
Many people have helped to incubate such eggs as have successfully hatched in this dissertation, and I would like to acknowledge here their contributions to the necessary temperature. If any parts of this thesis have failed to come to poultrition, it is surely not for want of warmth, and the fault in such cases is mine for having supplied rocks in place of fertile ova. Still, one can always hope that any such warmed-over pebbles may yet become the foundation of a hearty batch of stone soup to be cooked up in future research. (And even typos may have their uses, as witness the fifteenth-century Polish legal scribe mentioned on page 79.)

Foremost among the incubators, of course, is my supervisor, Elan Dresher, or, as he is known to his colleagues in the departmental band, the Maestro. His work on contrast has supplied the inspiration and the theoretical basis for the ideas that I have pursued in this thesis, and his counsel and encouragement have made it possible for me to write it. Furthermore, his intellectual delight in wrestling with tricky conceptual problems is infectious, and has made our discussions about this dissertation, and about phonology in general, not only fruitful but a great deal of fun. During my career as a graduate student, I have also had the good fortune to play music with Elan, and to serve with him on SGS Council, and I feel that I have learned a great deal from him not only as a linguist, but also as an academic more generally, and as a musician. In all his various roles, he is above all else a mensch.

Of the members of my supervisory committee, Keren Rice has the distinction of having been involved with this dissertation the longest, for my work on Czech voicing assimilation, which forms the core of chapter 2, had its first beginnings as a paper written for her intermediate phonology course. Keren saw before I did how those early ideas might
develop into something more mature and substantial, and I am grateful to her for all that she has done to help them get there.

Anyone who is surprised to see the name of a syntactician on the supervisory committee for a dissertation in phonology does not know Elizabeth Cowper very well. She has a truly impressive ability to see almost immediately the consequences of any sufficiently clearly stated theoretical proposal, and as a non-phonologist, she has a licence to ask the sorts of ‘naïve’ questions that force one to examine and justify one’s assumptions. In addition, our joint work on morphosyntactic feature geometry has given me a larger theoretical context for some of the questions addressed in this dissertation, and her moral support and high editorial standards played an important role in how, and how well, it got written.

I am also very grateful to Peter Avery, of York University, and Sharon Inkelas, of the University of California, Berkeley, for agreeing to read this dissertation and to serve on the examination committee. Each of them has published work that has had an important influence on how I think about phonology, and it was a great pleasure and privilege to talk with them at the defence; their comments there will be an important source of inspiration in my future work. (I am also grateful to Sharon for providing me with the more recent version of her work on archiphonemic underspecification, and to Peter for rides to the CLA, Jewel notwithstanding.)

Many other people who have taught me over the years have had an important influence, direct or indirect, on the eventual production of this document. I would like in particular to thank Ed Burstynsky, Philip Hamilton, and Mirco Ghini, who taught me in LIN 100 and got me hooked on linguistics in the first place; Veronika Ambros, who introduced me to the Prague School, raised my standards of scholarly rigour, and also provided some of the Czech data in chapter 2; Peter Reich, who aided my transformation into a graduate student and a Macintosh user; Diane Massam, who as graduate coordinator helped me get through the apparently inevitable crisis of
confidence that afflicts students in November of their M.A. year; Jack Chambers, whose encouragement resulted in my first refereed publication; Bill Idsardi, who, as a visiting professor, supervised my generals paper in phonology and gave me an excuse to revisit my first home in Toronto; and Alana Johns, who has been a continual source of interesting discussion, database-engineering gigs, and hospitality.

One very important part of my life in the Department of Linguistics has been F-Zero, the departmental band.¹ I’d like to thank everyone in our current lineup (the Maestro on guitar, harmonica, recorders, accordion, banjitar, spoons, and bonhomme gigueur; Elizabeth Cowper on keyboard, guitar, and recorder; Michael Szamosi on percussion; Christina Kramer on clarinet and saxophone; Manami Hirayama on flute; Bridget Jankowski on French horn; and Sarah Clarke on violin), and also everyone who has played with us in the past (too numerous to list here), for a lot of convivial music-making that has helped to keep me sane (or at least happy) over the years and given me something to say when people ask what I do besides linguistics.

To be a graduate student in linguistics at the University of Toronto is to be a member of a wonderfully collegial cohort that is more than the sum of its parts, which is saying a lot. I am grateful to everyone who has been part of this magical group in my time here, and in particular to Susana Béjar, my M.A.-year twin, who has always been a wonderful person with whom to talk about linguistics, play music, or go hat-shopping in the desert; to Chiara Frigeni, for inviting me to collaborate on her work on Shona, and for being the Beatrice (or Virgil, depending on your point of view) who guided my first steps into the realm of \LaTeX{} (a tool without which this dissertation would have been a nightmare to format); to David Bennett, who was my mentor in my first year as a graduate student; to Jean Balcaen, Naomi Cull, and Do-Hee (“Not Carl”) Jung for helpful discussion of Yowlumne; and to Sara Mackenzie for sharing her work

¹. For the record, the ambiguity between $F_0$ (fundamental frequency) and $F^0$ (head of a Focus projection) is deliberate.
on Luo and Nez Perce. I would also like to thank all the members of the phonology group and the syntax group for providing two especially good environments in which to share ideas.

Finally, I would like to express my deep and abiding gratitude to my family. It would be facile, but not false, to say that I learned to care about language from my mother, Carolyn Park Currie, who is an editor and a translator, and that I learned argumentation from my father, John T. Hall, who is a lawyer and an actor; the fact is that I have learned both of these things from each of them, and a great deal more besides. I am also very grateful to my sister and first student, Kathleen Currie Hall—I don’t think I can reasonably take credit for the fact that Kathleen is also doing a Ph.D. in phonology, but I certainly do take heart from it. A close relative with whom one can talk shop is capable of providing a variety of moral support that goes beyond what can be expected of family members who are not colleagues or colleagues who are not family, and it’s hard to imagine a greater spur to completing a thesis than a brilliant younger sibling nipping at one’s heels.
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CHAPTER ONE

Introduction

Understanding is made greater by contrast.
Aristotle, Rhetoric

The purpose of this thesis is to address two questions:

1. Can adequate phonological representations be constructed on the basis of phonemic contrasts alone? and

2. What is the relation between phonological and phonetic contrast?

The answer to the first of these questions appears, as of this writing, to be “Not quite.” Despite arguments against underspecification advanced by, for example, Calabrese (1995) and Steriade (1995), the approach to contrastive specification set out by Dresher, Piggott, and Rice (1994) and elaborated by Dresher (1998a, 1998b, 2003) has had considerable success in accounting for data from a variety of languages, including Cantonese (Barrie 2002, 2003; Barrie, Cowper, and Hall 2006); Old English (Béjar 1999; Moulton 2003); Yowlumne (D’Arcy 2003, 2004; Hall 2004b); Chamorro, Hixkaryana, Nyangumarda, Kirgiz, Turkish, Finnish, Hungarian, Mongolian, and Uyghur (D’Arcy
Chapter 1. Introduction

2004); Campidanian Sardinian and Latin (Frigeni 2003, 2005); Shona (Frigeni and Hall 2003); Czech, Slovak, and Polish (Hall 1998, 2003); Pulaar (Hall 2000); Tongan, Niuean, Hawaiian, Māori, and Tahitian (Herd 2005); Japanese (Hirayama 2003, 2005); Nez Perce (Mackenzie 2002; Mackenzie and Dresher 2003); Anywa, Luo, and Bumo Izon (Mackenzie 2005); Québécois French (Mercado 2002); Latvian (Vilks 2003); Manchu and related languages (Zhang 1996; Dresher and Zhang (in press); D’Arcy 2004); and Oroqen (Zhang 1996; D’Arcy 2004). However, Hall (2002) points out that while feature specifications assigned by Dresher’s Successive Division Algorithm can successfully predict which Czech consonants will undergo voicing assimilation and which ones will trigger it, the specifications make incorrect predictions about the phonetic results of the assimilation. As discussed in chapter 2, this problem can be solved by a minimal retreat from purely contrastive specification: features that are contrastive in one part of the Czech consonant inventory are specified prophylactically on a segment on which they are phonologically redundant, but these prophylactic features are invisible to phonological computation. This dissertation will examine other cases where redundant features may be necessary, and test the hypothesis that even when such features are crucially present in phonology, they are never phonologically active.

The second question is one that has attracted considerable attention in recent work (e.g., Flemming 1995, Kirchner 1997, Steriade 1997, Boersma 2000, Padgett 2003, inter alia), much of which is based on the premise that phonological computation makes detailed reference to the phonetic characteristics of surface forms. According to this view, the robust phonetic realization of underlying contrasts is an explicit goal of phonological derivations, and it is achieved imperfectly only because it is in frequent conflict with another phonetic goal, namely the minimization of articulatory effort. I will argue that the tendency to maximize phonetic distinctness can be accounted for in the context of a more abstract theory of phonological representations, and in a way that does not require the grammar to make any explicit comparisons of the phonetic distinctness of
sets of output segments. Instead, distinctness arises synchronically through phonetic enhancement of underlying contrastive feature specifications, and diachronically through the mechanisms of language acquisition.

The structure of this dissertation is as follows: The remainder of this chapter addresses the question of what information is encoded in phonological representations, and discusses some relevant features of the Successive Division Algorithm. Chapter 2 shows how the algorithm can be applied to the problem of Slavic voicing assimilation, and makes the case for the prophylactic specification of redundant features. Chapter 3 explores possible cases of prophylactic features in other languages, namely Yokuts and Pulaar. Chapter 4 deals with the relation between phonetic and phonemic contrast, providing a critical evaluation of dispersion theory (Liljencrants and Lindblom 1972) and a discussion of the roles of feature economy (Clements 2003) and robustness (Clements 2004) in determining the shapes of phonological inventories. Chapter 5 evaluates the formal and empirical consequences of combining contrastive specification with Optimality Theory.

1.1 On cats and dogs, and queer vowels

1.1.1 Irrelevant aspects of sense and sound

It is well known that speakers’ knowledge about linguistic expressions routinely extends beyond the properties of those expressions that are relevant to any given component of grammar. One obvious instance of this phenomenon is the fact that much of what a speaker knows about the meaning of a word is entirely irrelevant not only to the syn-
tactic properties of that word, but also to its behaviour in those areas of semantics that lend themselves to formal explanation. “For example,” writes Marantz (1995: 3), “the semantic difference between *dog* and *cat* drives no syntactic or compositional semantic principle, rule, or constraint; thus, whatever feature of *dog* that distinguishes *dog* from *cat* would not be a feature of Lexical items.” For the purposes of most formal semanticists, the meanings of the words *cat* and *dog* are as shown in (1):

\[
\begin{align*}
(1) & \quad a. \quad [\text{cat}] &= \lambda x . \text{CAT}(x) \\
& \quad b. \quad [\text{dog}] &= \lambda x . \text{DOG}(x)
\end{align*}
\]

In other words, all the semantic component of the grammar need know about either of these words is that it is a one-place predicate; for the purposes of computing agreement, the syntactic component may need to know that each of these forms is a singular noun that is [+animate] but [−human]. Attempting to decompose or further define the functions $\text{CAT}(x)$ and $\text{DOG}(x)$ would lead one into the question of whether to do so on the basis of the ‘symptoms’ (*sensu* Wittgenstein 1958) by which people typically recognize objects in the world as belonging to the categories ‘cat’ or ‘dog’ (e.g., length of tail, shape of muzzle, barking or meowing), or on the basis of the criteria by which a zoologist would assign animals to the families Felidae or Canidae. This is not a question for formal semantics, although the definition of the functions $\text{CAT}(x)$ and $\text{DOG}(x)$ obviously has an effect on the truth conditions of sentences whose denotations contain these functions.

In declining to elaborate the representations in (1), we can make a useful distinction between **featural** and **non-featural** meaning (following the terminology of Hall 2001). The featural meaning of a word comprises those aspects of its semantics that can be encoded in discrete formal expressions that lend themselves to Fregean composition or other comparable forms of calculation. Its non-featural meaning is everything else—information that might be represented in terms of encyclopedia entries, prototypes, three-dimensional models, or fuzzy sets. So, for example, the English past tense suffix
-ed bears purely featural meaning, expressible as [+past] or ‘prior to a specified reference time,’ while an expression such as long ago has, in addition to the meaning of ‘prior to a specified reference time,’ a non-featural expression of degree that cannot be formally quantified. (See also Jackendoff (1990: 32–33) on the limits of featural semantic representations and what may lie beyond them.)

Similarly, there is ample evidence that speakers have conscious or unconscious knowledge of considerably more information about speech sounds than is employed in formal phonology. Research on language variation has shown that listeners often use phonologically non-contrastive criteria in distinguishing speech associated with a particular region, register, or social group. To take a recent example, Rogers, Smyth, and Jacobs (2002) show that in Canadian English, subtle variations in acoustic vowel reduction may serve as a cue by which listeners recognize ‘gay-sounding’ speech (a robustly recognized accent which is stereotypically attributed to gay men, but which is not necessarily correlated with the actual sexual orientation of the speaker). Acoustic vowel reduction is, by definition, not phonological: Rogers, Smyth, and Jacobs (2002: 167), following van Bergem (1993), define it as “the phonetic phenomenon which occurs when the speaker intends to produce a full vowel, but for some reason does not fully attain the target.” The difference between a pair of vowels such as [i] and [i], then, lies entirely outside the phonological component of the grammar: phonetically, it is the result of different implementations of the same phonological surface form, but it is sociolinguistically significant as a marker of the gay-sounding lect. A listener perceiving one or the other of these sounds must abstract away from the difference between them in order to recognize the phoneme /i/, but may at the same time register the choice of variant on another level and use it in formulating ideas about the speaker. Like the semantic difference between cat and dog, the acoustic difference between [i] and [i] is irrelevant to the core computational component of grammar, even though it is demonstrably meaningful to some other facet of human cognition that deals with non-categorical, non-featural information.
1.1.2 Phonetics as phonology

These facts are worth reviewing partly because of a recent trend in phonology towards functional phonetic explanations of phonological phenomena. This approach, exemplified by, among others, Steriade (1997), Kirchner (1997), Flemming (1995, 2001), and Boersma (1998, 2000), seeks to characterize phonological processes as the consequence of antagonism between articulatory and auditory desiderata: ease of articulation is pitted against ease of perception. This conflict is generally represented in the framework of Optimality Theory (Prince and Smolensky 1993), and intuitively it is a natural correlate of the formal opposition in Optimality Theory between markedness constraints (which penalize marked surface representations) and faithfulness constraints (which mandate the preservation of underlying material). The phonology-as-phonetics school attributes functional motivations to these constraints: markedness constraints penalize surface forms that are difficult to say or hear, while faithfulness constraints aim to ensure that the listener will be able to reconstruct the underlying form. In this approach, constraints are universal because they are grounded in auditory and articulatory reality, and languages differ one from another only in how they resolve such conflicts as arise among the goals the constraints represent.

However, there are conceptual and empirical problems inherent in the attempt to reduce phonology to phonetics, and even in the apparently natural pairing of this approach with the formalism of Optimality Theory. In their efforts to make a phonological grammar sensitive to the non-categorical phenomena of phonetics, researchers have proposed various augmentations to the standard apparatus of Optimality Theory, including non-categorical constraint rankings (Boersma 1998; Boersma and Hayes 1999), constraint families that penalize a continuum of values (Flemming 1995; Boersma 1998; Boersma 2000), and weighted constraints (Flemming 2001). Some of these devices have the effect of raising to infinity the number of constraints, the number of possible constraint rankings, or both. All have the effect of characterizing categorical phonological phenomena
as accidental extreme cases at the edges of various phonetic continua, rather than as the consequences of discrete phonological computations.

For example, Boersma (1998, 2000) represents the conflict between ease of articulation and ease of perception in the articulation of the vowel /a/ as the conflict between two interleaved families of constraints. Ease of articulation is enforced by the constraints *Jaw(≥ 4 cm), *Jaw(≥ 3 cm), *Jaw(≥ 2 cm), and so on, which penalize the effort involved in lowering the jaw to a specified degree. The perceptual side of the competition is represented by the “acoustical faithfulness constraints” F1(|a|) ≥ 600 Hz, F1(|a|) ≥ 700 Hz, F1(|a|) ≥ 800 Hz, and so on, which mandate that the phonological lowness of the vowel be acoustically manifest in a first formant of a specified frequency. In fact, the constraint families are at least ten times as fine-grained as these examples would suggest, since the optimal output turns out to involve a jaw height of 2.3 cm and a first formant at 760 Hz, and in principle (if not in Boersma’s tableaux), each family is as numerous as the set of real numbers.

This infinity of constraints does not necessarily make the grammar unlearnable, because the ranking of constraints within a family may be assumed to be determined universally by the Elsewhere Principle. Yet even if the proliferation of constraints is not disastrous, neither is it particularly beneficial. Setting aside the matter of interspeaker variation, even for an individual speaker there is no single optimum F1 for [a], or even for [a] in a given phonological environment; there is always variability. Nor is there a single optimal jaw height; a speaker holding a pen between clenched teeth can produce an entirely intelligible [a] without having to go through a period of trial and error to rerank the constraints concerning the relative merits of controlling F1 by means of the jaw muscles as opposed to the tongue muscles (or, for that matter, to promote *DropPen).

The response to these objections is that the model does acknowledge the existence of variability; in fact, it predicts it. In Boersma’s approach, even the grammar of an adult speaker is not static. Continuous constraints are continuously being reranked along a
continuum of non-categorical rankings, and so the optimal combination of jaw height and F1 can never be stated categorically; rather, it can only be characterized in the stochastic terms in which a physicist might speak of the position and velocity of an electron. But this is precisely why it is not useful to build an ostensibly phonological grammar that is capable of making such fine-grained predictions in the first place: the distinction between an [a] with an F1 of 750 Hz and an [a] with an F1 of 760 Hz is not categorical because it is no more relevant to phonology than the distinction between cat and dog is to syntax. Moreover, it is unnecessary to use the abstract, formal tools of phonology to construct a fine-grained grammar of phonetic variants, because such variants can already be accounted for by the coarse-grained operation of the physical organs of speech production. Human motor control is imperfect; this fact exists quite independently of its relevance to phonetics, and there is no need to derive the resulting variability in the articulation of speech sounds from a model of the phonological component of the human language faculty. To suggest that phonological grammars make reference to the minutiae of phonetic production is to propose an unnecessary duplication of explanation; the variation in the height of an [a] is overdetermined if it is made to follow from phonological constraint interaction as well as from the fallibility of the vocal apparatus.1

1.3 From phonetics to phonology

What, then, is the purpose of integrating phonology and phonetics into a single grammar? The goal of this approach seems to be to account for the fact that phonological and phonetic processes are “strikingly similar” (Flemming 2001: 7), or, to put it another way, that the phonological processes attested in language are in some sense phonetically natural. However, it is possible to maintain the position that phonology is categorical and abstract without being at all surprised by the resemblance between, for instance,

1. The discussion in this paragraph owes much to conversations and classes with Bill Idsardi.
phonological assimilation rules and phonetic coarticulation effects. All that is required is a diachronic perspective on the interaction between phonetics and phonology: a phonetic phenomenon in the speech of one generation of speakers is construed by members of the next generation as evidence of a phonological generalization. This process is precisely analogous to the morphosyntactic process of grammaticalization, by which a word is gradually bleached of its non-featural content, its presence becoming subject to the requirements of the syntax rather than to nuances of connotation. For example, Guerts (2000: 781–2) summarizes as follows the steps by which the French word *pas* ‘step’ became a syntactically obligatory marker of negation:

Initially, negation in French was expressed by the particle *ne* […], which preceded the verb […]. In the context of motion verbs *ne* was optionally reinforced by the substantive *pas* ‘step’ […]. In due course, *pas* shed its connotation of movement and was reanalyzed as being party to a discontinuous negative construction […]. Finally, in present-day colloquial French, *pas* has come to be seen as the fulcrum of negation, and *ne* has been demoted to an optional element.

Such examples of syntactic grammaticalization have long been known and noted; for example, John Horne Tooke (1786) attempted to show that all words, and especially function words, which he described as “abbreviations,” are etymologically derived from members of the two “necessary” lexical classes of verb and noun.

The corresponding phonological development is also well attested. Jakobson (1929) writes of the phonologization of contrasts, whereby two previously allophonic variants become separate phonemes; one may also usefully speak of the phonologization
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of a process, in which a phonetically conditioned variation in the articulation of a sound is reinterpreted as an alternation resulting from a phonological rule.²

Along these lines, Ohala (2001: 49) identifies four stages by which a variation in sound can progress from one level of the grammar to another, and gives examples of alternations which are phonetically similar to one another, but which are governed by different levels (see also the Evolutionary Phonology of Blevins and Garrett (2004) and Blevins (2004a, 2006)). In the first, the phonetic stage, the alternations are “due purely to mechanical phonetic factors of the sounds involved”; for example, [t] tends to have a noisier release before [i] than before other vowels. In the second stage, the alternations have become phonologized, as in the case of Japanese, where /t/ is systematically affricated before /i/. The alternation in Japanese between [t] and [tc] is thus “due to the identity of the sounds involved, not their phonetic properties.” The third stage is morphological: the alternations become properties of morphemes rather than of phonemes, as exemplified by the contrast between the English nominalizing suffix -y in words like democracy, which changes the final consonant of the base to which it is attached, and the English diminutive suffix -y as in Ricky, which does not. The fourth and final stage is the lexical stage, in which the variants have become part of the set of arbitrary sound differences that distinguish different words; Ohala’s example of this is the pair of cognates cool and chill.

Ohala does not assume the existence of a Universal Grammar, but we may adopt something very much like his view of grammaticalization in a theory that does. A phonetic alternation passes from the first stage to the second when the learner fails to ‘correct’ for it and reconstruct the uniform phonological surface representation behind the acoustic variants. The learner therefore takes these variants to be evidence of differing surface forms, and generalizes a phonological rule to account for it, the ability to formulate such

². Here and in the immediately following discussion, any reference to phonological rules applies equally (mutatis mutandis) to the effects of phonological constraint rankings in a framework such as Optimality Theory.
rules being governed by UG. Once it has become part of the phonology, the rule will apply wherever its structural description is met, and the alternation may thus come to occur even in environments where it is not phonetically motivated. As Idsardi (1999: 3) puts it, “once a phonetic process has been modelled as phonological, it will be subject to pressures of simplicity in the phonology”—that is, it is likely to change in the direction of formal elegance rather than articulatory convenience. Even if it does not undergo formal simplification, its new status will be reflected in its categorical application: it will not be prevented from applying by extralinguistic articulatory factors. To revisit a previous scenario, a newly phonologized process of vowel lowering conditioned by adjacency to a pharyngeal consonant will not be overruled if a speaker attempts to pronounce the syllable /\text{\textipa{\textepsilon}}/ = [\text{\textalpha}] while holding a pen between the teeth, even if the muscular requirements of supporting the pen erase whatever coarticulatory advantage is to be gained by lowering the vowel.

The apparent functional naturalness of at least some phonological processes can thus be understood diachronically, on the basis of their origins in phonetic phenomena.\footnote{Of course, not all diachronic developments in the phonology of a language are due to the phonologization of phonetic processes; it is also possible for phonological change to be driven from within the phonology by structural pressures (see, e.g., Idsardi 1997a; Idsardi 1999). Phonologized rules can also become ‘denaturalized’ in a variety of ways (Hyman 1975: 173–8).}

What remains to be explained is the generality, abstractness, and opacity observed in the application of these phonologized processes, and the explanation lies not in articulation or audition, but in cognition (Kaye 1989; van der Hulst 2003). The question to ask is, what is the code in which phonological rules and representations are expressed?

This code need not, and thus by Occam’s razor should not, duplicate phonetic information that is already physically encoded in the mechanisms of production and perception.\footnote{This point is made quite emphatically by Hale and Reiss (2000).} Constraints along the lines of Steriade’s (1997) CONTEXTCues(F) (i.e., disallow the feature value [F] in positions where contextual cues to [F] are absent) or Boersma’s (2000) \texttt{\textup{REPLACE}}([a], /ɛ/, ≥ 30%) (i.e., disallow any realization of [a] that...}
will be misheard as /ɛ/ (30% of the time or more) arguably hold phonological processes too close to their origins, implying that these processes will apply only where they are still phonetically motivated, and that phonological computations have access to quite detailed information about the auditory consequences of their output. What is needed is a theory that limits the granularity of phonological formalism in such a way that it produces categorical phenomena systematically, rather than as accidental outliers at the edges of a phonetic continuum.

Theories of this sort have existed in various forms for a long time, some owing their discrete character to theoretical considerations, others perhaps to their formulators’ lack of access to spectrographic equipment. The challenge these theories now face, which is posed in part by the rise of phonetically based alternatives, is to come up with a principled way of determining what information phonological computation may refer to and what information it may not refer to. The task is made all the more challenging by the fact alluded to above: speakers’ knowledge of speech sounds extends beyond the information that can be shown to be relevant to grammar. In other words, not all sub-phonological (or rather extra-phonological) variation is “due purely to mechanical phonetic factors”—some of it is sociolinguistically conditioned. Furthermore, Hall (2002) argues on the basis of data from Czech voicing assimilation that there are some cases in which information not relevant to the phonological component of the grammar is crucially present during, but inaccessible to, phonological computation. This information, encoded in what Hall (2002) terms prophylactic features, cannot be referred to by any phonological rule or constraint, but serves to prevent phonological processes from neutralizing an underlying phonemic contrast.

The purpose of this thesis, then, is to address the question of what information must be represented in phonology, and how. I will adopt a version of contrastive specification based on the Successive Division Algorithm (which ensures the contrastive status of specified features by using them to divide sets of phonemes), show how it is
complemented by the restricted role of phonologically redundant features, and explore the consequences of applying this approach to rule-based and constraint-based theories of generative phonology. The result should be an improved understanding of what differences matter in phonology, and what differences are as irrelevant as the difference between cats and dogs.

1.2 Underspecification and contrast

The problem of what information is and is not relevant to phonology, although it has been brought into sharper relief by the rise of phonetically based theories, is not a new one. All theories of grammar that posit a more or less distinct phonological module necessarily assume, explicitly or implicitly, some form of underspecification. In order to explain systematic commonalities in the phonological behaviour of certain sets of segments, a theory of phonology must employ features that will categorically define natural classes, and this requires abstracting away from at least some phonetic detail.

1.2.1 The content of phonological features

Phonological features therefore generally represent phonetic characteristics, viewed at a suitable level of granularity. As is frequently noted in the literature (see for example Hyman 1975: 30–32), features may refer either to the properties of the sounds themselves or to the means of their production. For example, Jakobson, Fant, and Halle (1952) use auditory features such as [grave], [compact], and [strident]. Articulatory features, such as [coronal], [low], [advanced tongue root], or [delayed release], are more frequently used and have a longer history. Many phonologists have followed the precedent set by Chomsky and Halle (1968: 299), who describe distinctive features in primarily articulatory terms, but consider the acoustic and perceptual correlates of a feature to be of equal importance with its articulatory correlates. In some cases, alternative features have been proposed
that differ in sense but not in reference: thus in many phonemic inventories, Jakobson, Fant, and Halle’s auditory feature [grave], Rice’s (1995) articulatory feature [peripheral], and Flemming’s acoustic feature [low F2] will refer to the same or nearly the same set of segments, even though they pick out that set by means of different characteristics.

A few features are significantly ambiguous. For example, if [sonorant] is construed as an articulatory feature referring to the openness of the vocal tract, then /h/ is [+sonorant], but if it is construed as an auditory or acoustic feature referring to the presence of audible low-frequency energy, then /h/ is [−sonorant]. Alternatively, [sonorant] might be characterized as a purely phonological feature, in which case phonetically similar segments might have different values for [sonorant] in different languages. (See, for example, the use of the feature [SV] by Avery (1996).) Values for other purely phonological features can vary not only from language to language, but also from context to context. For example, Chomsky and Halle (1968) use the feature [syllabic] to indicate whether a segment serves as the nucleus of a syllable, so that /u/ and /i/ and /n/ are [+syllabic], while /w/ and /j/ and /n/ are [−syllabic]. However, in a theory that allows for richer representations of suprasegmental prosodic structure, such information can be encoded as a dependency relation (following Pike and Pike 1947), as in (2), rather than as a featural property of a segment. In the terminology of Prince and Smolensky (1993), the difference between [u] and [w] or [i] and [j] lies in whether the segment is parsed as a peak or as a margin.

\[
\text{(2) a. } \text{we'd} = /\text{wid}/ = /\text{u}i\text{d}/ \quad \text{b. } \text{you'd} = /\text{jud}/ = /\text{i}u\text{d}/
\]

\[
\begin{array}{c}
\text{O} \\
\text{|} \\
\text{R} \\
\text{|} \\
\text{N} \\
\text{|} \\
\text{C} \\
\text{|} \\
\text{u} \\
\end{array}
\quad \quad \quad
\begin{array}{c}
\text{O} \\
\text{|} \\
\text{R} \\
\text{|} \\
\text{N} \\
\text{|} \\
\text{C} \\
\text{|} \\
\text{u} \\
\end{array}
\]

\[
\text{σ}
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\[
\begin{array}{c}
\text{σ}
\end{array}
\]

\[
\begin{array}{c}
\text{σ}
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\begin{array}{c}
\text{σ}
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\begin{array}{c}
\text{σ}
\end{array}
\]
To the extent that there is reason to prefer articulatory features to auditory ones or vice versa, the relevant evidence comes from the interface between phonology and phonetics. Reich (1976) argues on the basis of various coarticulatory phenomena that the phonological features that serve as input to phonetic implementation take the form of instructions to begin particular articulations. For example, the segment /n/ consists of the (ordered) instructions ⟨No, Ac, Gv⟩, indicating that the nasal cavity is to be opened at the velum (No), the apex of the tongue is to form a closure (Ac), and the glottis is to be set to produce voicing (Gv). Most of Reich’s features represent actions without inherent endpoints, and so they tend to continue until the active articulator involved receives a countervailing instruction. In a sequence such as gnat /næt/, the velum is lowered for the /n/ and remains lowered into the /æ/, which contains no instructions concerning the velic aperture, but is raised for the /t/, which carries the instruction Nc (velic closure). The /æ/ is thus realized as partially nasal, but it is not nasalized throughout, because Nc precedes Ac in the articulatory instructions that make up the featural representation of /t/. More recently, the theory of Gestural Phonology (Browman and Goldstein 1986; Browman and Goldstein 1989) uses articulatory gestures as the basis of a phonological feature geometry.

On the other hand, Guenther et al. (1999) offer evidence that phonetic implementation can use different articulations to achieve a single auditory or acoustic target (see also Ladefoged 2005). They compared the acoustic and articulatory properties of American English /ʌ/ as produced by seven native speakers in the nonsense words /waɹəv/, /waɹɜæv/, /waɹˈæv/, /waɹəv/, /waɹəv/, and /waɹəv/. Their results showed considerable interspeaker and intraspeaker variation in articulation, with tongue shapes ranging along a continuum from a canonical retroflex [ɹ] to a canonical bunched [ɾ]. These disparate articulations, however, had quite consistent acoustic consequences: they generated the lowering of F3 that is the primary acoustic cue for English /ʌ/. With one exception—subject 2’s utterances of /wadəv/—all elicited versions of /ʌ/ had F3 minima well below
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2000 Hz (Guenther et al. 1999: 2859). Guenther et al. hypothesize that the various articulations of /æ/ involve trading relations among three different ways of lowering F3: increased constriction length, increased front cavity length, and decreased constriction area. While the acoustic target remains constant, the implementation varies according to the articulatory context: /waŋav/ favours a bunched [ɻ], with a tongue position closer to [g], while /wadav/ favours a retroflex [ɾ], with a tongue position closer to [d].

Such evidence in favour of acoustic targets does not necessarily contradict the basic insight of articulatorily based approaches such as Reich’s. For one thing, not all acoustic targets allow for as much articulatory variation as is permitted in the implementation of ‘lower F3.’ So, for example, if we change the meaning of the feature No from ‘open the nasal cavity’ to ‘add a supplementary source of resonance,’ the way to implement the instruction will still be to lower the velum. The same interactions among gestures will take place regardless of whether the instructions from the phonology are stated in articulatory or acoustic terms. In Reich’s stratificational framework, ‘features’ such as No or Ac are ultimately nothing more than labels attached to wires; to the extent that these features can be said to mean anything, what they mean is whatever happens when a signal passes through the relevant wire. At some point in the network, a wire labelled ‘lower F3’ will reach a disjunction and split into two wires labelled ‘make a laminoalveolar approximant’ and ‘make a retroflex approximant.’ For wires that do not split, there may be no basis for deciding whether the labels should refer to articulatory instructions or to acoustic ones.

A similar observation also applies to models which, unlike the stratificational approach, treat phonology as a discrete module, separate from other components of the grammar. Even if phonological computation is a black box whose internal structure is completely different from that of phonetic implementation, and which communicates with the latter only at a closely circumscribed featural interface, it may not be necessary, desirable, or even possible to attach specific phonetic meaning to the features at the
interface. The phonological component does not need to know whether the features it is manipulating refer to gestures or to sounds, just as the syntactic component does not need to know whether the words it is manipulating refer to dogs or to cats; it only needs to know that the features define segments and classes of segments. The phonetic component does not need to be told whether the features refer to gestures or to sounds, because it is itself the mechanism by which the features are converted into both gestures and sounds. So it does not matter whether a feature at the interface is called [peripheral], [grave], or [low F2], because the phonological component cannot differentiate among these alternatives, and the phonetic component will realize any one of them as all three.

In light of this, phonological features might not need names at all; for the purposes of describing the phonology of any given language, it would be possible to use arbitrarily numbered features $\pm 1$, $\pm 2$, $\pm 3$, and so on (cf. Kiparsky [1968] 1982: 120). However, the phonetic content of phonological features has played a crucial role in attempts to state crosslinguistic generalizations as universal constraints on phonological rules, representations, and inventories. If it is not possible to identify phonetic criteria for determining whether some feature in Language A is the same as a feature in Language B, then such constraints are difficult to formulate and test. Some such constraints, however, are matters of phonetic or even logical necessity, and will be respected even if they cannot be explicitly stated. For example, *[+high, +low] will emerge as a universal pattern even if the feature value that means ‘high tongue position’ is [+4] in one language and [+17] in another: if any language’s phonological component submits contradictory instructions to phonetic implementation, those instructions cannot be followed, no matter how they are encoded.

Other generalizations are less trivial. For example, Jakobson, Fant, and Halle (1952: 31) use the feature [+flat] to distinguish labialized or pharyngealized consonants from their [−flat] plain counterparts. Since a single auditory feature is used for the two different secondary articulations, Jakobson, Fant, and Halle’s feature system pre-
dicts that while languages may contrast either labialized /Č\textit{w}/ or pharyngealized /Č\textit{q}/ with plain /Č/, no language can make a phonemic distinction between /Č\textit{w}/ and /Č\textit{q}/. Their claim that labialization and pharyngealization are merely two realizations of the same feature is supported not only by the absence of attested languages with a contrast between the two kinds of [+flat] consonants, but also by evidence from borrowing: for example, in words borrowed from Arabic into Uzbek, the Arabic contrast between /Č\textit{q}/ and /Č/ is mapped onto the Uzbek contrast between /Č\textit{w}/ and /Č/. A more abstract account of the crosslinguistic absence of a contrast between /Č\textit{w}/ and /Č\textit{q}/ might refer to the representational complexity of secondary articulations, rather than relying on the universality of [±flat]. However, the relevant formal restriction would be difficult to formulate in wholly non-phonetic terms, because contrasts can exist between other secondary articulations—for instance, velarized /Č\textit{v}/ and palatalized /Č\textit{j}/ contrast with each other and with plain /Č/ in Scots Gaelic. If the impossibility of contrasting /Č\textit{w}/ and /Č\textit{q}/ is to be encoded in Universal Grammar, this suggests that UG must have at least some phonetic content.

However, it is not obvious that it is UG that is responsible for the crosslinguistic absence of /Č\textit{w}/–/Č\textit{q}/ contrasts. Even if UG does not specifically prohibit a contrast between labialization and pharyngealization, such a contrast, if it happened to develop in some language, would be diachronically unstable because of the auditory similarity between the two secondary articulations. Successive generations of learners might be expected either to fail to hear the contrast, in which case it would quickly become neutralized, or else to reinforce it by altering its phonetic realization; for example, the pharyngealized consonants might develop into an ejective series, or the labialized ones might trigger harmonic rounding of adjacent vowels. Furthermore, research on the phonology of sign languages suggests that the phonetic content of phonological universals either is quite abstract or else must be stated conditionally: in order to preserve even the simple generalization that all languages allow syllables of the form CV, we must either adopt
abstract definitions of the terms *consonant* and *vowel*, or else introduce a disjunction into the generalization to make its predictions contingent on modality. On the basis of considerations similar to these, Mielke (2004) makes a detailed case against the notion of innate phonological features, and proposes instead that features are an emergent abstraction.

This thesis will employ phonological features with phonetic names, for the sake of convention and convenience, not only in the formulation of phonological rules in individual languages, but also in the description of crosslinguistic generalizations. Even if it turns out that all phonological generalizations with phonetic content can be explained by the phonetic impossibility or diachronic instability of counterexemplification, phonological features and feature geometries are a useful and concise way of representing these generalizations. As long as such representations are not made out to be what they are not, they make an effective shorthand for various phenomena that are not yet fully understood, regardless of whether those phenomena ultimately turn out to be cognitive or phonetic. What we refer to as Universal Grammar is likely, especially when we are talking about the properties that make a human child a language acquisition device, to be a combination of facts about the mind and facts about the body. For example, Jakobson and Halle (1956) describe a universal hierarchy that determines the order in which children acquire phonemic contrasts; while it is certainly the mind that organizes these contrasts into a phonological system, it is probably the mouth and the ear that dictate that the child will distinguish /a/ from /u/ before learning the difference between /a/ and /æ/. To capture generalizations like Jakobson and Halle’s, it is sometimes convenient to write about a universal, partially ordered set of phonological features as if it is an object in the mind. In this thesis, then, which is primarily concerned with mental representations, feature names such as [voice], [low], and [peripheral] will be used for

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5. See, for example, Brentari (1995: §2.1.2) for a brief overview of various approaches to the syllable structure of American Sign Language, and Mielke (2004: §1.5.2) for further discussion of the implications of sign languages for distinctive feature theory.
their familiarity, and to reflect in a general way their phonetic correlates in the languages under discussion. Their precise phonetic content, however, is not crucial here, nor are the questions of whether that content is universal or language-specific and whether the features themselves are innate or emergent.

1.2.2 The Contrastivist Hypothesis

What do features crucially encode, then? At the phonology-phonetics interface, they must encode enough information to allow the phonetic component to realize distinct phonological surface forms distinctly. Within the phonological component, they must serve to distinguish which segments do and do not undergo any given phonological process. In lexical representations, they must be able to distinguish the members of a language’s phonemic inventory. In other words, as the possibility of using arbitrary numbers as features implies, phonological features minimally encode relations of difference and sameness. The notion that features encode contrast is central to many theories of linguistic representations, notably including those of Saussure (1916), Trubetzkoy (1939), Jakobson and Halle (1956), and Dresher (1998a, 1998b, 2003). If phonology operates on something less than fully detailed phonetic representations, contrastiveness is the logical criterion for determining what information should or should not be included.

Typically, theories of contrastive specification have been based on those contrasts that are found at the level of underlying representations. The contrastivist hypothesis may thus be stated as in (3):

(3) **Contrastivist Hypothesis:**

The phonological component of a language L operates only on those features which are necessary to distinguish the phonemes of L from one another.

The apparent simplicity of this hypothesis disappears in the face of the question of how to determine whether any given feature is necessary (contrastive) or unnecessary
(redundant) in distinguishing the phonemes of L. The need for explicit definitions of contrast and redundancy is pointed out by Dresher (2003), who surveys a number of definitions implicit in previous research.

1.2.3 The minimal pairs test

For example, Trubetzkoy (1939) considers a feature value to be contrastive for a given phoneme “if there is another phoneme in the language that is identical except for that feature” (Dresher 2003: 48). Thus the feature [voice] will be contrastive for the segments /t/ and /d/ whenever they are separate phonemes in the inventory of any language, because they are alike in place and manner of articulation, and can be distinguished from each other only by their voicing. The feature [nasal] will be contrastive on /d/ and /n/, which are identical in place, continuancy, and voicing. However, unless the inventory contains a voiceless coronal nasal /n̥/, [−nasal] will not be contrastive on /t/, and [+voice] will not be contrastive on /n/. This is illustrated in (4).

(4) a. Minimal-pair contrastive specifications for /t, d, n/

<table>
<thead>
<tr>
<th></th>
<th>t</th>
<th>d</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>voice</td>
<td>−</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>nasal</td>
<td>−</td>
<td>+</td>
<td></td>
</tr>
</tbody>
</table>

b. Minimal-pair contrastive specifications for /t, d, n, n̥/

<table>
<thead>
<tr>
<th></th>
<th>t</th>
<th>d</th>
<th>n</th>
<th>n̥</th>
</tr>
</thead>
<tbody>
<tr>
<td>voice</td>
<td>−</td>
<td>+</td>
<td>+</td>
<td>−</td>
</tr>
<tr>
<td>nasal</td>
<td>−</td>
<td>−</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

6. Dresher (2003: 48) refers to this as “extraction via minimal pairs,” and points out the use of similar approaches by Jakobson (1949) and Martinet (1964). Archangeli (1988) formulates an explicit algorithm for winnowing down a set of full specifications to those deemed contrastive by this test, and uses its failings as an argument for preferring Radical Underspecification (on which see §1.2.4) to this form of contrastive specification.
In (4a), there is no segment that differs from /t/ only in nasality, nor from /n/ only in voicing; in (4b), /n/ matches both those descriptions, and so both [voice] and [nasal] are contrastive for all four segments.

Dresher (2003) points out a problem with the minimal pairs approach which can be illustrated by considering the simple and widely attested vowel inventory /i, a, u/. Full specifications of these segments for four features are shown in (5).

(5) Full binary specifications for /i, a, u/

<table>
<thead>
<tr>
<th></th>
<th>i</th>
<th>a</th>
<th>u</th>
</tr>
</thead>
<tbody>
<tr>
<td>high</td>
<td>+</td>
<td>−</td>
<td>+</td>
</tr>
<tr>
<td>low</td>
<td>−</td>
<td>+</td>
<td>−</td>
</tr>
<tr>
<td>back</td>
<td>−</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>round</td>
<td>−</td>
<td>−</td>
<td>+</td>
</tr>
</tbody>
</table>

By the minimal pairs test, no feature value is contrastive for any of these segments, because there are no minimal pairs. Any two segments that differ in value for one feature have different values for at least one other feature as well. As a result, adopting the hypothesis that redundant features are unspecified has the disastrous effect of making it impossible to distinguish any phoneme from another, so long as redundancy is defined by the minimal pairs test. The obvious problem is that there are too many features. If contrastive feature specifications are supposed to be the minimal specifications required to distinguish the phonemes in an inventory, then four binary features are too many to be contrastive for the inventory in (5); distinguishing three items requires only two features. The question is, which two?

Of the six possible answers to this question, only one is clearly unacceptable. The three segments cannot be contrasted using only the features [high] and [low], because these features would fail to distinguish /i/ from /u/. For any segment in the inventory, the value for either of these features can be predicted from the value of the other by the rule [α low] ↔ [−α high]. Since the inventory has only a two-way height contrast, it
is redundant to use more than one height feature. Eliminating this redundancy is not difficult, but the minimal pairs test itself offers no way of pruning surplus features.

Given any other pair of features than [high] and [low], the minimal pairs test will identify some specifications as contrastive and others as redundant. Considering the various possibilities reveals further limitations of the test beyond its inability to arrive at any of them from a larger set of features. The feature values identified as contrastive in each of the five cases are shown in (6).

(6) Minimal-pair contrastive specifications for /i, a, u/

a. \[ \begin{array}{ccc} \text{high} & + & \text{−} \\
      \text{back} & \text{−} & + \end{array} \]

b. \[ \begin{array}{ccc} \text{high} & + & \text{−} \\
      \text{round} & + & \text{−} \end{array} \]

c. \[ \begin{array}{ccc} \text{low} & \text{−} & + \\
      \text{back} & \text{−} & + \end{array} \]

d. \[ \begin{array}{ccc} \text{low} & \text{−} & + \\
      \text{round} & + & \text{−} \end{array} \]

e. \[ \begin{array}{ccc} \text{round} & \text{−} & + \\
      \text{back} & \text{−} & + \end{array} \]

In each possible set of specifications, there is one segment with two contrastive feature values, and in each table in (6), this segment is shown between the other two. The segments on either side of it have one redundant (and thus unspecified) feature value each,
and in each case, these redundant feature values are the same as the middle segment’s contrastive value for the same feature. For example, in (6a), /u/ is contrastively [+high] and [+back]; /i/ is redundantly [+high], while /a/ is redundantly [+back]. A feature value is always contrastive if it applies to exactly one of the three segments, which leads to the following generalizations:

- If [round] is in the feature set, [+round] is contrastive on /u/.
- If [low] is in the feature set, [+low] is contrastive on /a/.
- If [high] is in the feature set, [−high] is contrastive on /a/.
- If [back] is in the feature set, [−back] is contrastive on /i/.

Conversely, if a feature value applies to exactly two of the three segments, then the minimal pairs test will deem it contrastive on one of them and redundant on the other. (Feature values that apply to none of the segments, such as [+consonantal] in this example, or to all of them, such as [+vocalic], are consistently and unproblematically judged redundant.)

If the redundant values are unspecified in the phonology, then there must be some rule or rules, applying at the end of the phonological computation, to fill in the missing values by default. For example, if the feature system is as shown in (6c), these redundancy rules will be as in (7).

(7) Redundancy rules for (6c)

a. [0 low] → [−low]

b. [0 back] → [+back]

1.2.4 Radical Underspecification

In every case, the set of values filled in by the redundancy rules will be coextensive with the set of contrastive feature specifications on the most highly specified segment.
According to the minimal pairs test, [−low] is contrastive on /u/ in (6c) because it is the only feature value that distinguishes /u/ from /a/, and [+back] is contrastive on /u/ because it is all that distinguishes /u/ from /i/. Yet if there are redundancy rules that will fill in these values, is it not redundant to specify them on /u/? By amending the minimal pairs test so as to take full advantage of the redundancy rules that will be necessary anyway, we can replace (6c) with the further reduced set of specifications in (8), with the possibly interesting consequence that the most-specified segment in (6c), /u/, is now completely unspecified.

(8) Specifications from (6c), revised in light of (7)

i  u  a
  low  +
  back  −

These specifications are precisely those predicted by the theory of Radical Underspecification (Archangeli 1988; Archangeli and Pulleyblank 1994), in which feature values are underlyingly unspecified if and only if they are filled in by redundancy rules. However, Radical Underspecification does not adhere to the Contrastivist Hypothesis as stated in (3). Under the approach of Archangeli and Pulleyblank, redundant values are absent from underlying representations, but not from the phonological computation: “predictable values are inserted by rule during the course of the derivation” (Archangeli 1988: 192; emphasis added). Because redundancy rules are interspersed among other phonological rules, Radical Underspecification predicts that redundant feature values will be unavailable to some rules, but available to others. Any given redundant value will be invisible to all rules that apply before it is filled in (potentially all phonological rules), and visible to all rules that apply after it is filled in (again, potentially all phonological rules). The difference between Radical Underspecification and contrastive specification as defined in (3) is summarized in (9).
(9) Contrastive specification and Radical Underspecification

\[
\begin{array}{|c|c|c|}
\hline
\text{Contrastive:} & \text{always present} & \text{Redundant values} \\
\hline
\text{Radical:} & \text{always present} & \text{absent and/or present} \\
\hline
\end{array}
\]

1.2.5 The Distinctness Condition

As Dresher (2003: 50–51) observes, the specifications selected as contrastive by the minimal pairs test do not satisfy the Distinctness Condition of Halle (1959), quoted in (10).

(10) Distinctness Condition (Halle 1959: 32):

Segment-type \{A\} will be said to be different from segment-type \{B\}, if and only if at least one feature which is phonemic in both, has a different value in \{A\} than in \{B\}; i.e., plus in the former and minus in the latter, or vice versa.

The effect of the Distinctness Condition is to prevent the absence of a positive or negative value from being used contrastively: two phonemes are not adequately differentiated, according to this condition, unless the feature specifications of one are logically incompatible with those of the other (cf. Frisch 1996: chapter 2). In (6c), /i/ and /a/ are not different from each other in Halle’s sense. Since /i/ is specified only as [−back] and /a/ only as [+low], the two sets of specifications could just as easily be two different descriptions of a single phoneme /æ/ as two different phonemes. The situation in (8) is even worse: no two phonemes are distinct. The entire inventory could be /æ/.

If we abandon the Distinctness Condition and permit the contrastive use of zero values, then we arrive at a system of ternary features, and new possibilities present themselves. Under these assumptions it is possible to differentiate the members of a three-vowel inventory using a single feature, as in (11).

(11) Ternary feature specifications for /i, a, u/

\[
i \quad a \quad u
\]

peripheral \quad − \quad 0 \quad +
1.2. Underspecification and contrast

Since the feature [peripheral] means, essentially, ‘back and/or round,’ it is not unreasonable from an articulatory point of view to characterize /i/, which is [−back, −round], as [−peripheral], /u/, which is [+back, +round], as [+peripheral], and /a/, which is [+back, −round], as [0 peripheral]. The minimal pairs test will judge all the specifications in (11) to be contrastive, since each vowel differs from the others only in one feature. However, this new possibility is not particularly helpful, since the minimal pairs test still provides no way of deciding which feature ought to be used in the first place. Furthermore, a ternary feature system applied to a four- or five-segment inventory in combination with the minimal pairs test could produce the same kinds of underspecification as a binary feature system applied to a three-segment inventory, and would then require a version of the Distinctness Condition (in which not only + and −, but also + and 0, and − and 0, would count as ‘different’ specifications, but none of +, −, and 0 would be distinct from the absence of a value) to prevent it from turning into a quaternary system. Allowing the valency of the features to expand unrestrictedly would of course be counterproductive; if every segment is a different value of the same feature, then segments are primitives of the theory, and there is no reason for having features at all.

1.2.6 Privative features

A potentially more elegant alternative would be to adopt privative features, in which case the Distinctness Condition is simply irrelevant. In a privative feature system, only the presence or absence of a feature is contrastive; there are no positive and negative values. Such a system allows for feature specifications that are minimal in the same way as those in (8), but which nonetheless adequately contrast all phonemes without implicitly permitting ternarity. Using privative versions of the features in (6d) results in the systems shown in (12).
Privative specifications for /i, a, u/, based on (6d)

\[
\begin{array}{c}
\underline{u} & \underline{i} & \underline{a} \\
\text{round} & \text{low} \\
\end{array}
\]

In (12), full specification, contrastive specification, and minimal specification are equivalent. The only rounded vowel, /u/, is specified as [round]; the only low vowel, /a/, is specified as [low]. Each of these specifications is contrastive, because it distinguishes the segment on which it appears from /i/, which is neither round nor low.

