Contrastive Hierarchies and Phonological Primes*

B. Elan Dresher
University of Toronto

1 Introduction

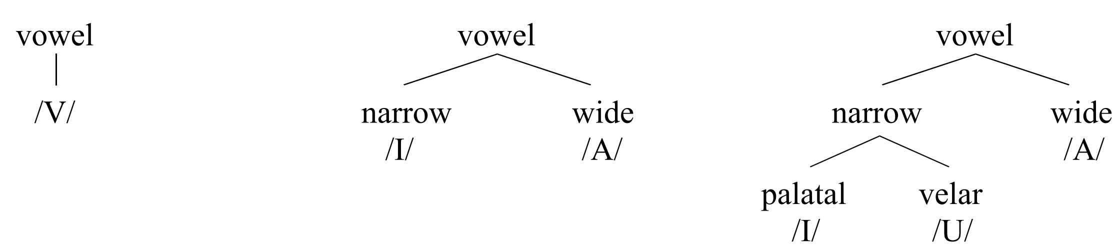
Contrastive Hierarchy Theory (Dresher 2009, 2018; Hall 2007, 2011) builds on Jakobson's (1941) basic insight that the contrasts of a language are organized in a hierarchical order. Contrastive Hierarchy Theory assumes that phonological primes are binary features, and in this sense parts company with versions of Element Theory and related approaches. Nevertheless, there are a number of affinities between Contrastive Hierarchy Theory and Element Theory, and in this paper I will try to highlight what I think are some points in common, as well as some differences.

I will start in section 2 with a review of the main ideas that I take from Jakobson (1941), and briefly mention what became of these ideas in the 1950s and 1960s. In section 3, I set out the main tenets of Contrastive Hierarchy Theory, and in sections 4 and 5 I discuss the status of phonological primes (features in Contrastive Hierarchy Theory, elements in Element Theory) with respect to phonetics and substance-free phonology. I will show that Contrastive Hierarchy Theory and Element Theory have a similar approach to these issues, whether we take the primes to be features or elements. Section 6 focuses on three- and four-vowel systems, where there may or may not be an important difference between Contrastive Hierarchy Theory and Element Theory with respect to contrast. Then section 7 briefly surveys some five-vowel systems with the aim of showing that contrastive hierarchies must be allowed to vary from one language to another. Section 8 makes the same point with a diachronic example, showing how the five-vowel system of West Germanic reorganized its system of contrasts in early Old English. Section 9 considers the issue of binary features versus single-valued elements. Section 10 is a brief conclusion.

2 The acquisition of phonological contrasts

Jakobson (1941) (English translation 1968, French in 1969) advances the notion that contrasts are crucial in phonological acquisition and that they develop in a hierarchical order. In particular, he proposes that learners begin with broad contrasts that are split by stages into progressively finer ones. The acquisition of vowel systems set out in Jakobson (1941) and its sequel, Jakobson and Halle (1956), follows this schema, as shown in (1).

(1) Early stages of vowel acquisition (Jakobson 1941; Jakobson and Halle 1956)
a. Stage 1 b. Stage 2 c. Stage 3



* I would like to thank Graziela Bohn for help with the Brazilian Portuguese analysis and examples, and Harry van der Hulst and William Idsardi for discussion of features. I am also grateful to two reviewers for insightful comments on an earlier draft.

At the first stage (1a), there is only a single vowel. As there are no contrasts, we can simply designate it /V/. Jakobson and Halle write that this lone vowel is the maximally open vowel [a], the "optimal vowel". But we do not need to be that specific: we can understand this to be a default value, or a typical but not obligatory instantiation.

In the next stage (1b) it is proposed that the single vowel splits into a narrow (high) vowel /I/, which is typically [i], and a wide (low) vowel, /A/, typically [a]. I will continue to understand these values as defaults; I use capital letters to represent vowels that fit the contrastive labels that characterize them.

In the next stage (1c) the narrow vowel splits into a palatal (front) vowel /I/ and a velar (back or round) vowel /U/, typically [u]. After these first stages, Jakobson and Halle allow variation in the order of acquisition of vowel contrasts. The wide branch can be expanded to parallel the narrow one. Or the narrow vowels can develop a rounding contrast in one or both branches. Continuing in this fashion we will arrive at a complete inventory of the phonemes in a language, with each phoneme assigned a set of contrastive properties that distinguish it from every other one.

I have been trying to reconstruct a history of "branching trees" in phonology (Dresher 2009, 2015, 2016, 2018). Early, though inexplicit, examples can be found in the work of Jakobson ([1931] 1962) and Trubetzkoy (1939) in the 1930s, continuing with Jakobson (1941) and Jakobson and Lotz (1949), then more explicitly in Jakobson, Fant, and Halle (1952), Cherry, Halle, and Jakobson (1953), Jakobson and Halle (1956), and Halle (1959). This approach was imported into early versions of the theory of Generative Phonology; it is featured prominently in the first Generative Phonology textbook by Robert T. Harms in (1968). Nevertheless, for reasons I have discussed (Dresher 2009: 96–104), branching trees were omitted from Chomsky and Halle's *The sound pattern of English* (*SPE;* 1968), and disappeared from mainstream phonological theory for the rest of the century.

In child language studies, however, branching trees continued to be used, for they are a natural way to describe developing phonological inventories (Pye, Ingram, and List 1987; Ingram 1988, 1989; Levelt 1989; Dinnsen et al. 1990; Dinnsen 1992, 1996; see Dresher 1998a for a review). Fikkert (1994) presents observed acquisition sequences in the development of Dutch onsets that follows this general scheme, and Bohn (2015) shows the routes that three children take in acquiring the vowel system of Brazilian Portuguese.

As a general theory of phonological representations, branching trees were revived by Clements, first in the form of an accessibility hierarchy (Clements 2001) and then as a robustness scale (Clements 2009), and independently at the University of Toronto, where they are called contrastive feature hierarchies (Dresher, Piggott, and Rice 1994; Dyck 1995; Zhang 1996; Dresher 1998b; Dresher and Rice 2007; Hall 2007; Dresher 2009; etc.). It is the latter approach I will be presenting here. It has gone under various names: Modified Contrastive Specification (MCS), or "Toronto School" phonology, or Contrast and Enhancement Theory, or Contrastive Hierarchy Theory, which is the name I use here. I do not claim there is any standard version of this theory; in what follows, I will present the theory as I understand it.

3 Contrastive Hierarchy Theory

Contrastive Hierarchy Theory has assumed that phonological primes are features; some Contrastive Hierarchy Theory analyses have used privative features, but I will stick to binary ones. The first major building block of our theory is that contrasts are computed hierarchically by ordered features that can be expressed as a branching tree. Branching trees are generated by what I call the Successive Division Algorithm (Dresher 1998b, 2003, 2009), given informally in (2):

(2) The Successive Division Algorithm
Assign contrastive features by successively dividing the inventory until every phoneme has been distinguished.

What are the criteria for selecting and ordering the features? Phonetics is clearly important, in that the selected features must be consistent with the phonetic properties of the phonemes. For example, a contrast between /i/ and /a/ would most likely involve a height feature like [low] or [high], though other choices are possible, e.g. [front] or [advanced/retracted tongue root]. Of course, the contrastive specification of a phoneme could sometimes deviate from the surface phonetics. For example, as discussed in section 6, in some Inuit dialects an underlying contrast between /i/ and /ə/ is neutralized at the surface, with both /i/ and /ə/ being realized as phonetic [i] (Compton and Dresher 2011). In this case, underlying /i/ and /ə/ would be distinguished by a contrastive feature, even though their surface phonetics are identical.

As this example shows, the way a sound patterns can override its phonetics (Sapir 1925). Thus, we consider as most fundamental that features should be selected and ordered so as to reflect the phonological activity in a language, where activity is defined as in (3), which is adapted from Clements (2001: 77):

(3) Phonological Activity
A feature can be said to be *active* if it plays a role in the phonological computation; that is, if it is required for the expression of phonological regularities in a language, including both static phonotactic patterns and patterns of alternation.

The second major tenet of Contrastive Hierarchy Theory has been formulated by Hall (2007) as the Contrastivist Hypothesis (4):

(4) The 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.

That is, only contrastive features can be phonologically active. If this hypothesis is correct, then (5) follows as a corollary:

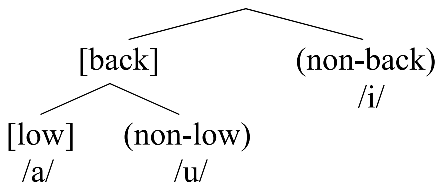
(5) Corollary to the Contrastivist Hypothesis
If a feature is phonologically active, then it must be contrastive.

One final assumption is that the two values of a feature are not symmetrical: every feature has a *marked* and *unmarked* value. I assume that markedness is language particular (Rice 2003, 2007), and is acquired based on phonological patterning. I will designate the marked value of a feature F as [F], and the unmarked value as (non-F). I will refer to the two values together as [±F].