This pair of privative features is a particularly good one for the inventory /i, a, u/, because in the binary version in (6d), all redundant feature values are negative values. Since adopting privative features entails eliminating negative values, converting (6d) to a privative system has the same effect as underspecifying all feature values that either (a) are deemed redundant by the minimal pairs test, or (b) are deemed contrastive, but would be supplied by the redundancy rules if they were left out anyway. Other combinations of features, however, do not permit such a happy alliance between privativity and the minimal pairs test. Privative versions of the systems in (6) are shown in (13), with redundant feature specifications in parentheses.

\[
\begin{array}{c}
\underline{a}. & \underline{i} & \underline{u} & \underline{a} \\
\text{(high)} & \text{high} & \text{back} \\
\text{(back)} \\
\end{array}
\]

\[
\begin{array}{c}
\underline{b}. & \underline{u} & \underline{i} & \underline{a} \\
\text{(high)} & \text{high} & \text{round} \\
\end{array}
\]

\[
\begin{array}{c}
\underline{c}. & \underline{i} & \underline{u} & \underline{a} \\
\text{low} & \text{back} \\
\text{(back)} \\
\end{array}
\]

\[
\begin{array}{c}
\underline{d}. & \underline{u} & \underline{i} & \underline{a} \\
\text{round} & \text{low} \\
\end{array}
\]
The system in (13d), repeated from (12), is the only one in which no marked features are deemed redundant by the minimal pairs test. In (13a), underspecification of redundant values is disastrous: the [high] on /i/ and the [back] on /a/ are both redundant, but underspecifying them would leave no way of distinguishing the two segments. This is a consequence of the fact that in the binary version in (6d), all redundant feature values are positive values. Converting the system to a privative one eliminates the contrastive negative values. The other three possibilities in (13b), (13c), and (13e) all correspond to binary systems in which one redundant value is negative and one positive. Contrastive specification in these cases produces sets of specifications in which a feature may be absent from a segment for either of two reasons: because it does not apply to that segment (as [high] does not apply to /a/ in (13b)), or because it does not contrast that segment from a minimally different segment (as [high] does not contrast /u/ from a minimally different segment in (13b)). In each of these systems, the redundant feature can be filled in by a default rule that makes reference to the other marked feature in the system. Redundancy rules for the systems in (13) are listed in (14).

(14) Redundancy rules for (13)

a. No redundancy rules are possible.

b. [round] → [high]

c. [low] → [back]

d. No redundancy rules are necessary.

e. [round] → [back]
Of the five systems in (13), four are tractable, and one of these, (13d), is particularly elegant. Unfortunately, the minimal pairs test is incapable of arriving at any of them given the full set of specifications in (15), which is a privative version of (5).

(15) Full privative feature specifications for /i, a, u/

<table>
<thead>
<tr>
<th></th>
<th>i</th>
<th>a</th>
<th>u</th>
</tr>
</thead>
<tbody>
<tr>
<td>high</td>
<td>high</td>
<td></td>
<td></td>
</tr>
<tr>
<td>low</td>
<td></td>
<td>back</td>
<td>back</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>round</td>
</tr>
</tbody>
</table>

In (15), as in (5), there are no pairs of segments that differ by only one feature, and so the minimal pairs test would judge all features to be redundant.

### 1.2.7 The Successive Division Algorithm

The minimal pairs test, then, is useless as a basis for contrastive specification unless it is supplemented by some means of selecting which features to use. The Successive Division Algorithm (SDA) (Dresher, Piggott, and Rice 1994; Dresher 1998a; Dresher 1998b; Dresher 2003) provides a mechanism for selecting features, and at the same time renders the minimal pairs test itself redundant. A version of this algorithm that uses privative features is shown in (16).\(^7\)

---

7. Dresher (1998a) uses privative features and refers to the algorithm as the Successive Binary Algorithm (SBA). Dresher (2003) presents a more general version with \( n \)-ary features, and calls it the Successive Division Algorithm. The SBA is simply a special case of the SDA; it is binary because privative features make binary divisions. An earlier version of the algorithm is presented by Dresher, Piggott, and Rice (1994) as the Continuous Dichotomy Hypothesis.
1.2. Underspecification and contrast

(16) **Successive Division Algorithm**

(privative version, adapted from Dresher (1998a)):

1. The input to the algorithm is an inventory (I) of one or more segments that are not yet featurally distinct from one another.

2. If I is found to contain more than one phoneme, then it is divided into two (non-empty) subinventories: a marked set M, to which is assigned a feature [F], and its unmarked complement set \( \overline{M} \).

3. M and \( \overline{M} \) are then treated as the input to the algorithm; the process continues until all phonemes are featurally distinct, which is trivially the case when I contains only one phoneme.

The SDA can be viewed as an acquisition algorithm that describes how a language learner builds phonological representations by discovering phonemic distinctions and using features to mark them. It can also be viewed more abstractly as a restriction on feature specifications. All feature specifications assigned by the SDA are contrastive, in that they all contribute non-redundantly to the process by which the members of the phonemic inventory I are distinguished from one another. This does not, however, guarantee that every feature assigned to a segment by the algorithm will be unpredictable from the other features on that segment, nor does it guarantee that the features assigned by the SDA will be deemed contrastive by the minimal pairs test. As we have seen, however, there are many cases in which it would be impossible to distinguish the segments in an inventory using only feature specifications that the minimal pairs test would consider contrastive.

One property particular to the privative version of the SDA is that the representations it generates for any inventory will always include one completely unmarked segment. In the initial stage, no features have been assigned; the input inventory is then divided into a marked set and an unmarked set. If there is only one phoneme in the unmarked set, that phoneme is sufficiently distinct from all the other members of the inventory, and no features need be assigned to it. If the unmarked set contains more than one phoneme, then it becomes the input to the algorithm, and as the steps are re-
peated, the unmarked set continues to be divided until there is only one fully unspecified segment.

An example of how the SDA works is given in (17), which shows one way in which the algorithm might divide and specify the inventory /i, e, a, u/. The steps taken by the algorithm are enumerated in (17a); the features assigned are diagrammed in (17b) as lines dividing the vowel space, and in (17c) as a tree showing the hierarchy of contrasts. In the tree in (17c), the features assigned to any phoneme (or any subinventory) can be found by tracing the most direct path to that phoneme (or subinventory) from the root node.

(17)  a. Dividing the inventory /i, e, a, u/

1. Input I = \{i, e, a, u\}
2. [low] divides I into M = \{a\} and \bar{M} = \{i, e, u\}
3. M cannot be divided further.
4. \bar{M} is submitted to the algorithm as I.
   4.1. Input I = \{i, e, u\}
   4.2. [high] divides I into M = \{i, u\} and \bar{M} = \{e\}
   4.3. M is submitted to the algorithm as I.
   4.3.1. Input I = \{i, u\}
   4.3.2. [back] divides I into M = \{u\} and \bar{M} = \{i\}
   4.3.3. M cannot be divided further.
   4.3.4. \bar{M} cannot be divided further.
4.4. \bar{M} cannot be divided further.

b. Feature specifications assigned by (17a)

<table>
<thead>
<tr>
<th></th>
<th>[back]</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>u</td>
</tr>
<tr>
<td>[high]</td>
<td></td>
</tr>
<tr>
<td>e</td>
<td>a</td>
</tr>
<tr>
<td>[low]</td>
<td></td>
</tr>
</tbody>
</table>
c. Feature hierarchy generated by (17a)

In this example, the one completely unspecified segment is /e/. The feature [back] is not specified on /a/ because once /a/ has been specified as [low], it is in a class by itself, and there is no need for the algorithm to assign any further features to it. In other words, the contrast between low and non-low vowels has wider scope than the contrast between back and non-back vowels.

The idea that contrasts have varying scope is central to the SDA. In the systems defined by the algorithm, features are contrastive or redundant not in an absolute sense, but only relative to a particular domain. For example, in (17) the feature [back] is contrastive only in the domain of high vowels. If the divisions were made in a different order, with [back] dividing the inventory before [high] or [low], the algorithm could derive a set of feature specifications in which [back] is contrastive over the whole inventory, as in (18). Given this ordering, [back] and [high] suffice to distinguish all four segments, and so [low] is not assigned to /a/ by the SDA.

(18)  

a. Feature specifications with [back] taking wide scope
b. Feature hierarchy with [back] > [high]

```
{\text{i, e, a, u}}

[\text{back}] \quad \emptyset
```

Because the algorithm does not specify the order in which features are to be used to make divisions, it allows for the fact that phonetically similar segments may behave differently in the phonologies of different languages. In the examples we have just seen, the SDA predicts that an inventory such as /i, e, a, u/ may be treated by the phonology as being either asymmetrical (as in (17)) or symmetrical (as in (18)), depending on the relative scope of the contrasts. In (17), /a/ emerges as a [low] vowel unspecified for place, while in (18) /a/ is specified for [back].

In principle, the number of possible orders of divisions grows extremely rapidly as the inventory to which the SDA is applied expands. If the order of divisions within each subinventory is independent of the other subinventories (i.e., if it is possible, for example, for [back] to take scope over [round] among the low vowels while [round] takes scope over [back] among the high vowels), then the number of possible orders of divisions when the SDA is applied to a set of \( n \) features to specify \( 2^n \) segments can be defined recursively as a function \( f(n) = n \cdot f^2(n - 1) \), with \( f(1) = 1 \). The values produced by this function for \( n \leq 6 \) are shown in Table 1.1.\(^8\)

This does not mean, however, that the algorithm generates vast numbers of different feature specifications for any given inventory. The figures in Table 1.1 are based on an idealized situation in which the divisions made by the algorithm define perfectly symmetrical binary-branching trees. Phonological inventories generally are not perfectly symmetrical; in a typical inventory, the division with the highest scope separates the seg-

---

\(^8\) These values constitute sequence number A052129 in the On-Line Encyclopedia of Integer Sequences (Sloane 2006), and are used in the definition of Somos’s quadratic recurrence constant \( \sigma \) (Weisstein 2006).
1.2. Underspecification and contrast

Table 1.1: Inventory size and number of possible sequences of divisions as functions of the number of features

<table>
<thead>
<tr>
<th>$n$ (features)</th>
<th>$2^n$ (segments)</th>
<th>$f(n)$ (orders of divisions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>576</td>
</tr>
<tr>
<td>5</td>
<td>32</td>
<td>1658880</td>
</tr>
<tr>
<td>6</td>
<td>64</td>
<td>16511297126400</td>
</tr>
</tbody>
</table>

Table 1.1: Inventory size and number of possible sequences of divisions as functions of the number of features

ments into two unequal subinventories, the larger of which comprises the consonants and the smaller the vowels. Furthermore, many of the features used to differentiate the segments within one of these subsets cannot be used at all in distinguishing the members of the other—for example, the feature [continuant] can be used to divide a typical consonant inventory, but not a typical vowel inventory. Because of the inherent phonetic asymmetry of most inventories, features do not cross-classify perfectly, and so the differentiation of an inventory of $2^n$ segments is likely to involve more than $n$ features. Finally, it is worth noting that in the ideal cases in Table 1.1, where features do cross-classify perfectly and all possible feature combinations are attested, no feature specifications are redundant. If six features are used to specify an inventory of 64 segments, then all 16 511 297 126 400 possible sequences of divisions will yield exactly the same results.

There may also be restrictions extrinsic to the algorithm itself that limit the number of possible orders in which features may be used to make divisions. For example, if the acquisition sequence described by Jakobson and Halle (1956) is indeed universal, and determined either by the relative phonetic salience of the contrasts or by some formal stipulation in UG, then the order of divisions in the SDA should be determined in the same way. Dyck (1995) offers evidence from Romance languages for a universal
partial ordering of contrasts along these lines. Both Hall (1998) and Mercado (2002) have put forward the idea that divisions based on contrasting phonological behaviour should take precedence over divisions based on wholly passive paradigmatic contrasts. That is, divisions made by assigning features that are demonstrably active in the phonology have higher scope than divisions made on the basis of evidence from minimal pairs. Also, Béjar (1998) proposes that the assignment of a marked feature value to a set of segments by the SDA should be constrained both by universal feature geometry and by formal properties of the set being divided. In §4.3.3, we will return to the possibility of constraining the order of divisions, in particular by requiring that all subinventories within a system follow the same hierarchy (which would reduce the number of possible sequences of divisions to $n!$) and by adopting some version of Clements’s (2004) principle of robustness as a further restriction on that hierarchy.

As mentioned at the beginning of this chapter, the SDA has been successfully applied to data from several different languages. The next two chapters deal with cases in which redundant features appear to play a crucial role—but one that, I argue, can be strictly limited.
Voicing assimilation and prophylactic features

Neutrinos, they are very small.
They have no charge and have no mass
And do not interact at all.

JOHN UPDIKE, “Cosmic Gall”

Voicing assimilation in Slavic languages provides evidence for the proposal that only phonemically contrastive features are active in the phonology, but that redundant features must sometimes be present and inactive. This chapter shows how voicing assimilation patterns found in Czech, Russian, Slovak, and Polish can be generated using the Successive Division Algorithm in combination with laryngeal features proposed by Avery (1996). Although the account of voicing assimilation offered by the proposed representations is quite elegant, the assumption that non-contrastive features are entirely absent from the phonological representations results in some surprising incorrect predictions. As we shall see, a segment that is crucially underspecified for the purpose of predicting

its voicing behaviour must be prophylactically specified for redundant place and manner features in order to prevent voicing assimilation from becoming total assimilation.

2.1 The basic pattern of Czech voicing assimilation

As in many other Slavic languages, obstruents in Czech exhibit both voicing assimilation and final devoicing. The phonemic consonant inventory of Czech is shown in Table 2.1, with orthographic forms indicated in angle brackets where they differ from the IPA symbols.

<table>
<thead>
<tr>
<th>MANNER</th>
<th>VOICING</th>
<th>PLACE</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>bilabial/</td>
<td>dental/</td>
<td>palatal/</td>
<td>velar/</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>labiodental</td>
<td>alveolar</td>
<td>postalveolar</td>
<td>glottal</td>
<td></td>
</tr>
<tr>
<td>STOP</td>
<td>voiceless</td>
<td>p</td>
<td>t</td>
<td>c ⟨t’⟩</td>
<td>k</td>
<td></td>
</tr>
<tr>
<td></td>
<td>voiced</td>
<td>b</td>
<td>d</td>
<td>j ⟨d’⟩</td>
<td>g</td>
<td></td>
</tr>
<tr>
<td>AFFRICATE</td>
<td>voiceless</td>
<td>ts ⟨c⟩</td>
<td>ř ⟨č⟩</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRIcATIVE</td>
<td>voiceless</td>
<td>f</td>
<td>s</td>
<td>ř ⟨š⟩</td>
<td>x ⟨ch⟩</td>
<td></td>
</tr>
<tr>
<td></td>
<td>voiced</td>
<td>v</td>
<td>z</td>
<td>ř ⟨ž⟩</td>
<td>ři ⟨h⟩</td>
<td></td>
</tr>
<tr>
<td>NASAL</td>
<td>voiced</td>
<td>m</td>
<td>n</td>
<td>ři ⟨ř⟩</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRILL</td>
<td>voiced</td>
<td>r</td>
<td>ři ⟨ř⟩</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LATERAL</td>
<td>voiced</td>
<td>l</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLIDE</td>
<td>voiced</td>
<td></td>
<td></td>
<td>j</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2.1: The phonemic consonant inventory of Czech

The two segments that display anomalous voicing behaviour are the trilled fricative /ř/ and the labiodental fricative /v/. The former consists of a laminal trill /r/ and a postalveolar fricative /ʒ/ articulated simultaneously or in close succession. It can
be heard, for example, in the proper name *Dvořák* /ˈdvɔːrək/.\(^2\) Czech /v/, although it is historically derived from an approximant */w/, is phonetically very short and very close; Palková (1994) and Kučera (1961) both describe it as stoplike. This property is not shared by its voiceless counterpart /f/. As discussed below in §2.2, /v/ and /r/ occupy a position intermediate between sonorants and obstruents with respect to voicing assimilation.

At the surface, all or nearly all Czech obstruent clusters agree in voicing. (The exceptions involve dialect variation in the behaviour of /v/, discussed in §2.2.) This pattern is shown in (19).\(^3\)

(19) Voicing agreement in Czech obstruent clusters

a. *hezká* [ˈfieskaː] ‘pretty (fem. nom. sg.)’
b. *kde* [ɡde] ‘where’
c. *léčba* [ˈleːtsba] ‘cure’
d. *vstal* [(f)stal] ‘he got up’
e. *lec+kdo* [ˈledzɡdo] ‘several people’
f. *lec+který* [ˈletskteriː] ‘many a (masc. nom. sg.)’

Consonant clusters containing sonorants may contain voiced or voiceless obstruents, as in the examples in (20), but not both.

(20) Clusters with sonorants

a. *prát* [ˈprat] ‘to beat’
b. *brát* [ˈbraːt] ‘to take’
c. *stroj* [stroj] ‘machine’
d. *zdroj* [zdroj] ‘source’
e. *délba* [ˈjelba] ‘division’
f. *délka* [ˈdeːlka] ‘length’
g. *msta* [msta] ‘vengeance’
h. *mzda* [mzda] ‘wages’

\(^2\) Johannes Brahms, in a letter of December 1877 to the publisher Fritz Simrock, made a typical attempt at representing the /r/ sound; he wrote: “Bei Gelegenheit des Staatsstipendiums freue ich mich schon mehrere Jahre über Sachen von Anton Dvořák (spr. Dvorschak) aus Prag” (Brahms 1917).

\(^3\) The Czech data in this chapter are drawn from Kučera (1961), Hála (1962), de Bray (1969), Townsend (1990), Palková (1994), Poldauf et al. (1994), and V. Ambros (p.c.).
However, obstruents on opposite sides of a syllabic sonorant need not agree in voicing, as shown in (21).

(21) No obligatory voicing agreement across syllabic sonorants
   a. hlt [filt] 'gulp (nom. sg.)'
   b. krbem ['křbem] 'fireplace (inst. sg.)'
   c. zrcadlo ['zr̩sadlo] 'mirror (nom. sg.)'

Word-final obstruents and obstruent clusters are consistently voiceless, including those that can be seen from alternations to be underlyingly voiced; this is shown in (22).

(22) Final obstruent devoicing
   a. muž [muʃ] 'man' (nom. sg.)
   b. mužem ['muʒem] 'man' (inst. sg.)
   c. myš [miʃ] 'mouse' (nom. sg.)
   d. myši ['miʃi] 'mouse' (inst.sg.)
   e. hrad [firat] 'castle' (nom. sg.)
   f. hradem ['firadem] 'castle' (inst. sg.)
   g. robot ['robot] 'robot’ (nom. sg.)
   h. robotem ['robotem] ‘robot’ (inst. sg.)
   i. hvozd [fivost] ‘deep forest’ (nom. sg.)
   j. hvozdem ['fivozdem] ‘deep forest’ (inst. sg.)
   k. host [fiost] ‘guest’ (nom. sg.)
   l. hostem ['fiostem] ‘guest’ (inst. sg.)

The voicing agreement illustrated in (19) appears to be produced by a process of regressive assimilation that involves both voicing and devoicing. This can be seen in the alternations exhibited by the prepositions s/s/ ‘with’ and z/z/ ‘from.’ Before sonorants, each of these prepositions surfaces in what we may infer to be its underlying form, as shown in (23).
2.1. The basic pattern of Czech voicing assimilation

(23) Realization of $s$ and $z$ before sonorants
   a. $s$ lesem ['slesem] ‘with a forest’
   b. $z$ lesa ['zlesa] ‘from a forest’
   c. $s$ mužem ['smužem] ‘with a man’
   d. $z$ muže ['zmuže] ‘from a man’

Obstruent-initial words, however, trigger assimilation of $s$ and $z$, as shown in (24). Before voiced obstruents (24a–d), both /s/ and /z/ surface as [z]; before voiceless obstruents (24e–h), both surface as [s].

(24) Realization of $s$ and $z$ before obstruents
   a. $s$ domem ['zdomem] ‘with a house’
   b. $z$ domu ['zdomu] ‘from a house’
   c. $s$ hradem ['zhradem] ‘with a castle’
   d. $z$ hradu ['zhradu] ‘from a castle’
   e. $s$ polem ['spolem] ‘with a field’
   f. $z$ pole ['spole] ‘from a field’
   g. $s$ chybou ['sxiboo] ‘with a mistake’
   h. $z$ chyby ['sxibi] ‘from a mistake’

Under the assumption that assimilation is implemented formally as the spreading of a marked feature from one segment to another, there are two possible ways of accounting for the voicing patterns observed so far. One possibility is that both voiced and voiceless obstruents have some marked voicing feature that is capable of spreading, as in the Laryngeal Voice systems described by Avery (1996). In a Laryngeal Voice system, all obstruents are marked with the feature [Laryngeal], with voiced obstruents being distinguished from voiceless ones by the presence of the dependent feature [Voice]; sonorants are marked with [SV] (an abbreviation for ‘sonorant voicing’ or ‘spontaneous voicing’; see Avery and Rice (1989), Piggott (1992), and Rice (1993)). These representations are illustrated in (25).
(25) Laryngeal Voice system (Avery 1996)

<table>
<thead>
<tr>
<th>VOICELESS OBSTRUENTS</th>
<th>VOICED OBSTRUENTS</th>
<th>SONORANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>t</td>
<td>d</td>
<td>n</td>
</tr>
<tr>
<td>Laryngeal</td>
<td>Laryngeal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Voice</td>
<td>SV</td>
</tr>
</tbody>
</table>

Given these representations, Czech regressive voicing assimilation could be generated by a rule that spreads a [Laryngeal] feature leftward from one obstruent to another, replacing the original [Laryngeal] feature of the obstruent on the left, as shown in (26). (Such a rule, since it has the effect of replacing two adjacent [Laryngeal] features with a single shared one, might be driven by the Obligatory Contour Principle (Leben 1973).) Segments specified with [SV] would be immune to assimilation.

(26) Deriving voicing assimilation by spreading [Laryngeal]

The other possibility is that only voiced obstruents have a marked feature, and that the apparently assimilatory devoicing in forms such as (24f) and (24h) is part of a more general rule of coda devoicing, which would also encompass the word-final devoicing in (22). This approach, which is similar to Avery’s account of similar voicing patterns in Russian, would rely on the assumption that s and z can form an onset with an immediately following sonorant, but not with an obstruent. Derivations along these lines for some of the forms in (23) and (24) are shown in (9).

4. Alternatively, the devoicing of one obstruent before another might be generated by reference to some other configuration of prosodic structure, such as the prosodic-word-initial appendices used by Goad and Rose (2003) to account for patterns of cluster simplification in children acquiring West Germanic languages. This alternative, though, does not offer a clear way of unifying pre-obstruent devoicing with final devoicing.
(27) Deriving voicing assimilation with coda devoicing

<table>
<thead>
<tr>
<th></th>
<th>a. s lesem (23c)</th>
<th>b. z lesa (23d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underlying form:</td>
<td>/s+les+em/</td>
<td>/z+les+a/</td>
</tr>
<tr>
<td>Syllabification:</td>
<td>sle.sem</td>
<td>zle.sa</td>
</tr>
<tr>
<td>Coda devoicing:</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Assimilatory voicing:</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Surface form:</td>
<td>[sle.sem]</td>
<td>[zle.sa]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>c. s polem (24e)</th>
<th>d. z pole (24f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underlying form:</td>
<td>/s+pol+em/</td>
<td>/z+pol+e/</td>
</tr>
<tr>
<td>Syllabification:</td>
<td>s.po.lem</td>
<td>z.po.le</td>
</tr>
<tr>
<td>Coda devoicing:</td>
<td>—</td>
<td>s.po.le</td>
</tr>
<tr>
<td>Assimilatory voicing:</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Surface form:</td>
<td>[s.po.lem]</td>
<td>[s.po.le]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>e. s domem (24a)</th>
<th>f. z domu (24b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underlying form:</td>
<td>/s+dom+em/</td>
<td>/z+dom+u/</td>
</tr>
<tr>
<td>Syllabification:</td>
<td>s.do.mem</td>
<td>z.do.mu</td>
</tr>
<tr>
<td>Coda devoicing:</td>
<td>—</td>
<td>s.do.mu</td>
</tr>
<tr>
<td>Assimilatory voicing:</td>
<td>z.do.mem</td>
<td>z.do.mu</td>
</tr>
<tr>
<td>Surface form:</td>
<td>[z.do.mem]</td>
<td>[z.do.mu]</td>
</tr>
</tbody>
</table>

This approach has conceptual and empirical disadvantages, however. The representations posited in (27c–f) require word-initial codas that either lack nuclei altogether or are preceded by empty codas; while such structures have been proposed elsewhere (see, e.g., Kaye (1992)), the theoretical consequences of adopting this analysis here are more drastic than the voicing assimilation facts appear to require. Empirically, there is no evidence independent of voicing assimilation to suggest that clusters of obstruents at the beginning of a phonological word cannot be syllabified together in Czech, and the positing of empty-headed initial syllables would disrupt the otherwise exceptionless generalization
that stress in Czech falls on the first syllable of the phonological word. Furthermore, if devoicing applies in word-medial codas, then its effects are entirely obscured by voicing assimilation. (There is no word-medial devoicing before sonorants, which can be taken to mean either that there is no coda devoicing or that an obstruent that is followed by a sonorant can always be parsed as an onset.) Most conclusively, though, the pattern of progressive assimilatory devoicing discussed in the next section demonstrates that even with a rule of coda devoicing, it would still be necessary for voiceless obstruents to have a marked feature that is capable of spreading.

2.2 The exceptions

Two obstruents present exceptions to the pattern of regressive assimilation described above. The first of these is /v/. This segment is a target for regressive assimilation, as revealed in (28) by the behaviour of the preposition /v/ (‘in, at, on’), and also for final devoicing, as shown in (29).

(28) /v/ as a target for regressive assimilatory devoicing

a. v lese  [vlese]  ‘in a forest’
b. v muži  [vmuʒi]  ‘in a man’
c. v domě  [vdomě]  ‘in a house’
d. v hradě  [vhradě]  ‘in a castle’
e. v pole  [fpole]  ‘in a field’
f. v chybě  [fxbje]  ‘in a mistake’
2.2. The exceptions

(29) /v/ as a target for final devoicing
   
   a. zpěv [spjef] ‘song’ (nom. sg.)
   b. zpěvem [spjevem] ‘song’ (inst. sg.)
   c. barev [‘baref] ‘colours’ (gen. pl.)
   d. barva [‘barva] ‘colour’ (nom. sg.)

However, /v/ does not trigger assimilatory voicing of a segment to its left. In some dialects of Czech, /v/ is devoiced following a voiceless obstruent; in others, it surfaces as voiced, creating an exception to the surface generalization that obstruent clusters agree in voicing. These patterns are shown in (30).

(30) /v/ as a non-trigger of regressive assimilatory voicing
   
   a. vrána [vra:na] ‘crow’
   b. s vránou [svraːnou] ∼ [sfraːnou] ‘with a crow’
   c. květ [kvjet] ∼ [kfjet] ‘flower’
   d. tvůj [tvu:j] ∼ [tfu:j] ‘your’
   e. tvůřit se [tvořit se] ∼ [tforřit se] ‘to take shape’
   ≠f. dvořit se [dvořit se] ‘to court’

The second exceptional segment is the trilled fricative /ɾ/, which also does not trigger assimilatory voicing. Instead, /ɾ/, according to de Bray (1969), is devoiced when it is adjacent to a voiceless obstruent on either side. The behaviour of /ɾ/ is illustrated in (31) and (32).

---

5. Palková (1994) says that /ɾ/ can trigger regressive assimilatory voicing across a morpheme boundary, as in (1), but indicates that forms such as those in (2) also occur.

(1) a. k řece [gretse] ‘to a river’
     b. máš říči [maːʃ ɾitʃi] ‘you (sg.) should speak’

(2) a. k řece [kretse] ‘to a river’
     b. máš říči [maʃ ɾitʃi] ‘you (sg.) should speak’
Chapter 2. Voicing assimilation and prophylactic features

(31) /r/ as a target of regressive assimilation and final devoicing

a. lékař ['le:karʃ] ‘doctor (nom. sg.)’
b. lékařem ['le:kaɾem] ‘doctor (inst. sg.)’
c. lékařství ['le:karʃtvj] ‘medicine (nom.)’
d. nářek ['naɾek] ‘lamentation (nom. sg.)’
e. nářky ['naɾɾki] ‘lamentations (nom. pl.)’

(32) /r/ as a target of progressive assimilatory devoicing

a. při ['pri] ‘near’
b. středa ['str̥eda] ‘Wednesday’

The anomalous behaviour of /v/ and /r/ means that the Czech system must contain at least four, and in some dialects five, distinct sets of laryngeal feature specifications in order to generate the four or five different attested voicing patterns summarized in Table 2.2. (In dialects in which /v/ is subject to progressive devoicing, /v/ and /r/ pattern together, and so there are only four distinct sets of voicing properties; in dialects in which /v/ is not devoiced, there are five.) Furthermore, the presence of progressive assimilatory devoicing suggests that voiceless obstruents must have some marked feature to spread; coda devoicing cannot account for the data in (32).

<table>
<thead>
<tr>
<th></th>
<th>DEFAULT REALIZATION</th>
<th>REGRESSIVE ASSIM.</th>
<th>PROGRESSIVE ASSIM.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TRIGGER</td>
<td>TARGET</td>
<td>TRIGGER</td>
</tr>
<tr>
<td><strong>SONORANTS</strong></td>
<td>voiced</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>/v/</td>
<td>voiced</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>/r/</td>
<td>voiced</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td><strong>VD. OBS.</strong></td>
<td>voiced</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td><strong>VLS. OBS.</strong></td>
<td>voiceless</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

Table 2.2: Summary of Czech voicing patterns
It is not surprising that /r/ should pattern differently from other obstruents. Historically, it is derived from a palatalized sonorant */r/; synchronically, it functions as the soft (i.e., palatalized) counterpart to /r/. It is also, because of its origins as a sonorant, the only voiced obstruent in the Czech inventory with no phonemic voiceless counterpart. Although the voiceless affricates /ts/ and /tʃ/ have no exact voiced counterparts, they have near counterparts in the voiced stop–fricative sequences /dz/ and /dʒ/. Kučera (1961) observes that underlying /dz/ sequences, as in podzim /podzim/ ‘autumn’ are phonetically realized as affricates in fast speech (as in [podzim]). In loanwords from English, Czech tends to realize the English affricate /dʒ/ as a /dʒ/ sequence, as in the examples in (33). (Other languages change this sound to /ʒ/ or /tʃ/.)

(33) Adaptation of English /dʒ/ into Czech
   a. džus [dʒus] ‘fruit juice’
   b. džez [dʒes] ‘jazz’
   c. džungle [ˈdʒʊŋɡle] ‘jungle’

In the terminology of Dresher (1998a, 1998b, 2003), the difference between /r/ and the voiceless affricates lies in the contrastive scope of their voicing properties. The affricates, which are capable of triggering assimilatory devoicing, are squarely within the obstruent system, and voicing is contrastive among obstruents in general. This is expressed formally in the fact that the SDA divides the obstruent inventory into voiced and voiceless subinventories before making other divisions (based on place and manner features) that would separate /ts/ and /tʃ/ from the other obstruents. Although Czech does not have phonemic /dz/ and /dʒ/, the entire set of voiced obstruents can thus be considered the ‘voiced counterparts’ of /ts/ and /tʃ/. The trilled fricative, on the other

---

6. Since the only segments subject to progressive assimilation are voiced by default, the triggering of progressive assimilation by other voiced segments would be phonetically vacuous.
hand, appears to be outside the obstruent system, and thus, like a sonorant, outside the scope of the voicing contrast.\(^7\)

From a diachronic perspective, /v/ is also not entirely an obstruent, but rather what might be called a ‘lapsed sonorant.’ Unlike its cognate segment in Russian (on which see, e.g., Hayes 1984), Czech /v/ has developed a phonetic stoplike quality alluded to earlier, but both are descended from \(*w/\). Although modern Czech /v/ does have a phonemic voiceless counterpart /f/, the relation between the two is somewhat oblique. Phonetically, /f/ does not share the stoplike quality of /v/, and while /v/ is a lapsed sonorant, /f/ is a recent innovation within the obstruent system. Most words containing /f/ are of foreign origin; others appear to be onomatopoeic. Some of these are listed in (34) and (35).

(34) /f/ in loanwords
   a. filiáška [filiaːlka] ‘branch office’
   b. fejeton [féjeton] ‘feuilleton’
   c. efemérní [efeměɾniː] ‘ephemeral’
   d. reflektor [reflektor] ‘searchlight’
   e. reliéf [relijeːf] ‘(bas-)relief’

(35) /f/ in onomatopoeia
   a. frkat [frk] ‘to sputter’
   b. fůukat [fůuk] ‘to whimper’

To some extent, then, the fact that /tʃ/ and /v/ behave differently from other obstruents is related to the fact that their voicing is less distinctive than the voicing on other obstruents. There is, it seems, a voicing contrast between segments which enter into voicing contrasts and segments which do not. As explained in the next section, this contrast is the key to accounting for the pattern.

---

\(^7\) The voiceless affricates do, however, pose an interesting problem for an Optimality Theoretic version of the SDA, as discussed in §5.3.2.
2.3 Accounting for Czech voicing assimilation

2.3.1 Dialects with four voicing classes

Let us first consider the simpler case of the dialects in which /v/ and /r/ pattern together. Employing the laryngeal features proposed by Avery (1996), we can characterize these dialects as mixed Laryngeal Voice / Contextual Voice systems.

In a Laryngeal Voice system ((25), repeated in (36a)), as discussed earlier, all obstruents are specified with a [Laryngeal] feature, and on voiced obstruents this feature hosts a dependent feature [Voice]; sonorants are specified with [SV]. In a Contextual Voice system (36b), however, [Laryngeal] is present only on voiceless obstruents; sonorants again have [SV]; and voiced obstruents are unspecified for voicing features. The Czech system (36c) shows a mixture of these two: most segments have representations characteristic of a Laryngeal Voice system, but the exceptional /r/ and /v/ are unspecified for voicing as in a Contextual Voice system.

(36) Laryngeal Voice, Contextual Voice, and mixed systems

a. Laryngeal Voice system (Avery 1996)

<table>
<thead>
<tr>
<th>VOICED OBSTRUENTS</th>
<th>VOICELESS OBSTRUENTS</th>
<th>SONORANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>/d/</td>
<td>/t/</td>
<td>/n/</td>
</tr>
<tr>
<td>Laryngeal</td>
<td>Laryngeal</td>
<td>SV</td>
</tr>
<tr>
<td>Voice</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b. Contextual Voice system (Avery 1996)

<table>
<thead>
<tr>
<th>VOICELESS OBSTRUENTS</th>
<th>VOICED OBSTRUENTS</th>
<th>SONORANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>/t/</td>
<td>/d/</td>
<td>/n/</td>
</tr>
<tr>
<td>Laryngeal</td>
<td>/</td>
<td>SV</td>
</tr>
</tbody>
</table>
c. Mixed LV/CV system (Czech dialects with four voicing classes)

<table>
<thead>
<tr>
<th>VOICED OBSTRUENTS</th>
<th>VOICELESS OBSTRUENTS</th>
<th>/r; v/</th>
<th>SONORANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>/d/</td>
<td>/t/</td>
<td>/r/</td>
<td>/n/</td>
</tr>
<tr>
<td>Laryngeal</td>
<td>Laryngeal</td>
<td></td>
<td>SV</td>
</tr>
<tr>
<td>Voice</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Given the representations in (36c), both regressive and progressive assimilation can be represented as spreading of the [Laryngeal] feature. The more usual pattern of regressive assimilation proceeds as shown in (37); this rule differs from the one shown in (26) only in that it additionally targets segments with no voicing specifications at all.

(37) Regressive assimilation rule (revised)

When several obstruents occur in a row, the rule in (37) applies iteratively from right to left, spreading the [Laryngeal] feature of the rightmost segment to all members of the cluster. The iterative application of the rule can be seen in forms such as leckdo /lets+kdo/ [ledzgo] ‘several people’ (Kučera 1961), as illustrated in (38).

(38) Derivation of le[zgo]o

a.  
   
   \[ \ldots \quad \text{ts} \quad \text{k} \quad \text{d} \quad \ldots \]
   
   \[ \quad \text{Laryngeal} \quad \text{Laryngeal} \quad \text{Laryngeal} \quad \text{Voice} \]

b.  
   
   \[ \ldots \quad \text{ts} \quad \text{k} \quad \text{d} \quad \ldots \]
   
   \[ \quad \text{Laryngeal} \quad \text{Laryngeal} \quad \text{Laryngeal} \quad \text{Voice} \]
Iterative application of the rule in (37) also accounts for the difference between forms such as *tvůj ‘your’ (realized as [tfuːj] or [tvuːj] but not [*dvuːj]) and víč vdolků ‘more muffins’ (underlyingly /viːts vdolkuː/; realized as [viːdz vdolkuː]). The /v/ in tvůj has no voicing features to spread to the preceding /t/, but the /v/ at the beginning of vdolků receives from the immediately following /d/ a [Laryngeal] feature with dependent [Voice], which it can then pass on to the /ts/ at the end of víč.

Word-final devoicing can also be generated by the same spreading mechanism. If a bare [Laryngeal] feature is inserted at the right edge of the phonological word—or if it is associated with the word boundary itself—the rule in (37) will spread it leftward to devoice a word-final obstruent or obstruent cluster, as shown in (39).

(39) Final devoicing

Progressive assimilation is generated by the rightward spreading of a [Laryngeal] feature to a target with no voicing features, as shown in (40). It does not matter whether this rule applies to all [Laryngeal] features or only to bare [Laryngeal] features: because
/v/ and /r/ surface as voiced in the default case, no phonetic change results if they assimilate to a voiced obstruent.

(40) Progressive assimilation

2.3.2 Dialects with five voicing classes

In dialects in which /v/ and /r/ pattern differently, five distinct sets of laryngeal features are needed. More specifically, /v/ must be distinguished from /r/ by some feature that protects it from progressive assimilation, but which does not prevent regressive assimilation and does not spread.

An appropriate set of representations for these dialects can be generated by treating /v/ as what Avery (1996), following Rice (1993), terms a **sonorant obstruent**—i.e., a voiced obstruent that bears the feature [SV]. This results in a system that combines elements of Laryngeal Voice and Contextual Voice systems (discussed in §2.3.1) with elements of a Sonorant Voice system. In an SV system, voiceless obstruents are unspecified for voicing features, while voiced obstruents and sonorants are specified for [SV]. True sonorants are distinguished from sonorant obstruents by the presence of manner features dependent on SV, such as [Nasal] or [Liquid]. The LV/CV/SV split is shown in (41).

(41) LV, CV, SV, and mixed systems

a. Laryngeal Voice system (Avery 1996)

<table>
<thead>
<tr>
<th>VOICED OBUSUENTS</th>
<th>VOICELESS OBUSUENTS</th>
<th>SONORANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>/d/</td>
<td>/t/</td>
<td>/n/</td>
</tr>
<tr>
<td>Laryngeal</td>
<td>Laryngeal</td>
<td>SV</td>
</tr>
<tr>
<td>Voice</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
b. Contextual Voice system (Avery 1996)

<table>
<thead>
<tr>
<th>VOICELESS OBSTRENUENTS</th>
<th>VOICED OBSTRENUENTS</th>
<th>SONORANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>/t/</td>
<td>/d/</td>
<td>/n/</td>
</tr>
<tr>
<td></td>
<td>Laryngeal</td>
<td></td>
</tr>
</tbody>
</table>

c. Sonorant Voice system (Avery 1996)

<table>
<thead>
<tr>
<th>VOICELESS OBSTRENUENTS</th>
<th>VOICED OBSTRENUENTS</th>
<th>SONORANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>/t/</td>
<td>/d/</td>
<td>/n/</td>
</tr>
<tr>
<td></td>
<td>SV</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

d. Mixed LV/CV/SV system (Czech dialects with five voicing classes)

<table>
<thead>
<tr>
<th>VOICED OBSTRENUENTS</th>
<th>VOICELESS OBSTRENUENTS</th>
<th>/r/</th>
<th>/v/</th>
<th>SONORANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>/d/</td>
<td>/t/</td>
<td>/r/</td>
<td>/v/</td>
<td>/n/</td>
</tr>
<tr>
<td></td>
<td>Laryngeal</td>
<td></td>
<td>Laryngeal</td>
<td>SV</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Voice</td>
</tr>
</tbody>
</table>

In these dialects, [SV] blocks progressive assimilation, but not regressive assimilation. The unspecified /r/ is thus still a target for both processes, but /v/ will not be progressively devoiced.

Evidence that regressive assimilation does in fact target sonorants can be found in forms such as moc lže /mots lʒe/ [modz lʒe] ‘much lies,’ which is similar to the víc vdolku example mentioned above. Although /l/ itself does not usually trigger regressive voicing, the /l/ in lže, which is immediately followed by a voiced obstruent, does. This suggests that the [Laryngeal] feature of the /ʒ/ spreads leftward onto the /l/, and thence onto the preceding /ts/. (Syllabic sonorants, however, do not transmit voicing features of adjacent obstruents, as in vlk /vlk/ [vlk] [*flk, *fìk] ‘wolf’ and the examples in (21).
This fact is, as Avery (1996) suggests for Russian, “related to their status as syllable heads, not as sonorants.”

Although they can receive [Laryngeal] features by spreading, true sonorants, unlike /v/, are not subject to assimilatory devoicing. When a segment with an [SV] feature receives a bare [Laryngeal] feature by spreading, its phonetic realization as voiced or voiceless depends on the presence or absence of additional features. If the segment is marked with [Nasal], [Approximant], [Liquid], or some other feature specifying a sonorant manner of articulation, then it will be realized as a voiced sonorant of the appropriate type. (Hayes (1984), discussing voicing assimilation in Russian, suggests that the phonetic implementation of sonorants may dictate voicing even if they have become specified as voiceless in the course of the phonological derivation.) If the segment does not bear such a feature, then [SV] will be overruled by the [Laryngeal] feature, and the segment will surface as voiceless. Thus true sonorants are protected from devoicing by the presence of a dependent on [SV], but /v/, which has only a bare [SV] feature, can be regressively devoiced.

The phonetic interpretation rules needed to realize all derivable combinations of voicing features are listed in Table 2.3 (p. 55). In this table, [Liquid] is used as an example of a dependent feature of [SV]; other dependent features specifying sonorant manners of articulation also have the effect of ensuring that a segment surfaces as voiced.

2.3.3 Dividing the inventory and assigning the features

All the phonologically active features needed for the account of Czech voicing assimilation described above can be assigned by the Successive Division Algorithm, and are thus contrastive by the definition adopted in this thesis. (The SDA and the definition of contrastiveness it provides are discussed above in §1.2.7.)

In dialects with four voicing classes, the divisions are as shown in (42). Sonorants are divided from obstruents by the assignment of the feature [SV]. Within the obstru-
2.3. Accounting for Czech voicing assimilation

<table>
<thead>
<tr>
<th>Features</th>
<th>Realization</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rt</td>
<td>voiced</td>
<td>[r] in říct [řist] ‘to speak’</td>
</tr>
<tr>
<td>Laryngeal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>St</td>
<td>voiceless</td>
<td>[t] and [r] in tří [trí] ‘three’</td>
</tr>
<tr>
<td>Laryngeal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voice</td>
<td>voiced</td>
<td></td>
</tr>
<tr>
<td>Rt</td>
<td>voiced</td>
<td>[b] and [r] in břeh [brex] ‘shore’</td>
</tr>
<tr>
<td>Laryngeal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>St</td>
<td>voiceless</td>
<td></td>
</tr>
<tr>
<td>Laryngeal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voice</td>
<td>voiced</td>
<td></td>
</tr>
<tr>
<td>Rt</td>
<td>voiced</td>
<td>[v] in voda [voda] ‘water’</td>
</tr>
<tr>
<td>SV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laryngeal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voice</td>
<td>voiced</td>
<td></td>
</tr>
<tr>
<td>Rt</td>
<td>voiced</td>
<td>[v] in v domě [vdomě] ‘in a house’</td>
</tr>
<tr>
<td>SV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laryngeal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voice</td>
<td>voiced</td>
<td></td>
</tr>
<tr>
<td>Rt</td>
<td>voiced (sonorant)</td>
<td>[l] in les [les] ‘forest’</td>
</tr>
<tr>
<td>SV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rt</td>
<td>voiced (sonorant)</td>
<td>[l] in délka [delka] ‘length’</td>
</tr>
<tr>
<td>SV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laryngeal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rt</td>
<td>voiced (sonorant)</td>
<td>[l] in lže [lže] ‘lies’ (3rd sg. pres.)</td>
</tr>
</tbody>
</table>

Table 2.3: Phonetic interpretation of voicing features

ents, the feature [Laryngeal] is assigned to those that are capable of triggering voicing assimilation. Finally, within the class identified by the feature [Laryngeal], the feature [Voice] distinguishes voiced obstruents from voiceless ones.
(42) Divisions yielding four voicing classes

<table>
<thead>
<tr>
<th>[SV]</th>
<th>[Laryngeal]</th>
</tr>
</thead>
<tbody>
<tr>
<td>{m, n, ŋ, l, r, j}</td>
<td>{v, ř}</td>
</tr>
<tr>
<td>{p, t, c, k, f, s, š, x, ts, ř}</td>
<td>{b, d, ř, g, z, ř fi}</td>
</tr>
<tr>
<td>[SV]</td>
<td>[Laryngeal]</td>
</tr>
</tbody>
</table>

For dialects with five voicing classes, the assignment of features, shown in (43), is somewhat different. The feature [SV] is assigned not only to true sonorants, but also to /v/. Within the class identified by [SV], the assignment of marked manner features is now crucial to determining voicing behaviour. As indicated in (43), /v/ is distinguished from the true sonorants by the fact that it is not a nasal, a liquid, or an approximant. (Similar divisions apply within the sonorants in (42), but are not relevant to their voicing behaviour; it is not clear which sonorant manner of articulation is unmarked in dialects with four voicing classes.) Within the set of segments that do not bear [SV], the divisions proceed as before: obstruents capable of triggering assimilation are distinguished from /ř/ by the specification of [Laryngeal], and within this set the voiced members are specified with [Voice].

(43) Divisions yielding five voicing classes

<table>
<thead>
<tr>
<th>[SV]</th>
<th>[Laryngeal]</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Nasal]</td>
<td>{m, n, ŋ}</td>
</tr>
<tr>
<td>[Approx.]</td>
<td>{j}</td>
</tr>
<tr>
<td>[Approx.]</td>
<td>{v}</td>
</tr>
<tr>
<td>[Liquid]</td>
<td>{l, r}</td>
</tr>
<tr>
<td>[SV]</td>
<td>[Laryngeal]</td>
</tr>
</tbody>
</table>

Both (42) and (43) depend on the possibility of assigning features that distinguish segments by their phonological behaviour, rather than their phonetic properties. In particular, the feature [Laryngeal] is associated not with any articulatory, auditory, or acoustic attribute of the sounds to which it is assigned, but rather with the ability to affect the realization of adjacent sounds by triggering voicing assimilation. It is, in
effect, the featural correlate of what Broch (1911: ¶197) refers to as “assimilierende Kraft” (“assimilatory power’’). However, as Jakobson and Halle (1956) observe, it is not at all unusual for distinctive features of one segment to be realized phonetically on a neighbouring segment:

The auxiliary role of redundancies must not be underestimated. Circumstances may even cause them to substitute for distinctive features. Jones [1950] cites the example of the English /s/ and /z/ which in the final position differ from each other solely in the degree of breath force. Although “an English hearer will usually identify the consonants correctly, in spite of their resemblance to one another,” the right identification is often facilitated by the concomitant difference in the length of the preceding phoneme: *pence* [pens] — *pens* [penz].

Hall (1998) and Mercado (2002) have argued that the SDA crucially makes divisions on the basis of how segments interact with other segments. In a theory in which only contrastive features are phonologically active, it is necessary that contrasts in phonological behaviour take precedence over contrasts in phonetic implementation.

### 2.4 A surface-oriented alternative

The approach to voicing assimilation taken here is an essentially formalist one, in that the possibility or impossibility of assimilation is determined by the presence or absence of certain formal phonological features. It is useful to contrast this approach with the more functionalist approach taken by Steriade (1997) in a general discussion of processes that neutralize laryngeal contrasts, and by Padgett (2002) in a treatment of Russian [v].

Steriade (1997), drawing on data from a wide range of languages, argues that the environments in which laryngeal contrasts are neutralized are precisely those in which the contrasts are phonetically most difficult to perceive. Because prevocalic and presonorant
Chapter 2. Voicing assimilation and prophylactic features

positions offer more robust voice onset time cues, obstruents are more likely to preserve their underlying voicing values in these environments than they are in preobstruent or word-final positions. Steriade offers empirical evidence that this cue-based account is superior to alternatives based on syllable structure in predicting the environments in which neutralization occurs. However, this evidence says nothing against a formal account based on segmental adjacency rather than on syllabic constituent structure.

Furthermore, Steriade’s (1997) phonetic approach has little to say about the direction of laryngeal neutralization, although Steriade (2001) discusses the question as it applies to the neutralization of place of articulation. When a segment loses its contrastive underlying voicing value, it may either take on a default voicing value or assimilate to the value of an adjacent segment. Which of these two kinds of neutralization occurs seems to depend not on Phonetic cues to voicing, but rather on the presence of other phonologically contrastive laryngeal features in the environment. Thus obstruents that are neutralized next to other obstruents tend to assimilate, while those that are neutralized next to sonorants or word boundaries tend to revert to a default value. The phonetic cue-based approach must therefore be supplemented by some theory of contrast and markedness. In an approach based on feature spreading, however, the environment and the direction of neutralization are determined by a single formal mechanism.

2.4.1 A functional account of Russian /v/...

Steriade’s approach also seems likely to have difficulty accounting for the anomalous behaviour of Czech /l/ and /v/. Progressive voicing assimilation is unexpected if the main trigger for laryngeal neutralization is an absence of robust VOT cues, nor is there any obvious cue-related reason for these two segments to behave differently from other Czech obstruents. However, Padgett (2002) offers a phonetic explanation of the similarly anomalous behaviour of [v] in Russian.
2.4. A surface-oriented alternative

Like Czech /v/, the corresponding Russian segment is historically derived from /w/. Its ambiguous quasi-sonorant, quasi-obstruent behaviour has led Lightner (1965), Hayes (1984), Kiparsky (1985), and others to propose that it is also synchronically /w/ underlyingly, although it surfaces in forms that are typically transcribed as [v] and [f]. As in Czech, it is a target for regressive voicing assimilation (44) and final devoicing (45), but not a trigger for voicing assimilation (46).

(44) Russian /v/ as a target of assimilation

a. [v reke] ‘in the river’
b. [v gorode] ‘in the city’
c. [f supe] ‘in the soup’
d. [f skva$ine] ‘in the chink’
e. [korovok] ‘cow (diminutive)’ (gen. pl.)
f. [korofka] ‘cow (diminutive)’ (nom. sg.)

(45) Russian /v/ as a target of final devoicing

a. [prava] ‘right’ (fem.)
b. [praf] ‘right’ (masc.)
c. [krovi] ‘blood’ (gen.)
d. [krof] ‘blood’ (nom.)

(46) Russian /v/ as a non-trigger of assimilation

a. [tver$] ‘Tver’ (place name)
b. [dver$] ‘door’
c. [ot+vesti] ‘to lead away’
d. [pod+vesti] ‘to lead up’
e. [s vami] ‘with you (pl.)’
f. [iz vami] ‘away from you (pl.)’

Padgett (2002) argues that this pattern follows from the fact that Russian /v/ is, phonetically and phonologically, a ‘narrow approximant’ [v]. Because it is phonetically
intermediate between an obstruent and a sonorant, it is also phonologically ambiguous. The voicing behaviour of [ʋ] results from the way in which it is treated by the constraints shown in (47).

(47) Constraints proposed by Padgett (2002)

a. \textsc{Ident}\textsubscript{PS}(voice): An output segment in pre-sonorant position has the same value for [voice] as its input correspondent.

b. \textsc{Agree}(voice): Within a clitic group, all contiguous [−wide, −nasal] segments share any [voice] specification.

c. \textsc{*D/}^8 \textsubscript{Vfi} [−wide, −nasal] segments should not be [+voice].

For Padgett, the positional faithfulness constraint \textsc{Ident}\textsubscript{PS}(voice) and its position in the constraint hierarchy are functionally motivated. Obstruents are, he argues (following Steriade 1997), more likely to maintain underlying voicing contrasts in environments where phonetic cues to voicing are more robust. Because pre-sonorant position is the best environment for voicing cues, \textsc{Ident}\textsubscript{PS}(voice) is both the most specific and universally the highest-ranking constraint mandating the preservation of underlying voicing feature values. In all other constraints of the form \textsc{Ident}_{env}(voice), the environment \textit{env} will include pre-sonorant position along with some subset of the next most favourable environments for voicing cues, and the members of the \textsc{Ident}_{env}(voice) constraint family are universally ranked from most specific to most general (Padgett 2002: 8).