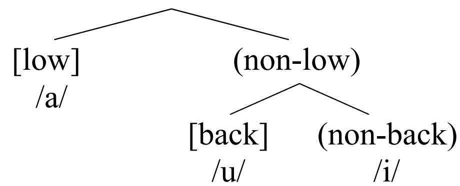
To see how the contrastive hierarchy works, consider a language with three vowel phonemes /i, a, u/. If the vowels are split off from the rest of the inventory so that they form a sub-inventory, then they must be assigned a contrastive hierarchy with two vowel features. Though the features and their ordering vary, the limit of two features constrains what the hierarchies can be. Two possible contrastive hierarchies using the features [back] and [low] are given in (6), and two more hierarchies, using [high] and [round], are shown in (7).

(6) Three-vowel systems with the features [back] and [low]

a. [back] > [low]

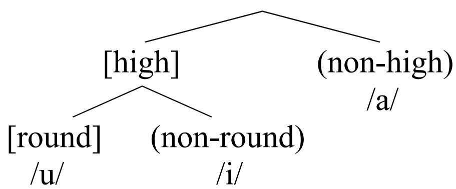


b. [low] > [back]

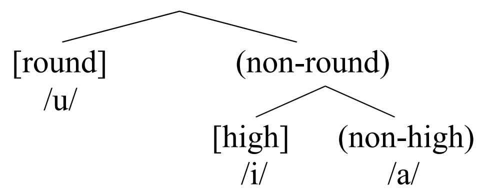


(7) Three-vowel systems with the features [high] and [round]

a. [high] > [round]



b. [round] > [high]



Synchronically, the hierarchy constrains phonological activity, since only contrastive features can be phonologically active. Thus, in (6a) both /a/ and /u/ can potentially trigger backing, since both are contrastively [back]; in (6b), only /u/ is contrastively [back], so we expect that /a/ would not cause backing in the phonology. Similarly, in (7a) we expect that both /i/ and /u/ would be able to cause raising, as they are both [high]; but in (7b), only /i/ is contrastively [high], and is the only potential trigger of a raising rule.

Diachronically, the hierarchy constrains neutralization and merger, as proposed by Ko (2010, 2012) and Oxford (2015):

(8) Diachronic phonological merger in Contrastive Hierarchy Theory

a. The Minimal Contrast Principle (Ko 2010: 191; 2012: 35–37)
Phonological merger operates on a minimal contrast—that is, on two segments that share a terminal branching node under a given contrastive hierarchy.

b. The Sisterhood Merger Hypothesis (Oxford 2015: 314)
Structural mergers apply to "contrastive sisters".

Given the hypothesis in (8), we expect that /u/ might merge with /a/ in (6a), with /i/ in (6b) and (7a), but that /i/ and /a/ could merge to the exclusion of /u/ in (7b); see Oxford 2015 for examples of merger patterns just like these in the history of the Algonquian languages. Typological generalizations can thus not be found by looking at inventories alone (say, /i, a, u/), or at individual phonemes (/a/), or phones ([a]), without also considering the relevant contrastive feature hierarchy.

Unless a phoneme is further specified by other contrastive features (originating in other phonemes), it is made more specific only in a post-phonological component. Stevens, Keyser, and Kawasaki (1986) propose that feature contrasts can be *enhanced* by other features with similar acoustic effects (see also Stevens and Keyser 1989; Keyser and Stevens 2001, 2006). Hall (2011) shows how the enhancement of contrastive features can result in configurations predicted by Dispersion Theory (Liljencrants and Lindblom 1972; Lindblom 1986; Flemming 2002). Thus, a vowel that is contrastively [back] and (non-low) can enhance these features by adding {round} and {high}, respectively, becoming [u]—enhancement features are indicated by curly brackets {}.

These enhancements are not universal, however, and other realizations are possible (Dyck 1995; Hall 2011).

4 Why are the primes as they are (whatever they are)?

In a volume titled *Where do phonological features come from?* (Clements and Ridouane 2011), most of the papers take the position that phonological features are not innate, but rather "emerge" in the course of acquisition. Mielke (2008) and Samuels (2011) summarize the arguments against innate features:

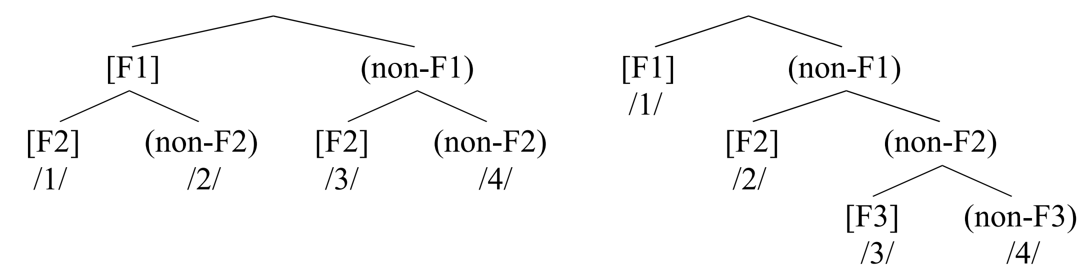
(a) from a biolinguistic perspective, phonological features are too specific, and exclude sign languages (van der Hulst 1993; Sandler 1993);
(b) empirically, no one set of features have been discovered that "do all tricks" (Hyman 2011 with respect to tone features, but the remark applies more generally);
(c) since at least some features have to be acquired from phonological activity, a prespecified list of features becomes less useful in learning.

But if features are not innate, what compels them to emerge at all? It is not enough to assert that features *may* emerge, or that they are a useful way to capture phonological generalizations. We need to explain why features inevitably emerge, and why they have the properties that they do. In particular, why don't learners, or some learners, simply posit segment-level representations? What controls the number of features—how broad or narrow are they? How many features should learners posit for three vowels, for example? Are there limits?

The contrastive feature hierarchy provides an answer to these questions: learners must arrive at a set of hierarchically ordered contrastive features. Thus, an inventory of three phonemes allows exactly two contrastive features. Two variants are shown in (9), differing in how marked features are distributed. A four-phoneme inventory can have a minimum of two features and a maximum of three, as in (10).

(9) Three-phoneme systems: F1 > F2
a. Marked value of F1 expands　　　b. Unmarked value of F1 expands

(10) Four-phoneme systems
a. Minimum number of features: 2　　　b. Maximum number of features: 3



In general, the number of binary features required by an inventory of *n* elements falls in the following ranges: the minimum number of features is equal to the smallest integer greater than or equal to $\log_2 n$, and the maximum number of features is equal to n–1. As can be seen in (11), the minimum number of features goes up very slowly as phonemes are added; the upper limit rises with *n*. However, inventories that approach the upper limit are extremely uneconomical. At the max limit, each new segment uses a unique contrastive feature unshared by any other phoneme. It has been proposed that phonological inventories prefer to reuse the same features, producing a tendency toward feature economy (de Groot 1931; Martinet 1955; Ohala 1980; Clements 2003; Lindblom et al. 2011; see Hall 2011 and Mackie and Mielke 2011 for discussion, and Cherry, Jakobson, and Halle 1953 for economy in the context of branching trees).[1]

(11) Number of contrastive features by inventory size

Phonemes	$\log_2 n$	min	max	Phonemes	$\log_2 n$	min	max
3	1.58	2	2	10	3.32	4	9
4	2	2	3	12	3.58	4	11
5	2.32	3	4	16	4	4	15
6	2.58	3	5	20	4.32	5	19
7	2.81	3	6	25	4.64	5	24
8	3	3	7	32	5	5	31

Thus, the contrastive hierarchy and the Contrastivist Hypothesis go a long way toward accounting for why phonological systems resemble each other in terms of representations, without requiring individual features to be innate. For the content of features, learners make use of the available materials relevant to the modality: for spoken language, acoustic and articulatory properties of speech sounds; for sign language, hand shapes and facial expressions. On this view, the concept of a contrastive hierarchy is an innate part of Universal Grammar (UG), and is the glue that binds phonological representations and makes them appear similar from language to language (Dresher 2014a).

It is important to emphasize that, though phonological features may make use of innate auditory dispositions, they are not the same as those, but are cognitive entities created by learners.[2] Thus, the contrasts indicated by features like [back] and [low] may be crosslinguistically common because we have neurons sensitive to formant transitions. So, it appears, do ferrets (Mesgarani et al. 2008). But ferrets do not necessarily have our kind of phonological representations.

5 Form and substance in phonology

I believe that Contrastive Hierarchy Theory and Element Theory are in agreement that phonological primes (features for Contrastive Hierarchy Theory, elements for Element Theory) are cognitive entities that are not determined by phonetics, in contrast to phonetically-based approaches to phonology (Steriade 2001; Flemming 2002; Hayes, Kirchner, and Steriade 2004).

[1] A reviewer writes that, even if we assume feature economy, there are far fewer primes in Element Theory (about six). This indeed is an issue worth studying further; the low number of elements, if it can be sustained empirically, might point to the need to further constrain possible feature systems. For a suggestion, please see the following note.

[2] There may be constraints on what sort of cognitive features can be created from these auditory dispositions; for example, we do not find "picket fence" features that divide up the acoustic space in discontinuous ways (Heffner, Idsardi, and Newman 2019). Constraints on what a feature can be (perhaps along the lines of the "dimensions" posited by Avery & Idsardi 2001) could bring the set of possible features closer to that of the elements of Element Theory.

On the other side, both Contrastive Hierarchy Theory and Element Theory are not as radical as various "substance-free" theories in separating phonological representations from phonetics (Hale and Reiss 2000, 2008; Odden 2006; Blaho 2008; Mielke 2008; Samuels 2011; Reiss 2017). Hall (2014) comments that substance-free theories, whose approach he traces back to Fudge (1967), are actually similar to substance-based theories in relegating the explanation for many aspects of phonology to phonetic factors and diachronic change.

Advocates of substance-free phonology argue that phonology is concerned only with formal notions and not with phonetic substance. However, the line between form and substance is not as clear cut as advocates of substance-free phonology make it out to be. Take markedness, for example. Reiss (2017: 429) writes, "The way forward, in the twenty-first century, is to abandon markedness". He assumes that markedness is not formal, but is part of substance. There are different notions of what markedness is, and some of them might fall under "substance"; but this is not the case for the version assumed in Contrastive Hierarchy Theory.

I have proposed (Dresher 2014a) that the learners' task is to arrive at a set of primes that account for the contrasts and phonological activity of their language. I have assumed that the primes are binary features, but much the same holds if we assume that they are privative features or elements. These primes are not arbitrary diacritics or numbers but have phonetic correlates. I also assume that features are asymmetrical in having a marked and unmarked value. These values, like the features themselves, are acquired by learners based on the evidence of their language. Since markedness, on this view, is inherent in the definition of a feature, I consider it to be a part of the formal side of phonology.

The same holds even more obviously of phonological theories influenced by Kaye, Lowenstamm, and Vergnaud (1985) (KLV). According to Jean-Roger Vergnaud (p. c.), one of the motivations for developing the KLV theory was to incorporate the *SPE* markedness theory directly into representations. For example, in Backley's (2011) *Introduction to Element Theory*, the vowels in a five-vowel system like the one in (12) differ in the complexity of their representations. Reflecting the *SPE* markedness theory (Chomsky and Halle 1968: 409), [e] and [o] have more complex representations than [i, a, u].

(12) Five-vowel system (Backley 2011)

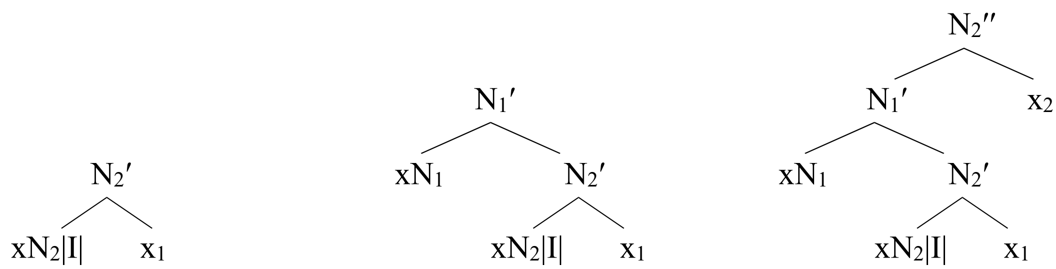
[i]	[e]	[a]	[o]	[u]
|I|	|I A|	|A|	|U A|	|U|

In GP 2.0 (Pöchtrager 2006, 2016; Živanović and Pöchtrager 2010; Kaye and Pöchtrager 2013; Voeltzel 2016) markedness is expressed structurally. The vowel [i] has a relatively simple representation (13a); [e] is essentially an [i] with an additional layer of structure (13b); and [ɛ] is an [e] with a further layer of structure (13c). These structures are formal phonological representations, so are not merely "substance", though they relate to phonetic substance.

Voeltzel (2016) summarizes Pöchtrager's (2016) account of vowel reduction in Brazilian Portuguese employing the representations in (13). In this account, the stressed position of a word has "room" for all three vowels. In the position before the stressed vowel there is no room for the most complex vowel, [ɛ], which reduces to [e]. The most reduction occurs in final unstressed position, where all three front vowels appear as [i].[3] It is an empirical question whether this theory is correct, but I see no grounds for considering it to be a case of "substance abuse".

(13) Vowel representations in GP2.0

a. [i] b. [e] c. [ɛ]



My reservations about this analysis concern variability and the phonetic interpretation of these representations. As mentioned above, I follow Rice (2003, 2007) in assuming that markedness is language particular. Thus, it does not appear to be the case that /e/ is always more marked than /i/ and that /ɛ/ is always more marked than /e/. Indeed, Nevins (2012) writes that Brazilian Portuguese dialects themselves differ with respect to whether [e] or [ɛ] is the result of neutralization. This is not an argument against a structural approach to markedness, but rather an argument that a given structure may have different phonetic interpretations in different systems. Nevins (2012) considers flexibility of interpretation to be a desirable property of Element Theory, in that it allows either /ɛ/ or /e/ to be assigned the more marked structure, as the evidence requires.[4] I would argue that the same holds of the relationship between other vowels, such as /i/ and /e/ or /i/ and /u/.

A second caveat is that this analysis equates the phonetic realizations of vowels in unstressed position with certain vowels in stressed position. For example, the above analysis suggests that final unstressed [i] in Brazilian Portuguese, which is the only front vowel in that position, is the same as stressed [í], which contrasts with two other front vowels. One might be able to argue that this is the case in some languages, but in many languages it is clear that the reduced vowels cannot be phonetically equated with particular stressed vowels. That is, neutralization is not always to the unmarked stressed vowel, but may be to a vowel that has a different representation from both the marked and unmarked stressed vowels (Trubetzkoy 1939: 71–72).

This actually appears to be the case in Brazilian Portuguese. According to Barbosa and Albano (2004), a São Paulo speaker had the seven stressed non-nasalized vowels shown in (14). They write (2004: 229) that in pre-stressed position, "the quality of the corresponding stressed vowel is roughly preserved". But this is not the case for unstressed vowels in final position.

(14) Vowels of Brazilian Portuguese, Paulista dialect (Barbosa and Albano 2004)

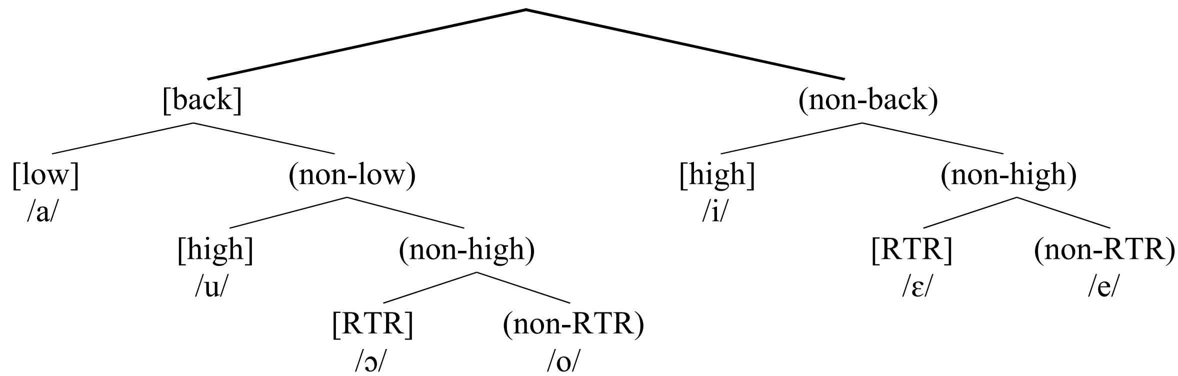
Stressed position	i	e	ɛ	a	ɔ	o	u
Before the stress	i	e		a	o		u
Final unstressed		ɪ		ɐ		ʊ	

[3] As we shall see in (14), the three front vowels are realized not as [i] but as [ɪ] in final position; thus, it is not obvious that this [ɪ] should be assigned the same representation as stressed [i].

[4] Specifically, he proposes that in "Southeastern" dialects the lax-mid vowels [ɛ, ɔ] are represented as headed |I,<u>A</u>|, |U,<u>A</u>| (marked, in our terms) and the tense-mid vowels [e, o] are unheaded (unmarked); in "Northeastern" dialects [e, o] are headed |<u>I</u>,A|, |<u>U</u>,A| and [ɛ, ɔ] are unheaded.