In Russian \textsc{Ident}\textsubscript{PS}(voice) also outranks the two constraints that generate neutralization of voicing features. \textsc{Agree}(voice) drives voicing assimilation. In a series of obstruents followed by a sonorant, the rightmost obstruent will retain its underlying voicing because of \textsc{Ident}\textsubscript{PS}(voice), and the non-final members of the cluster will assimilate

---

8. Padgett’s somewhat elliptical label for this constraint can be glossed as ‘disallow the voicing feature of [d] on segments that are no more sonorous than [ʋ]’; it is based on Steriade’s (1997) more general constraint (*D) against voiced obstruents.
Final devoicing is driven by *D/\text{v}/, for which Padgett (2002: 8) finds functional motivation in the fact that “it is difficult to maintain voicing given the build-up in supra-glottal pressure that obstruents entail.” Although this constraint itself does not refer to any specific environment, its low ranking ensures that its effects emerge only word-finally: in pre-sonorant position it is obscured by IDENT\text{PS}(VOICE), and in pre-obstruent position by AGREE(VOICE).

What is significant for the behaviour of /\text{v}/ is that it occupies the overlapping region between the two classes of segments referred to by the constraints in (47). IDENT\text{PS}(VOICE) refers to sonorants, the class defined by the feature [+sonorant]. AGREE(VOICE) and *D/\text{v}/ refer not to the complement class defined by [−sonorant] (i.e., obstruents), but rather to an overlapping class defined by the features [−wide, −nasal]. These features exclude most sonorants (approximants and nasals), but not the narrow approximant /\text{v}/. The relevant feature specifications Padgett posits for /\text{v}/ are shown in (48).

(48) Feature specifications for Russian /\text{v}/

\[
\begin{array}{c}
+/\text{v}/ \\
+\text{continuant} \\
+\text{approximant} \\
−\text{wide} \\
−\text{nasal} \\
+\text{sonorant}
\end{array}
\]

Because /\text{v}/ is [−wide, −nasal], it is subject to regressive voicing assimilation driven by AGREE(VOICE), as shown in the tableau in (49).

(49) /\text{layka}/ → [lafka] ‘bench’ (Padgett 2002: 20)

<table>
<thead>
<tr>
<th>/\text{layka}/</th>
<th>IDENT\text{PS}(VOICE)</th>
<th>AGREE(VOICE)</th>
<th>*D/\text{v}/</th>
<th>IDENT(VOICE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[\text{layka}]</td>
<td></td>
<td>*!</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>[\text{lafka}]</td>
<td></td>
<td></td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>[\text{layga}]</td>
<td>*!</td>
<td>**</td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>
However, because /ψ/ is [+sonorant], obstruents to its immediate left are required by IDENT\textsubscript{PS(voice)} to retain their underlying voicing values, as shown in (50).

(50) /s\_\textsubscript{verx}/ → [s\_\textsubscript{verx}] ‘above’ (Padgett 2002: 26)

<table>
<thead>
<tr>
<th>/s_\textsubscript{verx}/</th>
<th>IDENT\textsubscript{PS(voice)}</th>
<th>AGREE\textsubscript{(voice)}</th>
<th>*D/ψ</th>
<th>IDENT\textsubscript{(voice)}</th>
</tr>
</thead>
<tbody>
<tr>
<td>[s_\textsubscript{verx}]</td>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[z_\textsubscript{verx}]</td>
<td></td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[s_\textsubscript{ferx}]</td>
<td></td>
<td>*!</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Obstruents and /ψ/ are both subject to final devoicing motivated by the constraint *D/ψ, as in (51).

(51) /t\textsubscript{rez}/ → [t\textsubscript{rez}] ‘sober’ (Padgett 2002: 26)

<table>
<thead>
<tr>
<th>/t\textsubscript{rez}/</th>
<th>IDENT\textsubscript{PS(voice)}</th>
<th>AGREE\textsubscript{(voice)}</th>
<th>*D/ψ</th>
<th>IDENT\textsubscript{(voice)}</th>
</tr>
</thead>
<tbody>
<tr>
<td>[t\textsubscript{rez}]</td>
<td></td>
<td>!*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[t\textsubscript{rezf}]</td>
<td></td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[t\textsubscript{resf}]</td>
<td></td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[t\textsubscript{resf}]</td>
<td></td>
<td>*!</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In Russian, then, the phonetic and phonological properties of /ψ/ are neatly aligned. Jakobson (1978) describes Russian /ψ/ phonologically as occupying “an obviously intermediate position between the obstruents and the sonorants”; for Padgett (2002), this is a natural consequence of its articulatory and acoustic properties.

2.4.2 . . . is non-functional in Czech

Although Czech /v/ and Russian /ψ/ are very similar phonologically, it would be difficult to extend Padgett’s analysis to Czech. Like its Russian counterpart, Czech /v/ appears to occupy a phonological category intermediate between obstruent and sonorant. Pho-
netically, however, Czech /v/ cannot be characterized as a ‘narrow approximant,’ or as
being more sonorous than other Czech obstruents. On the contrary, it is generally described as being more like a stop than like a fricative (Kučera 1961; Palková 1994), as mentioned above in §2.1. From a phonetic point of view, there is no reason to classify it as a sonorant a priori.

The acoustic realization of /v/ can be seen in Figure 2.1, which shows spectrograms of the words voda /voda/ ‘water’ and váza /vaza/ ‘vase’. (The spectrograms were produced, using the speech analysis program Praat (Boersma and Weenink 1992), from recordings of a female native speaker of Czech. The recordings are part of a set of sound files designed to accompany the IPA Handbook (International Phonetic Association 1999).)

![Figure 2.1: Spectrograms of Czech voda /voda/ ‘water’ and váza /vaza/ ‘vase’](image)

Although in each of these examples [v] is clearly voiced, it is not particularly sonorous; there is a visible voice bar at the bottom of the spectrum, but it is not large, and there is no formant pattern above it. The [v] in váza is difficult to distinguish from the [b] in bota /bota/ ‘shoe,’ shown in Figure 2.2; if anything, the [v] appears to be less sonorous than the [b], which has a larger voice bar with another band of energy above it. To the extent that the feature [±sonorant] has identifiable phonetic content, Czech [v] appears to be phonetically [−sonorant].

In contrast with /v/ there is, however, one very sonorous Czech obstruent: /f/. Articulatorily, this sound is maximally open; in Padgett’s feature system, it would pre-
sumably be [+wide]. Acoustically, as illustrated in Figure 2.3, /fi/ is characterized by strong voicing and a clear formant pattern.

If phonetic characteristics were a reliable determinant of phonological behaviour, then we should expect /fi/ to be the first Czech obstruent to show sonorant-like pattern- ing. Yet /fi/ patterns phonologically as if it were /γ/: it is both a target and, as shown in (52), a trigger for regressive voicing assimilation.

(52) /fi/ as a trigger of voicing assimilation:
   a. s hradem [zfiradem] ‘with a castle’
   b. z hradu [zfiradu] ‘from a castle’
The pattern reflected in (52) is not entirely consistent: Short (1993a) reports that in some varieties of Czech /ť/ is subject to progressive assimilatory devoicing (yielding, for example, [s]xradem] instead of (52a)). This observation points to another obstacle in the way of a phonetic treatment of Czech voicing assimilation: in Padgett’s system, there is no obvious explanation for progressive assimilation. The /ť/ in s hradem, the /v/ in tvůj, and the /r/ in pří are all in pre-sonorant position, and so should be required by IDENTPS(VOICE) to retain their underlying voicing values. In the Russian case, a significant advantage of Padgett’s approach is that the right-to-left direction of assimilation need not be stipulated; it follows from the positional faithfulness constraints. In Czech, however, assimilation occurs in both directions, and does not appear to have any consistent phonetic motivation.

2.5 Extending the formal analysis

2.5.1 A formal account of the Russian pattern

While Padgett’s functional explanation of Russian voicing assimilation cannot account for Czech, the formalist analysis of Czech proposed above can easily be adapted to generate the Russian pattern. This section sketches one possible formal account of Russian voicing assimilation that follows very closely the analysis of Czech presented in §2.3; Avery (1996) offers a very similar account that uses the same featural representations, but with rules expressed in terms of syllable structure rather than segmental adjacency.

Russian, like those dialects of Czech in which /v/ and /ř/ pattern together, is a split LV/CV system, in which the anomalous segment /v/ is specified for neither [Laryngeal] nor [SV], as shown in (53).
Chapter 2. Voicing assimilation and prophylactic features

(53) Feature specifications for Russian

<table>
<thead>
<tr>
<th>VOICED OBSTRUENTS</th>
<th>VOICELESS OBSTRUENTS</th>
<th>/v/</th>
<th>SONORANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>/d/</td>
<td>/t/</td>
<td>/v/</td>
<td>/n/</td>
</tr>
<tr>
<td>Laryngeal</td>
<td>Laryngeal</td>
<td></td>
<td>SV</td>
</tr>
<tr>
<td>Voice</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As in Czech, Russian voicing assimilation spreads [Laryngeal] leftwards, replacing any [Laryngeal] feature that might already be present on the target. The assimilation rule is stated in (54).

(54) Russian voicing assimilation

\[
\begin{align*}
\text{Rt} & \leftarrow \text{Laryngeal} \\
\text{Laryngeal} & \leftarrow \text{Voice} \\
\end{align*}
\]

Final devoicing involves the word-final insertion of a bare [Laryngeal] feature, which is then spread leftward by the same process, as shown in (55).

(55) Final devoicing

\[
\begin{align*}
\text{Rt} & \leftarrow \text{Laryngeal} \\
\text{Laryngeal} & \leftarrow \text{Voice} \\
\end{align*}
\]

In forms such as /lavka/ [lafka] ‘bench,’ /v/ is a target for assimilation. In forms such as /sverx/ [sverx] ‘above,’ however, /v/ does not itself trigger assimilatory voicing, because it has no [Laryngeal] feature to spread. Word-finally, however, as in /trezv/ [tresf] ‘sober,’ final devoicing provides the /v/ with a bare [Laryngeal] feature, which then spreads leftward onto an adjacent obstruent.
In this brief formal treatment of Russian, I have departed from Padgett’s practice in transcribing the anomalous segment as /v/ rather than /v/. This does not indicate disagreement with Padgett’s statement of the phonetic facts of Russian; rather, I have done this merely for the sake of simplicity. At the phonetic level, the segment surfaces as either /v/ or /f/; the phonetic implementation rules that realize it as a fricative or as a narrow approximant are irrelevant, in the formal approach, to its phonological behaviour. At the phonemic level, there is no meaningful distinction to be made between /v/ and /v/: because the phonological system of Russian does not contrast these two segments, the underlying featural representation is indeterminate between them until it has been submitted to phonetic implementation. Under the theory of underspecification pursued here, underlying /v/ or /v/ is distinguished and defined only by its lack of the features [SV] and [Laryngeal]. Since there is no phonetic symbol for such an abstraction, I follow a long-standing convention in representing the segment with the simplest IPA symbol that is sufficiently close to its phonetic forms to avoid confusion.

2.5.2 Slovak

As argued by Hall (2003), the underspecified analysis of Czech proposed here can also be extended to Slovak and Polish.

The phonemic consonant inventory of Slovak is shown below in Table 2.4. Orthographic symbols are shown in angle brackets where they differ from the IPA symbols.

As in Czech and Russian, Slovak obstruents participate in a process of regressive voicing assimilation, which results in both devoicing (56) and voicing (57). Assimilation applies within derived words in (56a–d) and (57a–d), and between a preposition and its object in (56e–f) and (57e–g).

9. Length is contrastive on Slovak liquids only when they are syllabic.
<table>
<thead>
<tr>
<th>MANNER</th>
<th>VOICING</th>
<th>PLACE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>bilabial/</td>
</tr>
<tr>
<td></td>
<td></td>
<td>labiodental</td>
</tr>
<tr>
<td></td>
<td></td>
<td>dental/</td>
</tr>
<tr>
<td></td>
<td></td>
<td>alveolar</td>
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<tr>
<td></td>
<td></td>
<td>palatal/</td>
</tr>
<tr>
<td></td>
<td></td>
<td>postalveolar</td>
</tr>
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<td></td>
<td></td>
<td>velar/</td>
</tr>
<tr>
<td></td>
<td></td>
<td>glottal</td>
</tr>
<tr>
<td>stop</td>
<td>voiceless</td>
<td>p</td>
</tr>
<tr>
<td></td>
<td></td>
<td>t</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c ⟨t’⟩</td>
</tr>
<tr>
<td></td>
<td></td>
<td>k</td>
</tr>
<tr>
<td></td>
<td>voiced</td>
<td>b</td>
</tr>
<tr>
<td></td>
<td></td>
<td>d</td>
</tr>
<tr>
<td></td>
<td></td>
<td>j ⟨d’⟩</td>
</tr>
<tr>
<td></td>
<td></td>
<td>g</td>
</tr>
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<td>voiceless</td>
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<td></td>
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<td></td>
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<td>s</td>
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<td></td>
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<td>x ⟨ch⟩</td>
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<td></td>
<td></td>
<td>fi ⟨h⟩</td>
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<td>voiced</td>
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<td>n</td>
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<td></td>
<td>n ⟨ň⟩</td>
</tr>
<tr>
<td>trill</td>
<td>voiced</td>
<td>r, r: ⟨ř⟩²⁹</td>
</tr>
<tr>
<td>lateral</td>
<td>voiced</td>
<td>l, l: ⟨l⟩²⁹</td>
</tr>
<tr>
<td></td>
<td></td>
<td>š ⟨l’⟩</td>
</tr>
<tr>
<td>glide</td>
<td>voiced</td>
<td>j</td>
</tr>
</tbody>
</table>

Table 2.4: The phonemic consonant inventory of Slovak

(56) a. **srdečný** [sr̩dɛʃni:] ‘cordial’ (adj.)

b. **srdce** [sr̩tsɛ:] ‘heart’

c. **muža** [muʒa] ‘man’ (gen. sg.)

d. **mužstvo** [muʃstvo] ‘team’

e. **k tebe** [kɛcbe] ‘to you’

f. **z kina** [skina] ‘from a cinema’
2.5. Extending the formal analysis

(57) a. *prosit’* [prɔʃic] ‘to ask’
b. *prosba* [prɔzba] ‘request’
c. *mlatieb* [mlatjεp] ‘threshing’ (gen. pl.)
d. *mlatba* [mladba] ‘threshing’ (nom. sg.)
e. *k domu* [gdOmu] ‘to a house’
f. *z domu* [zdOmu] ‘from a house’
g. *s dievčatkom* [zdjeftatkom] ‘with a girl’

In Slovak, obstruents can also be voiced in assimilation to a following sonorant consonant or vowel, as illustrated in (58).

(58) a. *vlak* [vlak] ‘train’
b. *vlak mešká* [vlag meʃka:] ‘the train is late’
c. *vlak ide* [vlag ije] ‘the train is coming’
d. *tak+mer* [tagmr] ‘almost’
e. *s otcom* [zOtsOm] ‘with a father’
f. *viac+násobný* [viadnacsnobi:] ‘multiple’ (adj.)

However, assimilatory voicing triggered by sonorants occurs only across (some) morpheme boundaries. The word *vlá kho* in (59a), which Short (1993b) describes as containing an ‘opaque’ boundary, contrasts with the examples involving *vlak* in (58a-c). In (59c), assimilation does not occur across the boundary between the stem /xlap/ and the masculine instrumental plural suffix /-mi/, but in (59d), assimilation applies across the higher-level boundary between the modal *môže* and its subject.

(59) a. *vlá kho* [vlakno] ‘fibre’ (cf. (58a-c) above)
b. *chlap* [xlap] ‘guy’ (nom. sg.)
c. *chlap+mi* [xlapmi] ‘guys’ (inst. pl.)
d. *chlap môže* [xlab mwɔʃε] ‘a guy can’

Slovak obstruents, but not sonorants, are subject to final devoicing, as shown in (60).
As in Czech and Russian, /v/ in Slovak is a target (61), but not a trigger (62), for obstruent voicing assimilation.

Descriptions of Slovak do not mention /v/ as a trigger of the assimilatory voicing illustrated in (58).

Unlike Czech and Russian /v/, Slovak /v/ is not subject to word-final devoicing. Instead, syllable-final /v/, both word-finally and word-internally, is lenited to [w], as in the examples in (63).
2.5. Extending the formal analysis

(63)  a. pravý [pra.vi:] ‘true’
    b. pravda [praw.da] ‘truth’
    c. stav [staw] ‘position’
    d. stavba [staw.ba] ‘building’
    e. krv [krw] ‘blood’

The Slovak voicing assimilation facts can be treated in much the same way as the Russian ones. Again, the anomalous segment /v/ is unspecified for voicing features; sonorants have [SV], and regular obstruents have [Laryngeal], as shown in (64).

(64) Feature assignments for Slovak

<table>
<thead>
<tr>
<th>VOICED OBSTRUENTS</th>
<th>VOICELESS OBSTRUENTS</th>
<th>/v/</th>
<th>SONORANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>/d/</td>
<td>/t/</td>
<td>/v/</td>
<td>/n/</td>
</tr>
<tr>
<td>Laryngeal</td>
<td>Laryngeal</td>
<td>SV</td>
<td></td>
</tr>
<tr>
<td>Voice</td>
<td>Voice</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As in Czech and Russian, regressive voicing assimilation consists in the leftward spreading of a [Laryngeal] feature, and final devoicing is driven by the insertion of a bare [Laryngeal] feature before a word boundary.

(65) Voicing assimilation and final devoicing in Slovak

a. Voicing assimilation

```
\begin{array}{c}
\text{Rt} \\
\text{Laryngeal} \\
\text{Voice} \\
\end{array}
\right)
\quad \text{Rt}
\begin{array}{c}
\text{Laryngeal} \\
\text{Voice} \\
\end{array}
```

```
b. Final devoicing

\[
\begin{array}{c}
\text{Rt} \\
\mid \text{Laryngeal} \\
\mid \text{Voice} \\
\end{array} # \quad \rightarrow \quad \begin{array}{c}
\text{Rt} \\
\mid \text{Laryngeal} \\
\mid \text{Voice} \\
\end{array} \\
\]

In Slovak, however, the rule in (65b) must be bled by a rule that changes /v/ to [w] in coda position. As formulated in (66), this rule inserts the features [SV] and [Approximant] into a wholly unmarked segment that occurs in a coda.

(66) Slovak coda v-lenition

\[
\begin{array}{c}
\text{Rt}_\sigma \\
\mid \text{SV} \\
\mid \text{Approximant} \\
\end{array} \quad \rightarrow \quad \begin{array}{c}
\text{Rt}_\sigma \\
\mid \text{SV} \\
\mid \text{Approximant} \\
\end{array}
\]

The assimilatory voicing triggered by sonorants, illustrated in (58) above, is difficult to explain in any framework. I will not attempt to formulate a rule for it here, largely because it is not clear from the available data precisely what role morphological structure plays in defining the environment in which this process occurs. Given representations along the lines suggested in (64), it might be possible to represent this assimilation as leftward spreading of [SV]. However, this would require a revision of the feature geometry assumed in (64), in which a segment with a bare [SV] node is interpreted as nasal by default, and other sonorant manners of articulation are distinguished by features such as [Lateral], [Vibrant], and [Approximant] dependent on [SV]. Under these representations, spreading of [SV] should result in sonorization, not just voicing, producing forms such as [*vlaŋ meʃkaː] for vlak mešká in place of (58b).

The assimilation facts in (58) are, if anything, even more difficult to account for in cue-based approaches such as those of Steriade (1997) and Padgett (2002). Steriade’s positional markedness constraint hierarchy (67a) and Padgett’s positional faithfulness
constraint hierarchy (67b) both predict that voicing contrasts should be preserved in presonorant position if they are preserved anywhere at all.

(67) Cue-based constraint hierarchies

a. Positional markedness (Steriade 1997)
   \[
   \tau[\alpha \text{ voice}] / V - \text{sonorant} >> \tau[\alpha \text{ voice}] / V - \#
   \]
   \[
   >> \tau[\alpha \text{ voice}] / V + \text{sonorant}
   \]

b. Positional faithfulness (Padgett 2002)
   \[
   \text{IDENT}_{\text{PS}}(\text{voice}) >> \text{IDENT}_{\text{WF}}(\text{voice}) >> \text{IDENT}_{\text{PO}}(\text{voice})
   \]

   The hierarchy in (67a) says that marked voicing values are more strongly dispreferred in pre-obstruent positions than word-finally, and more strongly dispreferred word-finally than in presonorant positions. The one in (67b) says that underlying voicing specifications are more strongly required to be preserved in presonorant (PS) positions than word-finally (WF), and more strongly required to be preserved word-finally than in pre-obstruent (PO) positions. The positions in which neutralization actually occurs are determined either by the ranking of \text{IDENT}(\text{voice}) with respect to the constraints in (67a) or by the ranking of markedness constraints with respect to the hierarchy in (67b).

   In most contexts, in Slovak and in the other Slavic languages considered here, the underlying voicing specifications of obstruents are preserved in pre-sonorant positions, and neutralized word-finally (by devoicing) and in pre-obstruent positions (by assimilation). In order to generate the pattern in (58), it would be necessary to overrule the preference for preserving underlying voicing contrasts on presonorant obstruents in the appropriate morphological environment. This is already problematic for the cue-based approach, as there is no obvious functional reason for a morphological boundary to condition assimilation.

   The next problem is in determining the result of the neutralization. In the examples in (58), there are two possible descriptions of what is going on: either the obstruents
are assimilating in voicing to the following sonorants, or else they are being voiced by
default. The latter seems unlikely, since cue-based analyses of final devoicing generally
rely on the assumption that the default value for obstruents is \([-\text{voice}]\) (see, e.g., (47c)).
If the voicing in (58) is assimilatory, then there must be an \textit{Agree(voice)} constraint
similar to the one in (47b), but encompassing sonorants (including vowels) as well as
obstruents. In addition, the grammar must ensure that the obstruent assimilates to the
sonorant rather than vice versa; it seems reasonable to posit that the \textit{Ident(voice)}
constraints applying to sonorants outrank those applying to obstruents. (Note that the
positional faithfulness constraints in (67b) make the wrong prediction if they are under-
stood to apply both to sonorants and to obstruents: in the examples in (58c) and (58e),
the assimilated obstruents are in presonorant position, but the sonorants are followed by
obstruents.) This gives us the constraint hierarchy in (68) as a means of accounting for
the Slovak voicing assimilation facts, apart from the anomalous behaviour of /v/.

(68) a. \textit{Ident}_{\text{son}}(\text{voice}): Underlying voicing specifications of sonorants are
preserved in the output.

b. \textit{Agree}_{-\text{son}}(\text{voice}): Contiguous segments agree in voicing across the
relevant type of morphological boundary.

c. \textit{Ident}_{\text{PS}}(\text{voice}): An output segment in pre-sonorant position has
the same value for \([\text{voice}]\) as its input corre-
respondent.

d. \textit{Agree}(\text{voice}): Contiguous obstruents agree in voicing.

The tableau in (69) shows the calculation of the output form for \textit{vlak ide} (‘the
train is coming’).

11 If Slovak \textit{v}, like its Russian counterpart, is phonetically \([v]\), then Padgett’s account of Russian \textit{v}
could fairly readily be adapted to Slovak, the only difference being that in Slovak, \textit{v} complies with \textit{*D/\textit{v}}
syllable-finally by becoming \([+\text{wide}]\) rather than by becoming \([-\text{voice}]\). However, if Slovak \textit{v}
cannot be characterized as a ‘narrow approximant,’ then another explanation is required.
2.5. Extending the formal analysis

For the example in (69), the constraints in (68) generate the correct output. However, these constraints wrongly predict that voicing assimilation of obstruents to sonorants across morphosyntactic boundaries should apply left-to-right as well as right-to-left. For example, the phrase *prax a teória ‘practice and theory’ /praks#a#teória/ [pragz#a#teoria] (Short 1993b: 536) would be predicted to surface as [*pragz#a#d-teoria], with the conjunction a triggering assimilation of the voiceless obstruents on both sides of it, as shown in (70).

One initially plausible explanation for the observed pattern would be to say that while voicing of the /t/ in /praks#a#teória/ would violate IDENTPS(VOICE), the voicing of the /s/ at the end of prax violates only the lower-ranked constraint IDENTWF(VOICE). Ranking IDENTPS(VOICE) over AGREE+- (VOICE) would then produce the correct output [pragz#a#teoria]. This ranking, however, fails to predict the word-internal assimilation in examples such as tak+mer (58d) and viac+násobný (58f). Moreover, this analysis seriously dilutes the functional motivation for the constraints and their ranking: in order for its voicing feature to be neutralized, the /s/ at the end of prax must be treated as if it were not phonetically to the immediate left of a sonorant (which which would provide good cues to the voicing of the /s/), but in order for the /s/ to be voiced, it must be treated as phonetically adjacent to a voiced segment. The assimilation of obstruents to
sonorants in Slovak is thus at least as problematic for the cue-based approach as it is for the formal rule-based approach pursued here.

2.5.3 Polish

Polish, the most widely spoken of the West Slavic languages, also exhibits voicing patterns similar to those found in Czech and Slovak. In addition, the historical development of Polish shows how an anomalous segment similar to Czech /ř/ can be diachronically integrated into the regular obstruent voicing system. The phonemic consonant inventory of Polish is given in Table 2.5; as before, orthographic representations are supplied in angle brackets where they differ from the IPA symbols.

<table>
<thead>
<tr>
<th>MANNER</th>
<th>VOICING</th>
<th>PLACE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>bilabial/</td>
</tr>
<tr>
<td></td>
<td></td>
<td>labiodental</td>
</tr>
<tr>
<td>STOP</td>
<td>voiceless</td>
<td>p</td>
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<tr>
<td></td>
<td>voiced</td>
<td>b</td>
</tr>
<tr>
<td>AFFRICATE</td>
<td>voiceless</td>
<td>ts ⟨c⟩</td>
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<td></td>
<td>voiced</td>
<td>dz ⟨dz⟩</td>
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<td>FRICATIVE</td>
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<td>voiced</td>
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<td></td>
</tr>
<tr>
<td>GLIDE</td>
<td>voiced</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.5: The phonemic consonant inventory of Polish
As described by de Bray (1969), Polish obstruents participate in regressive voicing assimilation, which results in both voicing and devoicing, as illustrated in (71). This assimilation, as in the other languages considered so far, can occur across the boundary between a preposition and the word immediately following it, which are treated as a single phonological word (or clitic group).

(71) a. \textit{wódka} [vutka] ‘vodka’

b. \textit{odbiór} [odbiur] ‘(radio) reception’

c. \textit{odporność} [otpornoɕtɕ] ‘resistance’

d. \textit{obok domu} [oboq domu] ‘near the house’

e. \textit{obok tego domu} [obok tego domu] ‘near this house’

Polish obstruents are also subject to final devoicing, as in (72).

(72) a. \textit{już} [juʃ] ‘now’

b. \textit{brzeg} [bʐek] ‘shore’

c. \textit{przez} [pʃes] ‘through’

Polish /v/, written as ⟨\textit{w}⟩, undergoes regressive assimilatory devoicing when it precedes a voiceless obstruent, but does not trigger regressive assimilatory voicing when it follows one. Instead, like Czech /r̝f/ (and /v/ in some Czech dialects), it is subject to progressive assimilatory devoicing.

(73) a. \textit{w Gdyni} [v̞d̞iɲi] ‘in Gdynia’

b. \textit{w Polsce} [fpolstse] ‘in Poland’

c. \textit{dwa} [dva] ‘two’

d. \textit{twój} [tfuj] ‘your (sg.)’

e. \textit{kwaśny} [kfaɕni] ‘sour’

12. The historical reasons for the correspondence of ⟨\textit{rz}⟩ to /ż/ and /f/ are discussed below.
13. According to Rothstein (1993: 689), some speakers make a distinction between ⟨\textit{ch}⟩ /ʃ/ and ⟨\textit{h}⟩ /ɣ/, but most pronounce both ⟨\textit{ch}⟩ and ⟨\textit{h}⟩ as /x/. 
14. The Polish data discussed here are drawn from de Bray (1969), Stieber (1973), and Rothstein (1993).
These data support a treatment of Polish as an LV language with /v/ as an exceptional CV segment, as shown in (74).

(74) Voicing feature specifications for Polish

<table>
<thead>
<tr>
<th>VOICED OBSTRUENTS</th>
<th>VOICELESS OBSTRUENTS</th>
<th>/v/</th>
<th>SONORANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>/d/ Laryngeal</td>
<td>/t/ Laryngeal</td>
<td>/v/</td>
<td>/n/ SV</td>
</tr>
<tr>
<td>Voice</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As in Czech, regressive assimilation spreads a [Laryngeal] feature (with or without dependent [Voice]) leftward to any non-syllabic segment; progressive assimilation spreads a [Laryngeal] feature rightward, targeting only segments not already specified for either [Laryngeal] or [SV].

In addition, Polish once had the phoneme /zt/, but in virtually all dialects this segment has now been replaced by non-trilled fricatives /z/ and /ʃ/.

However, words that formerly contained /*zt/ commemorate the trilled fricative orthographically in the retention of the spelling ⟨rz⟩. The pattern of correspondence of ⟨rz⟩ to /z/ and /ʃ/ indicates that Polish /*zt/, like Czech /tʃ/, was subject to progressive assimilation.


Stieber (1973) concludes that Polish /*zt/ had voiced and voiceless allophones, the latter occurring word-finally and on either side of a voiceless obstruent, as in (76).

---

15. The cognate segment in Slovak merged with the non-fricative trill /tʃ/, which is a phonologically well-behaved sonorant.
2.5. Extending the formal analysis

(76) a. twarz \([*tfar] \rightarrow [tfaj]\) ‘face’
    b. krzak \([*k\rak] \rightarrow [kjak]\) ‘bush’
    c. pierzchać \([*p\eraxterc] \rightarrow [p\efaxterc]\) ‘to flee’

Stieber (1973) finds textual evidence of the gradual loss of \(/^{*}r\)/ in Polish from as early as 1411, in which year the thirteenth scribe of the Pyzdry law courts on three occasions misspelled the word pomoży (\(/^{*}\text{pomo}z\)/, ‘help!’) as pomorzy. This confusion of ⟨ż⟩ and ⟨rz⟩ suggests that for the scribe, both spellings represented the sound \(/\text{ʒ}/\).

Applying the split LV/CV system to Polish allows us to draw a seamless picture of the transition from \(/^{*}r\)/ to \(/\text{ʒ}/\) and \(/\text{ʃ}/\). Originally, \(/^{*}r\)/ would have had no voicing specifications, and would have been realized phonetically as it is in present-day Czech. Because the trilled fricative is a particularly difficult sound to articulate (it is generally the last phoneme acquired by Czech children), Polish \(/^{*}r\)/ gradually lost its trilled character, resulting in the realizations shown in (77).

(77) Surface forms of \(/^{*}r\)/ in Polish

\[
\begin{array}{c|c|c}
\text{Rt} & \text{Laryngeal} & \text{Voice} \\
\hline
\text{a. Beside voiced obstruents:} & \text{→ voiced:} & [*r] > [\text{s}] \\
\text{b. Beside voiceless obstruents and word-finally:} & \text{→ voiceless:} & [*r] > [\text{ʃ}] \\
\text{c. Elsewhere:} & \text{→ voiced:} & [*r] > [\text{s}] \\
\end{array}
\]

Some dialects of Polish already had phonemic \(/\text{ʒ}/\) and \(/\text{ʃ}/\), with the usual LV specifications for obstruent voicing. In these dialects, the phonetic forms in (77) would have been interpreted by the next generation of Polish learners as resulting from underlying \(/\text{ʒ}/\) and \(/\text{ʃ}/\). After voiceless obstruents in non-final position (as in przy, krzak, or pierzchać), \(/^{*}r\)/ \(/\text{ʃ}/\) would be taken as the result of underlying \(/\text{ʃ}/\), since an underlying
Chapter 2. Voicing assimilation and prophylactic features

/ʒ/ would be expected to trigger regressive voicing. After voiced obstruents (as in *brzeg*), and in non-final positions not adjacent to obstruents (as in *morze*), */ʃ/ [ʒ] would have to be interpreted as underlying /ʒ/. Everywhere else, either /ʒ/ or /ʃ/ would result in the correct surface form.\(^{16}\) In dialects that did not already have /ʒ/ and /ʃ/, */ʃ/ would simply become /ʒ/, retaining its underlying underspecification for voicing, and changing only in its phonetic implementation as a non-trilled fricative. Thus a mixed LV/CV system is consistent with the Polish voicing facts both synchronically and diachronically.

### 2.6 The need for prophylactic features

As we have seen in the preceding sections, underspecified representations compatible with the Successive Division Algorithm are highly successful in providing an account of the voicing assimilation phenomena in Czech, Russian, Slovak, and Polish. However, the feature specifications needed to generate the Czech pattern make an unexpected false prediction—one that cannot be corrected while maintaining the strongest version of the Contrastivist Hypothesis. In order to solve this problem, it is necessary to posit a minimal retreat from strong contrastivism, and to say that redundant features, although they are not active in the phonological computation, may nonetheless be present in it.

#### 2.6.1 The problem

The problem arises most clearly in those dialects of Czech that have segments exhibiting five distinct patterns of voicing behaviour. In these dialects, /ʃ/ undergoes progressive assimilatory devoicing, but /v/ does not. Accordingly, these dialects use the feature specifications shown in (41d), repeated below as (78). Obstruents that can trigger voicing assimilation have the feature [Laryngeal], with the voiced ones being further specified for

\(^{16}\) In the absence of evidence to the contrary from alternations, learners would presumably posit underlying representations identical to the surface forms, by some transparency principle along the lines of Prince and Smolensky’s (1993) Lexicon Optimization.
2.6. The need for prophylactic features

[Voice]. Sonorants and /v/ are specified for [SV], which protects them from progressive assimilatory devoicing; true sonorants are distinguished by the presence of additional features such as [Nasal] or [Liquid]. The trilled fricative /ɾ/ has no voicing feature specifications at all.

(78) Specifications for Czech dialects with five voicing classes

<table>
<thead>
<tr>
<th>VOICED</th>
<th>VOICELESS</th>
<th>/ɾ/</th>
<th>/v/</th>
<th>SONORANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBSTRUENTS</td>
<td>OBSTRUENTS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>/d/</td>
<td>/t/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laryngeal</td>
<td>Laryngeal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voice</td>
<td>Voice</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[SV]</td>
<td>[Laryngeal]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[Nasal] {m, n, n}</td>
<td>{p, t, c, k, f, s, f, x, ts, tʃ}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[Approx.] {j}</td>
<td>{v}</td>
<td>{ɾ}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[Liquid] {l, r}</td>
<td>{b, d, j, g, z, 3, f}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[SV]</td>
<td>[Laryngeal]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These representations can be assigned by the SDA, using the divisions shown in (43), repeated below as (79a); the corresponding feature hierarchy is shown in (79b).17

(79) a. Divisions yielding five voicing classes

<table>
<thead>
<tr>
<th>[SV]</th>
<th>[Laryngeal]</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Nasal] {m, n, n}</td>
<td>{p, t, c, k, f, s, f, x, ts, tʃ}</td>
</tr>
<tr>
<td>[Approx.] {j}</td>
<td>{v}</td>
</tr>
<tr>
<td>[Liquid] {l, r}</td>
<td>{b, d, j, g, z, 3, f}</td>
</tr>
<tr>
<td>[SV]</td>
<td>[Laryngeal]</td>
</tr>
</tbody>
</table>

17. There are several other feature hierarchies that would also produce (79a); for example, the divisions made by the features [Nasal], [Liquid], and [Approximant] will generate the same specifications regardless of the order in which they apply, and the relative ordering of [Laryngeal] and [SV] is likewise not crucial.
b. Feature hierarchy corresponding to (79a)

\[
\{b, d, j, g, z, ʒ, ɹ, p, t, ts, c, tʃ, k, f, s, ʃ, x, m, n, ň, r, l, j, v, ɹ\}
\]

Recall (from §1.2.7) that in a set of representations assigned by the SDA, there is always one maximally underspecified segment. In an inventory taken as a whole, there will be one segment with no marked features at all; in any subinventory, there will be one segment that bears no marked features other than the ones that define the subinventory.

In the Czech consonant inventory, the maximally underspecified segment is /ɹ/. Because it is the only segment that has neither [Laryngeal] nor [SV], its lack of voicing feature specifications suffices to make it featurally distinct from the rest of the inventory; accordingly, there is no need for the SDA to assign any other features to it. Once the divisions in (79) have been made, /ɹ/ is in a class by itself.

There will also be one maximally underspecified segment within the class of voiceless obstruents—i.e., one segment in the set \{p, t, c, k, f, s, ʃ, x, ts, tʃ\} will be specified only with the feature [Laryngeal]. In order to determine which segment this is, it would be necessary to determine which place and manner features are crucially active in Czech; however, this question need not be answered for the purposes of the present discussion. Only two facts are crucial here:

1. Whatever the least specified voiceless obstruent is, it cannot be /ɹ/; there is no phonemic voiceless counterpart to /ɹ/.
2. Whatever the least specified voiceless obstruent is, the spreading of a bare [Laryngeal] feature to /t/ will produce a segment that is featurally identical to it.

Suppose that the least marked voiceless obstruent happens to be /t/. In that case, spreading a bare [Laryngeal] feature onto /t/ will produce a segment that cannot in any way be distinguished from a /t/. The representations will predict, for example, that progressive assimilatory devoicing will cause /praːt/ to surface as [ptaːt], thus neutralizing the contrast between přát ([praːt], ‘to grant’) and ptát ([ptaːt], ‘to inquire’). This incorrect derivation of [ptaːt] from underlying /praːt/ is shown in (80).¹⁸

\[\begin{array}{cccc}
\text{P} & \text{R} & \text{A} & \text{T} \\
\text{Lar.} & \text{Lar.} & \text{Lar.} & \text{Lar.} & \text{Lar.} & \text{Lar.} \\
\text{P} & \text{R} & \text{A} & \text{T} \\
\text{Lar.} & \text{Lar.} & \text{Lar.} & \text{Lar.} & \text{Lar.} & \text{Lar.} \\
\text{P} & \text{T} & \text{A} & \text{T} \\
\\end{array}\]

Final devoicing would also incorrectly derive [t] (or whatever the least marked voiceless obstruent is) from /t/, causing, for example, the word lékař ([leːkəř], ‘doctor’) to surface as [⁎leːkat] (very nearly neutralizing it with lekat [leːkat], ‘to frighten’). The same problem applies to regressive assimilatory devoicing ([leːkarsťiː] [⁎leːkarsťiː], ‘medicine’ ≠ [⁎leːkatstviː]), and an analogous problem occurs in forms in which /t/ is adjacent to a voiced obstruent, as in břeh [brex] ‘shore’. In these latter cases, voicing assimilation should be phonetically vacuous, spreading a [Laryngeal] feature with dependent [Voice] onto a segment that would otherwise be voiced by default. However, the representations dictated by the SDA predict that /t/ next to a voiced obstruent should become featurally identical to the least specified voiced obstruent in the inventory; if this is /d/, for example, then břeh would be expected to surface as [⁎bdex].

³ It is not possible to overcome these problems simply by assigning features in a different order. Any sequence of divisions that assigns to /t/ features that would preserve

¹⁸ Abbreviations: Lab. = Labial; Voc. = Vocalic (or any feature distinguishing /aː/ from consonants); Lar. = Laryngeal. For the sake of simplicity, I have not shown the operation of the final devoicing rule formulated in (39), which would apply vacuously to the word-final /t/.
its distinctness under assimilation fails to predict its unique voicing behaviour. Consider for example the two alternative sequences of divisions sketched in (81). Each of these sequences assigns /r/ the features [Vibrant] and [Palatal], a combination of specifications which is not applicable to any other segment, and leaves /r/ with no voicing feature specifications. In (81a), the first feature assigned is [Vibrant], which places /r/ in a natural class with the sonorant /r/; in (81b), [Palatal] is the first feature, grouping /r/ with other segments that share its place of articulation.

(81) a. Vibrant > Palatal > other features

\[
\begin{array}{l|l}
\text{[Vibrant]} & \{p, t, c, k, f, s, f, x, ts, \hat{f}, \} \\
\{r\} & \{b, d, j, g, z, z, \hat{r}, \} \\
\text{[Palatal]} & \{v, m, n, p, j, l\} \\
\end{array}
\]

b. Palatal > Vibrant > other features

\[
\begin{array}{l|l}
\text{[Palatal]} & \{p, t, k, f, s, x, ts, \} \\
\{r\} & \{b, d, g, z, \hat{r}, \} \\
\text{[Vibrant]} & \{c, f, \hat{f}, j, z, p, j\} \\
\{v, m, n, j, l, r\} & \{b, d, j, g, z, \hat{r}, \} \\
\end{array}
\]

Again, however, there will always be one minimally specified segment in each subinventory. So, in (81a), /r/ will be specified only for [Vibrant], and there will be one other segment with no features at all. In (81b), there will be one segment with only [Palatal], and one other segment with no features at all. In each of these cases, then, there will be at least two other segments that, like /r/, have no voicing features. There will thus be no way to explain why these segments do not pattern with /r/ with respect
to voicing assimilation; the rule for progressive devoicing would have to be constructed arbitrarily so as to target a segment with the features [Palatal] and [Vibrant].

Analogous problems arise at least potentially with many, though not all, of the other anomalous segments discussed in this chapter. In Czech dialects with five voicing classes, /v/ is not problematic. Because it is the only segment specified for [SV] that does not also have any of the features [Liquid], [Nasal], or [Approximant], it will always be featureally distinguishable, even when it has been targeted by one of the voicing assimilation rules.

In Czech dialects with only four voicing classes, one or the other of /v/ and /r/ will inevitably be problematic. In these dialects, /v/ and /r/ form a natural class defined by the lack of marked voicing features. Within this subinventory, the SDA must distinguish /v/ from /r/ by assigning a marked feature to one or the other. If a marked feature is assigned to /v/, then fully unspecified /r/ poses the same problem as in dialects with five voicing classes. Suppose, then, that a marked feature is instead assigned to /r/. If /r/ is assigned the feature [Vibrant], then it will remain identifiable even after undergoing voicing assimilation: /r/ is the only other segment that could possibly be specified as [Vibrant], and it is distinguished from /r/ by the feature [SV]. However, the fully unspecified /v/ will then cause difficulties. Assimilatory devoicing of /v/ is not necessarily problematic, because /v/, unlike /r/, does have a counterpart among the voiceless obstruents: if /f/ happens to be the least specified voiceless obstruent, then a devoiced /v/ will be realized correctly. But the regressive assimilation rule in (37) will also spread a [Laryngeal] feature with dependent [Voice] onto /v/ from a voiced obstruent, and /v/ has no counterpart among the segments specified with [Voice]. The representations thus incorrectly predict that /v/, when it occurs to the immediate left of a voiced obstruent, will become identical to the least specified member of the set {b, d, j, g, z, ñ, ř}. 
Regressive assimilation could conceivably be split into two rules, at the cost of some formal elegance, so that one rule of regressive assimilatory devoicing would spread bare [Laryngeal] leftward onto any non-syllabic segment, and a separate rule of regressive assimilatory voicing would spread [Voice] leftward from one [Laryngeal] feature to another. The underspecified /v/ would then be immune to regressive assimilatory voicing, which would be phonetically vacuous anyway, since /v/ is voiced in the default case. However, this approach wrongly predicts that /v/ should block regressive assimilatory voicing. In reality, regressive assimilation spreads voicing through /v/, as in the example víc vdolků /viːts vdolkuː/ [vîªɻ vɗolkuː] ‘more muffins,’ in which the voicing of the /ts/ is indirectly triggered by the /d/ (cf. tvůj [tuvːj] ‘your’). The next recourse, then, would be to account for the transparency by constructing the regressive assimilatory voicing rule to treat (non-syllabic) segments lacking [Laryngeal] as invisible. This resolves the specification problem, but loses the unified treatment of regressive assimilation.

Similar problems arise in the other languages discussed in this chapter, in which /v/ is the only anomalous segment. In Russian, Slovak, and Polish, /v/ has a phonemic voiceless counterpart /f/, but no phonemic counterpart specified for [Voice]. As in Czech, then, either /v/ will be impossible to identify once it has received the features [Laryngeal] and [Voice], or the rule of regressive assimilation must be revised.

In any case, /ɾ/ in Czech dialects with five voicing classes poses a problem regardless of how assimilation is derived. Assimilatory devoicing must target /ɾ/, and /ɾ/ has no phonemic voiceless counterpart. It is therefore necessary to revise our assumptions about feature specifications so as to enable a devoiced /ɾ/ to be distinguished from the least specified member of the set of voiceless obstruents.
2.6. The need for prophylactic features

2.6.2 The solution

It seems, then, that it is necessary to retreat from the strongest version of the Contrastivist Hypothesis. As noted in §1.2.2, there are several different ways of interpreting the hypothesis, which is stated below in (82), repeated from (3).

(82) Contrastivist Hypothesis:

The phonological component of a language L operates only on those features which are necessary to distinguish the phonemes of L from one another.

In the strongest—and perhaps the most intuitive—interpretation, (82) can be taken to mean that non-contrastive features are wholly absent during the phonological computation: phonological representations never include redundant features, which are filled in only at the level of phonetic implementation, after all phonological operations have been completed.

However, a minimally weaker interpretation is possible, and in fact such an interpretation is precisely what is required to deal with the problem of /r/. In order to ensure that /r/ is realized as a trilled fricative even when it has undergone voicing assimilation, some redundant feature or features must be present on /r/ during the phonological computation. These features do not, however, need to be visible to the phonology in any way. The phonology makes absolutely no reference to them: they do not spread; they are not targets for spreading or delinking; they are not part of the structural description of any rule. No use is made of them until phonetic implementation, but they must be present before the phonological computation begins, because there is no way of filling them in afterwards.

The Czech data tell us that the contrastive specifications assigned by the SDA must be augmented with what I shall refer to as prophylactic features. A prophylactic...
lactic feature is a redundant feature that is crucially present in the representation of a segment before the phonological computation begins, but which is invisible to all phonological rules. By positing prophylactic features, it is possible to account for the Czech facts while maintaining the position that redundant features are phonologically inert, which is the essence of the Contrastivist Hypothesis.

In the case of /ř/ /ř/, it is not possible to determine the precise phonetic content of the prophylactic feature or features that must be specified. Depending on how place and manner of articulation are encoded among the obstruents, several possible specifications might work, but prophylactic specification of [Vibrant] will be sufficient given any plausible set of representations. The derivation in (83) shows how prophylactic [Vibrant] would ensure the correct surface realization of /ř/ → [ř] in the přát example from (80). The phonological invisibility of the prophylactic feature is indicated by the use of outlined letters.

\[
\begin{array}{c|c|c}
\text{Lab.} & \text{Vfr.} & \text{Voc.} \\
\hline
\text{pr} & \text{ř} & \text{a:} \\
\hline
\text{Lar.} & \text{Lar.} & \text{Lar.}
\end{array}
\]

\[
\begin{array}{c|c|c}
\text{Lab.} & \text{Vfr.} & \text{Voc.} \\
\hline
\text{pr} & \text{ř} & \text{a:} \\
\hline
\text{Lar.} & \text{Lar.} & \text{Lar.}
\end{array}
\]

So far as the phonological component of the grammar is concerned, a devoiced /ř/ is indeed identical to a /t/ (or whatever the least specified voiceless obstruent happens to be). However, when the output of the phonological component is passed on to phonetic implementation, the prophylactically specified feature [Vibrant] becomes visible, and ensures that the segment is realized correctly. (As noted above in §2.6.1, the only other Czech segment that might be specified with [Vibrant] is /r/, and /ř/ is distinguished from /r/ by the absence of [SV].)

20. In §3.1, we will see a case in which more evidence about the content of a prophylactic feature is available.
For /v/, in those systems in which it poses a similar problem, it is not possible to identify a single feature whose prophylactic specification would guarantee the correct realization of /v/ regardless of how the other phonemes of the system are represented. If /v/ is prophylactically specified with both [Labial] and [Continuant], then it will certainly be realized correctly; however, if either of these features is systematically underspecified in the obstruent system, then the other will suffice by itself. For example, if the marked aperture feature for consonants is [Interrupted] rather than [Continuant], and if this feature takes scope over place contrasts as in the partial feature hierarchy shown in (84), then prophylactic [Labial] on /v/ will produce the correct surface forms.\footnote{21}

\begin{center}
\begin{tabular}{c}
(84) Feature hierarchy with [Laryngeal] > [Voice] > [Interrupted] > [Labial]

\begin{verbatim}
   [Laryngeal]
     | [Voice]     | Φ
     | [Interrupted] | [Labial]
     | Φ         | Φ
{b}   {d, j, g}    {z, ř, fi}    {f}    {s, ř, x}
{p}   {t, ts, c, ř', k}    {f}    {s, ř, x}
\end{verbatim}
\end{tabular}
\end{center}

Given the feature specifications in (84), a /v/ specified prophylactically with [Labial] will become featurally identical (for the purposes of phonetic implementation) to /f/ when it receives a bare [Laryngeal] feature, and when it receives [Laryngeal] and [Voice], it will be distinct from /b/ by virtue of lacking [Interrupted], and from /z/, /ě/, and /ř/ by virtue of having [Labial]. Similarly, if [Labial] is systematically underspecified, as in (85), then /v/ need only be specified prophylactically with [Continuant].

\footnote{21. The obstruent inventory shown in (84) and (85) is that of Czech, and so these examples pertain most immediately to the case of Czech dialects with four voicing classes, given contrastive specification of [Vibrant] on /ř/. However, the same divisions could be made in the Slovak, Russian, or Polish obstruent inventories, with the equivalent effect.}
(85) Feature hierarchy with [Laryngeal] > [Voice] > [Lingual] > [Continuant]

In (85), the highest-ranking place contrast is based on the feature [Lingual]. Although labial consonants cross-linguistically tend to be more marked than coronals and dorsals, Clements and Hume (1995: 291) observe that there is evidence in favour of using the feature [Lingual] to identify non-labial consonants as a natural class in Slovak. Lingual consonants trigger backing of a following /æ/ to /a/, as in (86a); labials do not, as in (86b).

(86) a. /vnuːk+æ/ [vnuːtʃa] ‘grandson+dim.’
   b. /xlaːp+æ/ [xlaːpæ] ‘man+dim.’

If [Lingual] is indeed the marked place feature, and the obstruents are specified as in (85), then /v/ can be realized correctly given only a prophylactic [Continuant] feature. When devoiced, /v/ will become featurally identical to /f/; if it receives the features [Laryngeal] and [Voice] by spreading, it will be distinguished from /b/ by [Continuant], and from /z/ , /ʒ/, and /FI/ by the absence of [Lingual].

Although prophylactic features are by definition redundant features, their effect is to prevent the neutralization of an underlying phonemic contrast. In the case of /rɪ/ and /v/, prophylactic specifications ensure that voicing assimilation does not become total assimilation. Dresher (1998a) points out that when a feature is high in the contrastive hierarchy (i.e., early in the sequence of divisions made by the SDA), it is frequently impossible to identify for any given segment a single ‘counterpart’ of that segment with the opposite value for the high-ranking feature. Thus in Czech the ‘voiceless counterpart’ to /rɪ/ is not a single segment, but rather the whole set \{p, f, t, ts, s, c, tʃ, ʃ, k, x\}. This
asymmetric correspondence is due to the fact that the contrastive voicing, place, and manner features of Czech do not fully cross-classify with one another; in other words, there are accidental gaps in the inventory.\footnote{The gaps are accidental only in a purely formal and synchronic sense. The relevant formal definition of an accidental gap is given by Dresher (1998a), who states it in terms of binary features assigned by the SDA:}

In particular, there is a very large gap in the set of consonants that lack marked voicing features: Czech dialects with five voicing classes have only one such consonant, as compared to ten consonants with bare [Laryngeal] features, seven with [Laryngeal] plus [Voice], and seven with [SV]. There is also a small gap in the obstruent series: among the phonemes specified with [Laryngeal], there is none that is also [Vibrant]. The prophylactic specification of [Vibrant] on /\textipa{t}/ defines the phonological location of this gap, for the purposes of phonetic implementation. From a phonetic point of view, it would be meaningless to say that the voiceless counterpart of /\textipa{t}/ is the entire set of voiceless Czech obstruents. However, the feature that prevents phonetic implementation from attempting to realize a devoiced /\textipa{t}/ as a set of ten segments, or as the least marked member of that set, is not relevant to the phonological component of the grammar, because it is not phonologically contrastive. Instead, in its prophylactic role, it ensures that phonetic implementation will preserve properties of /\textipa{t}/ that are (perforce) not distinctive within its singleton subinventory.

The effect of the prophylactic feature on /\textipa{t}/ in Czech is schematized in (87). The vertical alignment of the segments represents their phonological specifications: phonologically, /\textipa{t}/ is parallel to /\textipa{t}/ and /\textipa{d}/ (supposing that these two segments are the least specified members of their respective classes). The prophylactic specification is repre-

\footnote{Diachronically, /\textipa{v}/ and /\textipa{t}/ owe their peculiar status to their origins as lapsed sonorants, as described in \S2.2. Furthermore, a system with two full sets of voiced obstruents, differing only in their ability to trigger voicing assimilation, would presumably be highly unstable because of the difficulties it would pose for acquisition.}
voiced assimilation and prophylactic features

sented as a dotted line that aligns /r\_f/ with the appropriate gaps in the voiced and
voiceless obstruent series, ensuring that when /r\_f/ undergoes voicing assimilation, it does
not merge with its apparent phonological counterparts.

\[(87) \quad p \ f \ t \ ts \ s \ c \ f \ j \ k \ x \]

\[r \]

\[b \ d \ z \ j \ 3 \ 9 \ fi \]

The necessity of prophylactic features arises in part from the fact that, in representations consisting of privative features assigned by the Successive Division Algorithm, there are two things that the absence of a feature can mean. A feature is **contrastively absent** from a segment if, in the division made by that feature, the segment in question was placed into the unmarked subinventory \(\bar{M}\): in such a case, the absence of the feature serves to distinguish the segment from all members of the marked set \(M\). However, if the segment in question has already been parcelled into a subinventory that cannot be divided by the feature, then the feature will be **non-contrastively absent** from the segment. The segment may or may not have the phonetic characteristic that the feature encodes, but in either case it is not marked for the feature because it has already been distinguished from any segments that may have the opposite value.

A very simple example of this is given in (88), in which the vowel inventory \{i, a, u\} is divided first by the feature [High], and then by [Back]. The feature hierarchy is in (88a), and the resulting divisions of the vowel space are in (88b).

\[(88) \quad \text{Division of } /i, a, u/ \text{ with } [\text{High}] > [\text{Back}]\]

\[a. \quad \{i, a, u\} \quad b. \quad \begin{array}{c}
  \{i, a, u\} \\
  \{u\} \quad \emptyset
\end{array}
\]

\[\begin{array}{c}
  \{i\} \\
  \emptyset
\end{array} \quad \begin{array}{c}
  \{i, a, u\} \\
  \emptyset
\end{array} \quad \begin{array}{c}
  \{i\} \\
  \emptyset
\end{array}
\]

\[\begin{array}{c}
  \text{[High]} \\
  \text{[Back]}
\end{array} \quad \begin{array}{c}
  \text{[High]} \\
  \text{[Back]}
\end{array}
\]

\[a \quad i \quad u \quad [\text{High}]
\]

\[\]

\[\]

\[\]

\[\]

\[\]

\[\]
In (88), there are two segments, /i/ and /a/, that lack the feature [Back]. In the case of /i/, [Back] is contrastively absent: the subinventory of [High] vowels is partitioned by the assignment of [Back] to /u/, and the absence of [Back] is crucial to the identity of /i/. For /a/, however, the absence of [Back] is non-contrastive: the partitioning of the inventory by [High] leaves /a/ in a class by itself, and so there is no role for [Back] to play in distinguishing /a/ from the remaining segments in the inventory. Even if /a/ is a back vowel phonetically, the representations predict that it will pattern with /i/ phonologically wherever the feature [Back] is relevant.

The distinction between contrastive and non-contrastive absence may be brought into sharper focus by considering the relation between the Successive Division Algorithm and the phonetic implementation rules that are required to realize the representations it builds. For every division made by the SDA, there is a corresponding redundancy rule governing the phonetic realization of the segments in the unmarked set. In fact, it is sensible to suppose that these rules are constructed as the algorithm proceeds, according to the formula in (89).

(89) **Metarule for the interpretation of contrastively unmarked segments** ([Micus]): Whenever a subinventory of segments that has been defined by the assignment to its members of a set of features $S$ is divided by the assignment of a feature [F], add the following instruction to the rules for phonetic implementation:

“Every segment whose feature specifications are a superset of $S$ must be realized as non-[F] unless it is specified with [F].”

Applied to the system in (88), [Micus] produces the following instructions:

1. Every segment whose feature specifications are a superset of {} must be realized as non-[High] unless it is specified with [High].

2. Every segment whose feature specifications are a superset of {[High]} must be realized as non-[Back] unless it is specified with [Back].
The first instruction, the redundancy rule for [High], is effectively unrestricted; every segment will have feature specifications that are a (not necessarily proper) superset of the empty set. This reflects the fact that the feature [High] takes scope over the entire inventory, and that its absence is therefore necessarily contrastive on any segment. The redundancy rule for [Back], however, applies only to the subinventory marked with [High], because the division predicated on [Back] is made only within the set of high vowels. The phonetic implementation rules governing the place of the non-high vowel (and, for that matter, all rules dealing with rounding, which is not contrastive anywhere in the system) are not predetermined by the algorithm. Given the specifications in (88), these rules might realize /a/ as [e] or [ɔ] or anything in between; or, for that matter, they might be quite vague as to the place and rounding of /a/, indicating only a non-high target whose particular qualities would vary in ways determined by coarticulation.

Prophylactic features are necessarily always features that, in the representations assigned by the SDA, are non-contrastively absent. It would be nonsensical to specify prophylactically a feature that is contrastively absent, for neither contrastive nor prophylactic features may contradict phonetic reality. If a segment has the phonetic characteristic denoted by a feature [F], and the subinventory to which it belongs is divided by the SDA using [F], then that segment must be (contrastively) specified with [F] at that step in the algorithm. Similarly, if a segment does not have the phonetic characteristic denoted by [F], then it cannot be specified with [F] prophylactically, because prophylactic features cannot be removed by the phonology and must therefore be implemented phonetically.

What prophylactic features prevent is the conflation of different phonetic implementation rules for distinct segments from which the same feature is non-contrastively absent. For example, in Slovak, Polish, Russian, and Czech dialects with four voicing classes, given the feature hierarchy in (85), [Continuant] is non-contrastively absent from both /b/ and /v/. The contrastive absence of [Laryngeal] and [SV] places /v/ into a
class which cannot be subdivided by [Continuant], and the presence of [Laryngeal] and [Voice], combined with the contrastive absence of [Lingual] does the same for /b/. Yet /b/ and /v/ require different instructions for phonetic implementation: /b/ is a stop, and /v/ is a continuant. This phonetic difference is somehow not obliterated by the phonological manipulation of contrastive features by voicing assimilation, which seems, from a phonological point of view, to move /v/ into the same class as /b/. The prophylactic specification of [Continuant] on /v/ ensures that /v/ remains associated with its own phonetic implementation rule for aperture, even after the application of voicing assimilation. Similarly, in Czech dialects with five voicing classes, the feature [Vibrant] is non-contrastively absent both from /t/ and from the least specified members of the voiced and voiceless obstruent series. Prophylactic specification of [Vibrant] on /t/ allows it to retain its own rules for manner and place of articulation, even when it has taken on obstruent voicing features.

2.7 Summary

The systems of featural representations posited for the languages examined in this chapter are summarized in (90).

(90) Summary of feature specifications for Czech, Russian, Slovak, and Polish

a. Varieties of Czech with five voicing classes:

<table>
<thead>
<tr>
<th>VOICED OBSTRUENTS</th>
<th>VOICELESS OBSTRUENTS</th>
<th>/t/</th>
<th>/v/</th>
<th>SONORANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>/d/</td>
<td>/t/</td>
<td>/v/</td>
<td></td>
<td>/n/</td>
</tr>
<tr>
<td>Laryngeal</td>
<td>Laryngeal</td>
<td>SV</td>
<td></td>
<td>Nasal</td>
</tr>
<tr>
<td>Voice</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
b. **Varieties of Czech with four voicing classes; earlier stage of Polish:**

<table>
<thead>
<tr>
<th>VOICED OBSTRUENTS</th>
<th>VOICELESS OBSTRUENTS</th>
<th>/t/ and /v/</th>
<th>SONORANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>/d/</td>
<td>/t/</td>
<td>/t/</td>
<td>/n/</td>
</tr>
<tr>
<td>Laryngeal</td>
<td>Laryngeal</td>
<td>/v/</td>
<td>SV</td>
</tr>
<tr>
<td>Voice</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>/C4/CP/CQ/CX/CP/D0</th>
<th>Vibrant Continuant</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>and/or</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In (90), features representing voicing and sonorancy and their dependents are shown below the segments, and other relevant features, including prophylactic features, are shown above them.

The rules that operate on these representations are summarized in (91). Regressive assimilation, shown in (91a), also forms the basis for the process of final devoicing shown in (91b). The only genuinely separate aspect of final devoicing is the insertion of a bare [Laryngeal] node at the end of the word; the subsequent association of this [Laryngeal] node with the final segment (replacing any [Laryngeal] node that might already be present

---

23. Note that whereas in (90a) the feature [Vibrant] is a prophylactic feature, in (90b) [Vibrant] is contrastive, serving to distinguish /r/ from /v/.
on the segment) can be treated as an effect of the regressive assimilation rule. Regressive assimilation and final devoicing apply in all four of the languages treated here; of the other two, progressive assimilatory devoicing (91c) applies only in Czech and Polish, and coda v-lenition (91d) only in Slovak.

(91) Summary of Slavic voicing processes

a. **Regressive voicing assimilation** (Czech, Russian, Slovak, Polish):

\[
\begin{align*}
\text{Rt} & \xrightarrow{\text{Laryngeal}} \text{Rt} \\
\text{Laryngeal} & \xrightarrow{\text{Voice}} \\
\text{Laryngeal} & \xrightarrow{\text{Voice}} \\
\end{align*}
\]

b. **Final devoicing** (Czech, Russian, Slovak, Polish):

\[
\begin{align*}
\text{Rt} & \xrightarrow{\#} \text{Rt} \\
\text{Laryngeal} & \xrightarrow{\text{Voice}} \\
\text{Laryngeal} & \xrightarrow{\text{Voice}} \\
\end{align*}
\]

c. **Progressive assimilatory devoicing** (Czech, Polish):

\[
\begin{align*}
\text{Rt} & \xrightarrow{\text{Rt}} \\
\text{Laryngeal} & \\
\end{align*}
\]

d. **Coda v-lenition** (Slovak):

\[
\begin{align*}
\text{Rt}\sigma & \xrightarrow{\text{SV}} \text{Rt}\sigma \\
\text{Approximant} & \\
\end{align*}
\]

On the basis of the Slavic voicing assimilation data considered in this chapter, it appears that a formal approach based on contrastive feature specifications is essentially
on the right track. However, the data have also compelled a retreat from the strongest version of the Contrastivist Hypothesis. In the minimally weakened version of the hypothesis, redundant features are permitted to be present, but not visible or active, during the phonological computation. Although the precise phonetic content of these prophylactic features has so far not been possible to pin down, their presence is demonstrably crucial to the correct phonetic realization of the output of the phonology. In the next chapter, we will consider cases that shed light on the content of prophylactic features and on the ways in which they might arise diachronically.
Prophylactic features in other languages

Prophylactic features were introduced in the preceding chapter as a means of dealing with a problem in accounting for Slavic voicing assimilation within the context of a theory of contrastive specification. This chapter shows how evidence from other languages sheds light on the questions of how the content of prophylactic features can be identified, and how such features might arise diachronically.

3.1 Identifying prophylactic features: Yowlumne

Yowlumne (also known as Yawelmani) Yokuts, a Penutian language of California, has been of particular interest to phonologists over the years for its patterns of vowel harmony, lowering, and shortening. While much research on Yokuts has focused on the opacity in the interactions among these processes, its relevance to this dissertation lies in the challenges it poses for the theory of contrastive specification assumed here (see §1.2.7).
The problem, which is also discussed by D’Arcy (2003), arises from the fact that the phonemic four-vowel system of Yowlumne behaves as if it is symmetrical with respect to vowel harmony, but appears asymmetrical with respect to vowel lowering. The Successive Division Algorithm cannot assign a set of features that will fully account for this pattern. However, the behaviour of the Yowlumne vowels can be generated within a theory of contrastive specification that includes prophylactic features (introduced in §2.6.2): redundant features that are present but not active in the phonological computation.

3.1.1 The data

The data on Yowlumne used in the phonological literature are drawn from fieldwork conducted by Stanley Newman in 1930 and 1931, published in Newman (1944). Here, we will be concerned primarily with two phonological processes affecting vowels: harmony and lowering.

The underlying inventory of vowel qualities in Yowlumne is shown in (92). There is also a contrast between long and short vowels, which may be attributed to the application of CV templates rather than to feature specifications on the vowels themselves (Archangeli 1985: 341–2).

(92) Underlying vowel qualities

/ɪ/ /ə/ /o/ /u/

Harmony and lowering, together with two other processes with which they interact, can be seen in the derivation of /c’uum+hn/ [c’omhun] ‘destroy+aorist,’ shown in (93).
3.1. Identifying prophylactic features: Yowlumne

(93) Derivation of /c’uum+hn/ [c’omhun] ‘destroy+aorist’

<table>
<thead>
<tr>
<th>Rule</th>
<th>Stephen Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epenthesis</td>
<td>c’uumhin</td>
</tr>
<tr>
<td>Harmony</td>
<td>c’uumhun</td>
</tr>
<tr>
<td>Lowering</td>
<td>c’oomhun</td>
</tr>
<tr>
<td>Shortening</td>
<td>c’omhun</td>
</tr>
<tr>
<td>SF</td>
<td>[c’omhun]</td>
</tr>
</tbody>
</table>

The derivation in (93) illustrates both the effects of the individual rules and the considerable opacity of their ordering. Epenthesis inserts an /i/ to break up unsyllabifiable consonant clusters. This rule feeds harmony, which spreads backness and roundness rightward between vowels of the same height. Lowering, which follows harmony, lowers all long vowels. (In the example in (93), harmony and lowering apply in counterbleeding order; in other contexts, the same ordering of the rules has a counterfeeding effect.) Shortening, which follows lowering (a counterbleeding ordering), shortens long vowels in closed syllables.

3.1.1.1 Harmony

The effects of Yowlumne’s height-dependent vowel place harmony can be seen more systematically in (94), which shows the realizations of the aorist and dubitative suffixes following stems with /i/ (94a–b), /u/ (94c–d), /a/ (94e–f), and /o/ (94g–h). The underlying form of the dubitative suffix is /-al/; the aorist suffix is underlyingly /-hn/, but it receives an epenthetic /i/ that is then subject to harmony. A suffix vowel is realized as back and rounded when it is preceded in the stem by a back round vowel of the same phonological height-class. Thus the epenthetic /i/ in the aorist suffix becomes [u] when it is preceded by an /u/ in the stem, as in (94c–d), and the /a/ of the dubitative suffix becomes [o] under the influence of a preceding /o/ (94g–h). The pattern is summarized schematically in (95).
(94) Alternations showing the operation of harmony (Kenstowicz and Kisseberth 1977: 35)

<table>
<thead>
<tr>
<th>Root</th>
<th>Aorist /-/hn/</th>
<th>Dubitative /-/al/</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. /xil/</td>
<td>[xil-hin]</td>
<td>[xil-al]</td>
</tr>
<tr>
<td>b. /giy/</td>
<td>[giy’-hin]</td>
<td>[giy’-al]</td>
</tr>
<tr>
<td>c. /dub/</td>
<td>[dub-hun]</td>
<td>[dub-al]</td>
</tr>
<tr>
<td>d. /hud/</td>
<td>[hud-hun]</td>
<td>[hud-al]</td>
</tr>
<tr>
<td>e. /xat/</td>
<td>[xat-hin]</td>
<td>[xat-al]</td>
</tr>
<tr>
<td>f. /max/</td>
<td>[max-hin]</td>
<td>[max-al]</td>
</tr>
<tr>
<td>g. /bok'/</td>
<td>[bok’-hin]</td>
<td>[bok’-ol]</td>
</tr>
<tr>
<td>h. /k'o/P/</td>
<td>[k’o?-hin]</td>
<td>[k’o?-ol]</td>
</tr>
</tbody>
</table>

(95) Summary of the effects of harmony

| i ... i/     | [i ... i]     | [i ... a/ | [i ... a] |
| u ... i/     | [u ... u]     | [u ... a/ | [u ... a] |
| a ... i/     | [a ... i]     | [a ... a] |
| o ... i/     | [o ... i]     | [o ... a] |

With respect to harmony, then, the vowel inventory acts as if it is phonologically symmetrical. There are two pairs of vowels, one at each height: in the high vowels, /u/ is the round counterpart of /i/, and in the non-high system, /o/ is the round counterpart of /a/. This symmetry is schematized in (96).

(96) Harmony: symmetrical pattern

| /i/ - - - - - - - - /u/ |
| /a/ - - - - - - - - /o/ |

3.1.1.2 Lowering

The operation of lowering, however, paints a different picture of the shape of the vowel inventory. The data in (97) show the lowering of long vowels; evidence for the underlying
heights of the vowels comes from the application or non-application of height-dependent harmony. (Note also that shortening applies to the long vowels in the aorist forms, because of the consonant-initial suffix /-hn/, but fails to bleed lowering.)

(97) Alternations showing the operation of Lowering (Archangeli 1984; D’Arcy 2003)

<table>
<thead>
<tr>
<th>ROOT</th>
<th>AORIST /-hn/</th>
<th>DUBITATIVE /-al/</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. /hiwiit/</td>
<td>‘walk’ [hiwet-hin]</td>
<td>[hiweet-al]</td>
</tr>
<tr>
<td>b. /c’uum/</td>
<td>‘destroy’ [c’om-hun]</td>
<td>[c’oom-al]</td>
</tr>
<tr>
<td>c. /?opoot/</td>
<td>‘get up’ [?opot-hin]</td>
<td>[?opoot-ol]</td>
</tr>
<tr>
<td>d. /p’axaat’/</td>
<td>‘mourn’ [p’axat’-hin]</td>
<td>[p’axaat’-al]</td>
</tr>
</tbody>
</table>

The effects of lowering are summarized in (98):

(98) Summary of the effects of lowering

a. /ii/ $\rightarrow$ [ee]
b. /uu/ $\rightarrow$ [oo]
c. /aa/ $\rightarrow$ [aa]
d. /oo/ $\rightarrow$ [oo]

What is unexpected, given the symmetrical pattern in (96), is the result of lowering when it applies to /ii/. While we might expect a lowered /ii/ to be realized as its phonemic non-high counterpart [aa], it instead surfaces as [ee], a vowel not present in the underlying inventory at all. The resulting asymmetrical pattern is schematized in (99).

(99)