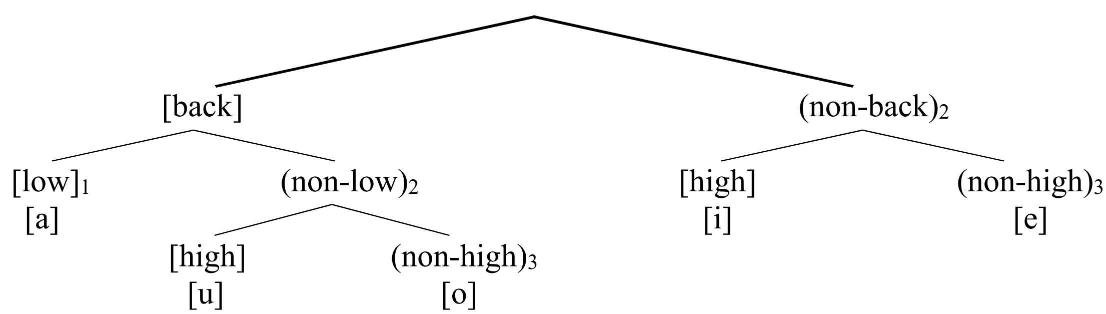
Spahr (2012) proposes a contrastive hierarchy account of Brazilian Portuguese vowel reduction; I have modified his hierarchy to that proposed by Bohn (2015, 2017) for the Paulista dialect. The tree in (15) shows the seven oral vowels in stressed position. The hierarchy is [back] > [low] > [high] > [RTR].[5] Bohn (2015, 2017) motivates this ordering based on the patterns of activity in this dialect (see also Bohn and Santos 2018).

(15) Paulista Brazilian Portuguese stressed vowels (Bohn 2015, 2017)



In pre-stress position (16), there are no [±RTR] contrasts under the (non-high) nodes numbered 3. Spahr proposes that these nodes are interpreted as archiphonemes à la Trubetzkoy. The new representations [back], (non-low, non-high) and (non-back, non-high) receive their own phonetic interpretations: in this case [o] and [e], but in other dialects [ɔ] and [ɛ].[6]

(16) Brazilian Portuguese vowels in pre-stress position (based on Spahr 2012)



In unstressed final position (17), the contrasts under the nodes numbered 2 are suppressed, and the segments under these nodes receive distinct phonetic interpretations as [ʊ] and [ɪ]. In this new set of contrasts the segment under node 1 also receives a distinct phonetic interpretation, [ɐ].[7]

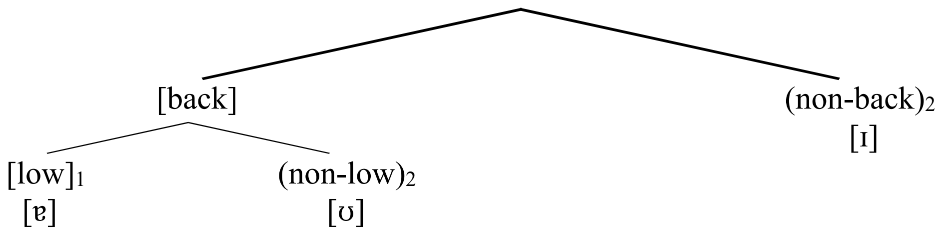
---

[5] I have changed Bohn's (2015, 2017) [ATR] to [RTR] to reflect the markedness in this dialect.

[6] In this case it would also be possible to propose that neutralization is to the unmarked member of the /e/ ~ /ɛ/ and /o/ ~ /ɔ/ contrasts. Such an analysis is not possible, however, for unstressed final position.

[7] The reduced hierarchies in (16) and (17) are derived by neutralization from underlying segments that are specified with all the features assigned to them by the full contrastive hierarchy in (15); for example, underlying /ɛ/, /ɔ/ appear as [e], [o], respectively, when unstressed, as in [bɛ́lʊ] 'beautiful' ~ [belézɐ] 'beauty' and [mɔ́rtʃɪ] 'death' ~ [mortáw] 'deadly'. That is, there is a single underlying system of hierarchical contrasts. This case should be distinguished from the reduced inventories that can be found in morphologically defined contexts, as in the case of many Romance languages where inflectional suffixes (desinences) use a reduced inventory of vowels as compared with roots. Dyck

(17) Brazilian Portuguese vowels in unstressed final position (based on Spahr 2012)



Like in GP 2.0, this analysis uses representational complexity, though in a different way. In both GP 2.0 and Contrastive Hierarchy Theory, this complexity is part of the formal representational apparatus, though it relates to aspects of phonetic substance. Neither analysis involves "substance abuse". The consequences of remaining completely free of substance in cases like these is that substance-free phonology also frees itself from providing a descriptively adequate account of vowel reduction patterns. Contrary to Reiss (2017), the way forward in the twenty-first century is not to abandon markedness and contrast on *a priori* grounds, but to incorporate them to the extent that they contribute to illuminating accounts of phonological patterns.

6 Contrast and Element Theory: Three- and four-vowel systems

At the Paris Conference on Theoretical Issues in Contemporary Phonology: Reading Tobias Scheer, I attempted (Dresher 2014b) to answer the challenge posed by Scheer (2010), that the contrastive hierarchy "is irrelevant should it turn out that unary primes are the correct approach to melodic representations." I argued there that contrastive hierarchies are relevant to representations made up of unary primes, as instantiated, for example, in Element Theory. Further, I proposed that Element Theory itself inherently relies on contrastive considerations—and hence, on contrastive hierarchies—to a greater extent than is often recognized. In this section I review some of those arguments.

With respect to the relevance of contrastive hierarchies, there have been a number of proposals to apply them to unary elements, so this is not a hypothetical possibility. One such is Carvalho (2011). As he points out, "the fundamental idea" of Contrastive Hierarchy Theory is that "infrasegmental structure […] reflects the way features combine and behave in a given language", uniting both representation and computation. Voeltzel and Tifrit (2013) and Voeltzel (2016) apply the hierarchical concept to representations of Scandinavian languages based on Element Theory. Voeltzel (2016) shows that an element-based hierarchy will not necessarily be a simple translation of a feature-based one; nevertheless, I would argue that it should follow the same basic principles of contrast and hierarchy. Van der Hulst (2018) has an extensive discussion illustrating how the Successive Division Algorithm can be applied to the elements of Radical CV Phonology (van der Hulst 1995, 1996, 2005, 2020).

While different versions of Element Theory may have different approaches to the role of contrast, I have proposed that most unary representational systems are based on contrast. I say this even if it may not be stated explicitly, and even if contrastive considerations are not always applied consistently. Consider the analysis of three-vowel systems by Backley (2011: 19). He observes that the vowels of both Tamazight (Berber, Northern Africa) in (18a) and Amuesha (Arawakan, Peru) in (18b) have the representations |I|, |U|, and |A|, despite their phonetic differences.

(1995) and Frigeni (2002) have proposed analyses of such cases that involve separate contrastive hierarchies for the desinential domain. There, different hierarchies are posited underlyingly, not just at the surface.

(18) Three-vowel systems (Backley 2011)

a. Tamazight

[i]	[u]	[a]
|I|	|U|	|A|

b. Amuesha

[e]	[o]	[ɐ]
|I|	|U|	|A|

Why are Amuesha [e] and [o] not represented as combinations of |I A| and |U A|, respectively, like [e] and [o] in the five-vowel systems shown in (12) above? Presumably, it is because they are not in contrast with other vowels that are represented |I| and |U|, and further, because they do not behave as if they have complex representations. As Backley (2011: 19) remarks, "the vowels […] are tokens of abstract phonological categories, and languages differ in the way they choose to phonetically interpret these categories." That is, it is phonological behaviour and contrast that govern the representations, in addition to phonetics.

In the case of Wapishana (Arawakan, Guyana and Brazil) in (19a), Backley (2011: 31) proposes that [ə] is an unspecified vowel. One reason is that its spectral pattern is different from the patterns typically associated with the basic elements |I|, |U|, and |A|. Again, though, phonetics is not the whole story. For English weak vowels, for example, Backley (2011: 50) proposes the assignments in (19b). Here, [ə] is assigned the element |A|, unlike in Wapishana, and another vowel, [ɨ], is the empty vowel. Which vowels are empty depends on how they behave. Notice also that the Wapishana and English vowel representations are minimally contrastive.

(19) Four-vowel systems (Backley 2011)

a. Wapishana

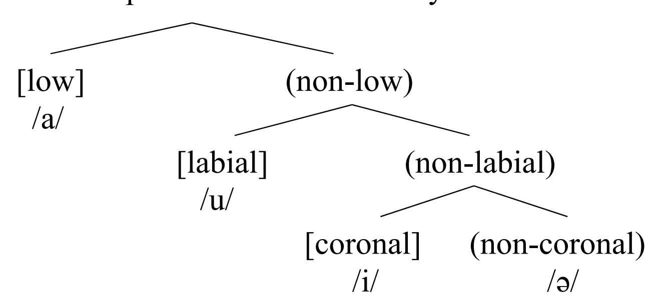
[i]	[u]	[a]	[ə]
|I|	|U|	|A|	| |

b. English weak vowels

[ɪ]	[ʊ]	[ə]	[ɨ]
|I|	|U|	|A|	| |

In fact, the Wapishana vowel inventory is very similar to that of Proto-Eskimo, the ancestor of the Inuit-Yupik languages. Proto-Eskimo is commonly reconstructed to have the vowels */i/, */u/, */a/, and a fourth vowel assumed to be some sort of central vowel which I write schwa */ə/, following Fortescue, Jacobson, and Kaplan (1994). Compton and Dresher (2011) propose that the Inuit-Yupik contrastive hierarchy is [low] > [labial] > [coronal], as shown in (20a).