```
| LOWERING:  |
| as asymmetrical pattern |
| /i/ | /u/ |
| /e/ | /o/ |
| /a/ |
```
3.1.2 Previous approaches

The Yowlumne patterns discussed here have already received much attention in the phonological literature; previous accounts include those of Kuroda (1967); Kisseberth (1969); Kenstowicz and Kisseberth (1977, 1979); Archangeli (1984, 1985); Archangeli and Suzuki (1997); McCarthy (1998); and D’Arcy (2003).

Early generative accounts of Yowlumne employ binary features, with no underspecification, and rely on rules of the sort proposed by Chomsky and Halle (1968). For example, Kenstowicz and Kisseberth (1977: 35) formulate the vowel harmony rule as shown in (100):

\[
\begin{array}{c}
V \\
\alpha\text{high}
\end{array}
\rightarrow
\begin{array}{c}
+\text{round} \\
+\text{back}
\end{array}
/ \begin{array}{c}
V \\
+\text{round} \\
\alpha\text{high}
\end{array}
C_0
\]

These accounts successfully and elegantly capture the crucial opaque interactions among the phonological processes through the use of rule ordering, but the rules themselves are expressed in a formalism that takes advantage of the power of full specification, binary features, and alpha-rules.

Archangeli (1984, 1985) presents an account that uses non-linear rules. In her approach, features are still binary, but subject to Radical Underspecification: all features that can be filled in by redundancy rules are absent from underlying representations. Accordingly, in Archangeli’s approach, the vowels of the Yowlumne inventory have the feature specifications shown in (101).

(101) Radically underspecified representations (Archangeli 1985: 340)

\[
\begin{array}{cccc}
/i/ & /a/ & /o/ & /u/ \\
\text{high} & - & - \\
\text{round} & + & +
\end{array}
\]
However, as discussed in §1.2.4, Radical Underspecification does not actually restrict the role of redundant features in the phonology: although non-contrastive features are systematically absent from underlying representations, they are filled in by rules in the phonological component of the grammar. Since redundancy rules are interspersed with other phonological rules, features that are absent from the underlying representation of a segment may still end up playing a crucial role in that segment’s phonological behaviour. For example, in the account of Yowlumne proposed by Archangeli (1985), the redundancy rule for the feature [±high] is ordered so as to feed harmony:

(102) Rule ordering posited by Archangeli (1985)

1. . . .

2. Redundancy rule for [±high]: [ ] → [+high]

3. Harmony

4. . . .

Archangeli’s account, then, does not shed any light on whether the Contrastivist Hypothesis can be maintained for Yowlumne; in the theory of Radical Underspecification, redundant features are banned from the lexicon, but not from the phonological computation. In the extreme case, although Archangeli does not suggest this for Yowlumne, all the redundancy rules could in principle apply at the very beginning of the derivation, with the result that Radical Underspecification would become indistinguishable from full specification.

More recently, Optimality Theoretic approaches to Yowlumne have focused on the problem of accounting for opacity in a framework that dispenses with ordered rules. For example, Archangeli and Suzuki (1997) are led by the opacity in the Yokuts system to expand the power of OT in three directions. First, in order to deal with the counterfeeding relation between Lowering and Shortening, they introduce the mechanism of “disparate correspondence” constraints such as the one in (103).
Unlike standard OT constraints, the one in (103) is neither a faithfulness constraint mandating the preservation of some aspect of the underlying representation, nor a markedness constraint enforcing surface well-formedness. Instead, it relates one property (length) of input segments with a different property (height) of their output correspondents.

A similar mechanism is needed to deal with the opaque ordering of harmony and lowering. Because Harmony is height-dependent, Archangeli and Suzuki need a constraint to ensure that vowels harmonize only if they have the same value for [±high], but the constraint has to refer to the vowels’ original height specifications, since their surface heights may be changed by lowering. However, the constraint cannot simply refer to input values for [±high], because harmony also applies to epenthetic vowels, which by definition have no input correspondents. Accordingly, Archangeli and Suzuki posit the “input–else” constraint shown in (104).

\[(104) \quad \text{RD}/[\alpha \text{HIGH}]^\text{IE}\]
\[\text{‘Tokens of [±round] in the output link vowels whose input specifications—if any, otherwise output specifications—for [±high] are identical.’}\]

Finally, Archangeli and Suzuki also propose well-formedness constraints on inputs, such as the one in (105).

\[(105) \quad \{V \approx [+\text{high}]\}_1\]
\[\text{‘Input vowels should be [+high].’}\]

The constraint in (105) has no effect on the selection of any output candidate; rather, it is intended to play a role in determining underlying feature specifications, which in OT are standardly held to be selected through Lexicon Optimization, a mechanism that
maximizes similarity between inputs and outputs. Archangeli and Suzuki introduce (105) in order to ensure that underlying /ii/ will not be reinterpreted by Lexicon Optimization as /ee/, since its output correspondents are always subject to lowering. However, the need for a constraint of this sort would likely be obviated by a more sophisticated theory of Lexicon Optimization, such as the one proposed by Inkelas (1995, 1996), which takes alternations into account. To the extent that the underlying height of /ii/ is important, it should be inferable by the learner from the effects of harmony, and need not be stipulated by a constraint such as the one in (105); in any case in which it is unlearnable, it is also inconsequential.

McCarthy (1998) offers a different approach to opacity in OT, based on Sympathy constraints, which enforce correspondence between the output and other members of the candidate set. Like the constraints proposed by Archangeli and Suzuki, Sympathy represents a substantial enhancement of the power of OT. Detailed theoretical and empirical criticisms of Sympathy are offered by Idsardi (1997b, 1998), who shows how Sympathy constraints can make a grammar both delicate and chaotic: minimal changes to the ranking of Sympathy constraints can yield drastically different grammars, and yet, in other contexts, major rerankings can correspond to what appears at the surface to be microparametric variation.

D’Arcy (2003) offers an account of Yowlumne that is much closer to the one pursued here: she employs privative features, subject to contrastive specification as defined by the Successive Division Algorithm, within the general framework of Lexical Phonology. D’Arcy argues that lowering is a post-lexical rule, and thus operates at a stage in the derivation at which redundant features have already been filled in. However, Blevins (2004b) argues that long vowel lowering in Yowlumne is not automatic and exceptionless, as one would expect a post-lexical rule to be; she cites examples of surface long high vowels such as the ones in (106).
Surface long high vowels in Yowlumne (Blevins 2004b)


'ama’ wakkiy ɛz:man ˈteknɪːs+aː+hin
and very.much to.no.avail excite+INCHOATIVE+AORIST
‘(S)he became very much excited, to no avail.’

b. Surface minimal pairs in which long high vowels distinguish extended aspect from non-extended aspect (Blevins 2004b: 44, citing Newman 1944: 55–61)

i. putˈwiyi- ‘whirl about’
   puttˈwiyi- ‘fill the air with whirling motion’

ii. hikˈwiyi- ‘make a hiccoughing sound’
   हिकˈwiyi- ‘make a panting sound’

Blevins (2004b) contends that long vowel lowering and vowel harmony in Yowlumne are not the product of phonological rules at all, but rather of morphological alternations, and suggests a paradigm-based account modelled after Hockett (1967). Here, I abstract away from the question of precisely where in the grammar these processes take place, focussing instead on how the phonological representations must be structured. Even if lowering and harmony are morphological, their regularity and their effects must be explicable in terms of phonological representations; the representations proposed here are compatible with the assumption that harmony and lowering apply at some point in the derivation at which redundant phonetic information is not accessible, which could be morphological, morphophonemic, or phonological.

3.1.3 The analysis

3.1.3.1 Accounting for harmony

In order to permit a satisfactory account of the attested height-dependent harmony pattern, two things are required of the featural representations. First, the feature [Peripheral]
(or its equivalent) must be active in the computation, since it must be spread by the harmony rule. Second, the vowels must be represented as falling into two natural classes on the basis of height, with the high vowels /i/ and /u/ in one class and the non-high vowels /a/ and /o/ in the other.

A suitable set of representations can be assigned by the SDA, using exactly two features to distinguish the four segments of the phonemic vowel inventory, as shown in (107). Since the features fully cross-classify, it makes no difference whether the height contrast takes scope over the place contrast or vice versa.

\[
\begin{array}{c|c}
\text{Peripheral} & \text{High} \\
\hline
/i/ & /u/ \\
/a/ & /o/ \\
\end{array}
\]

The harmony rule must spread [Peripheral] rightward between vowels that share either the presence or the absence of the feature [High]. Since the features are monovalent, the notion of a ‘shared absence’ of High cannot simply be represented as [−high]. However, there are other ways of representing the fact that /a/ and /o/ constitute a natural height class. Three possibilities suggest themselves:

1. There are actually two harmony rules: one applies specifically to pairs of vowels that share the feature [High], while the other applies specifically to pairs of vowels that share the feature [Peripheral].

---

1. Archangeli (1984, 1985) attributes the dependence of harmony on height to ‘coplanar’ representations in which [+round] is a dependent of [±high]. It would be possible to construct similar representations by giving [High] scope over [Peripheral] in the application of the SDA, and mapping the order of divisions onto a feature geometry (cf. Dyck (1995), Béjar (1998)), but this approach is not feasible given privative features. In the representations for /o/ and /a/, there is no [−high] feature for [Peripheral] to attach to; furthermore, since lowering must be implemented as the delinking of [High] rather than as the switching of [+high] to [−high], making [Peripheral] a dependent of [High] would incorrectly predict that a lowered /u/ should become /a/ instead of /o/.
unspecified for height. This possibility is, of course, unattractive in that it fails to
treat harmony as a unified phenomenon; for example, under such an account it is
entirely coincidental that both harmony rules apply in the same direction.

2. The feature [High] is a dependent of an organizing node—Aperture, for example—
whose presence is mandated by a universal feature geometry. Such a node would
not be a feature, and would thus not be assigned by the SDA, but its presence
would follow from the assignment of any feature dependent on it, as per the Node
Activation Condition of Avery and Rice (1989), which is paraphrased in (108) be-
low:

(108) NODE ACTIVATION CONDITION (adapted from Avery and Rice (1989)):
The specification of a feature entails the presence of its dominating node on
all segments in the domain in which that feature is contrastive.

Given the divisions in (107), the domain in which the feature [High] is contrastive
is the entire vowel inventory; accordingly, all vowels would have Aperture nodes,
and in the representations for /i/ and /u/, [High] would depend from Aperture.
Harmony could then be represented as the spreading of [Peripheral] between vowels
that share an Aperture node, on the assumption that consecutive vowels of the
same height would be required by the Obligatory Contour Principle (OCP; Leben
1973) to be linked to a single Aperture node.

3. The feature [High] is a dependent of the contrastive feature by which the SDA dis-
tinguishes vowels from consonants in Yowlumne. Instead of sharing a non-featural
organizing node such as Aperture, consecutive vowels of the same height would
share some distinctive feature, such as [Vocalic], that would be applicable to all
vowels, but which would host the [High] feature on /i/ and /u/. Making [High]
(but not the place feature [Peripheral]) a dependent of [Vocalic] seems reasonable
3.1. Identifying prophylactic features: Yowlumne

in light of the fact that the primary articulatory distinction between vowels and consonants is the degree of constriction in the oral cavity.

Here, I will assume that the third of these options is correct, because it introduces no structure into the representations that cannot be attributed to the operation of the SDA. However, the second option remains a viable fallback position in case evidence surfaces to suggest that [Consonantal], rather than [Vocalic], is the marked feature in Yowlumne, or that [High] cannot be a dependent of [Vocalic] for any other reason.

Given representations along these lines, the harmony rule can be formulated as spreading [Peripheral] rightward between two vowels that share a single [Vocalic] feature, with or without dependent [High], as shown in (109).

(109) (High)
     |
Vocalic
     |
Rt     Rt
     |
Peripheral

3.1.3.2 Accounting for lowering

Assuming that the marked aperture feature is [High], the rule of lowering simply delinks [High] from any vowel associated with two moras, as shown in (110).

(110) μ μ
     |
Rt
     |
Vocalic
     ±
High

In order to derive the attested pattern of Lowering, the featural representations must be such that lowering of /i:/ produces a segment that is not in the underlying inventory. The SDA can produce such a set of representations by means of the divisions shown in (111). The high vowels are identified by [High], and within this class, /i/ is distinguished from /u/ by [Coronal]. The two non-high vowels are distinguished from
each other by a further height feature rather than by a place contrast: /a/ is specified as [Low], and /o/ is unmarked.

(111)  [Coronal]

| /i/ | /u/ |
| [High] | [High] |
|       |       |
| /o/ |
| [Low] |
| /a/ |

As shown in (112), the representations derived in (111) correctly predict that applying the Lowering rule in (110) to /i:/ will produce an [ɛː] rather than either of the two underlying non-high vowels. A lowered /i:/ retains its [Coronal] feature and loses its [High] feature without acquiring a specification for [Low]; it will thus be realized as a mid front vowel.

(112)  µ µ  µ µ

Rt → Rt = [ɛː]

Vocalic Coronal Vocalic Coronal

÷

High

The problem is that the representations in (111) are incompatible with the requirements of harmony. [Peripheral] is not present, and /a/ and /o/ do not have the same aperture feature specifications. However, adjusting the representations to accommodate harmony would yield wrong predictions for lowering. For example, if [Peripheral] were the marked place feature distinguishing the two high vowels, then a lowered /i:/ would become featurally identical to /oː/, or if /a/ and /o/ are treated as belonging to the same height, with /o/ marked for [Peripheral], as in (107), then a lowered /i:/ would be expected to surface as /aː/. 
3.1.3.3 Prophylactic features

The situation in Yowlumne is similar to the problem with Czech voicing assimilation described in §2.6.1. In Czech, the contrastive feature specifications needed to account for voicing assimilation made it impossible to distinguish a devoiced /t̪i/ from some underlying voiceless obstruent; in Yowlumne, the representations dictated by the harmony facts make it impossible to distinguish a lowered /i:/ from the two underlying non-high vowels.

Again, the solution requires only a minimal retreat from the strongest version of the Contrastivist Hypothesis. In order to ensure that lowering of /i:/ does not produce [a:] (or [o:]), it is not necessary for redundant features to be active in, or visible to, any of the phonological rules of Yowlumne. Instead, a prophylactic feature of the sort introduced in §2.6.2 will suffice to differentiate the segments in question at the level of phonetic implementation. In order to be effective, this feature must be present before the phonological computation takes place, but the computation never needs to refer to it in any way.

Assuming that the phonologically active features are those suggested by the harmony facts, as in (113), repeated from (107), there appear at first to be two possible ways of assigning a prophylactic feature to solve the lowering problem.

(113) | [Peripheral]  
---|---
/i/ | /u/  
[High] | [High]  
/a/ | /o/  
[Peripheral]

The first possibility, which more closely parallels the approach taken with /t̪i/, involves assigning a prophylactic feature to /i/. If [Coronatal] is included as a prophylactic
specification on /i/, then at the level of phonetic implementation, that feature could
be used to realize a lowered /i:/ as farther forward (and consequently higher) than an
underlying /a:/.

The relevant set of representations is shown in (114); as in §2.6.2, the
prophylactic feature’s phonological invisibility is indicated by outlined letters.

\[
\begin{array}{cccc}
/i/ & /a/ & /o/ & /u/ \\
\text{Rt} & \text{Rt} & \text{Rt} & \text{Rt} \\
\text{Vocalic} & \text{Vocalic} & \text{Vocalic} & \text{Vocalic} \\
\text{Coronal} & \text{Peripheral} & \text{Peripheral} & \\
\text{High} & \\
\end{array}
\]

Given the representations in (114), the results of lowering would be as in (115),
which produces the same output as (112).

\[
\begin{array}{cc}
\mu & \mu \\
\text{Rt} & \to \\
\text{Vocalic} & \text{Coronal} \\
\text{High} & \\
\end{array} \rightarrow 
\begin{array}{cc}
\mu & \mu \\
\text{Rt} & \\
\text{Vocalic} & \text{Coronal} \\
\text{High} & \\
\end{array} = [eo]
\]

However, the prophylactic specification of [Coronal] makes an incorrect prediction
about the application of harmony to /i/, as illustrated in (116).

\[
\begin{array}{c}
\text{High} \\
\text{Vocalic} \\
/u \ldots i/ \rightarrow \\
\text{Rt} \\
\text{Peripheral} \\
\text{Coronal} \\
\end{array} \rightarrow \left[u \ldots y\right]
\]

According to (116), an /i/ to which harmony has applied should leave the deriv-
tion specified as both [Coronal] and [Peripheral]—and is thus incorrectly predicted to
surface as [y]. The prophylactic specification for [Coronal], although intended to produce
a non-underlying vowel only as the output of lowering, does the same thing to harmony:
it makes a harmonized /i/ distinct from an underlying /u/. 
3.1. Identifying prophylactic features: Yowlumne

However, there is an alternative way of using prophylactic features to resolve the problem posed by harmony and lowering. Instead of specifying /i/ with prophylactic [Coronal] to keep it distinct from /a/, we can make the same distinction by specifying /a/ with prophylactic [Low], yielding the representations shown in (117).

(117)

<table>
<thead>
<tr>
<th></th>
<th>/i/</th>
<th>/a/</th>
<th>/o/</th>
<th>/u/</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rt</td>
<td>Rt</td>
<td>Rt</td>
<td>Rt</td>
</tr>
<tr>
<td>Vocalic</td>
<td>Vocalic</td>
<td>Vocalic Peripheral</td>
<td>Vocalic Peripheral</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Given these specifications, a lowered /iː/ will again be featurally distinct from an underlying /aː/, as shown in (118).

(118)

<table>
<thead>
<tr>
<th></th>
<th>m m m m m m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rt</td>
<td>→ Rt = [eː] ≠ Rt [aː]</td>
</tr>
<tr>
<td>Vocalic</td>
<td>Vocalic</td>
</tr>
<tr>
<td>High</td>
<td></td>
</tr>
</tbody>
</table>

However, the prophylactic specification of [Low] also has consequences for harmony. The feature specifications in (117) predict that /a/ should remain [Low] even when it has been rounded. Just as harmonized /i/ with prophylactic [Coronal] should surface as [y], harmonized /a/ with prophylactic [Low] should surface as [ɔ] or [u].

In fact, it does. Newman transcribes the surface vowel inventory as [i, e, a, ɔ, u], and observes that “the back mid vowels ɔ and ɔ are always open, as in German voll and English law” (Newman 1944: 19).

However, it is not only harmonized /a/ that surfaces as [ɔ]; lowered /u/ and unaltered /o/ are also phonetically low. So we must assume that phonetic implementation realizes all non-high [Peripheral] vowels as [ɔ], regardless of whether they are specified with the prophylactic [Low] feature. Non-[Peripheral] vowels will be phonetically realized
as [i] if they are marked for [High], as [a] if they have prophylactic [Low], and as [e] if they have no aperture feature.

### 3.1.4 Conclusion

The account of Yowlumne harmony and lowering presented here allows the central claim of contrastive specification to be upheld: redundant features are not active in the phonological computation. Although the redundant feature [Low] is specified prophylactically on /a/, it is invisible to phonological rules, and has an effect only at the level of phonetic implementation, where it serves to distinguish /a/ from a lowered /i/.

Under this account, the combination of symmetry and asymmetry in the system, schematized in (119) (cf. (96) and (99)), results from representations in which the phonologically active features are symmetrical, but asymmetry is introduced by a prophylactic feature.

![Mixed pattern](image)

### 3.2 Emergence of prophylactic features: Pulaar

The case of Pulaar (also known as Pular or Fula), a Niger-Congo language spoken in Mauritania, Mali, Senegal, Gambia, and Guinea, provides an example of a harmony pattern that almost needs prophylactic features, but not quite. Although Archangeli and Pulleyblank (1994) argue that the phonology of Pulaar has to be able to spread a non-contrastive feature, purely contrastive specifications can, in fact, account for the data.
However, the Pulaar vowel inventory is one that could easily develop into a system that requires prophylactic features.

### 3.2.1 ATR harmony in Pulaar

The potential challenge posed by Pulaar for the Contrastivist Hypothesis involves a process of tongue root harmony. According to Paradis (1986, 1992), the underlying inventory of Pulaar has the five vowel qualities shown in (120). (Vowel length is phonemic, but not relevant here.)

\[
\begin{array}{cccc}
  & i & u & \\
\varepsilon & \varepsilon & a \\
\end{array}
\]

The surface inventory, however, has seven vowel qualities, as in (121).

\[
\begin{array}{cccc}
  & i & u & \\
  & e & o & \\
\varepsilon & \varepsilon & a \\
\end{array}
\]

The surface distribution of ATR and non-ATR mid vowels is, for the most part, predictable. Archangeli and Pulleyblank (1994), drawing on Paradis’s (1986) description and analysis of the Kaédi (Futankoore) dialect of Pulaar, offer the following generalization: mid vowels are [+ATR] when followed by another [+ATR] vowel, and [−ATR] otherwise. High vowels are [+ATR], and the low vowel /a/ is [−ATR], so [+ATR] mid vowels occur in all positions to the left of any high vowel as long as no /a/ intervenes.

This pattern is illustrated in (122), which shows alternations in mid vowels in noun stems. In the singular forms, which have a high vowel /u/ in the suffix, the stem
vowels surface as [+ATR]; in the diminutive plural forms, which have a mid vowel /ɔ/ in the suffix, all vowels surface as [−ATR].

(122) SINGULAR DIM. PL.

a. [sof-ru] [cɔf-ɔn] ‘chick’

b. [ser-du] [sɛr-kɔn] ‘butt of a rifle’

c. [mbe:l-u] [mbe:l-ɔn] ‘shadow’

d. [dog-o:-ru] [dog-ɔ-w-ɔn] ‘runner’

The same pattern can also be seen in (123), which shows harmony triggered in verb stems by the instrumental applicative suffix -ir.

(123) INFINITIVE INSTRUMENTAL INFINITIVE

a. [bɛt-ðɛ] ‘to weigh’ [bɛt-ir-ðɛ] ‘to weigh with’

b. [hɛl-ðɛ] ‘to break’ [hɛl-ir-ðɛ] ‘to break with’

The harmonic opacity of /a/ can be seen in the forms in (124). In these forms, the high vowel in the final suffix does not cause the mid vowel in the stem to be realized as [+ATR], because of the intervening /aː/.

(124) a. [bɔt-a:-ri] ‘lunch’

b. [pɔt-a:-li] ‘breaths’

c. [nɔd-a:-li] ‘call’

d. [ŋɔr-a:-gu] ‘courage’

In Paradis’s account, which is formulated in the Charm and Government framework of Kaye, Lowenstamm, and Vergnaud (1985), the [ATR] harmony is attributed to leftward spreading of the element I+. This element is a complex of feature values, as shown in (125), but only the ‘hot’ feature [+ATR] is expressed in the harmony process.
3.2. Emergence of prophylactic features: Pulaar

(125) Definition of $I+$ (Paradis 1992: 86; code-switching in the original)

\[
I+ = \begin{cases} 
-\text{round} \\
+\text{back} \\
+\text{haut} \\
+\text{ATR} \\
-\text{bas}
\end{cases}
\]

The approach taken by Archangeli and Pulleyblank (1994) is more directly comparable with the claims being tested here. According to Archangeli and Pulleyblank, the underlying vowel inventory of Pulaar is specified as in (126).

(126) Archangeli and Pulleyblank’s specifications for Pulaar vowels

<table>
<thead>
<tr>
<th>i</th>
<th>e</th>
<th>a</th>
<th>o</th>
<th>u</th>
</tr>
</thead>
<tbody>
<tr>
<td>+HI</td>
<td>+HI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+LO</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>+BK</td>
<td>+BK</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These underspecified representations are motivated by the principle of Representational Simplicity, which Archangeli and Pulleyblank formulate as in (127), in which the term **F-element** refers to any feature specification or class node.

(127) **REPRESENTATIONAL SIMPLICITY** (Archangeli and Pulleyblank 1994: 102):

The value of a representation is the inverse of the number of

a. terminal F-elements

b. associations to terminal F-elements

Representational Simplicity rules out the possibility of specifying the high vowels for $[+\text{ATR}]$ underlingly; the representations in (126) will be preferred over representations that incorporate an additional F-element associated with /i/ and /u/. Archangeli and Pulleyblank (1994: 134) conclude, then, that “although completely predictable, $[\text{ATR}]$ values play an active role in the phonology of Pulaar”—an explicit contradiction
of the Contrastivist Hypothesis. They propose two rules to account for the surface distribution of \(\pm\text{ATR}\): first, a redundancy rule (128) inserts \(+\text{ATR}\) on all high vowels, and then \(+\text{ATR}\) spreads leftward (129).

(128) Pulaar \(+\text{ATR}\) insertion (Archangeli and Pulleyblank 1994: 135)

\[
\begin{align*}
  +\text{ATR} \\
  \mu \rightarrow \mu \\
  +\text{HI} +\text{HI}
\end{align*}
\]

(129) Pulaar \(+\text{ATR}\) spread (Archangeli and Pulleyblank 1994: 135)

\[
\begin{array}{c}
  +\text{ATR} \\
  \mu \quad \mu \\
\end{array}
\]

The application of the spreading rule in (129) is constrained by a prohibition on the feature combination \([+\text{ATR}, +\text{low}]\), preventing it from targeting the vowel /a/, and also by a locality condition, which prevents it from passing over an /a/ to target a mid vowel on the other side.

3.2.2 The problem with Pulaar

On the basis of the facts considered so far, Pulaar ATR harmony does indeed appear to pose a serious challenge at least to the strongest version of the Contrastivist Hypothesis. The first thing to note, though, is that nothing in either the shape of the inventory or the principles of contrastive specification compels us to conclude that \([\text{ATR}]\) is redundant. If \([\text{ATR}]\) is given scope over \([\text{High}]\), then the Successive Division Algorithm will assign representations in which \([\text{ATR}]\) is contrastive, as in (130).
3.2. Emergence of prophylactic features: Pulaar

However, the representations in (130) do not offer a strictly contrastivist account of [ATR] harmony. Because [High] is no longer contrastive, these specifications predict that when [ATR] spreads to /ε/ or /ɔ/, the result will be identical to /i/ or /u/: the redundancy rule that implements underlyingly [ATR] vowels as phonetically high will also apply to vowels that have received [ATR] by spreading. For example, these representations incorrectly predict that [sof-ru] (122a) should surface as [*suf-ru], as shown in (131).

(131) Peripheral Peripheral

/sof-ru/ → s o f r u → s o f r u → [*suf-ru]

ATR ATR

In order to account for the attested pattern of harmony, the featural representations must meet two requirements: [ATR] must be specified on the high vowels /i/ and /u/, but [ATR] cannot be the only feature that distinguishes them from the mid vowels /ε/ and /ɔ/. In principle, the SDA can assign such representations. If the first division assigns [ATR] to the high vowels, then within the unmarked complement set {ε, a, ɔ}, the next division can assign a marked feature to /ε/ and /ɔ/, instead of assigning [Low] to /a/. The contrastive status of this feature depends on the fact that it serves to distinguish /ε/ and /ɔ/ from /a/, but it would have the additional consequence of
reinforcing the distinction between the mid vowels and the high ones, making the former identifiable even after spreading of [ATR].

A set of representations along these lines is shown in (132).

(132)

\[
\begin{array}{c|c|c}
\text{Peripheral} & \text{ATR} & \text{ATR} \\
\hline
i & \varepsilon & \varepsilon \\
\hline
u & o & o \\
\hline
\text{Mid} & \text{Mid} \\
\end{array}
\]

Given these representations, [sof-ru] will be derived correctly from underlying /sɔf-ru/, as shown in (133).

(133)

\[
\begin{array}{c|c|c|c|c}
\text{Peripheral} & \text{Peripheral} \\
\hline
\text{Mid} & \text{ATR} & \text{Mid} & \text{ATR} \\
\hline
s & \varepsilon & f & r & u & \rightarrow & \text{sof-ru} \\
\end{array}
\]

The obvious theoretical objection to (132) is that the use of [Mid] as a feature lacks independent justification. Most theories of phonology assume that only the high and low extremes of the vowel space are directly associated with features or other primitive components of phonological representations. Mid vowels are characterized by [−high, −low] in theories that use binary features; by the absence of [High] and [Low] in theories of privative features; and by the presence of conflicting pairs of elements such as [I, A] or [U, A] in Government Phonology. Within their respective frameworks, these representations have had considerable success in capturing generalizations about the phonological behaviour of the various height classes of vowels; the Pulaar data do not provide a compelling reason to abandon the hypotheses that underlie this phonological tradition.
3.2. Emergence of prophylactic features: Pulaar

There is also an empirical difficulty with the representations in (132). The assignment of the feature [Mid] leaves /a/ as the one fully unspecified vowel in the inventory; it is distinct from all other vowels by virtue of having neither [ATR] nor [Mid]. This makes it difficult to explain why /a/ is harmonically opaque: if /a/ is not specified as [Low], why should it block spreading of [ATR]? The representations in (132) appear to predict that /a/ should be a legitimate target for harmony. Moreover, spreading [ATR] onto /a/ would derive a vowel featurally identical to /i/, producing the incorrect surface forms in (134) in place of the attested ones shown in (124). The prediction that a single harmony process would comprise ATR–RTR alternations in the mid vowels and high–low alternations elsewhere is both incorrect for Pulaar and highly counterintuitive as a general prospect.

(134) a. /bɔxt-aː-ri/ *[bɔxt-iː-ri] ‘lunch’
  b. /pɔxf-aː-li/ *[pɔxf-iː-li] ‘breaths’
  c. /nɔdd-aː-li/ *[nɔdd-iː-li] ‘call’
  d. /nɔgɔr-aː-gu/ *[nɔgɔr-iː-gu] ‘courage’

The Pulaar facts appear to indicate, then, that the strongest version of the Contrastivist Hypothesis cannot be maintained: non-contrastive features must be present in the phonological computation. However, the data do not force us to Archangeli and Pulleyblank’s conclusion that a redundant feature must be phonologically active. Instead, prophylactic features again offer the possibility of a less drastic retreat.

If the feature specifications in (130) are supplemented with the prophylactic specification of [High] on /i/ and /u/, then the attested harmony pattern can be derived. For example, the derivation of [sof-ru] will proceed as in (131), from the perspective of the phonology, but the presence of prophylactic [High] on the /u/ will permit the two vowels to be realized differently at the level of phonetic implementation. This is illustrated in (135).
Chapter 3. Prophylactic features in other languages

(135)  
\[
\begin{array}{c}
\text{Peripheral} \quad \text{\textunderscore High}\text{\textunderscore} \\
/s\text{\textunderscore f\textunderscore ru}/ \rightarrow s\ f\ r\ u \rightarrow [s\text{\textunderscore o\textunderscore f\textunderscore ru}] \\
\text{ATR} \quad \text{ATR}
\end{array}
\]

The Successive Division Algorithm permits [ATR] to be treated as a contrastive feature in the Pulaar system, at the cost of making [High] redundant. Prophylactic specification permits the redundant feature [High] to be present but not active during the phonological computation. Taken together, these two theoretical devices make it possible to generate the Pulaar [ATR] harmony pattern without resorting, as Archangeli and Pulleyblank (1994) do, to spreading a redundant feature.

3.2.3 Pulaar without the problem

However, prophylaxis may not in fact be necessary to account for the Pulaar data. According to Paradis (1992: 90), there are five counterexamples to the generalization that [ATR] mid vowels occur only to the left of high vowels. These are listed in (136):

(136)  
a. [fof] ‘all’  
b. [gorgira\textunderscore gol] ‘aunt’  
c. [gorgol] ‘aunt’ (familiar)  
d. [-(g)el] diminutive singular  
e. [-(g)ol] noun class marker

Three of these (136a–c) are independent words, and Paradis argues that (136b) and (136c) have ATR mid vowels because they contain the noun class marker -(g)ol (136e). However, the two suffixes -(g)ol and -(g)el appear in a variety of other forms, and they trigger harmony in the stems that precede them, as illustrated in (137) and (138).
3.2. Emergence of prophylactic features: Pulaar

(137)  
<table>
<thead>
<tr>
<th>SINGULAR</th>
<th>DIM. SG.</th>
<th>DIM. PL.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suffix:</td>
<td>-(g)ol</td>
<td>-(g)el</td>
</tr>
<tr>
<td>a. [lef-ol]</td>
<td>[lef-el]</td>
<td>[lef-ən]</td>
</tr>
<tr>
<td>b. [ke:r-ol]</td>
<td>[ke:r-el]</td>
<td>[ke:r-ən]</td>
</tr>
<tr>
<td>c. [ce:lt-ol]</td>
<td>[ce:lt-el]</td>
<td>[ce:lt-ən]</td>
</tr>
<tr>
<td>d. [cef-ol]</td>
<td>[cef-el]</td>
<td>[cef-ən]</td>
</tr>
</tbody>
</table>

(138)  
<table>
<thead>
<tr>
<th>SINGULAR</th>
<th>DIM. SG.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suffix:</td>
<td>various</td>
</tr>
<tr>
<td>a. [m`bara:d-di]</td>
<td>[bara-gel]</td>
</tr>
<tr>
<td>b. [pe:m`baw-ɔ]</td>
<td>[pe:m`bow-el]</td>
</tr>
<tr>
<td>c. [hɔr-de]</td>
<td>[kor-el]</td>
</tr>
</tbody>
</table>

Paradis (1992) hypothesizes that the forms in (136) underlyingly contain sequences of mid (non-ATR) vowels and high vowels in hiatus: [-gel] is underlyingly /-gEil/, [-gol] is underlyingly /-gOul/, and [fof] is underlyingly /fOuf/. The underlying high vowel triggers harmony in the mid vowel and then deletes. This analysis is consistent with the general prosodic characteristics of Pulaar, but there is no conclusive evidence for rejecting the competing hypothesis that these forms contain underlyingly ATR mid vowels. (There is, however, circumstantial evidence from other dialects of Pulaar, in which the quantifier ‘all’ variously surfaces as [ɛuf] and [ɛoəf], in place of the Kaédi [fof].)

Archangeli and Pulleyblank (1994: 192) “suggest what appears to be the minimal hypothesis, that the vowels of these suffixes are underlyingly assigned [+ATR]”; this does not, however, affect the representations they assign to the other vowels in the Pulaar system. However, for the contrastivist position represented by the Successive Division Algorithm, the possible existence of underlyingly /e/ and /o/ makes all the difference in the world. If the underlyingly inventory includes all seven of the vowel qualities found on the surface, then both [ATR] and [High] can be considered contrastive. [ATR] distinguishes
{i, e, o, u} from {ɛ, a, ɔ}; then, within the [ATR] set, [High] distinguishes {i, u} from {e, o}. This is illustrated in (139).

(139)

\[
\begin{array}{c|c|c|c|c|c}
 & \text{Peripheral} & & & & \\
 & \text{[High]} & i & & u & \text{[High]} \\
 & e & & & o & \\
 & \text{[ATR]} & & & & \text{[ATR]} \\
 & \varepsilon & & & ɔ & \\
 & \text{[Low]} & & & & \text{[Low]}
\end{array}
\]

If /e/ and /o/ are indeed part of the underlying vowel inventory of Pulaar, then the [ATR] harmony facts are fully compatible with the strictest version of the Contrastivist Hypothesis. However, the status of these vowels is clearly no more than marginal; even if they are phonemic, they occur in only three morphemes.

The Kaédi dialect of Pulaar thus offers some insight into how prophylactic feature specifications might arise diachronically. If the three tokens of underlying /e/ and /o/ were lost, then the feature [High] would abruptly cease to be contrastive. Speakers would still, however, have to contend with the fact that the vowels that spread [ATR] are realized phonetically as high. One way of doing this would be to include [High] as an instruction for phonetic implementation that is present on these vowels before the beginning of the phonological computation, but which is not referred to during the computation itself. This prophylactic specification would then represent an intermediate stage between the loss of a feature’s contrastive status and the loss of its phonetic content.

The data discussed in this chapter and in the preceding one have shown that redundant information may sometimes need to be present in phonological representations, but does not need to be visible to the phonological computation. The next chapter looks
3.2. Emergence of prophylactic features: Pulaar

at the interaction between contrast and phonetics from a different perspective, showing how the surface phonetic shapes of inventories are determined and constrained in a theory of contrastive specification.
Phonemic and phonetic contrast

4.1 Situating the Contrastivist Hypothesis

In order to understand what the Contrastivist Hypothesis means, and how it compares to other hypotheses about phonological representations and inventories, it is useful first to situate it with respect to two extreme positions much like those discussed by Kiparsky ([1968] 1982: 119–120). The first of these says, in essence, that there are no such things as phonological representations: that each word in the mental lexicon is simply associated with an acoustic representation and a set of instructions for its articulation. So, for example, the English words tie, sty, die, and nigh might be associated directly with acoustic images such as the ones in Figure 4.1. Under this view, the connection between a lexical entry and the corresponding phonetic reality is unmediated by any more abstract representation of the latter or of its components; the phonetic form of a word is an unanalyzed whole.
Figure 4.1: Spectrograms of English *tie* (top left), *sty* (top right), *die* (bottom left), and *nigh* (bottom right)

This view is, in its simplest form, plainly untenable (although similarly phonetically rich representations, augmented by statistical generalizations thereover, form the basis of exemplar models of phonology; see, e.g., Johnson (1996), Lacerda (1997), and Pierrehumbert (2001)). It fails to predict phonotactic regularities in language; it fails to predict speakers’ ability to recognize words and morphemes in contexts that affect their phonetic realization in various ways; it fails to account for the psychological reality of the phonological segment. It is also extremely inefficient, as it requires the storage in the mental lexicon of a great deal of redundant information. This hypothesis is not, however, completely removed from either empirical reality or theoretical practice. Human beings are clearly able, in at least some circumstances, to store and use more phonetic
information than their native languages make reference to: it is possible, for example, to mimic another’s speech in some phonetic detail (see also §1.1.1). And some approaches to phonology, although they do not treat words as phonologically unanalyzed, do predict that a great deal of phonetic information is stored in the lexicon. For example, Optimality Theoretic constraints proposed by Flemming (1995) and Boersma (1998) apply to candidate forms that are specified to a degree that includes formant frequencies, and the principle of Lexicon Optimization dictates that much of this detail must also be reflected in the underlying representations. However, it is clear that the mental representation of speech sounds must include something other than raw phonetic material.

The inadequacy and inefficiency of unanalyzed phonetic representations might lead one to the opposite extreme. Observing that each language employs only a limited number of segments, one might suggest that these simply be enumerated for each language, as in (140). Each segment in the inventory would have its own detailed phonetic instructions for articulation and recognition, but a word would consist simply of an ordered list of indices to segments; for example, tie might be represented as $\langle 0, 111, 19 \rangle$, die as $\langle 1, 111, 19 \rangle$, sty as $\langle 2, 0, 111, 19 \rangle$, and so on.

<table>
<thead>
<tr>
<th>Segment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>voiceless coronal stop (t)</td>
</tr>
<tr>
<td>1</td>
<td>voiced coronal stop (d)</td>
</tr>
<tr>
<td>2</td>
<td>voiceless coronal fricative  (s)</td>
</tr>
<tr>
<td>3</td>
<td>voiced coronal fricative (z)</td>
</tr>
<tr>
<td>4</td>
<td>voiceless labial stop (p)</td>
</tr>
<tr>
<td>5</td>
<td>voiced labial stop (b)</td>
</tr>
<tr>
<td>6</td>
<td>voiceless labial fricative   (f)</td>
</tr>
<tr>
<td>7</td>
<td>voiced labial fricative (v)</td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>high front unrounded glide   (j)</td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>111</td>
<td>low central unrounded vowel  (a)</td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
</tbody>
</table>

1. A more detailed discussion of the interaction between Lexicon Optimization and underspecification can be found in chapter 5.
This approach removes phonetic information from lexical representations altogether; the only accessible information about a segment is whether it is or is not the same as another segment—a very literal-minded implementation of the Saussurean dictum that “il n’y a que des différences.” (Kiparsky (1982: 120) attributes this view to Hjelmslev ([1943] 1953), Householder (1965), Lamb (1966), and Fudge (1967).) Simple enumeration of the phonemes of a language, however, also fails to account for the observed phenomena of natural-language phonology. Specifically, it predicts that phonological alternations, if they exist at all, are entirely arbitrary, because it offers no means of defining natural classes of sounds. As Halle (1962) points out, under a purely alphabetic approach to segmental representations, there is no evaluation metric that will describe the statement in (141a) as simpler or more natural than the one in (141b).

(141) a. /a/ is replaced by /æ/ if followed by /i/, /e/, or /æ/.
    b. /a/ is replaced by /æ/ if followed by /i/, /p/, or /z/.

If segments are merely enumerated, then there is no way of predicting the generalization that phonological rules tend to refer to groups of segments that have one or more phonetic properties in common. In order for this to be reflected in the formalization of these rules, there must be some means of referring to a category such as ‘front unrounded vowel’ that is more elegant than simply listing the members of this category. The ability to define natural classes of sounds would also enable the formalism to express the idea that a rule changing /a/ to /æ/ is, regardless of the environment in which it applies, simpler or less drastic than, say, a rule changing /a/ to /s/: if a rule changes relatively few phonetic characteristics of a segment, then the input and output of the rule belong to a relatively small natural class. Finally, it would also be advantageous if the formalism could represent the fact that, in a rule such as (141a), the altered segment takes on one of the phonetic properties that define the class of segments that trigger the change.

In short, there is a need for phonological features. By supplying the phonetic content necessary to define natural classes, such features also differentiate the segments
of the phonemic inventory, thereby eliminating the need for a system of arbitrary indices like the one in (140). Instead, the features constitute a meaningful system of indices. For example, if we start with the assumption that indices are numbers, as in (140), then we can write these indices in base two, and assign to each bit a phonetic characteristic. If a segment has a particular characteristic, then the corresponding bit in its index will be 1; if it does not, the bit will be 0. This produces a system of binary distinctive features, illustrated in (142), which is similar to the one used by Cherry, Halle, and Jakobson (1953) for Russian. In this particular example, the numbers assigned to the segments in (142) are the same numbers that are assigned to them in (140), although they are written in base 2 in (142) and in base 10 in (140); the only real difference is that the numbers in (142) have meanings other than as mere indices.

<table>
<thead>
<tr>
<th>Vocalic</th>
<th>Back</th>
<th>High</th>
<th>Lab.</th>
<th>Cont.</th>
<th>Voice</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>voiceless coronal stop (t)</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>voiced coronal stop (d)</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>voiceless coronal fricative (s)</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>voiced coronal fricative (z)</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>voiceless labial stop (p)</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>voiced labial stop (b)</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>voiceless labial fricative (f)</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>voiced labial fricative (v)</td>
</tr>
<tr>
<td></td>
<td>:</td>
<td>:</td>
<td>:</td>
<td>:</td>
<td>:</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>high front unrounded glide (j)</td>
</tr>
<tr>
<td></td>
<td>:</td>
<td>:</td>
<td>:</td>
<td>:</td>
<td>:</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>low central unrounded vowel (a)</td>
</tr>
<tr>
<td></td>
<td>:</td>
<td>:</td>
<td>:</td>
<td>:</td>
<td>:</td>
<td></td>
</tr>
</tbody>
</table>

What the Contrastivist Hypothesis says, then, is that the amount of information directly encoded in these meaningful indices is no greater than it needs to be for the sake of their role as indices—that is, that a system like the one in (142) can be as efficient, or nearly as efficient, as a system like the one in (140). For example, Cherry, Halle, and Jakobson (1953), in specifying the forty-two phonemes they identify in Russian, use an average of 6.5 bits per phoneme once they have eliminated from each segment the
features whose values are indeterminate or irrelevant (e.g., $\pm$nasal] on vowels, which varies allophonically, or $\pm$stressed] on consonants). This average is not far from the hypothetical minimum of 5.39 ($= \log_2 42$), but the calculation does depend on the assumption that corresponding bits in different phonemes may refer to different properties, the interpretation of less significant bits being dependent on the values of more significant bits.

Exactly how many features can be assigned in total depends on how the Contrastivist Hypothesis is implemented. When contrastiveness is defined by the Successive Division Algorithm, and the features involved are either privative or binary, the greatest number of different features that can be assigned is only one less than the number of segments in the inventory. This hypothetical maximum can be reached only if each feature distinguishes only a single segment from the rest of the (sub)inventory under consideration, as in the schematic example in (143), which shows how the specification of an inventory of seven segments can use as many as six different binary (if the material shown in parentheses is included) or monovalent (if the parenthesized values are omitted) features.
(143) Six features dividing an inventory of seven segments

\[
\begin{align*}
\{S_1, S_2, S_3, S_4, S_5, S_6, S_7\} \\
\quad \xrightarrow{[+F1]} \quad \{S_1\} \quad \xrightarrow{[-F1]} \quad \{S_2, S_3, S_4, S_5, S_6, S_7\} \\
\quad \xrightarrow{[+F2]} \quad \{S_3, S_4, S_5, S_6, S_7\} \quad \xrightarrow{[-F2]} \quad \{S_2\} \\
\quad \xrightarrow{[+F3]} \quad \{S_3\} \quad \xrightarrow{[-F3]} \quad \{S_4, S_5, S_6, S_7\} \\
\quad \xrightarrow{[+F4]} \quad \{S_4\} \quad \xrightarrow{[-F4]} \quad \{S_5, S_6, S_7\} \\
\quad \xrightarrow{[+F5]} \quad \{S_5, S_7\} \quad \xrightarrow{[-F5]} \quad \{S_6\} \\
\quad \xrightarrow{[+F6]} \quad \{S_6\} \quad \xrightarrow{[-F6]} \quad \{S_7\}
\end{align*}
\]

In practice, however, this hypothetical maximum is rarely, if ever, reached. Many features tend to divide inventories into subsets that are rather less lopsided than those in (143), and features frequently cross-classify with one another, so that a single feature may be used to divide two or more separate subinventories. The reasons for this tendency have to do both with the phonetic shapes of typical phonological inventories and with the properties of the phonological features themselves and how they are assigned. For example, Clements (2003, 2004) identifies a principle of Feature Economy, according to which “languages tend to maximise the combinatorial possibilities of features across the inventory of speech sounds: features used once in a system tend to be used again” (Clements 2003: 287). However, there are other, potentially conflicting tendencies as well—for example, the tendency to maximize surface phonetic contrast, at least in some contexts. This chapter deals with the relation between phonetic and phonemic contrast,
and the degree to which each can be used to make reliable cross-linguistic generalizations about the shapes of phonological inventories, looking first at models of phonetic space and how segments are arranged within it, and then at the ways in which more abstract phonological representations give structure to this space.

4.2 Phonetic contrast and inventory shape

This section deals with spatial models of the auditory properties of speech sounds, in particular vowel space as conceived by Liljencrants and Lindblom (1972) and consonant space as discussed in Laver (1994). Such auditory spaces have particular significance for theories of phonology in which phonetic contrast plays an important role in determining the shapes of phonemic inventories (cf. §1.1.2). However, a close examination of the properties of auditory space reveals some surprising properties with potentially problematic consequences for these theories. In each case, the problems with the spatial model point out the need to constrain and define the phonetic space with an abstract, formal phonological structure.

Many phonetically oriented theories of phonology identify auditory contrast as an important determinant of phonological inventories. For example, Flemming (1995) derives inventory shapes from interactions among constraints on the number and strength of auditory contrasts between segments. The need to maintain salient auditory distinctions is weighed against the need to have a certain number of segments in the inventory, and against the desire to minimize effort on the part of the speaker. Similarly, Padgett (2002, 2003) proposes that the number of segments in a given subinventory determines the phonetic quality of those segments: for example, a language with a single voiced labial continuant is predicted to have /y/, while a language with two such continuants is expected to have the perceptually distinct /w/ and /v/.
One of the chief difficulties faced by this phonetic approach to phonology is the problem of representing and quantifying the notion of auditory contrast. Acoustic differences between sounds can be measured on a spectrogram, but the differences that look significant on a spectrogram do not correspond at all precisely with the differences that sound significant to the human ear. To capture auditory—as opposed to acoustic—differences, a more abstract model is needed. One particularly promising approach is to treat segments as points (or areas) in a multidimensional auditory ‘space.’ Such a space would be abstract, in that its dimensions would correspond to auditory features rather than to physical dimensions, but it would also be quantifiable, because it would be subject to certain mathematical laws. This section deals with two visions of auditory space. The first of these is a vowel space, proposed by Liljencrants and Lindblom (1972), within which vowels are moved away from one another in order to derive inventories with maximal contrasts. The second is a consonant space suggested by Laver (1994), in which segments are located closer together or farther apart based on their probability of being mistaken for one another. As we shall see, these models encode useful ideas, but their internal logic leads the theory in unexpected directions.

### 4.2.1 Vowel space

#### 4.2.1.1 The dispersion model of Liljencrants and Lindblom (1972)

Liljencrants and Lindblom (1972) describe an attempt to predict the shape of vowel inventories from a mathematical formula for maximizing contrast. In their model, vowels increase their distinctiveness by moving away from one another within the available acoustic space, like equally charged subatomic particles, or strangers in an elevator. Vowel space, for Liljencrants and Lindblom, is defined by the frequencies of the first, second, and third formants; each formant becomes a dimension. The shape and size of this space are of course limited by the range of the human voice and ear; Liljencrants
and Lindblom take the shape of their space from earlier work by Lindblom and Sundberg (1969). They then compress the space into two dimensions by incorporating the (rather small) third-formant dimension into the second-formant dimension. The resulting two-dimensional space is marked off in mels (a scale designed to reflect human auditory perception of pitch, and thus distinct from, but a function of, the raw acoustic measure of frequency in Hz; a fuller description can be found in Clark and Yallop (1995: 234–236) and works cited therein). The horizontal axis of the available vowel space (which corresponds to the first formant) extends from 350 mel to 850 mel (about 250 Hz to 750 Hz). The vertical axis (second and third formants combined) extends from 800 mel to 1700 mel at the left edge of the space, and narrows asymmetrically to a point (1150 mel) at the right edge. The top and bottom of the space are defined by the following two half parabolas:

\[
\begin{align*}
(144) \quad & \text{a. top: } y = 1150 + 550 \sqrt{\frac{850-x}{500}} \\
& \text{b. bottom: } y = 1150 - 350 \sqrt{\frac{850-x}{500}}
\end{align*}
\]

In general, lower \(x\) values correspond to higher vowels and higher \(x\) values to lower vowels; higher \(y\) values correspond to vowels that are farther front or less rounded, and lower \(y\) values to vowels that are farther back or more rounded. Figure 4.2 (based on Liljencrants and Lindblom’s Figure 3) shows approximate positions for fourteen vowels.

Having defined a vowel space, Liljencrants and Lindblom then go on to model the placement of vowels within that space. Three to twelve vowel points “are evenly placed on a circle of radius 100 mel, with its center at \([x] = 600\) and \([y] = 1200\) mel” (Liljencrants and Lindblom 1972: 842). (This circle is indicated in Figure 4.2.) The total ‘energy’ of the system is calculated using a metaphor in which vowels are thought of as electrons—each vowel acts on each other vowel with a force equal to the inverse of the square of the distance between them. The energy (E) of the system is the sum of the forces generated by each pair of vowels, given by the equation in (145). This sum is a measure of the tension generated by the acoustic similarities between vowels.
4.2. Phonetic contrast and inventory shape

Figure 4.2: Liljencrants and Lindblom’s (1972) vowel space

(145) Energy of a vowel inventory (Liljencrants and Lindblom 1972: 842)

\[ E = \sum_{i=1}^{n-1} \sum_{j=0}^{i-1} \frac{1}{(x_i - x_j)^2 + (y_i - y_j)^2} \]

where \( n \) is the number of vowels

A computer program (written in FOCAL) then calculates for each vowel the change in \( E \) that would result from moving the vowel a set distance in each of “a number of directions, usually six” (Liljencrants and Lindblom 1972: 842). The program chooses the direction that results in the lowest value for \( E \), and continues to move the vowel in that direction until \( E \) no longer decreases or the edge of the vowel space is reached, whereupon it chooses a new direction. The whole procedure is repeated until no further reductions in energy are obtained. It is not clear from Liljencrants and Lindblom’s description whether the vowels are moved simultaneously or in sequence—that is, whether the movement of the second vowel, for instance, is calculated using the original or the moved position of the first vowel. Moving the vowels in parallel seems to be the more principled choice, as different sequential movements of the same vowels could produce quite different results.
Liljencrants and Lindblom report that their program predicted the shapes shown in Table 4.1 for inventories of three to twelve vowels. They then go on to compare their model’s predictions with inventories reported in actual languages by other researchers, in particular Trubetzkoy (1929), Hockett (1955), and Sedlak (1969). The comparison is complicated by the fact that the attested inventories are described in phonemic terms, while the predicted inventories are phonetic, and by the variety of symbols used by the different writers. (It is not immediately obvious, for example, exactly where in Liljencrants and Lindblom’s vowel space to situate the /ɪ/ in Trubetzkoy’s description of Siang-Tang, or the /r/ that Hockett attributes to Mandarin.) However, some of the merits and faults of the computer model do come readily to light. The program’s inventories show much of the same sort of symmetry as naturally occurring inventories, and its choices for three- and six-vowel systems in particular correspond very closely indeed with at least some of the attested systems.

The preference of the program for vowels at the edge of the space is understandable in light of its basic principle of repulsion; however, this preference is not taken to such extremes in the attested inventories. The program does not generate more than one non-peripheral vowel in any system, and it generates no non-peripheral vowels at all in systems of fewer than ten vowels. In particular, the program never predicts the existence of [ø], which appears frequently in attested inventories with seven or more vowels. Meanwhile, the same centrifugal tendency that leads the program to posit too few mid central vowels also produces too many high vowels. While the program generates five close vowels in nine-, eleven- and twelve-vowel systems, none of the attested inventories

---

2. In Liljencrants and Lindblom’s (10), u and ʊ are shown as separate vowels, and there is no schwa. However, the ten-vowel inventory in their Figure 2 and Figure 4 has a schwa and only four close vowels, in positions similar to those of the close vowels in the seven- and eight-vowel inventories. I have restored the schwa and collapsed u and ʊ here based on these figures. Otherwise, Table 4.1 reflects the symbols and—as closely as possible—the positions assigned to the vowels in Liljencrants and Lindblom’s (3)–(12).

3. Here, I use the word *peripheral* to describe vowels that lie on the boundaries of the acoustic space depicted in Figure 4.2; this descriptive term should not be confused with the articulatory feature [Peripheral], which is discussed below.
4.2. Phonetic contrast and inventory shape

<table>
<thead>
<tr>
<th>3 VOWELS</th>
<th>4 VOWELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>u</td>
</tr>
<tr>
<td>a</td>
<td>e</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5 VOWELS</th>
<th>6 VOWELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>u</td>
</tr>
<tr>
<td>e</td>
<td>a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>7 VOWELS</th>
<th>8 VOWELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>i ü/u</td>
<td>i u</td>
</tr>
<tr>
<td>æ/a</td>
<td>æ a/a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>9 VOWELS</th>
<th>10 VOWELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>i ü u</td>
<td>i u</td>
</tr>
<tr>
<td>e æ æ</td>
<td>æ æ æ æ æ</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>11 VOWELS</th>
<th>12 VOWELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>i ü u i u</td>
<td>i ü u i u</td>
</tr>
</tbody>
</table>

Table 4.1: Predicted inventories (from Liljencrants and Lindblom’s (3)–(12) and Fig. 2)

has more than four vowels at any one height. This fact is not readily predictable from the shape of the vowel space alone: the space appears to be able to accommodate five high vowels as easily as four mid vowels, and there are languages with four mid vowels.

The facts can be made to follow, however, from phonological rather than phonetic considerations—for example, by restricting the number of contrasts that can be represented phonologically along a given acoustic dimension. Rice (1995) argues for the use of only two monovalent vowel-place features, [Peripheral] (which collapses [Labial] and [Dorsal]) and [Coronal]. This allows for at most four phonemic vowels at any given height: one with no features (among the high vowels, this would be i or u), one with [Coronal] only (i), one with [Peripheral] only (u or u), and one with both place features
(ii). In languages such as Turkish, in which there is a contrast between vowels that surface phonetically as [u] and [ɯ], the [ɯ] may be analyzed phonemically as /i/, since it behaves phonologically as if it is unmarked for place. One possible way of curbing the computer program’s fondness for high vowels, then, might be to restrict the search for phonetic contrast by means of phonological universals: if there are only two place features in Universal Grammar, then one cannot have more than four vowels at any height, no matter how wide the available vowel space may be. This approach fits better with the data than simply stating that five or more high vowels would be too acoustically close to be permitted, for the latter approach would in turn lead one to predict fewer mid and low vowels. Highly symmetric large inventories such as the attested examples in Table 4.2 would not be expected.4

<table>
<thead>
<tr>
<th>(a) L &amp; L’s (9a)</th>
<th>(b) L &amp; L’s (9dα)</th>
<th>(c) L &amp; L’s (12a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>i i u</td>
<td>i ü u</td>
<td>i ü i u</td>
</tr>
<tr>
<td>e ø o</td>
<td>e ø o</td>
<td>e ø ø o</td>
</tr>
<tr>
<td>æ æ c</td>
<td>æ æ c</td>
<td>æ æ æ æ</td>
</tr>
</tbody>
</table>

Table 4.2: Symmetrical nine- and twelve-vowel inventories

Boersma (1997) remarks that Liljencrants and Lindblom’s model tends to predict systems with disproportionately many place contrasts for their height contrasts. Boersma’s claim is that symmetries in inventories “are the language-specific results of general human limitations on the acquisition of perceptual categorization and motor skills” (Boersma 1997: 1). Clements (2003, 2004) suggests a more abstract approach: symmetry, to the extent that it exists, arises as a by-product of the tendency to maximize feature economy, and inventories are limited in size not only by perceptual considerations, but also by the number of features supplied by Universal Grammar. If UG forces us to

---

4. Liljencrants and Lindblom cite the following languages as having the inventories shown in Table 4.2: (a) Trukese, Thai, Temaoyan and Mazahua Otomi, and English (Hockett 1955); Kannada, Banda-Linda, Karen, and English (Sedlak 1969); (b) Estonian (Hockett 1955); (c) Tibetan (Sedlak 1969).
categorize vowels using two place features (as per Rice 1995), then the feature system explains why we can have no more than four high vowels, and why we can have as many as four low ones. Boersma uses an array of gestural and perceptual constraints to describe the interplay of symmetries and gaps in inventories: symmetry is inherent in the constraint set as a whole, and gaps arise from local hierarchical interactions between constraints. However, similar generalizations may be captured without positing and permuting constraints on the perception of individual feature values. The availability of phonetic space can still be used to explain why a language is more likely to have four high vowels than four low ones, but phonetic possibilities must be filtered through the systematizing principles of language before they can become phonological realities.

4.2.1.2 Variations on the dispersion model

Returning to Liljencrants and Lindblom’s algorithm, we can find even in their very phonetic model an analogue of phonological feature specifications. Recall that the vowels start out at regular intervals on the circumference of a circle. It is not at all surprising, then, that the program refused to produce an [ø]. Each vowel, repelled by the others, will move outward along a path collinear with the radius connecting its starting position to the centre of the circle (or as close an approximation to such a path as the limitations of the program permit). A different set of starting points could drastically change the results. Suppose one vowel is placed in the centre of the circle, with the rest evenly spaced along the circumference as before. The centre vowel, under equal force from each direction, will initially not move at all. Only when the shape of the space itself disrupted the symmetry of the surrounding vowels will the balance of forces be lost and the centre vowel disturbed. Thus not all of the centrifugal tendencies of the program are inherent in the notion of repulsion; these tendencies arise from the initial placement of the vowels as well.
Hall (1999) presents another program, written in Turing, that attempts to replicate and to refine Liljencrantz and Lindblom’s results. Like Liljencrantz and Lindblom’s program, it treats vowels as if they were electrons repelling one another with their electrical charges. However, it does differ from their program in a few aspects, mostly in order to take advantage of the availability of greater computing power. Rather than moving vowels by set amounts in set directions and evaluating which move is best, this program calculates the precise force exerted on each vowel by each other vowel, moves the vowels simultaneously, and then calculates again. This program does not consider the energy of the whole system, but moves each vowel according to the magnitude and direction of the forces acting upon it. Vowels are not allowed to move beyond the edge of the vowel space; if the next computed position for a vowel is out of bounds, it is adjusted to fall directly on the edge rather than beyond it. The calculation of positions and moving of vowels is performed in an infinite loop; eventually, the vowels move far enough apart that their effect on one another is no longer perceptible, or the edges of the space prevent them from moving any further.

As expected, the initial placement of the vowels has a great effect upon the output of the program. For example, Liljencrantz and Lindblom report that their program selects /i, a, u/ as the optimal three-vowel inventory. The program described in Hall (1999) does so, too, provided that the starting positions are at least approximately the ones shown in Figure 4.3.

However, the three vowels could just as well be placed on—or within—the starting circle in any number of different ways. For example, the starting positions shown in Figure 4.4 generate systems that approximate other attested three-vowel inventories. The starting positions in Figure 4.4a, which follow Liljencrantz and Lindblom’s parameters, produce an inventory with two front vowels (high and low) and one mid back vowel; this is similar to the system Sedlak (1969) attributes to Mikasuki. Departing from Liljencrantz and Lindblom’s practice of restricting starting positions to the circumference of the circle,
we can generate a vertical three-vowel inventory like the ones described by Trubetzkoy (1939) as occurring in various Caucasian languages; this is shown in Figure 4.4b.

Given the right input, the program can produce any of the observed three-vowel inventories, and probably most, if not all, of the attested inventories with more vowels. On the other hand, it is equally possible to select starting positions that generate systems that are both unattested and, by any account, highly unlikely. For example, rotating the starting positions in Figure 4.4b through ninety degrees produces a horizontal vowel
inventory /ɛ, ə, ɔ/, which, unlike any attested vowel inventory, has no height contrasts at all. This is illustrated in Figure 4.5.

![Figure 4.5: Generating the unattested inventory /ɛ, ə, ɔ/](image)

If the purpose of the program is to derive phonetic inventories, then the input starting positions may be seen as the phonological specifications of those vowels. In Figure 4.3, we could say, it is the feature [Peripheral] that tells the program that [u] has a somewhat lower F2 than the other vowels, and [Low] that tells it that [a] has a somewhat higher F1; the task of the program is to work out exactly how much is somewhat. The program, under this view, is doing the work of phonetic enhancement rules in assigning specific phonetic values to phonological contrasts. The input to the program may be constrained by universal statements about the markedness of features; for example, the inventory in Figure 4.5 could be ruled out by saying that no language may have both [Coronal] and [Peripheral] unless it has [Low]. This approach leaves the program with a considerably lesser role than Liljencrants and Lindblom seem to have imagined for it, but their program as it stands (or even with some of the modifications they suggest) cannot be a shaper of inventories. From the results they present, the program undergenerates—they show only one predicted inventory shape for each number of vowels. On the other hand, if we consider the possibilities that result from different inputs (even merely from rotations of their circle of starting points), the program overgenerates. It produces more
systems than are attested. Either the set of well-formed inputs must be defined, which solution leads back to the phonological view, or the algorithm itself must be extensively revised.

Some caution should be used, of course, in making inferences about Liljencrans and Lindblom’s program from the behaviour of the program in Hall (1999). Since Liljencrans and Lindblom are not entirely clear about some aspects of their program, Hall does not attempt to replicate its workings precisely, but rather to make as consistent an implementation as possible of the conceptual model behind it. One particular point of departure to note is their direction-choosing algorithm. Since they do not specify any of the “number of directions, usually six” that their program tests, or explain under which circumstances this number is not six,\(^5\) the program in Hall (1999) computes an exact direction based on the forces operating in the system, rather than choosing among a set of approximate directions. Because of this difference, it is impossible to tell from Hall’s program whether Liljencrans and Lindblom’s program could also have generated vertical and horizontal inventories such as those in Figures 4.4b and 4.5. In the program in Hall (1999), the middle vowel in such an inventory—the schwa—is acted upon in precisely opposite directions by the vowels on either side of it. If the outer vowels are equally spaced, the schwa will not move at all; if they are not, the schwa will move toward the farther one, but the schwa will not depart from the axis on which all three vowels lie. In Liljencrans and Lindblom’s program, however, movement is motivated by the energy of the system as a whole. Moving the schwa in either direction perpendicular to the three-vowel axis would make it farther from each of the other two vowels, and thus decrease the overall energy. However, moving the same distance in either perpendicular direction would yield the same decrease in energy, and so there is no non-arbitrary way to choose between the two. Since Liljencrans and Lindblom do not report which directions their

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5. One plausible inference is that the program simply rejects directions that would take a vowel out of the available space.
program tries, or what it does when opposite directions fare equally well, it is impossible to say what their program would do with an input of three collinear vowels. However, it seems reasonable to speculate that either their program would fail to generate the attested Figure 4.4b, or else it would also generate the unattested Figure 4.5.

Another question to consider is how thoroughly the analogy with electrons is—or should be—realized in the model. In the program in Hall (1999), the movement of each vowel at any step in the program is determined solely by the positions of the other vowels at that moment; the velocity imparted upon the vowel in earlier steps has disappeared entirely. In other words, the vowels, unlike electrons, have no momentum. A second version of the program, also described in Hall (1999), makes the vowels behave more like physical objects by allowing them to keep the velocity imparted to them at each step. The new velocity imparted by the set of forces acting on a vowel at each stage does not override the old velocity, but is rather added to it. The most important consequence of this refinement of the model is that there is no longer any guarantee that the movement of a vowel at any given moment has the result of reducing the energy of the system as a whole. One vowel, being repelled by a second, may accelerate so greatly that it cannot slow down soon enough to avoid coming too close to a third vowel that lies in its path. The presence of momentum leads the revised program to generate very different inventories from those of the original version. For example, the initial positions shown in Figure 4.6, which yield the unlikely /u, æ, a/ in the original program, produce /i, a, u/ in the revised version, but perhaps for the wrong reason.

Vowel 1, as expected, moves leftward, toward the [u] position, while vowels 2 and 3 move rightward and away from each other. When 2 and 3 hit the top and bottom boundaries of the space, they continue to move rightward along the edges. Because the space is slightly asymmetrical, vowel 2 reaches the [a] position before vowel 3. The momentum of vowel 3 causes it to continue moving rightward, even though it is now much closer to vowel 2 than to vowel 1. Only when vowel 3 is almost touching vowel 2
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Figure 4.6: Starting positions leading either to /u, æ, a/ or to /i, a, u/

is the force of vowel 2 enough to cancel out the momentum of vowel 3. Vowel 3 then moves very rapidly leftward until it hits the left edge of the vowel space at a point just below vowel 1. Vowels 1 and 3 then repel each other; vowel 1 moves straight upward and vowel 3 moves downward. When the system finally becomes stable, vowel 1 is [i], vowel 3 is [u], and vowel 2 is [a]. The resulting inventory is, of course, a very common one, but the manner in which the program arrives at it is rather capricious. The behaviour of the revised program shows that strengthening the analogy of electrons can only weaken the model’s ability to maximize contrast, as the presence of momentum allows vowels to move in counterproductive directions.

One logical way out of the problems with Liljencrants and Lindblom’s program would be to create an algorithm independent of any initially specified positions for the vowels. Instead of moving vowels by trial and error or in imitation of electromagnetic forces, the program would simply calculate the optimal set (or sets) of positions for a given number of vowels. Given a finite space and a finite number of points to place in that space, the program would find the arrangement(s) of points that would result in the lowest total energy. Such an approach would allow the model to make purely contrast-based predictions, independent of phonology and of ballistics. Not only the nature, but even the number of the solutions such a program would find would be determined only
by the shape of the space and the number of vowels—it is entirely possible that there would be more than one optimal arrangement for a given number of vowels. (Consider the hypothetical case of three vowels in a circular vowel space: as long as the vowels are evenly spaced along the circumference, they can be rotated through an infinite number of positions without increasing the total energy.)

The main practical problem with evaluating vowel systems in this fashion is the computational complexity involved. The number of inventories to be considered increases greatly with small increases to the number of vowels in the inventory or to the number of positions to be considered for each vowel. Furthermore, the number of these positions increases greatly with small decreases in the distance between positions. A truly thorough evaluation of the possibilities for even a small inventory would take a great deal of computing time using this method. However, a rough estimation of the ideal five-vowel inventory has been calculated by a third program discussed in Hall (1999). Given the distance between possible vowel positions (which defines the precision of the search), the program first calculates all the positions it needs to consider. It then examines all possible five-vowel inventories made up of subsets of those positions, calculating the ‘energy’ of each inventory as it goes. If the energy of the system the program is currently evaluating is the lowest it has seen so far, the program stores the inventory in order to compare it with subsequent possibilities. For this test, the program was told to consider vowel positions at 125 mel apart, of which 26 fit into Liljencrants and Lindblom’s vowel space. Using these positions, it is possible to construct 65,780 \((= \frac{26 \times 25 \times 24 \times 23 \times 22}{5 \times 4 \times 3 \times 2})\) unique five-vowel inventories. Of these, the one with the lowest energy is the \(W\)-shaped inventory shown in (146).

(146) The five-vowel inventory with the lowest ‘energy’

\[
\begin{array}{ccc}
\text{i} & \text{u} & \text{u} \\
\text{æ} & \text{a} \\
\end{array}
\]
This is not a frequent inventory among the world’s languages. Liljencrants and Lindblom (1972) mention three languages with inventories of a similar shape: Tabassaran and Kyuri (both Caucasian languages; the latter is also known as Lezghian) have /i, ü, u, e, a/ (Trubetzkoy 1929), and Huichol (Uto-Aztecan) has /i, i, u, e, a/ (Hockett 1955). Of the inventories surveyed by Maddieson (1984), the closest to the predicted pattern are Papago (Uto-Aztecan), with /i, i, u, o, a/, and Acoma (Keresan), with /i, i, u, e, a/.

The five-vowel inventory predicted by Liljencrants and Lindblom’s program, given in (147) as they present it in their (5), has a slightly higher total energy than the one predicted by the third program in Hall (1999).

(147) Five-vowel inventory predicted by Liljencrants and Lindblom (1972)

\[
\begin{array}{ll}
i & u \\
e & a \\
æ/a & \\
\end{array}
\]

However, this inventory is closer in shape to the extremely common five-vowel inventory in (148).

(148) Widely attested five-vowel inventory

\[
\begin{array}{ll}
i & u \\
e & o \\
a & \\
\end{array}
\]

The relative infrequency of the inventory in (146) suggests that the need to maximize distance is seldom the pre-eminent concern reflected in the structure of vowel inventories. Liljencrants and Lindblom’s program, with its arbitrary ‘phonological’ input, fared better; again the logical way to refine our predictions about phonetic inventory shape seems to be to eliminate the arbitrariness by using phonological universals.

The precise formulation of a phonological approach to cross-linguistic preferences in inventory shapes is, of course, a complicated matter which can be fully worked out only
in the larger context of phonological theory. However, there is no shortage of possible approaches. Rice and Avery (1993) observe that, among both vowels and consonants, fewer places of articulation are contrasted in the more sonorous segments. Just as languages tend to have fewer low vowels than high vowels, they also tend to have fewer liquids than nasals, and fewer nasals than obstruent stops. Rice and Avery account for this parallelism through the feature geometry: both sonorants and vowels are distinguished from obstruents by the presence of an [SV] node, and distinguished from one another by the various dependents of this node. The more sonorous a segment is, the more SV structure it has. Consequently, low vowels are inherently more complex than high vowels, and so have less ‘room’ to accommodate the additional structure required for place distinctions. With this feature system, the inventory in (146) could be characterized as more marked than the inventory in (148) (and thus dispreferred) because it contains the extra structure imposed by the presence of two low vowels. Rice and Causley (1998) add another facet to markedness by proposing a constraint against fully underspecified segments such as high central vowels, which are neither marked as low nor marked for place. Thus the inventory in (146) could be dispreferred either for its complex low vowels or for its nondescript [u].

A related view of markedness is offered by Béjar (1998), who uses a weight metric to derive feature specifications from inventory shape. According to this metric, whenever the Successive Division Algorithm distinguishes a subinventory from its complement by the assignment of a monovalent feature, the subset marked by the presence of the feature must be the smaller of the two. Under this view, it would be possible to relate the desire to reduce markedness in the system as a whole to a desire to make the smaller subset in each complementary pair as small as possible. Thus in both (146) and (148), low vowels would be a marked subset, because they are fewer than their non-low counterparts, but the marked subset in (148) is smaller than the marked subset in (146). Of course, merely minimizing the size of each marked subset in an inventory would not necessarily reduce
4.2. Phonetic contrast and inventory shape

the complexity of the whole, because it would increase the number of features required. However, if the number of different features used in a system is also considered as a measure of complexity, then (148) may be preferred over (146) for its symmetry. Once the low vowel [a] has been dealt with, the remaining four vowels in (148) form a tidy rectangular pattern that can be fully and logically described with two features. It is not so easy to find symmetry within (146). Cutting off [u] does leave a similar rectangle to the one in (148), but why should [u] be separate from the other high vowels? Béjar’s algorithm for feature assignment implies preferences both for symmetry and for smaller sets of marked items; although these preferences sometimes conflict with each other, it can be argued that (148) satisfies either of them better than (146) does. Whatever phonological mechanism is used to choose the inventory in (148) over the one in (146), it is clear that something more abstract than the range of the human voice is at work here. Underlying the phonetic shape of any inventory is a phonological structure.

In addition to pointing out the usefulness of phonological specifications, the trial-and-error program for selecting an inventory with minimal energy raises other questions about the idea of maximal contrast. The program found only one optimal system; the ‘energy’ of this system was $4.43 \times 10^{-5}$, while the energy of Liljencrants and Lindblom’s predicted five-vowel system is approximately $5.06 \times 10^{-5}$. How sensitive are human speakers to differences in contrastiveness? By how much do the energy levels of two systems have to differ for one of them to be preferred over the other? When more than one inventory shape is attested, as is the case for systems of all sizes, how much of the variation is attributable to the presence of alternatives which are more or less equally contrastive, and how much to the other requirements with which the need for contrast interacts? How frequent or infrequent need an attested inventory be in order to support or refute a theory that predicts it to be ‘preferred’? In order to incorporate a phonetically based notion of contrastiveness into the theory, it is necessary to understand more fully
the nature of the model itself as well as the phonological considerations that constrain it.

### 4.2.2 Consonant Space

The difficulties inherent in working with consonant space are even more basic than those met with in vowel space in the previous section. There is as yet no clear notion of what consonant space looks like, or even of how many dimensions it has. While Liljencrants and Lindblom’s organization of vowel space according to the frequencies of the first three formants certainly represents a simplification of phonetic reality, it is at least a clearly reasonable approximation. Consonants, however, cannot be characterized with such ease; in connected speech, their differences are more acoustically salient on the vowels they abut than on themselves. Furthermore, consonants do not fall into continua as readily as do vowels; for instance, one can produce a continuous vowel sound that gradually moves from [i] to [a], passing through all points in between, but one cannot produce an analogous continuum of, say, voiced stops from [b] to [g]. Even if such an articulatory continuum were possible, it would not necessarily correspond to an acoustic or auditory continuum; it is possible, for example, that [k] and [p] are auditorially closer to each other than either is to [t].

One attempt at quantifying the shape of consonantal space comes from Laver (1994), who offers the figures in Table 4.3 as “an initial attempt to give a global suggestion of auditory distance (and hence of acoustic dissimilarity) between segment-types representing the consonantal phonemes of English (RP)” (Laver 1994: 392).

Here, distance between two segments represents specifically the improbability of confusing them; thus [p] and [s], which are 95 units apart, are much less likely to be confused than [p] and [k], at 15 units apart. The distances are expressed on a scale that in principle extends from 0 (identity) to 100 (absolute dissimilarity); as it turns out, no two segments are closer than 15 units apart or farther than 95 units apart, and all
4.2. Phonetic contrast and inventory shape

Table 4.3: Auditory distances between consonants (Laver 1994: Fig. 13.1)

distances in the table are multiples of five. Laver claims that “it would be hypothetically possible to locate all segment-types in multidimensional auditory space” (Laver 1994: 391). However, the set of distances in Laver’s table cannot possibly correspond to a set of points in n-dimensional Euclidean space.6

Imagine a set of points that do inhabit Euclidean space. Any three points \( A, B, \) and \( C \) in this set will be coplanar; unless they are collinear, they will define a triangle \( \triangle ABC \). The distance between each pair of points \( (AB, BC, CA) \) will be the length of one side of the triangle. Now consider the line segments \( AB \) and \( BC \), which meet at point \( B \). If they meet at an angle of \( 180^\circ \), then \( A, B, \) and \( C \) are collinear, and the

6. The exact basis for the numbers shown in Table 4.3 is not fully clear; Laver (1994: 393) explains that they were “developed by the author from subjective auditory impressions (supported by some theoretical assumptions).”

\[ p \quad 25 \quad 15 \quad 65 \quad 70 \quad 90 \quad 95 \quad 85 \quad 95 \quad 95 \quad 20 \quad 55 \quad 30 \quad 60 \quad 70 \quad 65 \quad 60 \quad 70 \quad 75 \quad 85 \quad 85 \\
\[ t \quad 20 \quad 85 \quad 65 \quad 80 \quad 85 \quad 80 \quad 75 \quad 90 \quad 90 \quad 45 \quad 20 \quad 35 \quad 75 \quad 65 \quad 75 \quad 70 \quad 65 \quad 85 \quad 85 \\
\[ k \quad 80 \quad 85 \quad 95 \quad 90 \quad 85 \quad 95 \quad 95 \quad 85 \quad 35 \quad 45 \quad 20 \quad 65 \quad 70 \quad 55 \quad 60 \quad 80 \quad 90 \quad 85 \quad 85 \\
\[ f \quad 25 \quad 65 \quad 70 \quad 20 \quad 65 \quad 70 \quad 65 \quad 75 \quad 85 \quad 80 \quad 80 \quad 85 \quad 80 \quad 95 \quad 95 \quad 95 \quad 65 \\
\[ \emptyset \quad 70 \quad 65 \quad 35 \quad 25 \quad 70 \quad 65 \quad 80 \quad 75 \quad 85 \quad 85 \quad 90 \quad 85 \quad 95 \quad 95 \quad 95 \quad 65 \\
\[ s \quad 35 \quad 85 \quad 80 \quad 40 \quad 60 \quad 95 \quad 85 \quad 95 \quad 95 \quad 90 \quad 95 \quad 95 \quad 95 \quad 95 \quad 95 \quad 85 \\
\[ f \quad 80 \quad 75 \quad 55 \quad 45 \quad 95 \quad 90 \quad 95 \quad 85 \quad 95 \quad 90 \quad 95 \quad 95 \quad 95 \quad 65 \\
\[ v \quad 25 \quad 65 \quad 30 \quad 55 \quad 60 \quad 65 \quad 55 \quad 65 \quad 65 \quad 65 \quad 60 \quad 60 \quad 60 \quad 80 \\
\[ \emptyset \quad 60 \quad 25 \quad 50 \quad 45 \quad 75 \quad 65 \quad 65 \quad 70 \quad 70 \quad 70 \quad 70 \quad 80 \\
\[ z \quad 20 \quad 85 \quad 65 \quad 85 \quad 85 \quad 75 \quad 80 \quad 85 \quad 85 \quad 80 \quad 70 \quad 90 \quad 85 \\
\[ \emptyset \quad 80 \quad 70 \quad 85 \quad 85 \quad 85 \quad 85 \quad 85 \quad 80 \quad 75 \quad 75 \quad 90 \quad 85 \\
\[ b \quad 30 \quad 25 \quad 25 \quad 65 \quad 60 \quad 55 \quad 85 \quad 85 \quad 80 \quad 95 \\
\[ d \quad 30 \quad 60 \quad 30 \quad 65 \quad 80 \quad 80 \quad 80 \quad 75 \quad 95 \\
\[ g \quad 55 \quad 65 \quad 30 \quad 50 \quad 70 \quad 85 \quad 70 \quad 95 \\
\[ m \quad 20 \quad 20 \quad 55 \quad 75 \quad 85 \quad 95 \\
\[ n \quad 25 \quad 65 \quad 75 \quad 80 \quad 70 \quad 90 \\
\[ \eta \quad 35 \quad 70 \quad 85 \quad 75 \quad 90 \\
\[ w \quad 30 \quad 30 \quad 30 \quad 85 \\
\[ j \quad 50 \quad 45 \quad 85 \\
\[ x \quad 40 \quad 85 \\
\[ l \quad 85 \\
\[ h \]
length of $CA$ is equal to the sum of the lengths of $AB$ and $BC$. If $AB$ and $BC$ meet at a narrower angle, then $CA$ will be correspondingly shorter. Under no circumstances can $CA$ be longer than $AB + BC$.

If the ‘auditory space’ represented in Laver’s table were subject to the axioms of Euclidean geometry, we could expect any three consonants to be the points of a possible triangle. However, this is not the case. Consider the set of distances Laver posits for the segments $[\delta], [b], \text{ and } [k]$, shown in Table 4.4.

<table>
<thead>
<tr>
<th>$\delta$</th>
<th>b</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta$</td>
<td>50</td>
<td>95</td>
</tr>
<tr>
<td>b</td>
<td>35</td>
<td>k</td>
</tr>
</tbody>
</table>

Table 4.4: Distances between pairs drawn from the set \{\(\delta\), b, k\}

These consonants cannot be the points of a triangle $\triangle \delta bk$, because the distance from $[\delta]$ to $[k]$ (95) is greater than the sum of the distances from $[\delta]$ to $[b]$ and $[b]$ to $[k]$ ($50 + 35 = 85$). Nor is this group of consonants unique; Laver’s table contains 51 such impossible triads, which are listed in Table 4.5.

If Laver’s table of distances is correct, then auditory space is non-Euclidean in some way—for example, the dimensions of this space may be bent through still other dimensions. There may well be more departures from Euclidean geometry in Laver’s table than are revealed in Table 4.5, which reflects only non-Euclidean triads, and not larger sets of segments. If the notion of auditory distance is to be put to phonological use (as it is, for example, in Flemming (1995)), then we need a clearer picture of the space in which that distance is to be measured.

Departing from Euclidean geometry is not necessarily undesirable; however, because it has potentially drastic consequences both for the set of possible representations of auditory space and for the meaning of these representations, it is not a step to be taken lightly. Laver makes an even more fundamental departure from Euclidean space in his next table of distances, but this departure is acknowledged and explained. Laver’s
4.2. Phonetic contrast and inventory shape

Table 4.5: Non-Euclidean triads of consonants

<table>
<thead>
<tr>
<th>b d m</th>
<th>b m n</th>
<th>d n η</th>
</tr>
</thead>
<tbody>
<tr>
<td>g n η</td>
<td>b m η</td>
<td>d θ δ</td>
</tr>
<tr>
<td>f v 3</td>
<td>z θ 3</td>
<td>b d n</td>
</tr>
<tr>
<td>b m p</td>
<td>d p t</td>
<td>g p η</td>
</tr>
<tr>
<td>b p v</td>
<td>f j v</td>
<td>l w η</td>
</tr>
<tr>
<td>θ θ 3</td>
<td>b d p</td>
<td>d g η</td>
</tr>
<tr>
<td>d t z</td>
<td>g t η</td>
<td>b p θ</td>
</tr>
<tr>
<td>f l v</td>
<td>n w η</td>
<td>b g m</td>
</tr>
<tr>
<td>d k t</td>
<td>d t θ</td>
<td>g w η</td>
</tr>
<tr>
<td>b θ θ</td>
<td>f m v</td>
<td>f v 3</td>
</tr>
<tr>
<td>b g η</td>
<td>d k θ</td>
<td>f θ θ</td>
</tr>
<tr>
<td>j w η</td>
<td>b θ 3</td>
<td>f v w</td>
</tr>
<tr>
<td>f θ 3</td>
<td>b k m</td>
<td>d m n</td>
</tr>
<tr>
<td>g k η</td>
<td>k t η</td>
<td>d f v</td>
</tr>
<tr>
<td>f v η</td>
<td>v z 3</td>
<td>b k θ</td>
</tr>
<tr>
<td>d n t</td>
<td>g m η</td>
<td>b m t</td>
</tr>
<tr>
<td>d g n</td>
<td>f v θ</td>
<td>w η</td>
</tr>
</tbody>
</table>

Table 4.5 shows a table of ‘distances’ based on the likelihood that one consonant would be misheard as another by an automatic speech-recognition system (Laver 1994: 394). In this table, distance is not commutative—A is not necessarily as far from B as B is from A. For example, [ð] is more likely to perceived as [v] than vice versa, and so the distance from [ð] to [v] is only nine units, while the distance from [v] to [ð] is 16.

We now have pairs of points that cannot exist in one-dimensional Euclidean space, but we also have an experimentally tested reason for them. The situation might be modelled by imagining that [v] and [ð] are indeed points on a line, but that this line is curved or tilted through a second dimension so that [ð] is ‘higher’ than [v]. The auditory similarity of the two consonants is then expressed not in terms of distance, but as the time in which one can cover that distance by applying a fixed amount of force. Moving ‘uphill’ from [v] to [ð] thus takes longer than moving ‘downhill’ from [ð] to [v]. However, there would have to be more than one ‘downhill’ for the model to reflect the larger system of relationships. Consider the distances for [f], [d], and [b], which are summarized in Table 4.6.
Chapter 4. Phonemic and phonetic contrast

Distance
Segment 1 | Segment 2 | Distance from 1 to 2 | Distance from 2 to 1 | 'Higher' segment
---|---|---|---|---
f | d | 19 | 13 | d
b | f | 14 | 13 | f
d | b | 7 | 5 | b

Table 4.6: Distances between pairs drawn from the set \{f, d, b\}

In each pair of consonants in Table 4.6, the distance from the first segment to the second is longer than the distance from the second to the first, and so in the spatial model the second member of each pair would be represented as higher than the first. Thus [f] is higher than [b], which is higher than [d], which is higher than [f]. Not only is distance not commutative; height is not transitive. In order to capture this fact without creating a paradox, the dimension along which [f] is higher than [b] must be perpendicular to the direction specified as ‘downward’ in at least one of the other pairs. Such a model would account for the asymmetries of confusability, but it would also leave us with a segment space that consists of a yet unknown number of dimensions, distorted through at least two other dimensions, and supplied with a law of gravity. (A remaining perplexity for the spatial model is the fact that the ‘distance’ from each consonant to itself is greater than zero. Since the ‘distance’ from A to B is really a measure of how unlikely A is to be heard as B, the distance from any segment to itself simply indicates the overall susceptibility of that segment to misperception. However, this piece of information has no clear analogue in the spatial model.) Clearly the limitations of this very complex space must be better understood before it can be put to phonological use.

4.2.3 Conclusions

Both Liljencrants and Lindblom’s (1972) algorithm for modelling vowels as electrons and Laver’s (1994) system of distances between consonants contain useful notions for a theory of the geometry of auditory space. However, both of these approaches have mathematical consequences which their authors have not fully explored. Liljencrants and Lindblom’s
vowel program is too dependent upon its arbitrary starting points, which could, if their arbitrariness were eliminated, form the heart of a phonological account. Laver’s vision of distance removes auditory space from the purview of Euclidean geometry, creating an unspecified number of dimensions whose significance is left unclear. (For example, the shape of Liljencrants and Lindblom’s vowel space correctly suggests that there is less room for different places of articulation among low vowels than among high vowels; however, it is impossible to see the corresponding asymmetry between sonorants and obstruents reflected in Laver’s consonant space, because the space itself is impossible to visualize.) In each case, further clarification of the nature of segment-space and the forces that operate within it could lead to a more robust theory, from which generalizations about contrast might be made to follow mathematically.

### 4.3 Contrast, enhancement, and economy

#### 4.3.1 A second look at the minimal pairs test

The discussion of Liljencrants and Lindblom’s (1972) dispersion model and Hall’s (1999) variations on it in §4.2.1 revealed some of the limitations of a (primarily, but not quite purely) phonetic approach to predicting the shapes of inventories. What might an approach based on phonological contrast have to say about the subject?

The minimal pairs approach to contrastive specification, discussed earlier in §1.2.3, indirectly suggests an answer to this question that turns out to be ludicrously wrong in an informative way, because its predictions are almost diametrically opposed to those of the dispersionist model. As formalized by Archangeli (1988), the minimal pairs test takes an inventory of fully specified segments, identifies some feature specifications as contrastive, and discards the remaining ones as redundant. A version of Archangeli’s procedure, which Dresler (2003) refers to as the Pairwise Algorithm, is given in (149).
The Pairwise Algorithm

1. Fully specify all segments in the inventory.
2. Find each pair of segments that differ by only one feature value.
3. Label all such feature values as contrastive.
4. Delete all other (non-contrastive) feature specifications.

According to the definition of contrast encoded in the Pairwise Algorithm, the value of a feature $F$ on a segment $S$ is contrastive iff there exists some segment $S'$ such that $S$ and $S'$ differ only in their values for $F$.

As discussed in §1.2.3, the output of the Pairwise Algorithm is not always a viable set of feature specifications; sometimes its definition of contrastiveness is so strict that the features it leaves behind are inadequate to distinguish the segments from one another. This fact could simply be taken as evidence that the Pairwise Algorithm is useless; alternatively, it could be taken as an implicit prediction about the range of possible segmental inventories. If one wished to maintain an approach to contrastive specification based on the Pairwise Algorithm, then one would have to hypothesize (quite wrongly, but not uninterestingly) that there would be no attested phonemic inventories on which the algorithm fails.

What do such inventories look like? Dresher (2003) identifies two ostensibly different sets of circumstances under which the Pairwise Algorithm fails. “First,” he writes, “the Pairwise Algorithm will fail when there are too many features relative to the number of phonemes in the inventory” (Dresher 2003: 51). For example, consider what happens to a vowel inventory /i, a, u/, starting with full specifications for the features [±high], [±back], and [±round], as in (150).
4.3. **Contrast, enhancement, and economy**

(150) Full specifications of three features for /i, a, u/

\[
\begin{array}{ccc}
  i & a & u \\
  \text{high} & + & - & + \\
  \text{back} & - & + & + \\
  \text{round} & - & - & + \\
\end{array}
\]

These three features are considerably fewer than the full range of features for which these vowels might be specified, but they are still more than are needed to distinguish them. (Three binary features can distinguish up to eight phonemes; to distinguish three phonemes requires only two features.) Thanks to this surfeit, there are no minimal pairs in (150): /i/ and /a/ differ in both [±high] and [±back]; /a/ and /u/ differ in both [±high] and [±round]; and /u/ and /i/ differ in both [±back] and [±round]. Because there are no minimal pairs, the Pairwise Algorithm does not consider any of the feature specifications contrastive; deleting redundant specifications produces the result in (151):

(151) Contrastive specifications for /i, a, u/ as determined by the PA

\[
\begin{array}{ccc}
  i & a & u \\
  \text{high} & \\
  \text{back} & \\
  \text{round} & \\
\end{array}
\]

Indeed, each individual feature specification is redundant, provided that the others are present. For example, [+high] is not needed to distinguish /u/ from /a/, because [+round] suffices; at the same time, [+round] is not needed to distinguish /u/ from /a/, because [+high] suffices. The trouble, of course, is the “at the same time”; the Pairwise Algorithm fails because it lacks any notion of a contrastive hierarchy, which would make it possible to say that one of these features takes precedence over the other.

The second class of cases in which the Pairwise Algorithm fails does not involve a surfeit of features. Dresher (2003) uses the vowel inventory of Maranungku, shown in (152), as an illustration.
Full specifications of three features for Maranungku vowels

\[
\begin{array}{cccc}
\text{i} & \text{u} & \text{a} & \text{æ} \\
\text{high} & + & + & - & - & - \\
\text{low} & - & - & + & + & + \\
\text{back} & - & + & + & + & - \\
\end{array}
\]

Here, there are some minimal pairs, but not quite enough. The specifications designated contrastive by the Pairwise Algorithm are shown in (153).

Contrastive specifications for Maranungku vowels as determined by the PA

\[
\begin{array}{cccc}
\text{i} & \text{u} & \text{a} & \text{æ} \\
\text{high} & + & - & /u/ vs. /a/ \\
\text{low} & - & + & /a/ vs. /a/ \\
\text{back} & - & + & + & /i/ vs. /u/; /a/ vs. /æ/ \\
\end{array}
\]

The Pairwise Algorithm leaves specifications that fail to distinguish /i/ from /æ/.

The problem here is not that there are too many features to begin with; for a five-segment inventory, more than two binary features are required. Rather, the problem lies in how the vowels are arranged in the feature space. The problematic vowels /i/ and /æ/ enter into parallel contrasts: /i/ is the [−back] counterpart to /u/, while /æ/ is the [−back] counterpart to /a/. /i/ and /æ/ themselves do not constitute a minimal pair, because both [±high] and [±low] distinguish them, and neither /i/ nor /æ/ enters into any other minimal pair. As a result, each of them ends up specified only as [−back]. Dresher (2003) illustrates the situation graphically as in Fig. 4.7, by plotting segments along dimensions defined by features, and drawing paths between minimal pairs.

Dresher (2003: 53) writes that “whether or not an inventory has paths that make its members distinguishable by the Pairwise Algorithm is an accidental property, and should not be the basis of a theory of contrastiveness.” However, there is a broad pattern to the availability or unavailability of suitable paths. Hall (2004a) notes a potentially informative parallel between Dresher’s diagrams and the adjacency graphs employed by
4.3. Contrast, enhancement, and economy

Figure 4.7: Minimal contrasts in the Maranungku vowel system (Dresher 2003: 53)

Shannon ([1956] 1993). Shannon was concerned with the problem of calculating the zero error capacity \( C_0 \) of a noisy channel—i.e., the rate at which information can be transmitted once sufficient redundancy has been incorporated into the message to compensate for possible distortion of the signal. For a channel that transmits discrete signals, \( C_0 \) depends on the distinctness of the letters of the alphabet of which the messages are composed. Shannon defines adjacency as in (154).

\begin{equation}
\text{(154) Definition of Adjacency (adapted from Shannon 1993: 223):}
\end{equation}

Two letters \( \alpha \) and \( \beta \) are adjacent iff there is some letter \( \gamma \) such that both a transmitted \( \alpha \) and a transmitted \( \beta \) have a non-vanishing probability of being received as \( \gamma \).

Fig. 4.8 shows all possible patterns of adjacency for alphabets of up to five letters, and the \( N_0 (= \ln^{-1} C_0) \) calculated by Shannon (1993) for each configuration. In general, \( N_0 \) and \( C_0 \) decrease as the number of lines in the adjacency graph grows, although the placement of the lines is no less critical than their number.

What Dresher’s graphs and Shannon’s have in common is that their paths connect the segments or letters that are maximally similar. Rather than failing under two separate sets of circumstances (the ‘too many features’ case and the ‘not enough paths’ case), the Pairwise Algorithm fails when the segments in an inventory are too distinct from one another. A graph of the inventory in (150), plotted in Fig. 4.9, reveals that the ‘too
many features’ problem is simply a subcase of the ‘not enough paths’ problem—in this particular example, an extreme one, in that there are no paths at all.

\[
\begin{align*}
  &i \quad . \quad . \\
  &. \quad . \quad u \\
  &. \quad . \quad a
\end{align*}
\]

Key to axes: \(x=[\pm \text{back}], \ y=[\pm \text{high}], \ z=[\pm \text{round}]\)

Figure 4.8: Adjacency graphs for alphabets with 1–5 letters (Shannon 1993: 230)

Figure 4.9: Minimal contrasts in the inventory /i, a, u/
The problem with /i, a, u/ is not simply that there are too many features; rather, it is that there are too many features in which the segments of the inventory differ. The Pairwise Algorithm has no difficulty at all in extracting a usable set of feature specifications for the three-vowel inventory /u, i, ø/, even starting from a set of six features as in (155).

(155) Full specifications for /u, i, ø/  

<table>
<thead>
<tr>
<th></th>
<th>u</th>
<th>i</th>
<th>ø</th>
</tr>
</thead>
<tbody>
<tr>
<td>high</td>
<td>+</td>
<td>+</td>
<td>−</td>
</tr>
<tr>
<td>low</td>
<td>−</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>round</td>
<td>+</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>back</td>
<td>−</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>front</td>
<td>−</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>ATR</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

Here, even though there are four more features than are necessary for the task of distinguishing three phonemes, the arrangement of the vowels in the feature space is compact enough that the Pairwise Algorithm produces a different set of contrastive features for each vowel (although the resulting specifications do not comply with Halle’s (1959) Distinctness Condition, on which see §1.2.5). The output of the Pairwise Algorithm for the inventory in (155) is shown in (156).

(156) Contrastive specifications for /u, i, ø/ according to the PA  

<table>
<thead>
<tr>
<th></th>
<th>u</th>
<th>i</th>
<th>ø</th>
</tr>
</thead>
<tbody>
<tr>
<td>high</td>
<td>+</td>
<td>−</td>
<td></td>
</tr>
<tr>
<td>low</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>round</td>
<td>+</td>
<td>−</td>
<td></td>
</tr>
<tr>
<td>back</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>front</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATR</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