(20) a. Inuit-Yupik contrastive hierarchy: four-vowel inventory (Compton and Dresher 2011)



b. |A| |U| |I| | | Translation into elements

These asymmetric features are not far from a unary system. Indeed, they can easily be translated into elements as shown in (20b): [low] becomes |A|, [labial] becomes |U|, [coronal] becomes |I|, and the unmarked /ə/ becomes the empty element. In fact, exactly this tree and this ordering of elements is proposed for a four-vowel system by van der Hulst (2018).

Evidence for this type of representation for /ə/ comes from Yupik, which retains the four-vowel system. Though present in the inventory, schwa does not have the same status as the other vowels. According to Kaplan (1990:147), it "cannot occur long or in a cluster with another vowel"; instead, it undergoes dissimilation or assimilation when adjacent to full vowels. In other dialects underlying /ə/ has merged with /i/ at the surface, but can be distinguished from underlying /i/ by its distinct patterning. In the literature this vowel is known as "weak *i*", as opposed to the "strong *i*" that descends from Proto-Eskimo (P-E) *i. In Barrow Inupiaq (Kaplan 1981:119), weak *i* changes to [a] before another vowel, but strong *i* does not.

Original */i/ could cause palatalization of consonants, and some Inuit dialects show palatalization (or traces of former palatalization) (Dorais 2003: 33). In the word 'foot' in the North Baffin dialect (21a), *i* (from P-E *i) causes a following *t* to change to *s*. This assibilation is the most common manifestation of palatalization in Inuit dialects. Compare the retention of [t] after weak *i* (from P-E *ə) in 'palm of hand' (21b).

(21) Strong and weak *i* in North Baffin (Dorais 2003)

	Proto-Eskimo		North Baffin	
a. Strong *i*	*itəγaʁ	>	isiɣak	'foot'
b. Weak *i*	*ətəmaɣ	>	itimak	'palm of hand'

These examples support attributing a feature to /i/ that can cause palatalization: Compton and Dresher (2011) call it [coronal]. It is very similar to the role played by |I| in Element Theory. Compton and Dresher (2011) argue that there is evidence that the features [low] and [labial] are also phonologically active (participate in phonological processes).

For four-vowel dialects like the ones discussed above, then, Contrastive Hierarchy Theory and Element Theory are mostly in accord: each of /i/, /u/, and /a/ are represented by a single marked feature, and /ə/ is empty (in Element Theory) or completely unmarked (in Contrastive Hierarchy Theory). Now let us turn to three-vowel Inuit dialects.

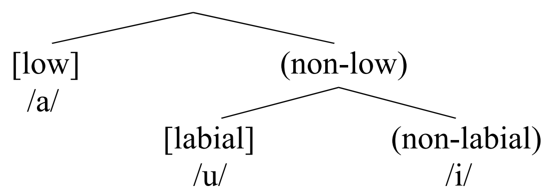
In many Inuit dialects the distinction between */i/ and */ə/ has been completely lost: these dialects have only three distinct vowels: /i/, /a/, and /u/. Dialects with palatalization or with signs of former palatalization occur across the Inuit region, as do dialects without palatalization. One might suppose that some dialects that once had palatalization would generalize it to occur after all /i/s, including original /i/ from *i and the new /i/ from *ə. But this is not the case. Compton and Dresher (2011) observe a generalization about palatalization in Inuit dialects (22):

(22) Palatalization in Inuit dialects (Compton and Dresher 2011)

> Inuit /i/ can cause palatalization (assibilation) of a consonant only in dialects where there is evidence for a (former) contrast with a fourth vowel; where there is no contrast between strong and weak *i*, /i/ does not trigger palatalization.

This generalization follows from the assumption that the feature hierarchy for Inuit and Yupik is [low] > [labial] > [coronal] as in (20). When the fourth vowel is in the underlying inventory, /i/ has a contrastive [coronal] feature that enables it to cause palatalization; but in the absence of a fourth vowel, [coronal] is not a contrastive feature, as shown in (23). By the Contrastivist Hypothesis, if a feature is not contrastive, it may not be active. Therefore, the restriction of a three-vowel inventory to two features, required by the Contrastivist Hypothesis and the Successive Division Algorithm, is supported by evidence from phonological patterning.

(23) Inuit-Yupik contrastive hierarchy: three-vowel inventory (Compton and Dresher 2011)



The result of our analysis is that the representation of an /i/ in a three-vowel dialect has no marked features; in this sense, it is closer to the representation of /ə/ in a four-vowel dialect than it is to that of /i/ in a four-vowel dialect, as we can see in (24), and even more clearly when we list only the marked features, as in (25).[8]

(24) Inuit-Yupik vowel systems

a. Four-vowel inventories

[a]	[u]	[i]	[ə]
[low]	[non-low, labial]	[non-low, non-labial, coronal]	[non-low, non-labial, non-coronal]

b. Three-vowel inventories

[a]	[u]	[i]
[low]	[non-low, labial]	[non-low, non-labial]

(25) Inuit-Yupik vowel systems (marked features only)

a. Four-vowel inventories

[a]	[u]	[i]	[ə]
[low]	[labial]	[coronal]	[ ]

b. Three-vowel inventories

[a]	[u]	[i]
[low]	[labial]	[ ]

In this light, let us return to Backley's (2011) analysis of three-vowel inventories in (18). He employs three elements, meaning that his analysis is not in accord with the Successive Division Algorithm and the Contrastivist Hypothesis. The prediction of the Successive Division Algorithm, as shown in detail for Element Theory by van der Hulst (2018), is that one vowel in every inventory should be empty. This prediction is supported in three-vowel Inuit dialects. We similarly expect one vowel in Tamazight and Amuesha (not necessarily the same one) to be empty; which one it is needs to be determined by investigating which elements are actually active in these languages.

Backley's analysis of three-vowel inventories does not comport with his practice in systems with four vowels, as in (19). It is also not consistent with his own statement (Backley 2011: 20) that "What counts in E[lement] T[heory] is the way a segment behaves, particularly in relation to natural classes and to other segments in the system. Its behaviour determines its phonological identity, and therefore, its element structure."[9]

---

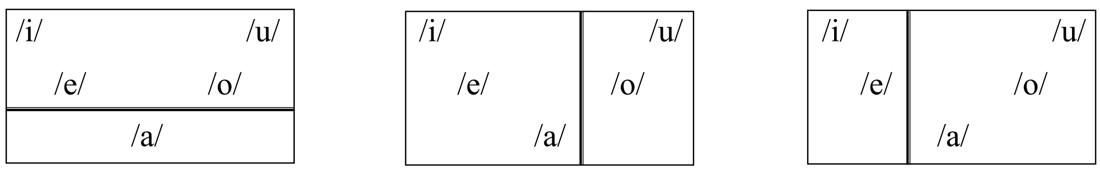
[8] Just to be clear, I assume that unmarked features appear in the representations and are visible to the phonology; I do not assume that features are privative. The point of listing only the marked features in (25) is to show more vividly the way in which [i] in a three-vowel system (25b) is like [ə] in a four-vowel system (25a).

[9] See also Cyran (2011), who proposes that two dialects of Polish have different phonological laryngeal systems despite having almost identical phonetic realizations. He argues that in Warsaw Polish voiced obstruents have an L-

7 Variability in contrastive hierarchies: Five-vowel systems

N. S. Trubetzkoy's *Grundzüge der Phonologie* (1939) (translated into French in 1949, into English in 1969, and into Spanish in a new edition in 2019) in some ways anticipated the theory of contrast I have been arguing for here. Trubetzkoy observes that in many five-vowel systems—he gives Latin as an example—the low vowel does not participate in tonality contrasts; "tonality" refers to backness or lip rounding, that is, properties that affect the second formant (F2). In the diagram in (26a), the low vowel /a/ is separated from the other vowels; in terms of contemporary distinctive features, we could say that the line draws the boundary of the feature [±low].