What this means, then, is that if the Pairwise Algorithm is taken not just as a means of identifying contrastive features, but also as a filter on inventories, then it tends to prefer inventories that minimize phonetic contrast and reject (by failing to provide viable specifications for) inventories of the sort predicted by Liljencrants and Lindblom (1972), in which the segments are widely distributed through the available space. This interpretation is, however, subject to two caveats. First, it should be borne in mind that comparison of discrete feature values provides only a rough approximation of auditory distinctness; to the Pairwise Algorithm, all features are equal, regardless of the robustness of their acoustic realization. Second, the ability or inability of the Pairwise Algorithm to generate usable feature specifications for an inventory does not correlate perfectly with the $N_0$ of the adjacency graph corresponding to the inventory. For $N_0$, only the presence or absence of paths between segments is significant; for the Pairwise Algorithm, the orientation of the paths in the feature space also matters, as illustrated by the two five-vowel inventories shown in (157a) and (157b).

(157) a. A successful five-vowel inventory where $N_0 = 3$

<table>
<thead>
<tr>
<th>Full specifications:</th>
<th>Contrastive specifications:</th>
<th>Graph:</th>
</tr>
</thead>
<tbody>
<tr>
<td>æ e i u u</td>
<td>æ e i u u</td>
<td>i−u−u</td>
</tr>
<tr>
<td>low + − − − −</td>
<td>low + −</td>
<td>e</td>
</tr>
<tr>
<td>high − − + + +</td>
<td>high − +</td>
<td></td>
</tr>
<tr>
<td>back − − − + +</td>
<td>back − +</td>
<td>æ</td>
</tr>
<tr>
<td>round − − − − +</td>
<td>round − +</td>
<td></td>
</tr>
</tbody>
</table>

7. Of particular note in this regard are features that lie along the same acoustic dimension; for example, /i/ differs from /e/ by only one feature, [±high], whereas /i/ differs from /e/ in [±ATR] as well. Acoustically, however, /i/ is closer to /e/ (setting aside any enhancements of length or diphthongization that might accompany the [±ATR] contrast), because the [±high] contrast and the [±ATR] contrast go in opposite directions along the same dimension.
4.3. Contrast, enhancement, and economy

b. An unsuccessful five-vowel inventory where \( N_0 = 3 \)

<table>
<thead>
<tr>
<th>Full specifications:</th>
<th>Contrastive specifications:</th>
<th>Graph:</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha \ \text{æ} \ e \ i \ u )</td>
<td>( \alpha \ \text{æ} \ e \ i \ u )</td>
<td>( i - u )</td>
</tr>
<tr>
<td>low ( + \ + \ - \ - )</td>
<td>low ( + \ - )</td>
<td>( \text{æ} )</td>
</tr>
<tr>
<td>high ( - \ - \ - \ + )</td>
<td>high ( - \ + )</td>
<td>( e )</td>
</tr>
<tr>
<td>back ( + \ - \ - \ - )</td>
<td>back ( + \ - \ - \ + )</td>
<td>( \text{æ} )</td>
</tr>
<tr>
<td>round ( - \ - \ - \ - )</td>
<td>round ( - \ - \ - \ + )</td>
<td>( \alpha )</td>
</tr>
</tbody>
</table>

Each of these inventories corresponds to a graph that is topologically equivalent to \( \bullet \bullet \bullet \bullet \bullet \bullet \), and which, if interpreted as an adjacency graph, would have an \( N_0 \) of 3; however, the inventory in (157b) has a pair of segments (\( /\alpha/ \) and \( /u/ \)) that enter into a parallel contrast and thus cannot be distinguished from each other, much as in the Maranungku example, while the one in (157a) does not suffer from this problem.

4.3.2 Finding the middle ground

So first she tasted the porridge of the Great, Huge Bear, and that was too hot for her; and she said a bad word about that. And then she tasted the porridge of the Middle Bear, and that was too cold for her; and she said a bad word about that too. And then she went to the porridge of the Little, Small, Wee Bear, and tasted that; and that was neither too hot nor too cold, but just right; and she liked it so well she ate it all up: but the naughty old Woman said a bad word about the little porridgepot, because it did not hold enough for her.

Robert Southey, “The Story of the Three Bears”

Despite these caveats, the general preference of the Pairwise Algorithm is for minimal contrasts. This is also why it fails as a means of contrastive specification: rather than requiring only that the representation of contrasts be minimal, it requires that the contrasts themselves be minimal, and that condition is clearly not met in the inventories of the world’s languages.

The opposite of the Pairwise Algorithm, as an approach to predicting inventory shapes, would require the maximization of pure phonetic distinctness. Liljencrants and
Lindblom’s (1972) dispersion theory approximates this extreme, but does not quite reach it. As shown earlier in §4.2.1.2, the phonetically arbitrary starting positions of the vowels in Liljencrants and Lindblom’s model have an appreciable effect on the resulting inventories. Somewhat closer to the purely phonetic approach was the third variation tried by Hall (1999), which simply attempted to calculate the vowel inventory with the lowest possible energy all at once, rather than approaching it from some particular starting point, and came up with the W-shaped inventory in (146). Even this model, however, incorporates some element of phonological structure, because it adopts Liljencrants and Lindblom’s assumption that the space to be explored is defined by the first three formants of the acoustic signal. If one views the possibilities for maximizing distinctness from a perspective that is genuinely purely phonetic, various other dimensions of contrast suggest themselves—for example, the vowels might differ in their fundamental frequencies, their duration, their method of phonation, or the presence or absence of nasality. A five-vowel inventory that maximized phonetic contrast with absolutely no regard for the usual phonological organization of these properties might look something more like (158).

(158) \[ \tilde{i}, \tilde{u}, \tilde{e}, \tilde{a}, \tilde{\rho} \]

The inventory in (158) is not at all typical of natural languages; in attested systems, length and nasality tend to cross-classify fairly extensively with other properties of vowels, and tones are generally best understood as autosegments independent of the vowels (and other tone-bearing segments) with which they associate.\(^8\)

If a purely phonetic approach predicts inventories like (158), and the Pairwise Algorithm prefers inventories like the equally implausible (155), how might a more balanced

---

\(^8\) In a similar vein, Ohala (1980) observes that a consonant inventory along the lines of /\[d, k’, ts, f, m, r, l//\], though its members are very distinct from one another auditorially, is quite unlike the consonant systems attested in natural languages.
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approach begin to explain why the inventories we actually find lie somewhere between these two extremes, and how would such an approach relate to the contrastivist hypothesis? Unlike the Pairwise Algorithm, the Successive Division Algorithm is capable of assigning a usable set of feature specifications to any inventory that is given to it; it handles inventories like (155) and (158) just as easily as it does /i, a, u/. The Successive Division Algorithm, then, would seem to have nothing to say about the shapes of inventories. It is a theory of how contrast is represented phonologically, rather than of how contrast is realized phonetically.

However, if the Successive Division Algorithm is combined with some fairly simple assumptions about phonetic enhancement of phonological contrasts, it can indeed make meaningful predictions about the surface shapes of phonemic inventories. By phonetic enhancement, I mean the addition to segments, in their phonetic realization, of properties that are not explicitly mandated by the phonological representations of those segments, but which reinforce the auditory salience of properties that are. For example, a vowel that is specified as being contrastively back, but unspecified for rounding, may be rounded by enhancement because acoustic effects of rounding (mostly lowering of the second formant) reinforce those of backness. I assume that phonetic enhancement cannot contradict contrastive feature specifications (not even the contrastive absence of a feature; see the Metarule for the Interpretation of Contrastively Unmarked Segments in (89) on page 93); thus a back vowel that is contrastively non-rounded will not become rounded by enhancement. Under this view, there is also no need to suppose that enhancement requires any sort of global comparison or evaluation of phonetic distance applied to the inventory as a whole, unlike the dispersion-theoretic approaches of Liljencrants and Lindblom (1972), Flemming (1995), Padgett (2003), and others.

9. Unlike Keyser and Stevens (2001) and Clements (2004), I do not differentiate here between phonetic enhancement and phonological enhancement; the version of the contrastivist hypothesis pursued in this dissertation relegates all redundant properties of segments to phonetics, regardless of whether they are represented by phonological features in other languages or even on other segments in the same language.
Because the Successive Division Algorithm works by making a sequence of cuts in the inventory, the underspecified segmental representations it assigns can be understood not simply as omitting redundant information, but also as treating segments as regions of phonetic space, rather than points in it. This idea follows Rice’s (1995: §4) discussion of the phonetic realization of underspecified vowels, in which she notes that a placeless vowel in opposition to a vowel of the same height specified as [Peripheral] will be realized as unrounded and either central or front, but a placeless vowel in opposition to both a [Peripheral] and a [Coronal] vowel could only be central, while a vowel that is unspecified for place by virtue of being the only vowel at its height is capable of spanning the full range of place and rounding.10 These possibilities are illustrated in (159) with partial vowel systems from languages discussed by Rice (1995).

(159) Phonetic realization of vowels unspecified for place

- **a. High vowels in Gonja:**
  
  /i/ = [i, ɪ, ɨ]  
  /u/ = [ʊ, ʊ̃]  
  (Rice 1995: 103)  

- **b. High vowels in Yimas:**
  
  /i/ = [ɨ]  
  /u/ = [ʊ, ʊ̃]  
  (Rice 1995: 107)  

- **c. Low vowel in Diyari:**
  
  /a/ = [æ, ə, ɒ, ʌ]  
  (Rice 1995: 106)  

To see the consequences of this for predicting the shapes of inventories, it is useful to consider how the Successive Division Algorithm would deal with the highly implausible three-vowel inventory /u, i, a/ from examples (155) and (156) above. Only two features are potentially contrastive in this inventory, namely [High] and [Round] (or [High] and
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[Peripheral], if we adopt the feature system of Rice (1995); in this example, the differences between the two possibilities are irrelevant, as are the differences between monovalent and binary features). The representations assigned by the Successive Division Algorithm will depend on the relative scope of these features; the two possibilities are shown in (160).

(160) Dividing the inventory /u, i, ø/

a. If [High] takes scope over [Round]

<table>
<thead>
<tr>
<th>([−Round])</th>
<th>([+Round])</th>
</tr>
</thead>
<tbody>
<tr>
<td>([+High])</td>
<td>i</td>
</tr>
<tr>
<td>([−High])</td>
<td>ø</td>
</tr>
</tbody>
</table>

b. If [Round] takes scope over [High]

<table>
<thead>
<tr>
<th>([−Round])</th>
<th>([+Round])</th>
</tr>
</thead>
<tbody>
<tr>
<td>([+High])</td>
<td>i</td>
</tr>
<tr>
<td>([−High])</td>
<td>ø</td>
</tr>
</tbody>
</table>

In (160a), [High] takes scope over [Round], and so /i/ and /u/ are both contrastively marked as high, and /u/ is also contrastively marked as rounded, with /i/ being contrastively unrounded. The third vowel, /ø/, is contrastively non-high, but its lack of rounding is not contrastive. If phonetic enhancement then applies to these representations, the contrastive rounding of /u/ may be enhanced by backing; the contrastive absence of rounding on /i/ may be enhanced by fronting; and the contrastive non-high height of /ø/ may be enhanced by lowering. In other words, phonetic enhancement, operating only on contrastive representations, may realize /u, i, ø/ as [u, i, a].

In (160b), the scope of [Round] and [High] is reversed. Here, /u/ is contrastively rounded, but its height is not contrastive. The other two vowels, /i/ and /ø/, are contrastively unrounded, and they contrast with each other in height. Phonetic enhancement
may again use place to reinforce the rounding contrasts, making /i/ and /ə/ front and /u/ back, and /ə/, being again contrastively non-high, may be realized as phonetically low. This set of enhancements would yield something along the lines of [o, i, æ], a less common inventory shape than [u, i, a], but still an attested one (Liljencrants and Lindblom (1972) cite Sedlak (1969) as reporting an inventory of this shape for Mikasuki; cf. Fig. 4.4a), unlike [u, i, ə]. On the other hand, because the vowel space is wider at the top than at the bottom, realizing /u/ as high rather than mid would make it possible to achieve a slightly lower F2, and thus a greater enhancement of the contrastive rounding; similarly, /ə/ could be made even lower if it is realized as less than fully fronted, so there is a tradeoff between enhancing its contrastive lack of rounding and its contrastively non-high height. Depending on the choices that are made here, the representations in (160b) could also very well lead to [u, i, a].

What (160) shows is that although the Successive Division Algorithm does not specifically disfavour the inventory /u, i, ə/, it is nonetheless incapable of assigning to that inventory any set of featural representations that could not also be interpreted as describing the inventory /u, i, a/. In the representations assigned to either system, the vowels are not assigned to specific points in the phonetic space; rather, only a few essential differences between them are marked. The representation of /u/ in (160b) says only that it is rounded, and so its phonetic realization could be anything from [y] to [œ] to [ə] to [u] to [ø]. In (160a), /u/ is somewhat more restricted, being specified as both round and high; still, it could be realized as anything from [y] to [y] to [u] to [u] to [u]. Nor is there any reason to assume that the phonetic realization of any segment will be consistent with respect to any properties other than those that are phonologically encoded; for example, vowels in prominent positions (e.g., the nucleus of a stressed syllable) will probably be subject to a greater degree of enhancement of underlying contrasts, while ones in weaker positions are likely to be less enhanced.
What about an inventory such as the one in (158)? Here, too, the Successive Division Algorithm will of course be able to assign a workable set of feature specifications. However, the algorithm cannot represent all of the ways in which the segments in (158) differ from one another phonetically, because it cannot possibly use more than four different features to specify an inventory of five vowels. Whatever specifications are assigned to this set of vowels (the possibilities are much more numerous here than in the case of (160)), some phonetic differences will go unrepresented, and, because many of the dimensions of phonetic contrast are unrelated to one another, the missing properties are not likely to be supplied automatically by enhancement. The Successive Division Algorithm does not rule out either /u, i, ø/ or /ɨːɭ, ʊ ɭ, u ɭ, ɛːɭ, aːɭ/ absolutely, but it does, in combination with phonetic enhancement, go some way toward explaining why neither is particularly likely to occur. As summarized in (161), while the Pairwise Algorithm minimizes contrast, and thus predicts inventories such as /u, i, ø/, and a purely phonetic theory of dispersion would favour inventories such as /ɨːɭ, ʊ ɭ, u ɭ, ɛːɭ, aːɭ/, the Successive Division Algorithm, by effecting a division of labour between contrastive phonological representations and phonetic enhancement, successfully finds the middle ground.

(161)  

a. **The Pairwise Algorithm**: Contrast (both phonological and phonetic) is minimal.

b. **The purely phonetic approach**: Phonetic contrast is maximal (and unconstrained by phonological structure).

c.  

i. **The Successive Division Algorithm**: Phonological contrast is represented minimally.

ii. **Enhancement**: Phonetic contrast is maximized within bounds set by phonological representations.
4.3.3 Feature economy

Another means by which the shapes of inventories may be constrained phonologically, and one that would disprefer /ɨ/, ɨ-, ʊ-, ə, æ, ə/, ě in particular, is Clements’s (2003, 2004) principle of feature economy, which Clements (2004: 9) defines as “the tendency to maximize feature combinations.” The greater the extent to which features cross-classify in an inventory, the closer the system approaches the ideal of maximizing the number of segments while minimizing the number of features used to distinguish them. (The example in (143) in §4.1 exhibited the antithesis of feature economy, with no cross-classification of features, and, as a result, used six features to distinguish seven segments.)

4.3.3.1 Economy, exploitation, frugality

Clements (2003: 289) suggests that feature economy can be quantified by an economy index $E$, calculated by dividing the number of segments in the inventory ($S$) by the number of contrastive features ($F$), as in (162). The $E$ of an inventory increases if more segments are added without an increase in the number of features, or if fewer features are used with no decrease in the size of the inventory.

(162) Clements’s feature economy index $E$

$$E = \frac{S}{F} \quad (\text{Clements 2003: 289; Clements 2004: 10})$$

The formula in (162), though it has the virtue of simplicity, makes it difficult to draw meaningful comparisons among inventories as to their economy, nor to evaluate the degree to which feature economy is offset by other considerations Clements (2004) mentions as relevant to the shapes of inventories, such as robustness. This is because
there is no upper bound on $E$; as the number of features increases, the potential maximum value of $E$, which is achieved when $S = 2^F$, grows very quickly, as illustrated in Figure 4.10.

$$x = F = \text{number of features}$$
$$y = \max E = \frac{\max S}{F} = \frac{2^x}{x}$$

Figure 4.10: The maximum possible value of Clements’s (2003, 2004) feature economy index ($E$) increases rapidly and without bound as the number of features ($F$) rises.

If there is no upper limit to $E$, and if each new fully utilized feature offers an even greater gain in economy than the one before it, then we might expect feature economy to exert considerable pressure toward very large inventories. This prediction does not appear to be correct (although it is difficult to test in the absence of a full model of the other considerations that interact with feature economy), nor does it seem to be precisely what Clements intends for feature economy to predict.
As alternative measures of feature economy, then, we might consider indices that use a bounded scale derived by comparing a given inventory to the economical ideal in which \( n \) features are used to distinguish \( 2^n \) segments. There are two obvious ways of doing this: either by comparing the actual number of segments \( S \) to the maximum number of segments \( 2^F \) hypothetically distinguishable by \( F \) features, or else by comparing the actual number of features \( F \) to the minimum number of features \( \log_2 S \) hypothetically needed to distinguish \( S \) segments. These two indices, shown in (163), represent the two sides of feature economy, which I will refer to as feature exploitation and feature frugality. The formula for each of these indices is designed so as to produce a range of values between 0 and 1, thereby making it possible to evaluate the feature exploitation and feature frugality of a system in the absolute as well as in comparison to other systems.

(163) a. **Feature exploitation index:** \( \frac{S}{2^F} \)

To what extent does the inventory approach the ideal of getting as many segments as possible out of its features?

b. **Feature frugality index:** \( \frac{\log_2 S}{F} \)

To what extent does the inventory approach the ideal of using no more features than mathematically necessary to specify its segments?

Although these two metrics share with Clements’s economy index the basic property that an inventory’s score increases whenever \( S \) increases and \( F \) does not, and whenever \( F \) decreases and \( S \) does not, the three indices produce rather different evaluations of the economy of actual inventories. Table 4.7 shows the economy, exploitation, and frugality indices for three consonant inventories discussed by Clements (2003), namely those of Hawaiian, French, and Nepali.

The first three columns of the table show values given by Clements (2003: 290) for the number of contrastive features \( (F) \), the number of segments \( (S) \), and the resulting economy index \( (E = \frac{S}{F}) \) for each inventory. As there is no upper bound to \( E \), it is difficult to say to what extent each of these inventories exhibits feature economy in any absolute
sense, but comparisons between them are possible. Clements (2003: 290) writes, “All systems show some degree of economy. However, of these systems, Hawaiian is the least economical and Nepali the most.” The exploitation and frugality indices in the fourth and fifth columns, however, tell a somewhat different story. None of the inventories has an exploitation index over 0.25, and Nepali, the inventory that rates the highest by Clements’s metric, has the lowest exploitation index by far. On the frugality index, the three inventories fare much better, and vary less widely. In this respect, the feature frugality index seems to be the one that best substantiates Clements’s claim that feature economy is a property strongly but variably exhibited by natural languages in general.

The fact that the largest inventory scores the lowest on the exploitation and frugality indices is suggestive of the ways in which feature economy interacts with other factors identified by Clements (2004) as shaping inventories, in particular with his principle of robustness, which holds that some contrasts are cross-linguistically preferred over others, in an order that correlates at least approximately with their auditory perceptibility. Clements (2004: 28) illustrates the difference between “more robust” and “less robust” contrasts with the examples in (164).

<table>
<thead>
<tr>
<th>Features</th>
<th>Consonants</th>
<th>Clements’s $E$</th>
<th>Exploitation $\frac{S}{F}$</th>
<th>Frugality $\frac{\log_2 S}{F}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hawaiian</td>
<td>5</td>
<td>8</td>
<td>1.60</td>
<td>0.25</td>
</tr>
<tr>
<td>French</td>
<td>7</td>
<td>18</td>
<td>2.57</td>
<td>0.14</td>
</tr>
<tr>
<td>Nepali</td>
<td>10</td>
<td>27</td>
<td>2.70</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Table 4.7: Economy indices for three consonant systems

Clements’s”
(164) More and less robust contrasts (Clements 2004: 28)

<table>
<thead>
<tr>
<th>MORE ROBUST</th>
<th>LESS ROBUST</th>
</tr>
</thead>
<tbody>
<tr>
<td>sonorant vs. obstruent</td>
<td>apical vs. nonapical</td>
</tr>
<tr>
<td>labial vs. coronal vs. dorsal</td>
<td>central vs. lateral</td>
</tr>
<tr>
<td>nasal vs. oral</td>
<td>aspirated vs. nonaspirated</td>
</tr>
<tr>
<td>stop vs. continuant</td>
<td>glottalized vs. nonglottalized</td>
</tr>
<tr>
<td>voiced vs. voiceless</td>
<td>implosive vs. explosive</td>
</tr>
</tbody>
</table>

As Clements (2004: 28) notes, the more robust contrasts are also ones that lend themselves readily to cross-classification (for example, labial vs. coronal vs. dorsal, stop vs. continuant, and voiced vs. voiceless cross-classify with one another fully or nearly fully in a great many systems), while ones that are less robust are often limited, sometimes by definition, to particular subinventories (for example, the apical vs. nonapical contrast is restricted to coronal consonants; implosive vs. explosive applies only to obstruent stops; and central vs. lateral is meaningful only for fricatives, approximants, and affricates).

If smaller inventories are more likely to use only the more robust contrasts, then it will be easier for them to achieve greater feature economy, whereas larger inventories, which need to use some of the less robust contrasts as well, will find it more difficult to approach the ideal ratio of segments to features, which, as shown in Figure 4.10, grows ever more rapidly as the size of the inventory increases. Clements’s economy index, because it makes no comparison between the actual ratio $\frac{S}{F}$ and the ideal, misses the economic cost of a large inventory.

### 4.3.3.2 Defining contrast, again

Another factor affecting the calculation of feature economy is the method by which features are identified as either contrastive or redundant, because, according to Clements (2003), only “globally distinctive” features are included in the enumeration of $F$. For
example, Clements (2003: 303) treats the subinventories /p, t, f, s/ and /p, t, ɸ, s/ as equivalent in terms of their economy, on the assumption that the characterization of each involves only two contrasts, [labial] vs. (unmarked) coronal and [−continuant] vs. [+continuant], the difference in place between bilabial /p/ and labiodental /f/ being redundant. Such judgments have a potentially significant effect on the calculations in Table 4.7. For example, Clements organizes the obstruents of French as in (165), suggesting that while the place difference between the bilabial stops and labiodental fricatives is not distinctive, the difference between the velar stops and the postalveolar fricatives is; indeed, he says (Clements 2003: 289) that the economy of the French system could be increased by changing /ʃ, z/ to /x, ɣ/, thereby eliminating the need for the feature [±posterior], or by adding postalveolar /tʃ, ɖ]/ to the stop series, thereby increasing the number of segments without requiring any new features.


\[
\begin{array}{ccc}
p & t & k \\
b & d & g \\
f & s & ʃ \\
v & z & ʒ
\end{array}
\]

The diagram in (166) shows how the Successive Division Algorithm could divide the French obstruents using the features assumed by Clements (2003) so as to give the inventory the shape shown in (165). Among the [−continuant] non-labial segments, [Dorsal] is contrastive, but the corresponding set of [+continuant] segments is divided by [±posterior] instead.  

11 For Clements (2003: 300), the features [Labial], [Coronal], [Dorsal], [Radical], [Spread Glottis], and [Constricted Glottis] are monovalent, while [±sonorant], [±consonantal], [±distributed], [±posterior], [±strident], [±lateral], [±voice], [±nasal], and [±continuant] are binary; (166) reflects this mixture of feature valencies. As Clements (2004: 290) lists [Labial] and [Dorsal] but not [Coronal] as distinctive in French, I assume here that the coronal place of articulation is unmarked.
Chapter 4. Phonemic and phonetic contrast

(166) Divisions in the French obstruent inventory suggested by (165)

<table>
<thead>
<tr>
<th></th>
<th>Labial</th>
<th>Dorsal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>−posterior</td>
<td>p</td>
<td>t</td>
</tr>
<tr>
<td>+posterior</td>
<td>b</td>
<td>d</td>
</tr>
<tr>
<td>−voice</td>
<td>f</td>
<td>s</td>
</tr>
<tr>
<td>+voice</td>
<td>v</td>
<td>z</td>
</tr>
<tr>
<td>−cont</td>
<td>[+posterior]</td>
<td>[+posterior]</td>
</tr>
</tbody>
</table>

However, this is not the only possible order of divisions. Although the feature [±posterior] or [±anterior] is usually employed only for the purpose of making distinctions within the class of coronal consonants, nothing in the way in which this feature is typically defined suggests that it cannot be used to mark the difference between /t, d/ and /k, g/. For example, Halle and Clements (1983) write that “Anterior sounds are produced with a primary constriction at or in front of the alveolar ridge. Posterior sounds are produced with a primary constriction behind the alveolar ridge.” The feature value [+posterior] is thus redundant among segments that are already specified as [Dorsal], but if [±posterior] is given higher scope in the contrastive hierarchy, then [Dorsal] is not needed at all in the French system, as shown in (167).

(167) Divisions in the French obstruent system with [±posterior] ≫ [Dorsal]

<table>
<thead>
<tr>
<th></th>
<th>Labial</th>
<th>−posterior</th>
<th>+posterior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voice</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>−posterior</td>
<td>p</td>
<td>t</td>
<td>k</td>
</tr>
<tr>
<td>+posterior</td>
<td>b</td>
<td>d</td>
<td>g</td>
</tr>
<tr>
<td>−voice</td>
<td>f</td>
<td>s</td>
<td>ʃ</td>
</tr>
<tr>
<td>+voice</td>
<td>v</td>
<td>z</td>
<td>ʒ</td>
</tr>
<tr>
<td>−cont</td>
<td>[+posterior]</td>
<td>[+posterior]</td>
<td></td>
</tr>
</tbody>
</table>

The divisions shown in (167) reduce the number of features needed to differentiate the French consonants from seven to six. (The two not shown in (166) and (167) are [±sonorant] and [±nasal], which are needed to distinguish the sonorants from the
obstruents and from one another.) This would increase the $E$ of the French consonant inventory from 2.57 to 3.00, while the feature exploitation index would go from 0.14 to 0.28 and the feature frugality index from 0.60 to 0.69. The difference between (167) and (166) is thus a potentially meaningful one as far as the evaluation of feature economy is concerned. Nor do these two examples exhaust the possible ways of dividing the inventory. Dresher (2003), citing earlier analyses by Trubetzkoı (1939) and Martinet (1964), suggests that place contrasts might be more important in French rather than less so, and shows that if the obstruents are organized as in (168), the feature [±continuant] ceases to be contrastive.

(168) The French obstruents (based on Dresher 2003: 54, after Martinet 1964)

\[
\begin{array}{ccccccc}
p & f & t & s & z & k \\
b & v & d & z & ʒ & ɡ \\
\end{array}
\]

Eliminating [±continuant] in this way would require at least three place features (to distinguish six places of articulation). If exactly three are used, then (168) is as economical as (167); if four are employed, then it scores the same as (166); and if five place features (the logical maximum) are used, then it will result in an $E$ of 2.25, an exploitation index of 0.07, and a frugality index of 0.52.

Under the view of contrast represented by the Successive Division Algorithm, the question of which of these various possibilities best characterizes the French obstruent inventory is an empirical one, but one that can be resolved only by considering the phonological behaviour of the consonants, not by examination of the inventory alone. For Clements, however, (165) is the only possibility, although it is not immediately clear why this is so. In a discussion of the difference between feature economy and symmetry, Clements (2003: 291) briefly alludes to the idea that the French inventory might be organized along the lines of (167):

[The principle of symmetry] may sometimes have heuristic value in leading the analyst to useful hypotheses. When unconstrained by feature analysis,
however, it reduces to the subjective exercise of lining up phonemes on the page. (For instance, the ‘symmetry’ of the French consonant system could be increased by putting postalveolar consonants and velar consonants in the same column [...] , in spite of their different place features.)

Under the Successive Division Algorithm, the “exercise of lining up phonemes on the page” is not a subjective one; even though the organization of phonemes can vary from one language to another, they are organized according to their contrastive features, not “in spite of” them. It is useful here to follow Twaddell (1962) in drawing a distinction between true phonological symmetry and “merely ordinal parallelism.” Twaddell (1962: 136) writes:

[M]erely ordinal parallelism does not constitute symmetry in itself, nor does a merely ordinal parallelism of itself lead to discovering valid linked-unit components. For example, by setting up a mode-of-action unit “sealing of oral–nasal channel” (plus subsequent unsealing) one arrives at the possibility of an ordinal parallelism for certain English obstruents:

\[
\begin{align*}
& \text{p} & \text{t} & \text{c} & \text{k} \\
& \text{f} & \emptyset & \text{s} & \check{s}
\end{align*}
\]

That is diagrammatic symmetry, but of a merely ordinal sort. For any specification of the linked-unit component which differentiates /c/ from both /t/ and /s/, and which is shared by both /c/ and /s/, will be uneconomical, to put it mildly.

For Twaddell, any symmetrical arrangement of an inventory that can be motivated by phonetically meaningful distinctive features (in Twaddell’s terms, by the “linked units” and “mode-of-action units” that serve as components of phonemes) is worth considering, but arrangements that ignore features and align segments according to parity of number alone are uninsightful. The difference in place of articulation between /c/ and /s/ cannot
be ignored in organizing the English obstruent inventory, not because such differences are inherently insurmountable, but because there exist contrasting segments /t/ and /s/ that must, in any reasonable feature system, align more closely with /s/ and /ʃ/, respectively, than /s/ and /ʃ/ align with each other. By this logic, the alignment of /k/ and /g/ with /ʃ/ and /ʒ/ in (167) should be considered a legitimate possibility, but it would be ruled out if the inventory included any of the segments /x, ʒ, ɬ, ŋ/. The Successive Division Algorithm, by making feature specifications dependent on contrast, permits feature-based symmetries to vary from language to language, but offers no licence for “merely ordinal” symmetries.

Clements’s theory shares with the Successive Division Algorithm the idea that redundant differences (for example, the difference in place between /p, b/ and /f, v/ in (166)) are to be set aside; each assumes that only features that are contrastive at least somewhere in the inventory count. The difference between the two approaches lies in their procedures for determining whether a feature meets this criterion. Clements (2003: 319) offers the following definition of distinctiveness, which suggests that he is relying on the Minimal Pairs Test to identify contrastive features; the example (18) to which he refers is reproduced below as (169):

Features are distinctive or redundant at two levels: (i) the system as a whole, and (ii) the segment. We will say that a feature is distinctive at the system level, or GLOBALLY distinctive, if it crucially distinguishes at least one pair of sounds in the system; otherwise it is globally redundant. For example, the feature [+voiced] is globally distinctive in any system containing either subsystem in (18), since it crucially distinguishes T from D. A feature is distinctive in a segment, or LOCALLY distinctive, if it crucially distinguishes that segment from another; otherwise it is locally redundant in that segment. For example, [+voiced] is locally distinctive in D in both subsystems in (18),
and it is locally distinctive in B in subsystem A, but it is locally redundant
in B in subsystem B.

(169) Clements’s (2003: 319) example (18)

<table>
<thead>
<tr>
<th>subsystem A</th>
<th>subsystem B</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>T</td>
</tr>
<tr>
<td>B</td>
<td>D</td>
</tr>
<tr>
<td>B</td>
<td>D</td>
</tr>
</tbody>
</table>

Under the Successive Division Algorithm, whether [+voice] is (locally) distinctive
or redundant on /B/ in subsystem B will depend on whether the voicing contrast in
the inventory has wider or narrower scope than the place contrast. Under the Minimal
Pairs Test, as Clements indicates, the absence of /P/ from subsystem B guarantees that
voicing will be redundant on /B/, and, for that matter, that coronality (or non-labiality)
will be redundant on /T/.

As discussed in sections 1.2.3 and 4.3.1 above, the Minimal Pairs Test is an in-
adequate means of identifying contrastive features. When faced with a pair of segments
that differ in two or more properties, with no other segments intermediate between them
(for example, /t/ and /b/ in a language that lacks /p/ and /d/, or, to take a less exotic
element, /p/ and /f/ in a language that does not also have /ϕ/ or /p/), the Minimal
Pairs Test cannot by itself identify which property is the contrastive one. The presence
of each potentially contrastive property renders the other(s) redundant.

However, Clements does not in fact encounter the paradoxes that would arise from
total reliance on the Minimal Pairs Test. This is because he also assumes the existence
of a contrastive hierarchy that is capable of resolving potential impasses by identifying
one feature as more important than another, making the more important feature the
contrastive one and the less important feature redundant. For Clements (2003), the
relevant hierarchy is the accessibility scale proposed by Clements (2001: 80, 90), shown
in (170). Some features rank in two or more different places on the scale depending on
the context in which they are potentially contrastive—for example, [Dorsal] is contrastive among obstruents (170d) before it is contrastive among nasals (170k).

(170) Consonant feature accessibility scale (Clements 2001: 80, 90)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. [Coronal]</td>
<td></td>
</tr>
<tr>
<td>b. [±sonorant]</td>
<td></td>
</tr>
<tr>
<td>c. [Labial]</td>
<td></td>
</tr>
<tr>
<td>d. [Dorsal]</td>
<td>[−sonorant]</td>
</tr>
<tr>
<td>e. [±strident]</td>
<td></td>
</tr>
<tr>
<td>f. [±nasal]</td>
<td></td>
</tr>
<tr>
<td>g. [±posterior]</td>
<td>[+sonorant, −nasal]</td>
</tr>
<tr>
<td>h. [±lateral]</td>
<td>[+sonorant]</td>
</tr>
<tr>
<td>i. [±voice]</td>
<td>[−sonorant]</td>
</tr>
<tr>
<td>j. [±spread glottis]</td>
<td></td>
</tr>
<tr>
<td>k. [Dorsal]</td>
<td>[+nasal]</td>
</tr>
<tr>
<td>l. [±posterior]</td>
<td>[+strident]</td>
</tr>
<tr>
<td>m. [±constricted glottis]</td>
<td></td>
</tr>
<tr>
<td>n. [±continuant]</td>
<td>[−voice, −sonorant]</td>
</tr>
<tr>
<td>o. [±posterior]</td>
<td>[+nasal]</td>
</tr>
<tr>
<td>p. [±posterior]</td>
<td>[−sonorant]</td>
</tr>
</tbody>
</table>

A similar notion underlies Clements’s (2004) principle of robustness. Robustness, according to Clements (2004: 27), “holds that there is a universal hierarchy of features such that languages draw upon higher-ranked feature in the hierarchy before drawing upon lower-ranked features in constituting their inventories.” Clements (2004: 31) gives the partial robustness hierarchy shown in (171). The robustness scale in (171) differs from the accessibility scale in (170) in a few potentially important ways: it gives a partial ordering of features rather than a total one; it does not restrict any features to a
particular context; and it gives a somewhat different ranking of features—in particular, 

\[ \pm \text{continuant} \] ranks significantly higher in (170) than it does in (171).

(171) Robustness scale for consonant features (Clements 2004: 31)

a. \[ \pm \text{sonorant}, \text{Labial}, \text{Coronal}, \text{Dorsal} \]

b. \[ \pm \text{continuant}, \pm \text{posterior} \]

c. \[ \pm \text{voiced}, \pm \text{nasal} \]

d. \[ \text{Glottal} \]

e. other features

In the case of /t/ and /b/, either hierarchy would give the major place contrast precedence over the voicing contrast. In the case of /p/ and /f/, the hierarchy in (171) would clearly rank the \[ \pm \text{continuant} \] contrast above the minor place contrast, but (170) would seem to give priority to \[ \pm \text{strident} \]. In the French obstruent inventory in (165), \[ \text{Dorsal} \] must take precedence over \[ \pm \text{posterior} \] under either hierarchy, and so the velar stops and the postalveolar fricatives end up having different place features. The consonant inventory of Hawaiian offers an instructive example of the difference between the two hierarchies. Clements (2003: 288, 290) divides the inventory as shown in (172a), following (170), whereas the robustness hierarchy in (171) would suggest instead the divisions in (172b).

(172) Contrasts in the Hawaiian consonant inventory


<table>
<thead>
<tr>
<th>[Labial]</th>
<th>h</th>
<th>[Spread Glo.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Constr. Glo.]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[\pm\text{sonorant}]</td>
<td>p</td>
<td>k</td>
</tr>
<tr>
<td>[\pm\text{nasal}]</td>
<td>m</td>
<td>n</td>
</tr>
<tr>
<td>[\pm\text{nasal}]</td>
<td>w</td>
<td>l</td>
</tr>
<tr>
<td>[Labial]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
b. Divisions based on (171)

\[
\begin{array}{cccc}
\text{Labial} & \text{Dorsal} & \text{?} & \text{\,-cont.} \\
\text{p} & \text{k} & \text{h} & \text{\,\,+cont.} \\
\text{\,-sonorant} & \text{\,\,+sonorant} & \text{\,-cont.} & \text{\,\,+nasal} \\
\text{\,+cont.} & \text{w} & \text{\,-nasal} & \\
\end{array}
\]

The difference between (172a) and (172b), while potentially important for predictions about the phonological patterning of the Hawaiian consonants (see Herd (2005: §5.2.1) for evidence from loanword adaptations that points to (172a)), does not affect the economy indices calculated for Hawaiian in Table 4.7; (172b) merely replaces [Constricted Glottis] and [Spread Glottis] with [Dorsal] and [\pm\,continuant], keeping the total number of features at five.¹²

For Clements, then, a hierarchy of robustness or accessibility like the ones in (170) and (171) serves two purposes: not only is it a hypothesis about the principles governing the phonetic shapes of phonemic inventories, but it is also, at least some of the time, a guide to determining which phonetic differences in a given inventory are to be counted as phonemic distinctions. There is, perhaps, a potential for circularity here. It would be an abuse of the duality of robustness, for instance, to use the hierarchy in (171) to analyze all /p/ vs. /f/ contrasts as stop vs. continuant contrasts, and then to take that analysis as evidence that stop vs. continuant contrasts are cross-linguistically preferred

¹² The divisions shown in (172b) follow Clements’s (2004: 30) assumption that /l/ is [\,-continuant], i.e., that the feature [\pm\,continuant] refers specifically to the maintenance of a central, as opposed to a lateral, airflow through the oral cavity. If /l/ were considered [\,+continuant], though, then [\pm\,continuant], which ranks above [\pm\,nasal] in the robustness hierarchy, would distinguish /l/ and /n/ as well as /m/ and /w/, thereby eliminating the need for [\pm\,nasal] and reducing the total number of features to four, for an E of 2.00, an exploitation index of 0.50, and a frugality index of 0.75.
over bilabial vs. labiodental contrasts, and thus as support for the hierarchy in (171). Drawing inferences in the opposite direction, however, is legitimate: if there are more /p/ vs. /f/ contrasts in natural languages than there are /φ/ vs. /f/ contrasts, then it is reasonable to use that fact as a basis for analyzing /p/ vs. /f/ contrasts as being primarily contrasts of continuancy. It is inferences of the latter sort that Clements (2004) draws, and his robustness hierarchy makes testable predictions about implicational relations among contrasts—so, for example, it should be true not only that more languages contrast labial stops with labial continuants than contrast bilabials with labiodentals, but also that the presence of a /φ/ vs. /f/ contrast is a strong predictor that both fricatives also contrast with /p/.

4.3.3.3 Economy, robustness, and the Successive Division Algorithm

For the purpose of calculating feature economy, Clements’s (2003, 2004) use of a hierarchy of contrasts is ultimately more significant than his stated adherence to the Minimal Pairs Test. Using the Minimal Pairs Test, with a hierarchy such as (170) or (171) brought in only to resolve the problems that arise from non-minimal pairs of segments, does in some circumstances produce different feature specifications for individual segments from those that would be assigned by the Successive Division Algorithm constrained by the hierarchy in (171), but the two methods’ predictions about the globally distinctive or redundant status of features should be the same. Consider, for example, the stop inventory in (173).

(173) An asymmetrical stop inventory

\begin{align*}
\text{p} & \quad \text{t} & \quad \text{k} \\
\text{b} & \\
\end{align*}

According to the Minimal Pairs Test, the only feature that will be contrastive on /b/ in (173) will be [+voice], because the only minimal contrast /b/ enters into is with /p/. Because this contrast is a minimal one, the position of [±voice] in the robustness scale is irrelevant. For the Successive Division Algorithm, though, the contrastive
hierarchy is always relevant. According to the robustness scale in (171), [Labial] takes precedence over [±voice], and so the SDA will first use [Labial] to divide /p/ and /b/ from /t/ and /k/, and then [±voice] to distinguish /p/ and /b/ from each other, with the result that both [Labial] and [+voice] will be contrastive on /b/. However, [Labial] will be globally distinctive in both systems, because it crucially distinguishes /p/ from /t/. Using either method of determining contrast, the globally distinctive features in (173) will be [Labial], [Dorsal], and [±voice], resulting in an $E$ of 1.33, an exploitation index of 0.50, and a frugality index of 0.67.

Because the Successive Division Algorithm is also a learning algorithm, it can potentially be used to explain the mechanisms by which such principles as feature economy and robustness exert their influence on inventories. In the simplest and strongest formulation, robustness and economy would constrain the algorithm categorically. Robustness would require that the algorithm make divisions only in sequences compatible with (171); features higher on the scale would always take precedence over lower-ranking ones. This approach would still allow for a lower-ranking feature to be contrastive in cases where a higher-ranking feature does not divide the inventory, as in the case of Zoque, which Clements (2004: 33) mentions as a partial exception to the general tendency toward robustness. In the Zoque obstruent inventory, shown in (174), voicing is not contrastive, but stridency (which Clements assumes is responsible for the contrast between /t/ and /ts/) is.

(174) The obstruent inventory of Zoque (Clements 2004: 33, citing Wonderly 1951–52)

\[
\begin{array}{cccc}
  p & t & ts & f \\
  t & s & f & c \\
  k & s & f & \end{array}
\]

The feature [±voice] cannot divide the Zoque obstruent inventory, and so even though [±voice] ranks higher in the robustness hierarchy than [±strident], the Successive Division Algorithm will use [±strident] in the specifications it assigns to (174), and it will not use [±voice]. By itself, then, using the robustness hierarchy to constrain the Suc-
cessive Division Algorithm guarantees only that more robust contrasts will be favoured in the phonological representations of inventories when they are phonetically present, not that they will necessarily be phonetically present to begin with. However, if the robustness hierarchy is combined with the mechanism of enhancement discussed in §4.3.2, the result will be a diachronic tendency toward the introduction and phonologization of more robust contrasts. For example, consider the hypothetical case of a language with the implausibly non-robust obstruent inventory shown in (175).

(175) An inventory composed entirely of coronal plosives

<table>
<thead>
<tr>
<th>[-posterior]</th>
<th>[+posterior]</th>
</tr>
</thead>
<tbody>
<tr>
<td>[-strident]</td>
<td>[+strident]</td>
</tr>
<tr>
<td>[−distributed]</td>
<td>[+distributed]</td>
</tr>
<tr>
<td>p</td>
<td>s</td>
</tr>
<tr>
<td>b</td>
<td>z</td>
</tr>
<tr>
<td>t</td>
<td>k</td>
</tr>
<tr>
<td>d</td>
<td>g</td>
</tr>
</tbody>
</table>

The acoustic distinctness of the sounds in (175) would be expected to be enhanced through the use of non-distinctive properties. One possible set of enhanced realizations is shown in (176), in which [+continuant] enhances [+strident], [Labial] enhances the non-strident [-posterior] segments, and [Dorsal] enhances the feature combination [+posterior, +distributed]. Each of these enhancements is compatible with the contrastively specified features of the segments to which it applies, because there are no segments in (175) that are contrastively non-labial, non-dorsal, or non-continuant, and each increases an acoustic difference that was already present.

(176) Enhancing the contrasts in (175)

<table>
<thead>
<tr>
<th>[-posterior]</th>
<th>[+posterior]</th>
</tr>
</thead>
<tbody>
<tr>
<td>[-strident]</td>
<td>[+strident]</td>
</tr>
<tr>
<td>[−distributed]</td>
<td>[+distributed]</td>
</tr>
<tr>
<td>p</td>
<td>s</td>
</tr>
<tr>
<td>b</td>
<td>z</td>
</tr>
<tr>
<td>t</td>
<td>k</td>
</tr>
<tr>
<td>d</td>
<td>g</td>
</tr>
</tbody>
</table>

Given the surface forms in (176), though, an implementation of the Successive Division Algorithm constrained by the robustness hierarchy would give the more robust
enhancement features precedence over the less robust contrastive features, and arrive at the specifications shown in (177) instead.

(177) Reanalyzing the contrasts in (176)

<table>
<thead>
<tr>
<th>[Labial]</th>
<th>[+continuant]</th>
<th>[−continuant]</th>
<th>[Dorsal]</th>
<th>[−voice]</th>
</tr>
</thead>
<tbody>
<tr>
<td>p</td>
<td>s</td>
<td>t</td>
<td>k</td>
<td>g</td>
</tr>
<tr>
<td>b</td>
<td>z</td>
<td>q</td>
<td></td>
<td>+voice</td>
</tr>
</tbody>
</table>

A preference for feature economy (or frugality) could also be implemented as a restriction on the Successive Division Algorithm. It is reasonable to assume that, in the implementation of the Successive Division Algorithm, subinventories, once they have been identified, are processed in parallel with one another rather than one at a time—so, for example, if the inventory is first divided into consonants and vowels, the divisions within one of these sets need not wait until the members of the other set have been fully differentiated. Feature economy, then, can be implemented as a principle that each division, when it is introduced, simultaneously divides every subinventory in which it is non-vacuous. In other words, the inventory would be required to be divided according to a single hierarchy of features that would apply to all subinventories, even when the robustness scale allows for variation in the scope of features from one inventory to another. For example, the place features [Labial], [Coronal], and [Dorsal] are unordered with respect to one another by the robustness hierarchy, and so languages may vary in the order in which they use these features to divide their inventories. Within any given language, however, the order would be required to hold throughout the inventory, so that, for instance, if [Labial] has wider scope than [Coronal] among the sonorants, the same must be true for the obstruents. This principle would simplify the application of the algorithm, constrain the number of possible orders of divisions, and promote feature economy by maximizing cross-classification of features. If the order of divisions must be the same across all subinventories, then the maximum number of possible sequences of
divisions of an inventory using $F$ features (setting aside for now the additional restrictions potentially imposed by the robustness hierarchy) is only $F!$; as shown in Table 4.8, this is much smaller than the number of possible sequences if each subinventory can have a different order of divisions (the formula for which was discussed in §1.2.7).

<table>
<thead>
<tr>
<th>Features ($F$)</th>
<th>Sequences of divisions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>One feature hierarchy ($F!$)</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>120</td>
</tr>
<tr>
<td>6</td>
<td>720</td>
</tr>
</tbody>
</table>

Table 4.8: Numbers of possible sequences of divisions under two sets of assumptions

If feature economy is to restrict the sequence of divisions in this way, then the accessibility scale in (170) cannot also be used as a constraint on the Successive Division Algorithm, because it explicitly specifies different orders of features for different subinventories. (As a prediction about the likelihood that a feature will actually be contrastive in any given subinventory, though, (170) is still tenable: for example, saying that [+lateral] must be applied wherever possible when it is applied at all does not require one to deny that this feature is more likely to be applicable among sonorants than among obstruents.) For this reason, I focus instead on the robustness scale in (171), which does not give rise to this incompatibility.

The categorical implementation of robustness, and perhaps also of feature economy, however, can be problematic for the Contrastivist Hypothesis, which is not a consideration for Clements. Clements (2001: 87; 2003: 328; 2004: 47 fn. 8) assumes that it is possible for non-distinctive features to be phonologically active, a view that significantly
reduces the empirical content of statements about whether a particular feature is or is not contrastive in a given system. If, on the other hand, we adhere to the Contrastivist Hypothesis, then there is evidence that the robustness hierarchy in (171) cannot be an absolute restriction on the Successive Division Algorithm, and less conclusive evidence suggesting that it may be necessary to allow subinventories to have different orders of divisions.

Evidence against incorporating robustness into the Successive Division Algorithm comes from Mackenzie’s (2005) analysis of dental harmony in Anywa. In Anywa, dental /t/ and /d/ contrast with alveolar /t/ and /d/, but there is only a single anterior coronal nasal, /n/, which nonetheless participates in dental harmony, surfacing as [n] when it appears in roots also containing /t/ or /d/, as illustrated in (178).

(178) Dental harmony in Anywa (Mackenzie 2005: 176, citing Reh 1996)

<table>
<thead>
<tr>
<th>Dental roots</th>
<th>Alveolar roots</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. nùɗò ‘to lick’</td>
<td>d. núud ‘to press something down’</td>
</tr>
<tr>
<td>b. ōɗóʊŋ ‘mud’</td>
<td>e. din ‘to thrash something’</td>
</tr>
<tr>
<td>c. tʊɗ ‘ropes’</td>
<td>f. tʊud ‘pus’</td>
</tr>
</tbody>
</table>

Mackenzie (2005) argues that /n/ participates in dental harmony in Anywa because it is contrastively specified for [−distributed], and she draws an instructive contrast with the behaviour of /n/ in Luo, which also has no phonemic dental counterpart, but which is ignored by dental harmony, as in (179).