(26) Five-vowel systems with different contrastive structures (based on Trubetzkoy 1939)
a. Latin b. Archi c. Japanese

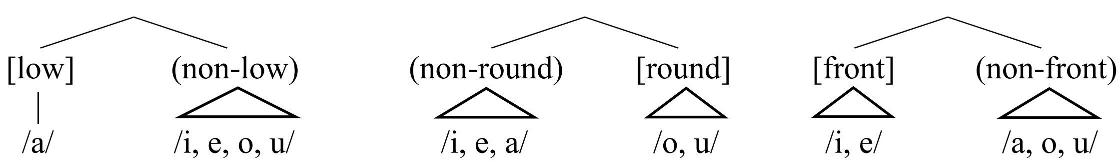


Trubetzkoy observes that other types of five-vowel systems exist. In Archi (East Caucasian), a language of Central Daghestan, a consonantal rounding contrast is neutralized before and after the rounded vowels /u/ and /o/. "As a result, these vowels are placed in opposition with […] unrounded *a*, *e*, and *i*. This means that all vowels are divided into rounded and unrounded vowels, while the back or front position of the tongue proves irrelevant" (Trubetzkoy 1969: 100–101). In (26b), the dividing line represents the boundary of [±round].

Trubetzkoy argues that neutralization of the opposition between palatalized and non-palatalized consonants before *i* and *e* in Japanese shows that these vowels are put into opposition with the other vowels /a, o, u/ (26c). The governing opposition is that between front and back vowels, "lip rounding being irrelevant" (Trubetzkoy 1969: 101).

Trubetzkoy's discussion of these vowel systems amounts to giving priority to a different contrast in each system: in terms of binary features, to [±low] in Latin, to [±round] in Archi, and to [±front] in Japanese. In other words, these features stand at the top of their respective hierarchies, which can be represented as the partial branching trees in (27). Trubetzkoy does not tell us the details of the other contrasts in each system; what the other two (or, more unusually, three) features are depends on the evidence from each language.

(27) Partial contrastive hierarchies for the vowel systems in (26)
a. Latin b. Archi c. Japanese



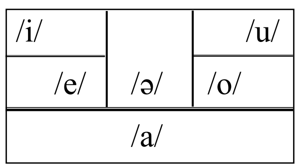
element and voiceless obstruents are unmarked; in Cracow Polish voiceless obstruents have an H-element and voiced obstruents are unmarked (and passively voiced). According to Cyran (2011: 77), "spectrograms are not telling us what type of system we are dealing with. They only provide the information on the phonetic side of the equation." The crucial evidence bearing on the phonological system comes, in our terms, from phonological activity—in this case, the sandhi phenomena in Polish—which show that Cracow Polish is an H-system and Warsaw Polish is an L-system.

Finally, Trubetzkoy considers systems with five vowels plus a central "indeterminate vowel", often written as /ə/. He writes that in the usual case, this vowel "does not stand in a bilateral opposition relation with any other phoneme of the vowel system", but is "characterized only negatively". If we follow the Latin pattern, /a/ is the only [low] vowel, and /i, e, o, u/ are distinguished by tonality contrasts; in terms of binary features, these are typically [±high], [±front], and one of [±back] or [±round]. /ə/ is thus (non-low, non-high, non-front, non-back/non-round), that is, "characterized only negatively". We can diagram these contrasts as in (28a).

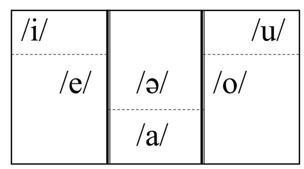
However, Trubetzkoy observes that in Bulgarian, the pairs /i, e/, /ə, a/, and /u, o/ neutralize in unstressed syllables. This suggests that the central vowel has a special relationship with /a/, as shown schematically in (28b), where pairs of vowels that neutralize are separated by a dashed line; see Spahr (2014) for a Contrastive Hierarchy Theory analysis of this system. I conclude that vowel systems show considerable variability in their contrastive feature hierarchies, as shown by their patterns of phonological activity.

(28) Systems with five-vowels plus one (based on Trubetzkoy 1939)

a. Common pattern



b. Bulgarian



In the next section we will see how gradual phonetic changes can eventually trigger a change in the contrastive hierarchy of a five-vowel system.

8 Contrastive hierarchies in diachronic phonology: Old English *i*-umlaut

The rule of *i*-umlaut began in early Germanic as a phonetic process that created fronted allophones of the back vowels when */i(ː)/ or */j/ followed (V. Kiparsky 1932; Twaddell 1938; Benediktsson 1967; Antonsen 1972; Penzl 1972). In the examples in (29), */u/ is fronted to [y] and /oː/ is fronted to [øː]:

(29) Examples of *i*-umlaut

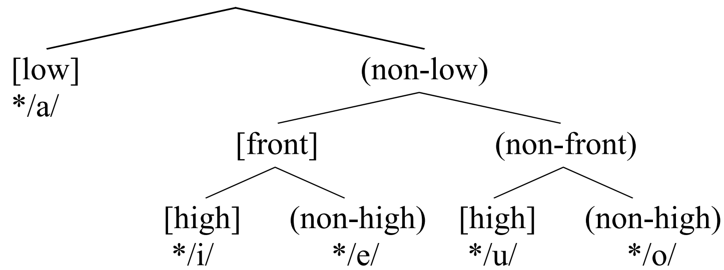
Gloss	'evil N.S.'	'foot N.P.'
Early Germanic	*ubil	*foːt+i
i-umlaut	*ybil	*føːt+i

At a certain time, the West Germanic vowel system had five short and five long vowels (Antonsen 1965; Ringe and Taylor 2014: 106). I will henceforth disregard the latter (see Dresher 2018 for discussion of the long vowels). Inspired by the analysis of Purnell and Raimy (2015), I have argued (Dresher 2018) that at this stage West Germanic had the vowel feature hierarchy [low] > [front] > [high], as in (30). The evidence for these specifications, following Antonsen (1972), is that */a/ could cause lowering of */i/ and */u/,[10] and */i/ ~ */e/ and */u/ ~ */o/ were distinguished by a single feature, [high]. Following Lass (1994), Ringe (2006: 148), and Purnell & Raimy

[10] The phoneme */o/ derives from a lowered allophone of Proto-Germanic */u/ (Twaddell 1948; Antonsen 1972)

(2015), I assume that the feature that distinguishes */i, e/ from */u/ is [front], because /i/ could cause fronting of back vowels.

(30) West Germanic feature hierarchy (Dresher 2018): [low] > [front] > [high]



Given our analysis of the West Germanic vowel system, the result of fronting */u, o/ in the contrastive phonology would be to change their (non-front) feature to [front]; this would simply make them identical to */i, e/. But *i*-umlaut crucially preserves the rounded nature of the fronted vowels. It is clear from (30) that the feature [round] is not contrastive at this stage. Therefore, the enhancement feature {round} must be in play at the point that */u, o/ are fronted, so that they become not merely [non-low, front], but also remain {round}, as shown in (31).

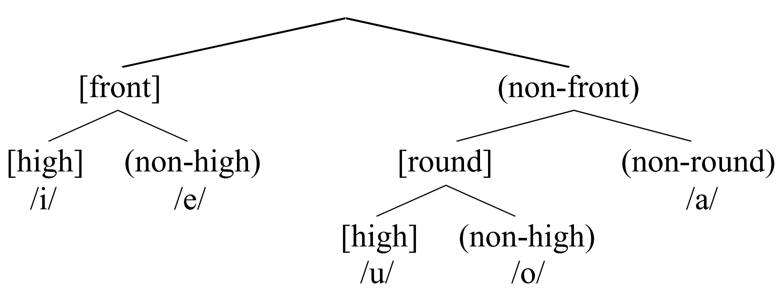
(31) *i*-umlaut must involve the enhancement feature {round}

*u	b	i	l	→	*y	b	i	l
(non-low)		(non-low)			(non-low)		(non-low)	
(non-front)		[front]			[front]		[front]	
[high]		[high]			[high]		[high]	
{round}		{non-round}			{round}		{non-round}	

This analysis is consistent with the assumption of many commentators, beginning with V. Kiparsky (1932) and Twaddell (1938), that *i*-umlaut began as a late phonetic rule and was not part of the contrastive (lexical) phonology. There is evidence, however, that *i*-umlaut became a lexical rule even while it was still creating fronted allophones of the vowels */u/ and */o/ (Liberman 1991; Fertig 1996; Janda 2003; see P. Kiparsky 2015 for discussion). How could this happen?

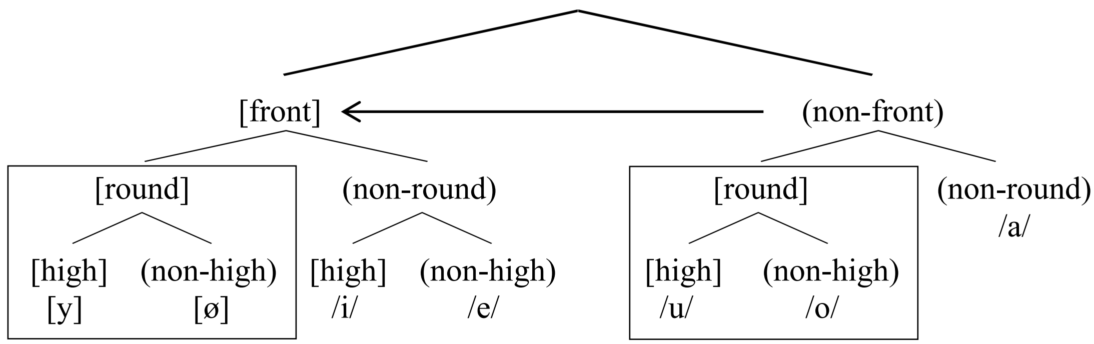
Recall that {round} is a non-contrastive enhancement feature in the West Germanic feature hierarchy in (30). However, another hierarchy can be constructed that includes [round] as a contrastive feature. This hierarchy requires demoting [low] to allow [round] to be contrastive over the non-front vowels. The new hierarchy, [front] > [round] > [high], yields the tree in (32).

(32) West Germanic feature hierarchy 2 (Dresher 2018): [front] > [round] > [high]



Now changing the (non-front), [round] vowels to [front] results in new front rounded vowels, which begin as allophones (33). They are thus what Moulton (2003) calls “deep allophones”: they can arise in the contrastive phonology because they consist only of contrastive features.

(33) Fronting of /u, o/ in West Germanic feature hierarchy 2



Notice that in the new feature hierarchy /a/ no longer has a [+low] feature. Unlike earlier */a/, I know of no evidence that this West Germanic /a/—as in Old English, for example—requires an active [low] feature. This kind of connection between contrast and activity is exactly what Contrastive Hierarchy Theory predicts.

9 Binary features versus elements

Before concluding, I would like to briefly consider what might appear to be the most significant difference between Contrastive Hierarchy Theory and Element Theory: namely, the fact that, at least in my version of it, the former utilizes binary features and the latter has privative (single-valued) elements.[11] Conceptually, contrastive specification with a binary feature [±F] can result in a ternary distinction between segments that are specified [F], segments specified (non-F), and segments not specified for F (0 F). In a privative feature system, there is only a binary distinction between [F] and nothing, thus conflating (non-F) with (0 F). One question, then, is whether we ever need to distinguish between these two.

As reviewed in Dresher (2014b), this distinction is relevant in the analysis of the co-occurrence restrictions discussed by Mackenzie (2009, 2011, 2013). For example, in Ngizim (Chadic), pulmonic (plain) obstruents must agree in voicing (34a), but implosives may co-occur with both voiceless and voiced obstruents, as illustrated in (34b).

(34) Ngizim voicing harmony (Mackenzie 2013: 301, citing Schuh 1997)

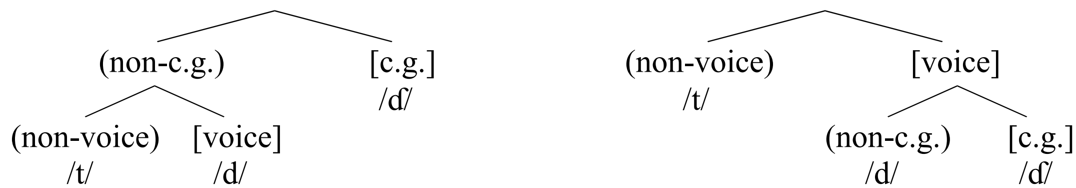
a. Pulmonic consonants			b. Pulmonic and implosive consonants	
gâːzá	‘chicken’	*k…z	kìːɗʉ́	‘eat (meat)’
dә́bâ	‘woven tray’	*t…b	fә́ɗʉ́	‘four’
kútә́r	‘tail’	*g…t	pәɗә́k	‘morning’
tásáu	‘find’	*d…s	dә̀ɓú	‘give water’

Mackenzie proposes that Ngizim obstruents are specified by two laryngeal features, [±voice] and [±constricted glottis] ([±c.g.]); the features are ordered [c.g.] > [voice], which results in

[11] I have discussed this issue in more detail in Dresher (2009: 32–34) and Dresher (2014b). I note again that there are versions of Contrastive Hierarchy Theory that do not assume binary features.

implosives being unspecified for [±voice], as shown in (35a). Given these representations, voicing harmony in Ngizim can be seen to require that obstruents may not have different values of [±voice]; obstruents unspecified for [±voice] do not participate in the harmony. On this analysis it is necessary to distinguish between (non-voice), which participates in harmony, and (0 voice), which does not.

(35) Three laryngeal classes (Mackenzie 2009, 2013)
a. Ngizim b. Hausa



A defender of single-valued features or elements could point out that it is possible to replicate an analysis that uses both values of a binary feature by adding another unary feature (see Dresher 2012 for a similar comparison between binary features and feature-geometric dependencies). For example, one could propose that a unary |voice| element is a dependent of some element like |pulmonic| which applies to /t, d/ but not /ɗ/. The unary representations would have to be flexible enough to accommodate the facts of Hausa (Newman 2000), another Chadic language in which voiced consonants must agree with respect to [±c.g.], but a voiceless pulmonic consonant can co-occur with an implosive. Mackenzie proposes that in Hausa the laryngeal features are ordered [voice] > [c.g.] as in (35b); now, harmony applies to obstruents with a specification for [±c.g.].

It is worth trying to discover under what conditions binary-feature analyses can be replicated with elements, and vice-versa, as a way of determining what the empirical differences between these theories really are. Depending on what other constraints are put on representations, the issue of one value versus two values may not turn out to be as significant as it might appear.

10 Conclusion

To sum up, many phonologists have had the intuition that the phonological systems of the world's languages use a limited set of primes, be they features or elements. I have argued that this is because Universal Grammar requires speakers to construct contrastive feature hierarchies, and these hierarchies limit the number of primes available to the phonology. It follows that feature hierarchies show considerable crosslinguistic variability. In this respect, Element Theory posits fewer primes than Contrastive Hierarchy Theory; if this position can be maintained, it would suggest that there are more constraints on possible features than those imposed by contrast.

I have also proposed that Contrastive Hierarchy Theory and Element Theory have in common that they take a middle course between phonetic determinism on one side and substance-free phonology on the other. In both theories, phonological primes are cognitive entities that form a bridge between the mental representations and operations of the phonological component and their external phonetic manifestations. Both theories (Element Theory a bit inconsistently) posit a connection between contrastive representations and phonological activity: as in the vowel systems of Inuit-Yupik and West Germanic, changes in one are associated with changes in the other.

References

Antonsen, Elmer H. 1965. On defining stages in prehistoric Germanic. *Language* 41. 19–36.

Antonsen, Elmer H. 1972. The Proto-Germanic syllabics (vowels). In Frans van Coetsem & Herbert L. Kufner (eds.), *Toward a grammar of Proto-Germanic*, 117–140. Tübingen: Max Niemeyer.

Avery, Peter & William J. Idsardi. 2001. Laryngeal dimensions, completion and enhancement. In T. Alan Hall (ed.), *Distinctive feature theory*, 41–70. Berlin-New York: Mouton de Gruyter.

Backley, Phillip. 2011. *An introduction to Element Theory*. Edinburgh: Edinburgh University Press.

Barbosa, Plínio A. & Eleonora Cavalcante Albano. 2004. Brazilian Portuguese. *Journal of the International Phonetics Association* 34. 227–232.

Benediktsson, Hreinn. 1967. The Proto-Germanic vowel system. In *To honor Roman Jakobson*, Vol. 1, 174–196. The Hague & Paris: Mouton.

Blaho, Sylvia. 2008. *The syntax of phonology: A radically substance-free approach.* Tromsø: University of Tromsø dissertation.

Bohn, Graziela. 2015. *Aquisição das vogais tônicas e pretônicas do Português Brasileiro.* São Paulo: University of São Paulo dissertation.

Bohn, Graziela Pigatto. 2017. The acquisition of tonic and pre-tonic vowels in Brazilian Portuguese. *Journal of Portuguese Linguistics* 16(7), 1–5. DOI: https://doi.org/10.5334/jpl.184

Bohn, Graziela Pigatto & Raquel Santana Santos. 2018. The acquisition of pre-tonic vowels in Brazilian Portuguese. *Alfa: Revista de Linguística* (São José do Rio Preto) 62(1). 191–221.

Carvalho, Joaquim Brandão de. 2011. Contrastive hierarchies, privative features, and Portuguese vowels. *Linguística : Revista de Estudos Linguísticos da Universidade do Porto* 6. 51–66.

Cherry, E. Colin, Morris Halle & Roman Jakobson. 1953. Toward the logical description of languages in their phonemic aspect. *Language* 29. 34–46.

Chomsky, Noam & Morris Halle. 1968. *The sound pattern of English*. New York, NY: Harper & Row.

Clements, G. N. 2001. Representational economy in constraint-based phonology. In T. Alan Hall, (ed.), *Distinctive feature theory*, 71–146. Berlin: Mouton de Gruyter.

Clements, G. N. 2003. Feature economy in sound systems. *Phonology* 20. 287–333.