<table>
<thead>
<tr>
<th>Dental roots</th>
<th>Alveolar roots</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. ɗumo ‘breast’</td>
<td>c. dino ‘deaf, stopped up’</td>
</tr>
<tr>
<td>b. ɗʊn ‘brave man’</td>
<td>d. ɗin ‘small’</td>
</tr>
</tbody>
</table>

Mackenzie (2005) attributes the different phonological behaviour of unpaired /n/ in Anywa and Luo to different contrastive hierarchies governing the specification of features in the two languages. In Luo, the features [±sonorant] and [±nasal] take scope
over [±distributed], and so /n/ is divided from the other coronal stops without being specified for [±distributed]; as a result, it is transparent to dental harmony. In Anywa, [±distributed] has a wider scope, and the contrastive hierarchy is as in (180), with the result that /n/ is distinctively [−distributed], and consequently a participant in the harmony process.

\[
\begin{array}{c}
\{t, d, t, d, n\} \\
\text{[+distributed]} & \text{[−distributed]} \\
\text{[+voice]} & \text{[−voice]} & \text{[+sonorant]} & \text{[−sonorant]} \\
\text{d} & \text{t} & \text{n} & \text{d} & \text{t} \\
\end{array}
\]

Strict adherence to the robustness hierarchy in (171), in which [±sonorant] belongs to the top tier of features and [±distributed] to the bottom tier, would preclude the order of divisions shown in (180), making [−distributed] redundant on /n/ in Anywa, and thus offering no principled contrast-based account of the difference between Anywa /n/ and Luo /n/.

The evidence against imposing a uniform sequence of divisions across all subinventories is somewhat less conclusive. Most of the analyses that have so far been advanced in the Successive Division Algorithm framework do not rely on crucially distinct orders of divisions for different subinventories, even in cases where similar contrasts are marked by different features in different parts of the inventory. One instance in which independent ordering seems as if it might be necessary is in D’Arcy’s (2004) analysis of Hungarian vowel harmony. In Hungarian, the long vowel /eː/ is transparent to place harmony, but short /ɛ/ patterns as a front vowel. D’Arcy derives this behaviour by dividing the Hungarian vowel inventory as shown in (181), using the vowel place features [Coronal] and [Peripheral] proposed by Rice (1995).
4.3. Contrast, enhancement, and economy

(181) Divisions in the Hungarian vowel inventory (based on D’Arcy 2004: 31)

<table>
<thead>
<tr>
<th>[Peripheral]</th>
<th>[Coronal]</th>
</tr>
</thead>
<tbody>
<tr>
<td>[High]</td>
<td>i/i:</td>
</tr>
<tr>
<td></td>
<td>e:</td>
</tr>
<tr>
<td>[Low]</td>
<td>ε</td>
</tr>
<tr>
<td>[Coronal]</td>
<td></td>
</tr>
</tbody>
</table>

Among the high and mid vowels, [Peripheral] crucially takes scope over [Coronal], cutting off the rounded non-low vowels from the unrounded ones. [Coronal] is then contrastive only among those non-low vowels that are already specified for [Peripheral], which accounts for the transparency of /i/, /iː/, and /eː/ to place harmony. Among the low vowels, however, only [Coronal] is specified, and [Peripheral] is not needed, because there are no front rounded low vowels. The presence of [Coronal] as the marked place feature in this set ensures that /ɛ/ will pattern with /y/, /yː/, /ø/, and /øː/ with respect to place harmony.

The question is, does this set of feature assignments depend on giving [Coronal] scope over [Peripheral] in the low subinventory? Or, to put it another way, would /n/ and /aː/ necessarily end up being specified as [Peripheral] if [Peripheral] is given scope over [Coronal]? The question is not an easy one to answer, or even to formulate in readily answerable terms. If we ask whether /n/ and /aː/ are phonologically [Peripheral], the answer is no—but this cannot be the only criterion for whether a feature applies to a segment: if it were, we could say that the relative scope of [Coronal] and [Peripheral] among the non-low vowels does not matter, because /i/, /iː/, and /eː/ are not phonologically [Coronal], and so even if [Coronal] had wider scope, they would not be specified with it. Such an approach would seriously endanger the falsifiability of the Contrastivist Hypothesis. On the other hand, if we ask whether /n/ and /aː/ are [Peripheral] pho-
netically, there is no single definitive answer. For short /ɒ/, the answer would seem to be yes, since it is both back and round. Long /aː/, on the other hand, is unrounded and somewhere in the central-to-front range. D’Arcy (2004: 30), citing Vago (1980), considers the difference in quality between /ɒ/ and /aː/ (which she transcribes as /a/ and /aa/) to be a redundant phonetic enhancement of their contrast in length, which she represents as a difference in moraic structure rather than a featural one.

Perhaps the best way of resolving the question is to turn to the characterization of the feature [Peripheral] given by Rice, who refers to it as “a cover feature that subsumes the velarity and labiality features” (Rice 1995: 74). D’Arcy’s (2004) treatment of Hungarian /ɛ/ as [Coronal] and /ɒ/ and /aː/ as unmarked for place accords with Rice’s (1995: §2.4.1.2) brief discussion of Hungarian, in which /ɒ/ and /aː/ are treated as underlyingly central and unrounded, and thus with Rice’s (1995: 80) prediction that “Coronal is present phonologically on a front unround vowel only if it has a central counterpart.” If /ɒ/ and /aː/ in Hungarian do not fall within Rice’s definition of the feature [Peripheral], then it is possible for the Successive Division Algorithm to derive the specifications shown in (181) with a single, global feature hierarchy in which [Peripheral] consistently takes scope over [Coronal]. Hungarian, then, does not provide clear support for the claim that the ordering of divisions must be permitted to vary between subinventories, although permitting [Coronal] to take wide scope among the low vowels would obviate the potentially vexed question of whether /ɒ/ and /aː/ are ‘really’ not [Peripheral]. Such questions, however, will inevitably arise in a theory of phonological feature specifications involving any appreciable degree of underspecification and abstractness; clear and consistent definitions of the features involved are a necessary, but perhaps not always sufficient, condition for ensuring that satisfactory answers can be found.

13. Indeed, Rice (1995: 75) proposes that [Peripheral] takes precedence over [Coronal] in vowel systems universally, but D’Arcy (2004: §3.1.2) presents data from Chamorro which suggest that this is not always the case, and Dresher and Zhang’s (in press) analysis of Manchu and Xibe also requires [Coronal] to take wider scope.
It seems, then, that it may be possible to incorporate feature economy into the Successive Division Algorithm by requiring a consistent order of divisions to hold across subinventories,\textsuperscript{14} but that the robustness hierarchy cannot be stated as anything stronger than a tendency. Within the context of the Contrastivist Hypothesis, evidence that a feature is phonologically active must always take precedence over other considerations in determining the order of divisions (as Mercado (2002) has observed). This fact is not in any fundamental way incompatible with the idea that more robust contrasts have priority over less robust ones, because the evidence available to the learner acquiring the contrast includes much more than just auditory impressions of individual segments. A contrast that is marked not only by a difference in the phonetic properties of segments, but also in their phonotactic properties or in their influence on, or capacity to be influenced by, other segments, is a phonologically robust contrast, and phonological robustness must be attended to by any learner who is acquiring a phonological system, as opposed to an unstructured collection of phonetic material.

Even without any explicit attempt to incorporate feature economy into the Successive Division Algorithm, the Contrastivist Hypothesis as implemented in the SDA would still predict one of the diachronic effects of feature economy identified by Clements (2003). Clements (2003: §5) notes that feature economy is increased by the extension of globally distinctive features to series of segments on which they are locally redundant, through the creation of allophones that later develop into separate phonemes. An example of this is discussed by Moulton (2003), who offers a contrastivist account of the development of voiced fricatives in Old English. In Old English, the voiceless fricatives /f/, /θ/, and /s/ had no phonemic voiced counterparts, but surface [v], [ð], and [z] arose

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\textsuperscript{14} Whether this is indeed possible may depend in particular on the extent to which the same features are used to divide consonantal and vocalic inventories, which is a matter of considerable interest in its own right (and on which see, e.g., Clements and Hume (1995: §3.4) and sources cited therein). Using features that cut across these major subinventories is in itself a boon to feature economy, but it may also increase the difficulty of finding a single consistent order of divisions for any complete phonemic inventory.
through intervocalic voicing of /f/, /θ/, and /s/, and, in the case of [v], though inter-
vocalic spirantization of /b/. Moulton (2003) describes the voiced fricatives as “deep
allophones,” because they involve allophonic combination of globally distinctive features
(voicing and continuancy), rather than the contextual introduction of globally redun-
dant features (as in, for example, the process that derives [r] from /t/ and /d/ in Modern
English). The eventual phonemicization of /v/, /ð/, and /z/ (through partial loss
of the environments conditioning voicing and spirantization) increased the feature economy
of the Old English inventory, because it added three new phonemes without requiring
any new distinctive features. The Contrastivist Hypothesis, because it states that only
distinctive features are phonologically active, favours scenarios such as this one to the
extent that phonological rules can be represented by spreading and deletion of existing
feature values rather than insertion of new ones. Spreading and deletion give rise to
new combinations of contrastive features, increasing $S$ without increasing $F$, whereas
the introduction of new feature values increases both $S$ and $F$, with potentially mixed
results for economy. Both types of processes occur in natural language, but by making
an explicit connection between contrast and phonological activity, the Contrastivist Hypo-
thesis makes distinctive features more likely, and redundant ones somewhat less likely,
to be involved in the synchronic and diachronic creation of new segments.

In this chapter, then, we have seen that the Contrastivist Hypothesis as imple-
mented in the Successive Division Algorithm offers diachronic explanations, based in
patterns of acquisition, for the general tendencies toward feature economy, phonetic dis-
tinctness, and robustness exhibited by the phonological inventories of natural languages.
Unlike some dispersion-based models of inventory shape, the Successive Division Algo-
rithm does not rely on explicit comparisons of phonetic distinctness or on global eval-
uation of inventories, and the constraints it places on the number of features that can
be assigned limit the number of phonetic dimensions along which distinctness is likely
to be maximized. The Successive Division Algorithm is also broadly compatible with
Clements's (2003, 2004) principles of robustness and feature economy, the latter of which suggests a way in which the algorithm itself can be constrained. In the next chapter, we will consider the extent to which the insights of the Successive Division Algorithm, and of contrastive specification more generally, are compatible with Optimality Theory (Prince and Smolensky 1993), and thus independent of the choice between rules and constraints as formalizations of phonological patterns.
CHAPTER FIVE

Contrast and Optimality

The rise of Optimality Theory (Prince and Smolensky 1993) as a dominant approach to phonology has raised new questions for the contrastivist position. In principle, because the contrastivist hypothesis is a hypothesis about representations, its predictions should be orthogonal to the question of whether phonological alternations are due to rules or to constraints; in either case, what the theory of contrastive specification supplies is a way of determining how much information is available to the mechanisms of phonology, whatever form those mechanisms take.

However, there are two particular aspects of Optimality Theory that pose serious difficulties for any theory that seeks to restrict underlying phonological representations. These are Lexicon Optimization, which Prince and Smolensky (1993: §9.3) propose as a procedure for selecting a single underlying form from among several that yield the same output, and Richness of the Base, which states that the constraint grammar of a language
should produce phonotactically well-formed outputs for all conceivable inputs, including those which are not—and could not be—present in that language’s lexicon.

The principle of Richness of the Base is motivated by the Optimality-Theoretic hypothesis that phonological alternations are generated by the same constraints responsible for static phonotactic generalizations. A successful constraint hierarchy must therefore meet two criteria: for each actual input form in the language, it must produce the correct corresponding output, and for all other inputs, it must produce outputs that are possible, if unattested, surface forms. The contrast between systematic and accidental gaps in the set of surface forms is sharply defined: an unattested surface form represents a systematic gap if and only if there is no possible input form for which it is the optimal output; otherwise, its absence is accidental. According to Richness of the Base, all language-specific systematic gaps must be due to the constraint hierarchy; there can be no language-specific restrictions on inputs, nor on the set of candidates from which the output is selected.¹ In the case of systematic gaps, it is frequently impossible to say, for a given hypothetical input, specifically what the output should be,² although evidence from loanword adaptations is instructive in some cases. In any event, Richness of the Base is clearly at odds with the view of contrastive specification embodied in the Successive Division Algorithm, under which languages are predicted to vary (within limits) as to the range of underlying representations they permit.

One initially plausible compromise between Richness of the Base and contrastive specification would be to say that each language has a finite inventory of segments whose

¹ Universal restrictions on these aspects of the grammar, however, may account for systematic gaps that hold cross-linguistically.
² On this point, Mackenzie and Dresher (2003) offer a relevant discussion of Baković’s (2000) analysis of the Nez Perce vowel system. The surface vowel inventory of Nez Perce is [i, æ, a, ɔ, u], and Baković argues for a constraint ranking that will, among other things, ensure that an input /o/ will be mapped to an output [ɔ], and not to any other vowel in or out of this attested set. However, as Mackenzie and Dresher observe, “no evidence is adduced that an input /o/ does in fact surface as [ɔ] and not, say, as [u].” Indeed, no evidence from the phonological behaviour of native Nez Perce morphemes can be adduced that would shed light on the question; in the absence of evidence about loanwords, we know that /o/ must surface as one of [i, æ, a, ɔ, u], but we cannot know which one.
featural representations are determined by the Successive Division Algorithm; any structure that can be built from the segments in the inventory is a possible input, but items containing other combinations of features into segments are not. Under this view, loan-word adaptation would need to be accounted for by other means, for example by a theory of how foreign acoustic stimuli are mapped onto native phonemic representations. However, as we shall see in §5.2, even this relativized version of Richness of the Base would create serious problems for certain kinds of underspecification.

The difficulty arises not from Richness of the Base alone, but from Richness of the Base taken in combination with Lexicon Optimization, which (like Kiparsky’s (1982) Alternation Condition) militates in favour of resemblance between input and output forms. When a single attested surface form is the optimal output for more than one possible input, Lexicon Optimization predicts that the learner will posit as the actual underlying form the one of these for which the output form incurs the least serious constraint violations. Because the output form is the same for each input, surface markedness constraints are irrelevant for Lexicon Optimization; it is the input-output faithfulness constraints in the grammar, and their ranking relative to one another, that determine which input is chosen. The selected input form will therefore resemble the surface form as closely as possible; in fact, in the absence of alternations that would provide evidence to the contrary, and setting aside the possibility of opaque input–output relations introduced by non-standard sorts of constraints, the two forms will be identical. One consequence of this is that it is difficult for underlying representations to be underspecified for any features that are present in their corresponding surface forms: the filling in of unspecified feature values introduces a putatively unnecessary mismatch between input and output.

5.1 Alternant Optimization

Prince and Smolensky (1993) do not provide an explicit mechanism for incorporating data from alternations into the computation of inputs. Inkelas (1995, 1996),
however, does provide such a mechanism, which she calls Alternant Optimization, and shows how it can yield underspecified input forms in a rather narrowly circumscribed set of cases. Her discussion of Alternant Optimization as it applies to the specification of voicing features in Turkish and ATR in Yoruba offers an instructive point of comparison with some of the Czech data considered in chapter 2.

Alternant Optimization is a refinement of Lexicon Optimization that compares candidate input forms that all yield the same attested set of surface forms in all relevant contexts. Inkelas defines Alternant Optimization as follows:

\[ \text{(182) Alternant Optimization (Inkelas 1995: 6–7):} \]

Given a grammar \( G \) and a set \( S = \{S_1, S_2, \ldots, S_i\} \) of surface phonetic forms for a morpheme \( M \), suppose that there is a set of inputs \( I = \{I_1, I_2, \ldots, I_j\} \), each of whose members has a set of surface realizations equivalent to \( S \). There is some \( I_i \in I \) such that the mapping between \( I_i \) and the members of \( S \) is the most harmonic with respect to \( G \), i.e. incurs the fewest marks for the highest ranked constraints. The learner should choose \( I_i \) as the underlying representation for \( M \).

Alternant Optimization allows for the underspecification of phonological material that is both alternating and predictable. Unpredictable information must be stored because it cannot otherwise be recovered; non-alternating material is stored because optimization never introduces unnecessary discrepancies between input and output.\(^3\)

\[ 5.1.1 \text{ Turkish voicing alternations} \]

Among the examples Inkelas (1995) uses to show how underspecified inputs can arise is the voicing behaviour of root-final stops in Turkish (Inkelas and Orgun 1994). The examples in (183) and (184) suggest a straightforward pattern of coda devoicing: some

\[^3\text{But cf. Krämer (2006), who argues that the underlying forms of predictable material are indeter-}
\text{minable, or, at best, contingent upon theory-internal choices about the formalization of features and}
\text{faithfulness constraints.}\]
5.1. Alternant Optimization

stops are consistently voiceless, while others are voiced prevocically but voiceless word-finally and before consonants.

(183)  a. [sanat+uu] ‘art+acc.’
       b. [sanat+um] ‘my art’
       c. [sanat] ‘art’
       d. [sanat+lar] ‘arts’

(184)  a. [kanad+uu] ‘wing+acc.’
       b. [kanad+um] ‘my wing’
       c. [kanat] ‘wing’
       d. [kanat+lar] ‘wings’

However, there are also a few Turkish roots that end in non-alternating voiced stops, as in (185).

(185)  a. [etyd+y] ‘étude+acc.’
       b. [etyd+ym] ‘my étude’
       c. [etyd] ‘étude’
       d. [etyd+ler] ‘études’

As the example in (185) suggests, many of the roots in this third category are borrowings rather than native Turkish morphemes. However, Inkelas (1995) and Inkelas and Orgun (1994) reject the hypothesis that these ‘exceptional’ morphemes are marked as belonging to a separate cophonology that lacks coda devoicing. Indices linking morphemes to cophonologies are, they argue, essentially diacritic features that usurp the place of ordinary phonological feature specifications without offering any genuinely explanatory insight. As a reductio ad absurdum, Inkelas (1995) points out that a cophonology-based account of the Turkish data in (183–185) could dispense with underlying voicing contrasts altogether, instead assigning the root in (183) to a cophonology in which all root-final stops are devoiced in all environments, the root in (184) to a cophonology in which they
are voiced in onsets and voiceless in codas, and the root in (185) to one in which they are always voiced. The proliferation of cophonologies burdens the grammar with the unedi-
fying task of translating such gnomic notations as “belongs to Cophonology B” into the arbitrary differences in sound that serve to distinguish one morpheme from another.

Inkelas (1995) argues that the three-way distinction in voicing behaviour can and should be attributed to a ternary distinction in underlying values for voicing features. The non-alternating stops at the ends of /sanat/ and /etyd/ are specified as [−voice] and [+voice], respectively, while the alternating stop at the end of /kanaD/ has no underlying value for [±voice]. The alternations in (184) then arise from the constraints in (186):

(186)  

a.  MAX[VOICE] Input values of [±voice] are present in the output.

b.  CODACond Stops in coda position are [−voice].

c.  Voice Stops are [+voice].

d.  Dep[VOICE] Output values of [±voice] are present in the input.

If the constraints in (186) are ranked in the order in which they are listed, underspecified stops such as the one at the end of /kanaD/ will have voicing values filled in to comply with the preferred surface pattern (voiceless in codas, voiced elsewhere), but specifications for [±voice] that are present underlingly will never be overwritten; the alternations are generated in a purely structure-filling way. In the tableaux in (187–189), the winning candidates never violate the top-ranked constraint MAX[VOICE]; alternations therefore arise only in the case of /kanaD/, where the underspecification of the final segment makes MAX[VOICE] vacuous.

4. For a monovalent analysis, cf. Avery (1996: §5.3), who proposes that non-alternating voiced consonants are specified with [SV] and voiceless consonants with [Laryngeal], while alternating consonants are underspecified.
### 5.1. Alternant Optimization

#### (187) a.

<table>
<thead>
<tr>
<th></th>
<th>/sanat+ui/</th>
<th>MAX[voice]</th>
<th>CODACond</th>
<th>Voice</th>
<th>Dep[voice]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>/sanatui</td>
<td></td>
<td></td>
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<td></td>
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<td>*</td>
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<td>*</td>
<td></td>
</tr>
</tbody>
</table>

#### (187) b.

<table>
<thead>
<tr>
<th></th>
<th>/sanat/</th>
<th>MAX[voice]</th>
<th>CODACond</th>
<th>Voice</th>
<th>Dep[voice]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>/kanad</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>*</td>
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<td></td>
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</tbody>
</table>

#### (188) a.

<table>
<thead>
<tr>
<th></th>
<th>/kanaD+ui/</th>
<th>MAX[voice]</th>
<th>CODACond</th>
<th>Voice</th>
<th>Dep[voice]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>/kanatui</td>
<td></td>
<td></td>
<td>*</td>
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<td>**!</td>
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</tbody>
</table>

#### (188) b.

<table>
<thead>
<tr>
<th></th>
<th>/kanaD/</th>
<th>MAX[voice]</th>
<th>CODACond</th>
<th>Voice</th>
<th>Dep[voice]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>/kanad</td>
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<td>*</td>
<td></td>
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<td></td>
<td></td>
<td>**!</td>
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<td></td>
</tr>
</tbody>
</table>

#### (189) a.

<table>
<thead>
<tr>
<th></th>
<th>/etyd+y/</th>
<th>MAX[voice]</th>
<th>CODACond</th>
<th>Voice</th>
<th>Dep[voice]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>/etyty</td>
<td>*!</td>
<td></td>
<td>**</td>
<td>*</td>
</tr>
</tbody>
</table>

#### (189) b.

<table>
<thead>
<tr>
<th></th>
<th>/etyd/</th>
<th>MAX[voice]</th>
<th>CODACond</th>
<th>Voice</th>
<th>Dep[voice]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>/etyt</td>
<td>*!</td>
<td></td>
<td>**</td>
<td>*</td>
</tr>
</tbody>
</table>
The underspecification of the /D/ in /kanaD/, which Inkelas (1995, 1996) refers to as ‘Archiphonemic Underspecification,’ involves the use of a binary feature to make a ternary distinction. This places Inkelas’s analysis into apparent conflict with Halle’s (1959) Distinctness Condition (discussed above in §1.2.5), which states that one segment can be said to differ from another only if they have opposite values for some feature. However, Inkelas’s analysis of the Turkish data does not rely on the claim that /D/ is phonemically distinct from /d/ or from /t/. Rather than suggesting that Turkish has three phonemically distinct coronal plosives, one of which is unspecified for [±voice], Inkelas appears to be saying instead that there are only two phonemic coronal plosives, /t/ and /d/, and that the morpheme /kanaD/ is underspecified as to which of these its final segment is. At any rate, the conclusion is inescapable that the three different patterns of voicing behaviour in (183–185) must correspond to three different underlying representations.

In a grammar that includes the constraint ranking in (186), the underlying representation of /kanaD/ will necessarily be underspecified as to the voicing of the final segment, because this is the only input form that produces the attested range of output forms in (184). If the segment in question is specified either as [+voice] or as [−voice], it will fail to alternate. Alternant Optimization is not required here, because there is no choice to be made among possible input forms.

### 5.1.2 Yoruba ATR harmony

Inkelas (1995) uses Yoruba ATR harmony to demonstrate that Alternant Optimization can produce underspecified inputs when there is a choice to be made. The Yoruba

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5. Archiphonemic Underspecification as Inkelas uses it is not limited to the underspecification of features on segments; for example, Inkelas (1996: §5.1) proposes that certain Hausa morphemes that surface with predictably alternating high and low tones in different contexts are archiphonemically underspecified for tone. See also Inkelas (1995: §6.2) for arguments that Stanley’s (1967) objections to ternarity do not apply in the present case, and Reiss (2003) for further discussion.
nominalizing prefix /O-/ predictably takes on the [±ATR] value of the first vowel to its right, as illustrated in (190).  

(190)  
- a. [de] ‘to hunt’  
- b. [o+de] ‘hunter’  
- c. [kú] ‘to die’  
- d. [ò+kú] ‘corpse’  

The pattern in (190) can obviously be quite straightforwardly derived if the prefix /O-/ is underlyingly unspecified for [±ATR]. Unlike the Turkish case, however, such archiphonemic underspecification here is not a matter of descriptive necessity. Data such as those in (191) indicate that Yoruba tongue root harmony is not a purely structure-filling process.

(191)  
- a. [àwò] ‘colour’  
- b. [ejò] ‘snake’  
- c. [àwò ejò] ‘colour of a snake’  
- d. [owó] ‘money’  
- e. [omò] ‘child’  
- f. [owó omò] ‘child’s money’  

The data in (191) suggest that the constraint or constraints responsible for driving harmony (Inkelas (1996) uses the name `atr.harmony` as an abbreviation for whatever set of constraints is involved) must outrank not only `Dep[ATR]` but also `Max[ATR]`: underlying specifications for [±ATR] can be overwritten in order to produce a harmonic surface form. Because of this ranking, the prefix /O-/ will surface with the appropriate values for [±ATR] in all contexts regardless of whether it is underlyingly specified as

---

6. For the sake of explicitness, all [-ATR] vowels in the data are transcribed here with the diacritic [\[\], including the low vowel [a], which has no [+ATR] counterpart. [+ATR] vowels are unmarked. The data are from Pulleyblank (1988) and Archangeli and Pulleyblank (1989), cited in Inkelas (1995).
Chapter 5. Contrast and Optimality

[±ATR], [−ATR], or neither. The choice of underlying representation is now a matter for Alternant Optimization, shown in the tableau in (192).

(192)

<table>
<thead>
<tr>
<th></th>
<th>A. O.</th>
<th>Max[ATR] : Dep[ATR]</th>
</tr>
</thead>
<tbody>
<tr>
<td>/o-/</td>
<td>[o+də]</td>
<td>*! :</td>
</tr>
<tr>
<td></td>
<td>[ù+kú]</td>
<td>* :</td>
</tr>
<tr>
<td>/ø-/</td>
<td>[ø+də]</td>
<td>*! :</td>
</tr>
<tr>
<td></td>
<td>[ø+kú]</td>
<td>* :</td>
</tr>
<tr>
<td>O/-</td>
<td>[o+də]</td>
<td>:</td>
</tr>
<tr>
<td></td>
<td>[ù+kú]</td>
<td>:</td>
</tr>
</tbody>
</table>

Inkelas assumes that harmony involves the sharing of a [±ATR] feature between two segments. If the target segment is specified for [±ATR] in the input, then it will incur a violation of Max[ATR] in the output, because the underlying instance of the feature must be deleted to enable the target to share the feature associated with the trigger (even if the two instances of the feature have the same value in the input). Underlying /O-/ on the other hand, incurs no relevant faithfulness violations: since there is no underlying instance of [±ATR] in the way, there is no need to violate Max[ATR], and since the surface specification for [±ATR] was already present on the trigger of harmony, there is no violation of Dep[ATR]. The underspecified input form is therefore chosen as optimal.

Taken together, the Turkish and Yoruba examples illustrate the two ways in which underspecified inputs can arise in Inkelas’s system. An underspecified input must either be the only possible input that gives rise to the attested range of output forms, as in the Turkish case, or else it must be preferred by Alternant Optimization in the competition among several possible inputs. In the case of the anomalous Czech segments discussed in the following section, however, neither of these conditions consistently applies.
5.2 Alternant Optimization applied to Czech

5.2.1 The constraints and their ranking

As discussed in §2.2, /v/ and /r/ pattern differently from other Czech consonants with respect to voicing assimilation. While other obstruents both trigger and undergo regressive voicing assimilation, /r/ and (in some dialects) /v/ assimilate to voiceless obstruents on either side, as illustrated in (193).^7

(193) Voicing behaviour of /v/ and /r/

a. v lese [’vlese] ‘in a forest’
b. v pole [’fpole] ‘in a field’
c. květ [kfjet] ‘flower’
d. tvůj [tfu:j] ‘your’
e. nářek [’narek] ‘lamentation (nom. sg.)’
f. nářky [’narki] ‘lamentations (nom. pl.)’
g. při [pri] ‘near’
h. středa [’streda] ‘Wednesday’

Both /v/ and /r/ assimilate to voiceless obstruents both reggressively (as in (193a–b) and (193e–f)) and progressively (as in (193c–d) and (193g–h)). The predictable alternations in their voicing suggest that they should be amenable to Archiphonemic Under-specification of the sort that Inkelas (1995) applies to Turkish /D/. Applying Inkelas’s ternary use of the binary feature [±voice] to Czech, we can say that /V/ and /R/ have no specification for that feature, while the other voiced obstruents are specified as [+voice] and the voiceless ones as [−voice]. Given those representations, and assuming that output forms must be fully specified for all relevant features, the constraints in (194), appropriately ranked (e.g., in the order shown, although not all aspects of this ranking are

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7. For the sake of simplicity, this section deals only with those dialects in which /v/ and /r/ pattern together; a more comprehensive discussion of the Czech data may be found in §2.2.
crucial), will generate the attested patterns. Here, for the sake of comparison with the cases discussed by Inkelas (1996), I follow her in assuming that featural faithfulness is evaluated by constraints that apply to values of binary features; as Krämer (2006) points out, these assumptions have consequences for the extent to which underspecification is preferred or permitted by Lexicon Optimization.

\[ \begin{align*}
(194) & \quad \text{MAX[sonorant]} \quad \text{Input values of } [\pm \text{sonorant}] \text{ are in the output.} \\
& \quad \text{b. } *[+\text{son}, -\text{voi}] \quad \text{All sonorants are voiced.} \\
& \quad \text{c. } \text{MAX[voi]} / \underline{[+\text{son}]} \quad \text{The rightmost underlying instance of } [\pm \text{voice}] \\
& \quad \quad \quad \text{to the left of each sonorant is preserved in the output.}^{8} \\
& \quad \text{d. } *[+\text{voice}] / \underline{\#} \quad \text{Word-final segments are voiceless.} \\
& \quad \text{e. } \text{AGREE[voice]} \quad \text{Adjacent obstruents have identical values for} \\
& \quad \quad \quad [\pm \text{voice}]. \\
& \quad \text{f. } \text{MAX[voice]} \quad \text{Input values of } [\pm \text{voice}] \text{ are in the output.} \\
& \quad \text{g. } \text{Voice} \quad \text{Segments are voiced.} \\
& \quad \text{h. } \text{DEP[voice]} \quad \text{Output values of } [\pm \text{voice}] \text{ are in the input.}
\end{align*} \]

The crucial rankings of these constraints are as follows:

- \text{MAX[sonorant]}, *[+\text{sonorant}, -\text{voice}] \gg *[+\text{voice}] / \underline{\#}: \\
  Sonorants will always be voiced, even word-finally. (This will be true even if sonorants are not underlyingly specified as [+voice].)

- \text{*[+\text{voice}] / \underline{\#} \gg MAX[voice], Voice, DEP[voice] :}
  All obstruents are subject to final devoicing.

8. The somewhat ungainly formulation of this constraint is designed to ensure that an underlying \([\pm \text{voice}]\) specification need not be in immediately pre-sonorant position to be preserved; rather, it will be preserved so long as no other \([\pm \text{voice}]\) specification intervenes between it and the next vowel or sonorant consonant to its right. This is for the sake of clusters such as the one at the beginning of the word \(t\rotatebox{90}{\text{i}}\) /\(t\text{Ri}/\) \([\text{tr}i]\) (‘three’), in which the /t/, although it is not adjacent to the vowel, nonetheless determines the voicing of the whole cluster because the /Ri/ has no \([\pm \text{voice}]\) feature.
5.2. Alternant Optimization applied to Czech

- **Max[voice] / +son / Agree[voice] / Max[voice], Dep[voice]:**
  In a non-final obstruent cluster, the rightmost obstruent that is underlyingly specified for [$\pm$voice] will retain its specification, and the other obstruents in the cluster will assimilate to it.

- **Agree[voice] / Voice / Dep[voice]:**
  An obstruent that is unspecified for [$\pm$voice] will assimilate to another obstruent on either side, but if there is no adjacent obstruent to assimilate to, it will be voiced by default.

- **Max[voice] / Voice / Dep[voice]:**
  Default voicing applies only to segments with no underlyingly specification for [$\pm$voice].

The tableaux in (195–197) illustrate the interactions of these constraints in various relevant contexts. In (195), underlying /V tom/ yields surface [ftom], illustrating the application of regressive assimilation to underspecified /V/:

(195)

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<tbody>
<tr>
<td>[fdom]</td>
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<td>[vtom]</td>
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<tr>
<td>[vdom]</td>
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<td>*</td>
<td>**</td>
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<tr>
<td>[ftom]</td>
<td>*</td>
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</tbody>
</table>

In (195), Agree[voice] ensures that the /Vt/ cluster will undergo assimilation, and Max[voice] / +son preserves the underlying voicelessness of the /t/ (at the cost of violating Voice).
The next example illustrates both word-final obstruent cluster devoicing and progressive assimilation of underspecified /V/:

\[(196)\]

<table>
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<tbody>
<tr>
<td>[fivost]</td>
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<td>**</td>
<td>**</td>
<td>***</td>
<td></td>
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<tr>
<td>[fivozd]</td>
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<td>*!</td>
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<td></td>
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<tr>
<td>[fivozt]</td>
<td></td>
<td>*!</td>
<td>*</td>
<td>*</td>
<td>**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[hfost]</td>
<td></td>
<td>*!</td>
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<td>****</td>
<td>****</td>
<td></td>
<td></td>
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<tr>
<td>[fifost]</td>
<td></td>
<td>*!</td>
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<td>***</td>
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</tbody>
</table>

In the word-initial /fiV/ cluster, faithfulness mandates that the /fi/ be voiced, and AGREE ensures that the /V/ will follow suit; here, there is no conflict with the default constraint Voice, and the only faithfulness violation incurred is the necessary violation of Dep[voice] incurred by inserting any value at all for [±voice] on the /V/.

At the opposite end of the word, *[+voice]/-# requires that the final /d/ surface as [-voice], and AGREE ensures that the /z/ follows suit.

In (197), we can see both regressive assimilation affecting a regular obstruent and progressive devoicing affecting /R/:

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9. The possibility of underspecification in the output (see, e.g., Itô, Mester, and Padgett 1995) is not contemplated in the tableaux in (195–197). In the cases Itô, Mester, and Padgett consider, the phonetic realization of the underspecified segments is not at issue; here, to permit the underspecified segments /V/ and /R/ to occur in the output would simply pass the problem of their realization over to another component of the grammar.
5.2. Alternant Optimization applied to Czech

(197)

<table>
<thead>
<tr>
<th>/od tRi:/</th>
<th>MAX[son]</th>
<th>+[son, -voi]</th>
<th>MAX[voi]</th>
<th>+[son]</th>
<th>-[voice]</th>
<th>MAX[voice]</th>
<th>DEP[voice]</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ot tri:]</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>***</td>
<td>**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[od tri:]</td>
<td>*</td>
<td>*!</td>
<td>*</td>
<td>**</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[od tri:]</td>
<td>*</td>
<td>*!</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[od dri:]</td>
<td>*!</td>
<td>*</td>
<td>*</td>
<td>**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[ot tri:]</td>
<td>*!</td>
<td>*</td>
<td>*</td>
<td>**</td>
<td>****</td>
<td>***</td>
<td></td>
</tr>
</tbody>
</table>

In (197), AGREE again enforces assimilation. Since the /R/ has no underlying specification for [+voice], MAX[voice] /—[+son] chooses the voicing feature of the /t/—the rightmost specified segment in the cluster—as the one that must be preserved.

5.2.2 The empirical difficulty

WITHNAIL: Free to those that can afford it; very expensive to those that can’t.

Bruce Robinson, Withnail & I

Given underspecified representations for underlying /V/ and /R/, the constraint hierarchy in (194) produces the right outputs. But there is no way of guaranteeing that /V/ and /R/ will consistently be underspecified; Richness of the Base tells us that we should also be able to deal with input forms that include fully specified /f/, /v/, /x/, and /r/, which will behave exactly like regular obstruents. Czech does have an /f/, although only marginally (it occurs only in loanwords and onomatopoeia), but the other three predicted segments do not exist.

This is the crucial difference between the Czech situation and the Turkish one: Turkish has all three of /t/, /D/, and /d/. In Turkish, Richness of the Base makes
the right prediction; fully specified, non-alternating forms do exist parallel to the underspecified ones, and if some particular morpheme containing /D/ does not happen to have counterparts containing /t/ and /d/, the gap is merely accidental. In Czech, however, the underspecification is crucially at the level of the segment, rather than the morpheme: in order to account for the surface distribution of [f], [v], [ř], and [ř], the underlying segments /V/ and /Rř/ must lack voicing specifications wherever they occur; the absence of underlying specified counterparts is systematic. Given standard OT assumptions, there is no way of barring the fully specified segments from the input. The input cannot be constrained directly, and the unwanted segments cannot be banned by output well-formedness constraints, because they do appear in surface forms. This problem will confront any Optimality-Theoretic treatment of a system in which segments (as opposed to morphemes) appear to be underlyingly underspecified for some property that they exhibit in surface forms.

One initially plausible though unorthodox approach might be to suggest that Richness of the Base is relativized to phonemic inventories. Under this view, a constraint grammar must produce phonotactically well-formed outputs for any input sequence of segments drawn from the phonemic inventory of the language, but need not cope with feature combinations that do not correspond to such segments. However, even this relatively drastic measure is of no avail, because Lexicon Optimization ensures that fully specified /v/, /ř/, and /ř/ will in fact be part of the phonemic inventory of Czech. In non-alternating contexts, such as dva [dva] ‘two’ and tří [tré] ‘three’, Lexicon Optimization selects an input form that is identical to the output, as illustrated in (198) and (199).
5.2. Alternant Optimization applied to Czech

(198)

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>/dva/</td>
<td>[dva]</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>/dVa/</td>
<td>[dva]</td>
<td></td>
<td></td>
<td>*!</td>
</tr>
<tr>
<td>/dVa/</td>
<td>[dva]</td>
<td>*!</td>
<td>*</td>
<td>*</td>
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</tbody>
</table>

(199)

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<tr>
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<tbody>
<tr>
<td>/tri/</td>
<td>[tri]</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>/tRi/</td>
<td>[tri]</td>
<td></td>
<td></td>
<td>*!</td>
</tr>
<tr>
<td>/tri/</td>
<td>[tri]</td>
<td>*!</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

If fully specified /v/, /r/, and /r/ freely occur in inputs, as predicted by Richness of the Base, then we should expect to find, for example, forms such as */vra:n-/ alongside attested /Vra:n-/ (‘crow’); there would be no difference between the two in isolation, but when preceded by s (‘with’), the former would produce *[zvra:noʊ], as in (200), instead of the attested [sfra:noʊ]

(200)

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</thead>
<tbody>
<tr>
<td>[svra:noʊ]</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>*[zvra:noʊ]</td>
<td></td>
<td>*</td>
<td>!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[sfra:noʊ]</td>
<td>*!</td>
<td>*</td>
<td>*</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>[zvra:noʊ]</td>
<td></td>
<td>**</td>
<td>*</td>
<td>**</td>
<td></td>
</tr>
</tbody>
</table>
5.2.3 The theoretical conundrum

There was only one catch.

Joseph Heller, *Catch-22*

The only orthodox way out is to ensure that even fully specified inputs will produce the correct range of surface forms—that is, we need to make sure that /v/, /ɹ/, and /ɻ/ will act just like /V/ and /R/.

This can be done in a very simple and unprincipled way by replacing the constraints MAX[VOICE]/_ [+SONORANT] and MAX[VOICE] in the hierarchy in (194) with constraints that apply only to segments other than /V/ and /R/, and demoting the more general MAX[VOICE] constraint to below VOICE, as in (201):

(201)

a. MAX[SONORANT]
b. *[+SONORANT, −VOICE]c. MAX[VOICE]/_ [+SONORANT], except for /v/ and /ɹ/
d. *[+VOICE]/_ #
e. AGREE[VOICE]f. MAX[VOICE], except for /v/ and /ɹ/
g. VOICEh. MAX[VOICE]i. DEP[VOICE]

Given this new constraint hierarchy, both the fully specified /vraːn-/ and the underspecified /Vraːn-/ will alternate as desired. As shown in (202), even an underlyingly voiced /v/ is subject to progressive assimilatory devoicing under the ranking in (201).
Now that the underspecified form is no longer crucial to the analysis, Alternant Optimization selects it as the optimal input, as shown in (203):

This would be a satisfactory result if there were a principled basis for formulating constraints with the effect of (201c) and (201f). For this to be possible in the simplest case, two conditions must apply. First, there must be some way of characterizing /V/ and /R/ as a natural class on grounds independent of their voicing behaviour; second, there must be a reason for this class of segments to have a separate (and thus independently rankable) Max[voice] constraint from the one that applies to other obstruents.
An initially promising approach would be to try to relate the un-obstruent-like phonological properties of /V/ and /R_/ to some un-obstruent-like phonetic property, as Padgett (2002) does for Russian /v/. But, as argued in §2.4.2, this doesn’t seem to be possible for Czech /V/, which is much farther removed phonetically from its */w/* ancestor than its Russian cousin is. The trilled fricative /R_/ is at least arguably phonetically intermediate between a sonorant and an obstruent, but there is no obvious basis for saying the same of /V/. At the same time, any attempt to group /V/ and /R_/ together will have difficulty excluding /fi/, which is phonetically very sonorous, but patterns phonologically as an ordinary obstruent.

If there is no independent synchronic basis for treating /V/ and /R_/ as a natural class, then another possibility would be to postulate the existence of a larger and more fine-grained family of MAX[voice] constraints—say, one for each segment. Such an approach would have ample precedent in OT; for example, Prince and Smolensky (1993: §8.1.2) explode the constraint HNUC (204) into a hierarchy of more specific constraints (205) penalizing the parsing of particular segments as syllabic peaks.

(204) The Nuclear Harmony Constraint (HNUC): A higher sonority nucleus is more harmonic than one of lower sonority. I.e., if |x| > |y| then Nuc/x ≻ Nuc/y.

(Prince and Smolensky 1993: 17)

(205) Peak Hierarchy: *P/t ≫ ... ≫ *P/i ≫ *P/a

(Prince and Smolensky 1993: 147)

If each segment has its own MAX[voice] and MAX[voice] / _ [+son] constraints, then an appropriate ranking of these constraints, such as the one shown in (206), can produce the effects of the hierarchy in (201) without any need to say that /V/ and /R_/ comprise a natural class.
(206)  a. Max[sonorant]

b. *[+son, −voice]

c. \[
\begin{align*}
\text{Max[voice]} & / z \quad \text{Max[voice]} / t \\
\text{[+son]} & \quad \text{[+son]}, \ldots
\end{align*}
\]

d. *[+voice]/#

e. Agree[voice]

f. Max[voice]/z, Max[voice]/t, Max[voice]/x, ...

g. Voice

h. Max[voice]/v, Max[voice]/r

i. Dep[voice]

This approach, however, introduces some new difficulties. First, the constraints in (206c, f, h), unlike Prince and Smolensky’s peak hierarchy, have no obvious intrinsic ranking. In the peak hierarchy, a constraint against parsing a less sonorous segment as a peak will in every language outrank a constraint against parsing a more sonorous segment as a peak; this is how the constraints in (205) replicate the effects of the single constraint HNuc. Although other constraints can be freely interleaved with the ones in the peak hierarchy, the *P constraints themselves have a universally fixed ranking that enforces surface well-formedness. The Max[voice] constraints, however, are faithfulness constraints, and there is no analogous basis for assigning them a consistent cross-linguistic ranking. The more general constraint from which they are expanded, unlike HNuc, makes no comparison between segments; it merely states that all underlying instances of [±voice] should be preserved in the output. Nor is there any other clear rationale for imposing a fixed ranking on the Max[voice] constraints. Cross-linguistically, there are many processes that change the voicing features of some segments and not others, but no property of segments appears to correlate universally with susceptibility or re-
sistance to voicing or devoicing in the way that sonority correlates with acceptability in syllable peaks. Sonority is frequently relevant to voicing and devoicing processes, but some of these processes target less sonorous segments (e.g., final obstruent devoicing in many languages), while others target more sonorous ones (e.g., high vowel devoicing in Japanese and in Québécois French). One fruitful approach to this variation has been to say that sonorants and obstruents have different kinds of voicing feature specifications underlyingly (see, e.g., Rice and Avery 1989); it is not clear how any fixed ranking of the Max[voice] family could achieve similar results. And if these constraints must be freely rankable with respect to one another, then the typological consequences of exploding Max[voice] are much more drastic than the consequences of exploding Hnuc; the new constraints allow for much more variation among possible grammars.

A second and graver problem is that the exploded Max[voice] constraints themselves are not so easy to formulate as they at first appear. The proposed constraints are relativized to segments, but segments are not representational primitives. A properly formalized version of a constraint such as Max[voice]/d cannot simply refer to the segment /d/, but must instead specify a set of feature values. But what set of feature values will reliably identify /d/ in all languages, which, if we assume that constraints are universal, is what Max[voice]/d must be able to do? A full set of specifications might include [-sonorant], [+coronal], [-continuant], [+anterior], [-nasal], and perhaps others. However, Alternant Optimization predicts that any of these features can be unspecified in an input form if its value is both variable and predictable—for example, if there is a /d/ that predictably surfaces as [n] in some environments, it may be underspecified for [±sonorant] and [±nasal]; a /d/ that alternates predictably with [Ø] may be underspecified for [±continuant]; and so on. Furthermore, since Alternant Optimization applies to individual morphemes, rather than to segments or inventories, a single segment /d/ may have multiple representations even within a single language. There is no set of features that will reliably and uniquely identify the segment /d/ (or any other seg-
5.2. Alternant Optimization applied to Czech

In all contexts in all languages, and so the constraint MAX[VOICE]/D (or any other faithfulness constraint referring to a particular input segment) cannot be formulated in a language-independent way.

If it is not possible for the necessary constraints to be formulated in terms of input segments, an alternative might be to formulate them in terms of output segments. Rather than penalizing the deletion of [±voice] specifications from particular underlying segments, the new constraints would penalize particular surface segments when they do not retain the [±voice] specifications of their input correspondents. For example, MAX[VOICE]/D would be replaced by a local conjunction of the more general faithfulness constraint MAX[VOICE] with the markedness constraint *[t]. However, Moreton and Smolensky (2002) argue that MAX constraints cannot be conjoined with markedness constraints, because the domain of the conjunction’s application cannot be specified: MAX applies to input domains, and markedness constraints to surface domains. The exploded version of the MAX[VOICE] constraints therefore cannot be reformulated along these lines.

5.2.4 An emergency of unmarkedness

It seems that the anomalous behaviour of Czech /V/ and /R/ must be stipulated, one way or another. One way of doing this would be to put the stipulation into the constraint hierarchy, by means of constraints like the ones in (201c) and (201f). This approach would seem to weaken the Optimality-Theoretic hypothesis that constraints are universal, in a dangerously unfalsifiable way; including constraints such as MAX[VOI] /— [+SON], except for /V/ and /R/ in the universal inventory of constraints makes no testable predictions about languages other than Czech, because the effects of these constraints can always be masked by other constraints.

An alternative approach would be to retreat from the predictions of Richness of the Base and Lexicon Optimization, and put the stipulation into the phonemic inventory.
This would require us to say that there can be language-specific restrictions on the underlying representations of segments, and it would mean elevating the phonemic inventory to the status of something other than an epiphenomenon. Richness of the Base could still permit all sequences of phonemes as potential inputs—the only phonotactic properties that would no longer be in the jurisdiction of Con would be gaps in the phonemic inventory. There are two obvious objections to this approach, each of which is, however, answerable. The first objection is that the constraint grammar would no longer be either responsible for, or equipped to deal with, non-native input forms; an alternative account would therefore be needed for various loanword adaptation phenomena. One possible answer to this would be to account for such phenomena from the perspective of perception rather than of production, by means of a theory of how acoustic stimuli are mapped onto phonological representations (see, e.g., Boersma (1998); Lahiri and Reetz (2002)). The second objection is that the possibility of constraining inputs adds a new source of power to the theory. However, this power can be constrained by a sufficiently restrictive set of principles for generating inventories of feature combinations, such as is provided by the Successive Division Algorithm.

Even assuming that these objections can be overcome, restrictions on input forms represent a fairly drastic departure from orthodox OT. In light of this, it is worthwhile to keep in mind that the problems posed by the Czech data do not necessarily apply only to languages in which, as in Czech, underspecification appears to be crucial. If Richness of the Base does indeed allow all possible combinations of features to appear in input segments, then it predicts not only the appearance of fully specified underlying /v/, /ɾ/, and /ɾ/ in Czech, but also the appearance of underspecified segments such as the Turkish /D/ in Czech and in all other languages as well. If features may be freely present or absent in input forms, then unattested alternating segments may in fact be predicted by grammars constructed on the tacit assumption that all input segments are fully specified. The hypothetical universality of constraints such as the ones that drive
voicing assimilation in Czech and final devoicing in Czech and Turkish suggests that even in languages that do not ordinarily exhibit these phenomena, they should show up as Emergence of the Unmarked effects when Richness of the Base supplies an input segment that is underspecified enough to make higher-ranking faithfulness constraints irrelevant. The problem that shows up so clearly in the Czech case may therefore be lurking undetected in many apparently well-behaved systems as well.

5.3 Optimality Theory and the Successive Division Algorithm

5.3.1 Recreating the monovalent analysis

The discussion in the preceding sections has, for the sake of comparing Czech with Inkelas’s (1995, 1996) treatment of Turkish, focused on the possibility of using a binary feature $\pm$voice and Inkelas’s Archiphonemic Underspecification. It is not clear that the feature specifications used there are compatible with the version of contrastive specification embodied in the Successive Division Algorithm. In order for the SDA to leave /v/ and /r̝/ unspecified for $\pm$voice, these segments would have to be distinguished (either as a pair or individually) from all other Czech phonemes by means of other features ranking higher in the contrastive hierarchy. (To say that /v/ and /r̝/ are contrastively $[0$ voice] would make $\pm$voice into a truly ternary feature, rather than a binary feature that is sometimes underspecified.) In the case of /r̝/, this is not difficult; the postalveolar fricative trill can be distinguished from the other segments on the basis of its place and manner of articulation. With /v/, however, the task is not so easy, because there is a (marginal, but not negligible) phoneme /f/ that at least arguably differs from /v/ only in its voicing. Any set of divisions based on features other than $\pm$voice will therefore place /f/ and /v/ in the same subinventory. It might be possible to overcome this difficulty
by positing that the reported phonetic stoplike character of /v/, which it does not share with /f/, is encoded in a contrastive phonological feature, which would then serve to divide /v/ from /f/ (and the other obstruents) without recourse to [±voice]. It is not clear, though, exactly what this feature would be, nor is there any obvious independent reason to suppose that it is contrastive.

It is therefore worthwhile to examine how Optimality Theory might interact with the account of Czech based on the Successive Division Algorithm that was presented in §2.3, in which the anomalous segments are underspecified for voicing in a formally different way: they contrastively lack the monovalent feature [Laryngeal], and thus, because the absence of [Laryngeal] places them in a class within which the (also monovalent) feature [Voice] makes no distinctions, [Voice] is therefore also omitted from these segments, even though they are voiced in the default case. For varieties of Czech in which /v/ and /r/ pattern together, this results in the feature specifications in (36c), repeated below as (207).

(207) Mixed LV/CV system (Czech dialects with four voicing classes)

<table>
<thead>
<tr>
<th>VOICED OBSTRUENTS</th>
<th>VOICELESS OBSTRUENTS</th>
<th>/r, v/</th>
<th>SONORANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>/d/</td>
<td>/t/</td>
<td>/r/</td>
<td>/n/</td>
</tr>
<tr>
<td>Laryngeal</td>
<td>Laryngeal</td>
<td>SV</td>
<td></td>
</tr>
<tr>
<td>Voice</td>
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An OT account of Czech based on these specifications will run into essentially the same problems that affect the binary analysis using Archiphonemic Underspecification. One possible such account might employ the constraints in (208), ranked in the order in which they are listed.

(208) a. Max[SV]:

If a segment is associated with an [SV] node in the input, then its output correspondent (if any) is associated with a corresponding [SV] node.
b. *[SV, Lar]:
   No output segment should be associated with both [SV] and [Laryngeal].

c. Lar/___#:
   Every word-final output segment should be associated with a bare [Laryngeal] node.\textsuperscript{10}

d. Max[Lar]/___[SV]:
   If a segment followed by a sonorant is associated with a [Laryngeal] node in the input, then its output correspondent (if any) is associated with a corresponding [Laryngeal] node.

e. Align(Lar, L, \omega, L):
   The leftmost extent of each [Laryngeal] node is aligned with the left edge of the phonological word.

f. Max[Lar]:
   If a segment is associated with a [Laryngeal] node in the input, then its output correspondent (if any) is associated with a corresponding [Laryngeal] node.

g. Max[Voice]:
   If a [Laryngeal] node is associated with a [Voice] feature in the input, then its correspondent in the output (if any) is associated with a corresponding [Voice] feature.

h. Align(Lar, R, \omega, R):
   The rightmost extent of each [Laryngeal] node is aligned with the right edge of the phonological word.

\textsuperscript{10} This constraint might more intuitively be formulated as *Voice/___#, but such a constraint would fail to generate final devoicing of /v/ and /\textipa{f}/, which are not underlyingly specified for [Voice]. The final devoicing constraint must therefore motivate not only the deletion of underlying [Voice] features, but also the insertion of [Laryngeal] nodes on these underspecified segments.
i. Dep[Lar]:

If an output segment is associated with a [Laryngeal] node, the corresponding input segment (if any) is associated with a corresponding [Laryngeal] node.

Voicing assimilation is driven by the two ALIGN constraints, whose formulation follows the template established for such constraints by McCarthy and Prince (1993, 1995) and Kirchner (1993), inter alia.\(^{11}\) Regressive assimilation is capable of affecting segments that are underlyingly specified with [Laryngeal], because the constraint that motivates it, Align(Lar, L, ω, L), outranks Max[Lar]. Progressive assimilation, driven by Align(Lar, R, ω, R), will affect only the anomalous segments /v/ and /ɾ/: Max[Lar] prevents it from applying to other obstruents, and *[SV, Lar] and Max[SV] protect sonorants from any sort of laryngeal assimilation. In sequences of non-exceptional obstruents, the leftward direction of assimilation is not guaranteed by Align(Lar, L, ω, L), but is instead determined by two other constraints. If the cluster is non-final, the high ranking of Max[Lar]/—[SV] dictates that the [Laryngeal] node of the rightmost obstruent must be preserved. If the cluster is word-final, Lar/—# requires that the rightmost obstruent, and thus the entire cluster, be voiceless. The effects of these constraints are illustrated in (209–211). (In order to save space, each tableau includes only those constraints that are relevant to the evaluation of the most plausible candidates.)

The tableau in (209) shows the mapping from underlying /s domem/ to surface [z domem] (s domem, ‘with a house’), in which the /s/ undergoes regressive assimilation triggered by the /d/.

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11. Wilson (2004) and McCarthy (2004) point out several conceptual and empirical drawbacks of ALIGN constraints. However, the span-based alternative proposed by McCarthy (2004) is designed on the assumption that features are binary. A span-based account of Czech using the representations in (207) would require constraints to refer, rather awkwardly, to spans whose extents are defined by the absence of [SV], but whose heads defined with reference to the presence of [Laryngeal].
Assimilation is enforced by $\text{ALIGN}(\text{Lar}, \ L, \ \omega, \ L)$, which rules out the candidate in which there are two [Laryngeal] nodes, one of which is not aligned with the left edge of the word. This constraint is satisfied when the surface correspondents of the /s/ and the /d/ share a surface correspondent of either of the two underlying [Laryngeal] nodes; $\text{MAX}[\text{Lar}] / \text{[SV]}$ determines that the pre-sonorant [Laryngeal] node of the /d/ is the
one that will be preserved. This [Laryngeal] node is prevented from spreading farther to
the right by *[SV, LAR].

Final obstruent cluster devoicing is illustrated in (210), which shows the mapping
from /vjezd/ to [vjest] (vjezd, ‘entrance, gateway, driveway’).

| (210) |
|---|---|---|---|---|
| SV | SV | v | j | e | z | d | Lar_i | Lar_j | Voice | Voice |
| SV | SV | v | j | e | s | t | Lar_i or j |
| | | | *** | * | * | * | |
| SV | SV | v | j | e | z | t | Lar_i | Lar_j | Voice |
| | | | ****! | * | * | * | |
| SV | SV | v | j | e | z | d | Lar_i or j | Voice |
| | | | *! | *** | * | * | * |
| SV | SV | f | j | e | s | t | Lar_i or j |
| | | | *!* | * | * | **** | |

LAR/ — # ensures that the underlying /d/ will surface with a bare [Laryngeal]
node, becoming [t], and ALIGN(LAR,L,ω,L) dictates that this node be shared with the
adjacent /z/, which accordingly surfaces as [s]. As in the previous example, *[SV, Lar] prevents the [Laryngeal] node from spreading onto sonorants or vowels; the blocking effect of the [SV] nodes also protects the /v/, which would otherwise assimilate.\(^{12}\)

Finally, (211) shows how progressive assimilation targets underspecified /ɾ/ in tɾi /tɾi/ [tri] (‘three’).

Because the /ɾ/ is underlyingly specified with neither [Laryngeal] nor [SV], the [Laryngeal] node of the /t/ can spread to it in order to eliminate one violation of ALIGN(LAR,R,ω,R). Spreading the [Laryngeal] node farther, which would eliminate the

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\(^{12}\) I assume here that either an undominated constraint or GEN itself bars the spreading of the [Laryngeal] node from skipping over the /e/ and the /j/ to target the /v/.
remaining $\text{ALIGN}(\text{Lar}, R, \omega, R)$ violation and satisfy $\text{Lar}/\_\_\_\#$, is again ruled out by $^*[\text{SV, Lar}]$.

The monovalent account, reformulated in Optimality Theory, is just as susceptible as the binary account to the problem described in §5.2.2. If the constraint hierarchy permits output correspondents of /v/ and /ᵣᵣ/ to be associated with [Laryngeal] nodes—as it must, if it is to generate the attested patterns of assimilation—then there is no way, within standard Optimality Theory, to exclude such specified representations from input forms. Indeed, as in the binary version, there are cases in which underlyingly specified versions of /v/ and /ᵣᵣ/ will be not only tolerated, but required. For example, Lexicon Optimization will select as the underlying form for [ᵣᵣᵣᵣ] a representation in which the [Laryngeal] node is already shared between the first two segments, as shown in (212).

(212)

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</table>

As before, if /v/ and /ᵣᵣ/ underlyingly have no voicing features, the correct pattern can be generated, but the only way of ensuring that they will lack voicing features is to employ constraints that refer to /v/ and /ᵣᵣ/ specifically (and that pick out these segments by some characteristic or characteristics other than the absence of [Laryngeal]). In the
autosegmental approach outlined in this section, such constraints might resemble the LICENSE[VOICE] constraint posited by Itô, Mester, and Padgett (1995) to account for postnasal voicing in Japanese. In Itô, Mester, and Padgett’s analysis, the feature [Voice] is not normally licensed to appear on nasals, because it is redundant on them. [Voice] is licensed only when it is associated with an obstruent, and any instance of [Voice] that is so licensed is free to associate with an adjacent nasal segment as well. As a result, a nasal will surface with [Voice] if and only if it is followed by an obstruent with which it can share the feature. In this way, Itô, Mester, and Padgett explain why a nasal by itself does not pattern as a voiced consonant with respect to Lyman’s Law, but an obstruent following a nasal must be voiced and is visibly so to Lyman’s Law. In the Czech case, we might posit a LICENSE[LAR] constraint that would insist that every [Laryngeal] node must be licensed by being associated with an obstruent other than /v/ or /r/. Such a requirement, however, is subject to the same objections that apply to MAX[voice], except for /v/ and /r/ in §5.2.3—why should these two segments in particular fail to license [Laryngeal]?

5.3.2 Translating the Successive Division Algorithm

The discussion in the preceding sections suggests that the standard assumptions of Optimality Theory are incompatible with the kind of underspecification needed to account for Czech. However, Mackenzie and Dresher (2003) argue that it is possible to translate any contrastive hierarchy of the sort used by the Successive Division Algorithm into an OT constraint hierarchy, using an example from Nez Perce. In the remainder of this chapter, I will show that one problem that arises when Mackenzie and Dresher’s approach is applied to Czech can be resolved through the use of constraints inspired by Itô, Mester, and Padgett’s (1995) LICENSE[VOICE], but that a larger problem remains.
Mackenzie and Dresher (2003), who use binary features, propose the contrastive hierarchy shown in (213) for the underlying vowel inventory of Nez Perce. Not all aspects of the hierarchy contribute crucially to the feature values it assigns; for example, if $\pm\text{ATR}$ were given scope above $\pm\text{round}$ instead of vice versa, the feature specifications would remain the same, because $\pm\text{round}$ cannot divide the low vowels at all, and the two features fully cross-classify among the non-low vowels. As discussed below, though, the ranking of these features does have an at least potentially significant effect on the constraint hierarchy into which the contrastive hierarchy is translated.

(213) Nez Perce vowels (Mackenzie and Dresher 2003: 286)

a. Contrastive hierarchy for Nez Perce vowels

\begin{align*}
\{\text{æ, a, i, } & \text{, u, } \text{ɔ}\} \\
[+\text{low}] & \quad [\text{−low}] \\
[+\text{ATR}] & \quad [\text{−ATR}] \\
\text{æ} & \quad \text{a} \\
\text{[−round]} & \quad [\text{−round}] \\
\text{i} & \quad \text{ɛ} \quad \text{u} \quad \text{ɔ} \\
\text{[−ATR]} & \quad [\text{+ATR}] \\
\text{[−low]} & \quad [\text{+low}] \\
\text{[−ATR]} & \quad [\text{+ATR}] \\
\text{[−ATR]} & \quad [\text{+ATR}]
\end{align*}

b. Divisions in the Nez Perce vowel inventory

\begin{align*}
[\text{−round}] & \quad [\text{+round}] \\
[+\text{ATR}] & \quad \text{i} \quad \text{u} \quad [\text{+ATR}] \\
[\text{−low}] & \quad [\text{−ATR}] \\
\text{ɛ} & \quad \text{ɔ} \quad [\text{−ATR}] \quad [\text{−low}] \\
[\text{+low}] & \quad [\text{+ATR}] \\
\text{æ} & \quad [\text{+ATR}] \quad [\text{+ATR}] \\
[\text{−ATR}] & \quad \text{a} \quad [\text{−ATR}]
\end{align*}

Any contrastive hierarchy, Mackenzie and Dresher (2003) argue, can be translated into a constraint hierarchy according to a few simple rules. The resulting partial constraint ranking will ensure that for any input supplied by the rich base, features that

---

13. Following the analysis of Hall and Hall (1980), Mackenzie and Dresher (2003: 284) claim that the surface vowel [i] corresponds to two different underlying vowels, /ɛ/ and /i/, which are phonetically neutralized.
are contrastive will be preserved by faithfulness constraints, and redundant features will be filtered out either by specific constraints of the form $*[F, \Phi]$, which prohibit the specification of a particular feature $F$ in the context of some set of feature values $\Phi$, or by the catchall constraint $*[F]$ at the bottom of the hierarchy, which penalizes all feature specifications. A modified version of Mackenzie and Dresher’s rules is given in (214). I have replaced Mackenzie and Dresher’s (2003) IDENT-IO constraints with MAX constraints, partly for compatibility with the constraint systems used in the preceding sections, and partly to make it explicit that these faithfulness constraints are violated by the deletion of feature values, and not just by the changing of a + to a − or vice versa. I have also stated the rules declaratively where Mackenzie and Dresher (2003) state them procedurally, and eliminated some rankings that are not crucial to the preservation of contrastive specifications or the removal of redundant ones (on which see below).

(214) Converting a contrastive hierarchy into a constraint hierarchy (adapted from Mackenzie and Dresher 2003: 288–9)

- For every feature $F_i$ such that $F_i$ is contrastive in inventory $I$:  
  - $\text{MAX}[F_i] \gg *[F]$
  - For all $\Phi$ such that $\Phi$ is a set of feature values defining a subinventory $I_\Phi \subset I$ in which $F_i$ is not contrastive, and such that there is no $\Phi'$ such that $\Phi' \subset \Phi$ and $\Phi'$ defines a superinventory $I_{\Phi'} \supset I_\Phi$ in which $F_i$ is also not contrastive:
    - $*[F_i, \Phi] \gg \text{MAX}[F_i]$
  - For every feature $F_j$ such that some value of $F_j$ is in $\Phi$:
    - $\text{MAX}[F_j] \gg *[F_i, \Phi]$
- For every feature $F_k$ such that $F_k$ is not contrastive in inventory $I$:  
  - $*[F] \gg \text{MAX}[F_k]$
For the Nez Perce example, the contrastive hierarchy in (213) translates into the constraint rankings in (215).

(215) Constraint rankings for Nez Perce

- **Max[low] ⪰ *[F]**
  The feature [±low] is contrastive for all segments.

- **Max[low] ⪰ *[round, +low] ⪰ Max[round] ⪰ *[F]**
  The feature [±round] is non-contrastive for [+low] segments, but contrastive elsewhere in the inventory.

- **Max[ATR] ⪰ *[F]**
  The feature [±ATR] is contrastive within both the [+low] and the [−low] subinventories.

- ***[F] ⪰ Max[F_k], for all F_k /∈ {[±low], [±round], [±ATR]}**
  Any other features are non-contrastive (within the vowel inventory; contrastive features in the larger segmental inventory are ignored here).

Mackenzie and Dresher (2003: 288) give a total ranking of the relevant constraints, shown in (216), rather than the partial ranking shown in (215).

(216) Mackenzie and Dresher’s constraint hierarchy for Nez Perce

\[
\]

Some of the rankings in (216), although they are suggested by the feature hierarchy in (213), are not strictly necessary to the task of enforcing the representations assigned by the Successive Division Algorithm. For example, the ranking of IO-Ident[low] over IO-Ident[ATR] reflects the fact that [±low] has scope over [±ATR] in the feature hierarchy. However, this ranking is not critical, because both [±low] and [±ATR] are contrastive in all subinventories, and so there are no constraints against any combination.
of values for these two features. Including such rankings in the output of the rules in (214), as Mackenzie and Dresher (2003) do, produces constraint hierarchies that step beyond the predictions of the Successive Division Algorithm in an unnecessary but interesting way, giving the contrastive hierarchy an additional role in determining other aspects of the phonology and phonotactics of the language. Ranking IO-IDENT[low] over IO-IDENT[ATR] has no effect on the set of representations permitted by the constraints in (216), but it does have a potential effect on the way these constraints interact with the rest of the grammar. If there is a sufficiently high-ranking constraint elsewhere in the grammar that can be satisfied by an unfaithful mapping of either a [±low] feature specification or a [±ATR] one, Mackenzie and Dresher’s ranking will ensure that the underlying [±low] value is preserved at the expense of the [±ATR] specification. Mackenzie and Dresher’s algorithm for translating a feature hierarchy into a constraint ranking thus goes beyond the contrastivist hypothesis per se to predict that the contrastive scope of a feature is directly related to its resistance to being changed by phonological processes. This is an interesting prediction, but not one that can readily be tested using the data under consideration here.

Even without these additional scope-based rankings, the constraints enforcing contrastive specification have consequences that go beyond the core predictions of the Successive Division Algorithm when they are incorporated into a larger constraint grammar. Mackenzie and Dresher (2003: 288) write:

We will assume that the output of an OT version of the SDA is the same as the output of the algorithm itself: a set of contrastive specifications from which redundant feature specifications are excluded. In the case of Nez Perce, we will also assume that the output of this evaluation contains the [−ATR] counterpart of /i/. We will not attempt to model [ATR] harmony in this algorithm. How the processes of neutralization and [ATR] harmony are to be incorporated is not crucial to our proposal for modelling contrast.
In the case of Nez Perce, it is true that the implementation of the phonological processes in which the vowels participate does not interact critically with the implementation of contrastive specification. This is because the surface vowel inventory of Nez Perce is a subset of the underlying inventory, and so the full constraint grammar does not need to permit any vowels in the output that contain combinations of features other than those shown in (213). The neutralization of /ɛ/ and /i/ can be accomplished either in phonetic implementation, with two different sets of output feature specifications simply being pronounced identically, or perhaps by a constraint *[−LOW, −ROUND, −ATR] (in which case the ranking of IO-IDENT[ATR] below IO-IDENT[LOW] and IO-IDENT[ROUND] does become crucial), although this latter approach might interfere with the implementation of harmony.

However, Mackenzie and Dresher’s approach does run into difficulties when applied to Czech voicing assimilation, which, unlike Nez Perce vowel harmony, is not structure-preserving. The first difficulty, which involves the affricates /ts/ and /ʃ/, is akin to the challenge posed to structuralist phonemics by similar data in Russian, famously pointed out by Halle (1957, 1959) (see also Anderson (2000)). This difficulty can be surmounted by a modification of the rules in (214) involving constraints inspired by Itô, Mester, and Padgett (1995). The second difficulty is related to the one discussed in §2.6.1, and casts doubt on the mutual compatibility of the basic assumptions of Optimality Theory and the version of contrastive specification being pursued in this dissertation.

5.3.3 The problem of the affricates

In Czech, as in Russian, the voiceless affricates /ts/ and /ʃ/ have no phonemic voiced counterparts (although there are /dz/ and /dʒ/ sequences, as discussed in §2.2), but they do participate in voicing assimilation as both triggers and targets. Assimilation of /ts/ and /ʃ/ to voiced obstruents gives rise to surface segments [dz] and [dʒ] that are not present in the underlying inventory, as in (217).
Because /ts/ and /tʃ/ behave like the other voiceless obstruents with respect to assimilation, they must have the same laryngeal feature specifications as the other voiceless obstruents, even though their voicelessness is not contrastive. As Dresher (1998a) points out for Russian, the Successive Division Algorithm can easily accommodate this necessity by giving the features [Laryngeal] and [Voice] scope over the feature that distinguishes the affricate manner of articulation, which I will assume here to be [Delayed Release]. A partial contrastive hierarchy showing the scope of the relevant features in Czech is given in (218); here, [Del(ayed) Rel(ease)] is assumed also to be ordered after [Cont(inuant)], on the grounds that [Delayed Release] is potentially contrastive only for stops, although this ordering is not essential. Place features are set aside here, as are the features that divide the non-[Laryngeal] class of segments, because their scope has no immediate bearing on the current problem.

(218) Feature hierarchy showing the position of affricates in Czech

A full translation of the hierarchy in (218) into a constraint ranking would require a revised version of (214) that works with monovalent features like the ones employed here. The formulation of such a set of rules is made somewhat awkward, though far
from impossible, by the need to refer to contrastively absent feature values in defining subinventories in which various features are redundant. In the present example, the crucial constraint rankings, shown in (219), can all be stated in terms of marked features.

(219) Constraint rankings enforcing relevant aspects of the hierarchy in (218)

\[
\max[\text{Laryngeal}] \gg \max[\text{Voice}] \gg *[\text{Delayed Release, Laryngeal, Voice}] \gg \max[\text{Delayed Release}] \gg *[F]
\]

The rankings in (219) ensure that no voiced obstruent will be specified with [Delayed Release] (because \([\text{Delayed Release, Laryngeal, Voice}]\) outranks \([\text{Delayed Release}]\)), and that this will be achieved by means of non-preservation of [Delayed Release] rather than of [Voice] or [Laryngeal] (because \([\text{Laryngeal}]\) and \([\text{Voice}]\) outrank \([\text{Delayed Release}]\)), but that [Delayed Release] will be allowed as a feature of voiceless obstruents (because \([\text{Delayed Release}]\) outranks \([F]\)).

The problem is that, because of voicing assimilation, the grammar does need to permit [Delayed Release] and [Voice] to co-occur on surface segments, even though this combination of features is not present in the underlying inventory and thus not among the representations assigned by the Successive Division Algorithm. The tableau in (220) shows what happens when the constraints in (219) are combined with the constraints from (208) that drive the relevant aspects of voicing assimilation. The resulting constraint hierarchy correctly predicts that the underlying /\text{le\'eba}/ of éba will become voiced, but incorrectly predicts that it must therefore cease to be an affricate. In the winning candidate, \([\text{*le\'iba}]\), the feature [Delayed Release] is deleted from the /\text{le\'iba}/ in order to satisfy \([\text{Delayed Release, Laryngeal, Voice}]\), the constraint that rules out the actual output form [le\'iba]. Other candidates that manage to preserve the [Delayed Release] feature without violating \([\text{Delayed Release, Laryngeal, Voice}]\) are ruled out because they violate the constraints that drive assimilation: the candidate \([\text{*le\'iba}]\), with no assimilation, violates Align(Lar, L, \omega, L), and \([\text{*le\'iba}]\), with as-
5.3. Optimality Theory and the Successive Division Algorithm

Simulation in the wrong direction, is ruled out by the positional faithfulness constraint $\text{Max}[\text{Laryngeal}]/-\text{[SV]}$.

(220)

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<th>Del Rel</th>
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<td>Max[Del Rel]</td>
<td>Align(Lar$_i$, Lar$_j$)</td>
<td>Max[Voice]</td>
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<td>Max[Voice]</td>
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<td>Max[Del Rel]</td>
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<td>Max[Voice]</td>
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Reversing the ranking of $^[\text{Delayed Release, Laryngeal, Voice}]$ and Max-[Delayed Release] would produce the attested output [leːʤba], but would also incorrectly allow underlying voiced affricates to surface faithfully, defeating at least one purpose of the inventory-defining constraint hierarchy in (219).
5.3.4 Revising the translation rules

From this point, there are two possible ways forward. One is to say that the constraints that enforce the contrastive hierarchy are not part of the same computation that generates non-structure-preserving phonological processes such as Czech and Russian voicing assimilation. Under this view, the constraint ranking produced by (214) could either be a filter on the rich base, serving only to define the inventory of the language and to restrict the input to another constraint grammar that deals with alternations, or it could be combined with other constraints in an early level of a multi-stratal OT grammar (Kiparsky 2000; Kiparsky 2002). Either of these approaches would represent a departure from the strict parallelism of Optimality Theory as it was originally formulated, though by no means an unmotivated one. The range of possible implementations of these ideas and the diversity of the data that would bear on them, place a full exploration of this approach beyond the purview of the present discussion.

The other way forward, which will be examined in greater depth here, is to revise the cooccurrence constraints that penalize non-contrastive features so that they allow combinations of features such as [Delayed Release, Laryngeal, Voice] to arise through spreading but not as faithful mappings of underlying segments. Although the distinction is a derivational one, it can be stated in surface-oriented terms: an otherwise illicit combination of features is tolerated if one of the offending features is shared with a segment on which it is licit.14 This formulation is reminiscent of Itô, Mester, and Padgett’s (1995)

14. One might also contemplate translating the distinction into Optimality-Theoretic terms more literally by means of input–output anti-faithfulness constraints. For example, one might formulate a constraint InDep[LARYNGEAL, VOICE, DELAYED RELEASE], which would say that if these three features appear together on an output segment, at least one of them must be absent from the segment’s input correspondent. This approach, however, leads to some rather perversely opaque mappings; for instance, an underlying /ʃba/ sequence will surface as [ŋba], but underlying /ʒba/ will become [ʃba]. In addition to producing such peculiar results, input–output anti-faithfulness represents a fundamental departure from the basic Optimality-Theoretic notion that all constraints are either faithfulness constraints or markedness constraints (cf. the trans-derivational anti-faithfulness constraints of Alderete (2001), which only compare outputs). The anti-alignment constraints proposed here instead are straightforwardly markedness constraints, and their effects are much less chaotic.
License[Voice] constraint, which allows nasals to be specified for [Voice] if and only if they share the feature with an adjacent obstruent. Here, however, it is not possible to say that redundant features must be licensed by being shared, because in forms such as [lex̥ba] the shared features are [Laryngeal] and [Voice], which take higher scope in the contrastive hierarchy, rather than [Delayed Release], the feature that is redundant within the subinventory defined by them. Instead of License[Delayed Release], then, we can replace *[Delayed Release, Laryngeal, Voice] with the anti-alignment constraint shown in (221).\footnote{Anti-alignment constraints referring to prosodic domains have previously been proposed by Downing (1998), Buckley (1998) and Inkelas (1999), inter alia; the application of such constraints to features is a logical extension.} The features [Delayed Release], [Laryngeal], and [Voice] are not prohibited from being associated with the same segment, but their extents must not coincide exactly; the spans of segments with which they are associated cannot be identical.

\begin{align*}
\text{(221) Disalign[Delayed Release, Laryngeal, Voice]: The output contains no set of instances of the features [Delayed Release], [Laryngeal], and [Voice] such that the leftmost segment associated with each feature is the leftmost segment associated with each of the other features and the rightmost segment associated with each feature is the rightmost segment associated with each of the other features.}
\end{align*}

This constraint will penalize a /d̥z/ or /dz/ that does not share any of the features in question with a neighbour, or that shares all of them with the same set of neighbours (in a cluster of two or more voiced affricates), but it will not penalize a voiced affricate that shares its [Laryngeal] node with a non-affricate. The tableau in (222) shows what sorts of configurations are and are not permitted by the constraint in (221).
Chapter 5. Contrast and Optimality

Candidates (222a) and (222b) violate the anti-alignment constraint; the three features [Delayed Release], [Laryngeal], and [Voice] share both their left edge and their right edge. Candidate (222c), which occurs in words like léčba, is allowed; the features coincide at one edge, the left, but at the other edge, [Laryngeal] and [Voice] are shared with another segment beyond the extent of [Delayed Release]. In candidate (222d), the converse is true: [Delayed Release] is shared between the segments, while only one of them has both [Laryngeal] and [Voice]. Candidate (222d) satisfies the disalignment constraint, but such sequences do not occur in Czech; they are ruled out instead by the alignment constraints that drive voicing assimilation, ALIGN(LAR, L, ω, L) and ALIGN(LAR, R, ω, R).
\( \omega, R \), which effectively penalize any cluster of obstruents that have separate [Laryngeal] nodes.

Generalizing from this, we can revise the translation rules in (214) so that they employ anti-alignment constraints instead of coöccurrence constraints; the resulting new set of rules is shown in (223).

\[(223) \text{ Converting a contrastive hierarchy into a constraint hierarchy (revised)}\]

- For every feature \( F_i \) such that \( F_i \) is contrastive in inventory \( I \):
  - \( \text{MAX}[F_i] \gg *[F] \)
  - For all \( \Phi \) such that \( \Phi \) is a set of feature values defining a subinventory \( I_{\Phi} \subset I \) in which \( F_i \) is not contrastive, and such that there is no \( \Phi' \) such that \( \Phi' \subset \Phi \) and \( \Phi' \) defines a superinventory \( I_{\Phi'} \supset I_{\Phi} \) in which \( F_i \) is also not contrastive:
    - \( \text{DISALIGN}[F_i, \Phi] \gg \text{MAX}[F_i] \)
  - For every feature \( F_j \) such that some value of \( F_j \) is in \( \Phi \):
    - \( \text{MAX}[F_j] \gg \text{DISALIGN}[F_i, \Phi] \)
- For every feature \( F_k \) such that \( F_k \) is not contrastive in inventory \( I \):
  - \( *[F] \gg \text{MAX}[F_k] \)

Substituting the new anti-alignment constraint for the old coöccurrence constraint in the hierarchy in (220), we arrive at the tableau in (224), which correctly produces the output \([\text{le:q}ba]\).
The revised constraint hierarchy now correctly predicts that voiced affricates will not occur unless they share their voicing features with some other obstruent, but it also introduces a new problem: it fails to rule out forms such as *[b\text{\#a}]*, in which a [Laryngeal] node associated with a voiced affricate is shared with an obstruent to its left rather than to its right. Such a configuration satisfies the anti-alignment constraint (being the mirror image of (222c), but cannot actually arise in Czech, because underlying affricates are...
voiceless and voicing assimilation is regressive (apart from the also problematic case of /v/ and /ɾ/, on which more later). The Optimality-Theoretic account cannot distinguish between feature-sharing structures that arise through spreading and ones that are present in the input. How, then, can we rule out [bɔːɡa] and its ilk in a principled way? The generalization that needs to be expressed is that there are no (necessarily) underlyingly voiced affricates in Czech,\textsuperscript{16} and so the relevant constraint ranking ought to be derivable from the contrastive hierarchy in (218), which defines the shape of the Czech consonant inventory.

The answer lies in positional faithfulness, which plays a crucial role in determining the direction of assimilation. It is the positional faithfulness constraint MAX[LAR]/---[SV] that determines, for example, that s domem will be realized as [zdomem] rather than [*stomem] in (209). The rules in (223) partially determine the rankings of unqualified faithfulness constraints such as MAX[LARYNGEAL], but so far they have had nothing to say about positional faithfulness.

The revised version of (223) in (225) shows how positional faithfulness may be taken into account. As before, each unqualified faithfulness constraint is ranked above or below anti-alignment constraints referring to the same feature according to that feature’s contrastive scope. Positional faithfulness constraints are analogously ranked with respect to asymmetrical anti-alignment constraints: positional faithfulness constraints referring to an environment on the left-hand side are ranked with respect to constraints penalizing left-alignment, and positional faithfulness constraints referring to an environment on the right-hand side (such as MAX[LAR]/---[SV]) are ranked with respect to constraints penalizing right-alignment.

\textsuperscript{16}In other words, every voiced affricate at the surface is one that would be voiced even if its input correspondent were voiceless; however, an affricate that is always to the left of a voiced obstruent, and therefore non-alternatingly voiced at the surface, will by Lexicon Optimization be voiced underlyingly as well.
Converting a contrastive hierarchy into a constraint hierarchy (final version)

- For every feature \( F_i \) such that \( F_i \) is contrastive in inventory \( I \):
  - \( \text{Max}[F_i] \gg *[F] \)
  - For all \( \Phi \) such that \( \Phi \) is a set of feature values defining a subinventory \( I_{\Phi} \subset I \) in which \( F_i \) is not contrastive, and such that there is no \( \Phi' \) such that \( \Phi' \subset \Phi \) and \( \Phi' \) defines a superinventory \( I_{\Phi'} \supset I_{\Phi} \) in which \( F_i \) is also not contrastive:
    - \( \text{Disalign}[F_i, \Phi] \gg \text{Max}[F_i] \)
    - For every feature \( F_j \) such that some value of \( F_j \) is in \( \Phi \):
      - \( \text{Max}[F_j] \gg \text{Disalign}[F_i, \Phi] \)
      - For all \( X \) such that there is a positional faithfulness constraint of the form \( \text{Max}[F_j]/X \_\_ \):
        - \( \text{Max}[F_j]/X \_\_ \gg \text{Disalign-L}[F_i, \Phi] \gg \text{Max}[F_i] \)
      - For all \( Y \) such that there is a positional faithfulness constraint of the form \( \text{Max}[F_j]/\_\_Y \):
        - \( \text{Max}[F_j]/\_\_Y \gg \text{Disalign-R}[F_i, \Phi] \gg \text{Max}[F_i] \)
  - For every feature \( F_k \) such that \( F_k \) is not contrastive in inventory \( I \):
    - \( *[F] \gg \text{Max}[F_k] \)

For the Czech case, this new formulation gives us the ranking shown in (226) in addition to the ranking in (224).

\[
\text{Max}[Lar]/\_\_SV \gg \text{Disalign-R}[Delayed Release, Laryngeal, Voice] \gg \text{Max}[Delayed Release]
\]

The crucial new constraint here is \( \text{Disalign-R}[Delayed Release, Laryngeal, Voice] \), which prohibits these three features from sharing a right edge. This constraint will penalize a configuration such as \([*b\_\_a]\), but not one such as \([g\_\_a]\). The
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ranking shown in (226) thus ensures that while voiced affricates can be the result of voicing assimilation, they cannot occur in the position of a trigger of assimilation, i.e., as the rightmost obstruent in a pre-sonorant cluster.

The rules in (225) do not explicitly rank Disalign-R[Delayed Release, Laryngeal, Voice] and Disalign[Delayed Release, Laryngeal, Voice] with respect to each other, but we can assume that the more specific constraint (the one penalizing alignment on both sides) is ranked above the more general one (the one penalizing alignment on the right-hand side) as a matter of course (see, e.g., Beckman 1998: 34–35). This leads to the ranking shown in the tableaux in (227), which now correctly disallows [*b₄a], as shown in (227a), while permitting [d₄ba]—which can be derived either from underlying /ɬba/, as in (227b), or from underlying /d₄ba/.

(227) a.

<table>
<thead>
<tr>
<th>Del Rel</th>
<th>b</th>
<th>ɖ</th>
<th>a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Larᵢ</td>
<td>Larⱼ</td>
<td>Voice</td>
</tr>
<tr>
<td></td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

This leads to the ranking shown in the tableaux in (227), which now correctly disallows [*b₄a], as shown in (227a), while permitting [d₄ba]—which can be derived either from underlying /ɬba/, as in (227b), or from underlying /d₄ba/.
5.3.5 Optimality and prophylaxis

The revised translation rules in (225) thus make it possible to deal with the Czech affricates in a reasonably principled way. However, the more deeply anomalous segments /ř/ and /v/ remain problematic. According to the analysis presented in §2.3.3, these segments lack [Laryngeal] nodes contrastively rather than redundantly. The constraint rankings generated by (225) will therefore do nothing to prohibit these segments from combining with [Laryngeal] nodes. Indeed, as discussed in §2.6.1, there will be a segment in the underlying inventory that is featurally identical to /ř/ except for the addition of
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a bare [Laryngeal] node, and another that has [Laryngeal] and [Voice]. The problem, of course, is that when /r/ undergoes voicing assimilation, it does not become either of these segments; instead, a devoiced /r/ becomes [r˚], and one that assimilates to a voiced obstruent remains /r/. In §2.6.2, this problem is dealt with by means of prophylactic features: there are non-contrastive features of /r/ that, though invisible to the phonological computation, are present on the segment underlyingly and ensure that it will be realized correctly at phonetic implementation even if it has undergone voicing assimilation.

Prophylactic features, however, are essentially incompatible with Richness of the Base, and also with Freedom of Analysis, the principle that GEN is essentially unrestricted in its ability to supply candidate forms. If Richness of the Base were to apply to prophylactic features, then any input segment could be arbitrarily specified with any combination of features that would be invisible to the phonological computation, but pronounced at phonetic implementation, the result of which would be utter chaos. In order for prophylactic features to do their job, they must be confined to specific phonemes—for example, in varieties of Czech with five voicing classes, it must be the case that a segment lacking both [Laryngeal] and [Voice] is prophylactically specified with features identifying it as /r/. In Optimality Theory, however, ensuring the presence of a feature in the input does not by itself guarantee that the feature will be present in the output. Whereas in a derivational theory of phonology the surface form resembles the underlying representation except where it has explicitly been altered by rules, in Optimality Theory the output resembles the input only insofar as it is explicitly required to do so by faithfulness constraints (or by such markedness constraints as may happen to be best served by coincidental resemblance to the input). Prophylactic features, by definition, cannot be referred to by the phonological computation, so there can be no faithfulness constraints to require their presence (or absence) in the output. The only way to make

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17. Prince and Smolensky (1993: 6) explain that GEN works by “freely exercising the basic structural resources of the representational theory”; see Blaho, Bye, and Krämer (to appear) for extended discussion.
prophylactic features work as intended in OT would be to restrict GEN so that every segment in any candidate must bear exactly the same set of prophylactic features as its input correspondent (or no prophylactic features, if it has no input correspondent).

Rather than revising the basic assumptions of Optimality Theory, one might instead prefer to formulate a theory of feature invisibility that would be compatible with those assumptions and provide a viable alternative to prophylactic features. For example, Blaho and Bye (2005) present an analysis of Czech /rɪ/ in Biaspectual Phonology, a version of OT in which the output form “is interpreted by two extragrammatical systems, a phonetic interpretation system Φ and a lexical recognition system Λ” (Blaho and Bye 2005: 3–4; boldface in the original). Phonological material in the output may be visible to either of these systems, or to both, or to neither. The anomalous behaviour of /rɪ/ when it is preceded by a voiceless obstruent is derived from the fact that it appears as [+sonorant] to Λ (and thus is not the head of a span, and thus does not determine the voicing of the cluster) but as [−sonorant] to Φ (and thus is susceptible to assimilatory devoicing). The effect is that /rɪ/, which Blaho and Bye (2005) characterize as a “cryptosonorant,” has a sort of dual identity similar to that of Russian /v/ in the treatment of Padgett (2002), but more abstract.

This approach, while technically ingenious, relies quite heavily on some very specific constraints. The key constraints that determine the representation, and thus the behaviour, of /rɪ/ are shown in (228).

\[(228)\] Constraints on the two aspects of /rɪ/ (Blaho and Bye 2005: 7)

a. \(\ast r^{\Lambda}\): Post-alveolar trills are not visible to Λ as [−son].

b. \(\ast r^{\Phi}\): Post-alveolar trills are not visible to Φ as [+son].

In other words, the anomalous behaviour of /rɪ/ is connected by means of these constraints to its identity as a post-alveolar trill, rather than being derived from its underlying specifications for voicing or sonorancy. The theoretical apparatus employed by
Blaho and Bye (2005) is very powerful, and the typological range of possible cryptosegments appears to be essentially unconstrained.

5.4 Conclusions

Blaho and Bye’s approach, while compatible with Freedom of Analysis and Richness of the Base, is fundamentally different in character from the underspecification analyses discussed earlier in this chapter, and this difference is indicative of a more basic theoretical difference between OT and the theory of contrast presented in this dissertation. Under the latter, the main differences between languages are in their phonemic inventories and the features that define them; while phonological rules also vary from one language to another, their basic character is consistent: marked features can spread or be delinked, while unmarked features are inactive. This approach to phonology has a certain affinity with the view of syntax outlined by Chomsky (1989: 44):

It has been suggested that parameters of UG do not relate to the computational system, but only to the lexicon. We might take this to mean that each parameter refers to properties of specific elements of the lexicon or to categories of lexical items; canonical government, for example. If this proposal can be maintained in a natural form, there is only one human language, apart from the lexicon, and language acquisition is in essence a matter of determining lexical idiosyncracies. Properties of the lexicon too are sharply constrained, by UG or other systems of the mind/brain.

Under a derivational approach to phonology employing the Successive Division Algorithm and formally natural autosegmental rules, the phonemic inventory takes on
a role in the phonological system analogous to that of the lexicon in syntax.\footnote{Chomsky (1989: 70 fn. 2), citing Bromberger and Halle (1989), does specifically exempt phonology from his suggestion that languages differ only in their lexicons and not in their rules; subsequent developments in phonological theory, however, suggest that the degree to which phonological rules vary may not be particularly great.} The set of representations generated by the Successive Division Algorithm determines not only what segments are present in a given language, but also how those segments are expected to behave in phonological derivations.

In Optimality Theory, on the other hand, all languages have the same set of input forms, being subject to Richness of the Base, and all the differences between them are due to their different rankings of universal constraints—an alternative source of parametric variation. The more specific and numerous the constraints in UG are hypothesized to be, the wider the expected range of variation in grammars. Underlying inventories in OT are merely by-products of the constraint grammar. To the extent that it is possible to translate a theory of contrastive specification into OT terms, as in §5.3.2–5.3.4, the translation relies on constraints that are based on properties of particular inventories (such as \textsc{Disalign-R[Delayed Release, Laryngeal, Voice]}), and whose inclusion in a universal inventory of markedness constraints seems tenuous. Although the contrastivist hypothesis is a theory of representations, and Optimality Theory is a theory of constraint interaction, the two theories are not independent and freely combinable, because they make conflicting assumptions about the locus of arbitrary cross-linguistic variation.
The preceding chapters have outlined specific aspects of a view of contrast and its role in a comprehensive theory of phonology. By way of a conclusion, I would like in this final chapter to step back and take a brief look at how these aspects fit together into a whole. Here, then, is an outline of that whole:

**Phonological representations are based on contrast** (chapter 1; also §4.1). In any theory of phonology, representations must include enough information to distinguish contrasting phonemes. From a methodological perspective, it is useful to begin from the hypothesis that they contain no more information than this, and then see whether this amount of information is sufficient to account for attested phonological patterns. In a great many cases, it seems that it is.

**Features are assigned by successive division of the inventory** (§1.2.7). In order to test the Contrastivist Hypothesis, it is necessary to have a principled means of determining whether a feature is contrastive or redundant. The Successive Division
Algorithm provides such a means, while allowing for a measure of variation among languages. Languages with superficially similar inventories may exhibit different phonological patterns attributable to different orders of divisions, but in all cases the Successive Division Algorithm assigns features that suffice to differentiate the phonemes of the underlying inventory, and in no case does it assign a feature that does not serve to distinguish at least one phoneme from at least one other phoneme.

**Redundant features are not phonologically active,** even though they may sometimes need to be present during the phonological computation (chapters 2 and 3). The strongest possible version of the Contrastivist Hypothesis is contradicted by cases in which redundant information crucial to the correct phonetic realization of segments would be irrecoverable at the end of the phonological computation if it is not present from the beginning. However, in the cases analyzed in chapters 2 and 3, the phonological computation does not actually need to refer to the redundant information in any way. The necessary retreat from the strong hypothesis is therefore minimal: redundant features must sometimes be present in phonological representations, but not active or even visible.

**Phonetic contrast serves phonemic contrast** (chapter 4). To the extent that languages exhibit a tendency to maximize the surface phonetic distinctness of contrasting segments, this tendency can be attributed synchronically to the mechanism of phonetic enhancement, and diachronically to the role of phonetic salience in the acquisition of phonemic contrasts. Phonetic enhancement typically reinforces auditory differences that are encoded in contrastive phonological feature specifications—a classic example being the use of lip rounding to enhance contrastively back vowels. In a system in which all specified features are contrastive, enhancement will increase the overall phonetic distinctness from one another of the phonemes in the inventory, without recourse to any mechanism of explicit global
comparison. A natural preference for robust contrasts in acquisition will cause enhancement features to tend to be reinterpreted as contrastive features when they are more salient than the contrasts they originally reinforced.

**Contrastive specification restricts underlying representations** (chapter 5). Although the view of phonological representations presented here is in principle compatible with either a rule-based or a constraint-based view of the phonological computation, it does require that inputs to that computation be constrained by the contrastive hierarchy, a requirement that potentially conflicts with the Optimality-Theoretic principle of Richness of the Base. While it is possible to translate a contrastive hierarchy into a constraint hierarchy (§5.3), the interaction between the constraints enforcing contrastive specification and the rest of the grammar is potentially problematic, and there is no good way of implementing in Optimality Theory prophylactic features of the sort discussed in chapters 2 and 3.

In the view of phonology outlined here, the role of contrast is central, and its representation, though permissive of a certain degree of cross-linguistic variation, is systematic.
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ROA = Rutgers Optimality Archive (http://roa.rutgers.edu/)