Clements, G. N. 2009. The role of features in speech sound inventories. In Eric Raimy & Charles E. Cairns (eds.), *Contemporary views on architecture and representations in phonological theory*, 19–68. Cambridge, MA: MIT Press.

Clements, G. N. & Rachid Ridouane (eds.). 2011. *Where do features come from? Cognitive, physical and developmental bases of distinctive speech categories.* Amsterdam: John Benjamins.

Compton, Richard & B. Elan Dresher. 2011. Palatalization and "strong *i*" across Inuit dialects. *Canadian Journal of Linguistics/ Revue canadienne de linguistique* 56. 203–228.

Cyran, Eugeniusz. 2011. Laryngeal realism and laryngeal relativism: Two voicing systems in Polish? *Studies in Polish Linguistics* 6.45–80.

Dinnsen, Daniel A. 1992. Variation in developing and fully developed phonetic inventories. In Charles A. Ferguson, Lisa Menn & Carol Stoel-Gammon (eds.), *Phonological development: Models, research, implications*, 191–210. Timonium, MD: York Press.

Dinnsen, Daniel A. 1996. Context-sensitive underspecification and the acquisition of phonetic contrasts. *Journal of Child Language* 23. 31–55.

Dinnsen, Daniel A., Steven B. Chin, Mary Elbert & Thomas W. Powell. 1990. Some constraints on functionally disordered phonologies: Phonetic inventories and phonotactics. *Journal of Speech and Hearing Research* 33. 28–37.

Dorais, Louis-Jacques. 2003. *Inuit uqausiqatigiit: Inuit languages and dialects (second, revised edition)*. Iqaluit: Nunavut Arctic College.

Dresher, B. Elan. 1998a. Child phonology, learnability, and phonological theory. In Tej Bhatia & William C. Ritchie (eds.), *Handbook of language acquisition*, 299–346. New York: Academic Press.

Dresher, B. Elan. 1998b. On contrast and redundancy. Presented at the annual meeting of the Canadian Linguistic Association, Ottawa. Ms., University of Toronto.

Dresher, B. Elan. 2003. Contrast and asymmetries in inventories. In Anna-Maria di Sciullo (ed.), *Asymmetry in grammar, volume 2: Morphology, phonology, acquisition*, 239–257. Amsterdam: John Benjamins.

Dresher, B. Elan. 2009. *The contrastive hierarchy in phonology*. Cambridge: Cambridge University Press.

Dresher, B. Elan. 2012. Is harmony limited to contrastive features? In A. McKillen & J. Loughran, eds., *Proceedings from Phonology in the 21st Century: In Honour of Glyne Piggott. McGill Working Papers in Linguistics* 22.1, 16 pages. https://secureweb.mcgill.ca/mcgwpl/sites/ mcgill.ca.mcgwpl/files/elan_mcgwpl_paper_edit_0.pdf

Dresher, B. Elan. 2014a. The arch not the stones: Universal feature theory without universal features. *Nordlyd* 41 (2). 165–181.

Dresher, B. Elan. 2014b. Contrastive hierarchies in Element Theory. Presented at the Conference on Theoretical Issues in Contemporary Phonology: Reading Tobias Scheer, École des Hautes Études en Sciences Sociales (EHESS), Paris, February 2014. Posted at https://sites.google.com/site/rtsfrench/.

Dresher, B. Elan. 2015. The motivation for contrastive feature hierarchies in phonology. *Linguistic Variation* 15. 1–40.

Dresher, B. Elan. 2016. Contrast in phonology 1867–1967: History and development. *Annual Review of Linguistics* 2. 53–73.

Dresher, B. Elan. 2018. Contrastive feature hierarchies in Old English diachronic phonology. *Transactions of the Philological Society* 116 (1). 1–29.

Dresher, B. Elan, Glyne L. Piggott & Keren Rice. 1994. Contrast in phonology: Overview. *Toronto Working Papers in Linguistics* 13.1. iii-xvii.

Dresher, B. Elan & Keren Rice. 2007. Markedness and the contrastive hierarchy in phonology. http://homes.chass. utoronto.ca/~contrast/.

Dyck, Carrie. 1995. *Constraining the phonology-phonetics interface, with exemplification from Spanish and Italian dialects.* Toronto, ON: University of Toronto dissertation.

Fertig, David. 1996. Phonology, orthography, and the umlaut puzzle. In Rosina L. Lippi-Green & Joseph C. Salmons (eds.), *Germanic linguistics: Syntactic and diachronic*, 169–184. Amsterdam/Philadelphia: John Benjamins.

Fikkert, Paula. 1994. *On the acquisition of prosodic structure (HIL Dissertations 6)*. Dordrecht: ICG Printing.

Flemming, Edward S. 2002. *Auditory representations in phonology*. New York, NY: Routledge.

Fortescue, Michael, Steven A. Jacobson & Lawrence D. Kaplan. 1994. *Comparative Eskimo dictionary with Aleut cognates*. Fairbanks: Alaska Native Language Center.

Frigeni, Chiara. 2002. Metaphony in Campidanian Sardinian: A domain-based analysis. *Toronto Working Papers in Linguistics (Special Issue on Contrast in Phonology)* 20. 63–91.

Fudge, Erik C. 1967. The nature of phonological primes. *Journal of Linguistics* 3. 1–36.

Groot, A. W. de. 1931. Phonologie und Phonetik als Funktionswissenschaften. *Travaux du Cercle Linguistique de Prague* 4. 116–147.

Hale, Mark & Charles Reiss. 2000. “Substance abuse” and “dysfunctionalism”: Current trends in phonology. *Linguistic Inquiry* 31. 157–169.

Hale, Mark & Charles Reiss. 2008. *The phonological enterprise*. Oxford: Oxford University Press.

Hall, Daniel Currie. 2007. *The role and representation of contrast in phonological theory.* Toronto, ON: University of Toronto dissertation.

Hall, Daniel Currie. 2011. Phonological contrast and its phonetic enhancement: Dispersedness without dispersion. *Phonology* 28. 1–54.

Hall, Daniel Currie. 2014. On substance in phonology. *Actes du congrès annuel de l’Association canadienne de linguistique 2014/Proceedings of the 2014 annual conference of the Canadian Linguistic Association.* Posted at http://cla-acl.ca/actes-2014-proceedings/.

Halle, Morris. 1959. *The sound pattern of Russian: A linguistic and acoustical investigation*. The Hague: Mouton. Second printing, 1971.

Harms, Robert T. 1968. *Introduction to phonological theory*. Englewood Cliffs, NJ: Prentice-Hall.

Hayes, Bruce, Robert Kirchner & Donca Steriade (eds.). 2004. Phonetically based phonology. Cambridge: Cambridge University Press.

Heffner, Christopher C., William J. Idsardi & Rochelle S. Newman. 2019. Constraints on learning disjunctive, unidimensional auditory and phonetic categories. *Attention, Perception, & Psychophysics* 81. 958–980. https://doi.org/10.3758/s13414-019-01683-x

Hulst, Harry van der. 1993. Units in the analysis of signs. *Phonology* 10. 209–241.

Hulst, Harry van der. 1995. Radical CV phonology: the categorial gesture. In Jacques Durand & Francis Katamba (eds.), *Frontiers of phonology*, 80–116. Essex: Longman.

Hulst, Harry van der. 1996. Radical CV phonology: the segment-syllable connection. In Jacques Durand & Bernard Laks (eds.), *Current trends in phonology: Models and methods*, 333–361. Salford: ESRI.

Hulst, Harry van der. 2005. The molecular structure of phonological segments. In Philip Carr, Jacques Durand & Colin J. Ewen (eds.), *Headhood, elements, specification and contrastivity: Phonological papers in honour of John Anderson*, 193–234. Amsterdam: John Benjamins.

Hulst, Harry van der. 2018. *Asymmetries in vowel harmony – A representational account*. Oxford: Oxford University Press.

Hulst, Harry van der. 2020. *Principles of Radical CV Phonology: A theory of segmental and syllabic structure*. Edinburgh: Edinburgh University Press.

Hyman, Larry M. 2011. Do tones have features? In John A. Goldsmith, Elizabeth Hume & W. Leo Wetzels (eds.), *Tones and features*, 50–80. Berlin: Mouton De Gruyter.

Ingram, David. 1988. Jakobson revisited: Some evidence from the acquisition of Polish phonology. *Lingua* 75. 55–82.

Ingram, David. 1989. *First language acquisition: Method, description and explanation*. Cambridge: Cambridge University Press.

Jakobson, Roman. [1931] 1962. Phonemic notes on Standard Slovak. In *Selected writings I. Phonological studies*, 221–230. The Hague: Mouton (1962). [In Czech in Slovenská miscellanea (Studies presented to Albert Pražak). Bratislava, 1931.]

Jakobson, Roman. 1941. *Kindersprache, Aphasie, und allgemeine Lautgesetze*. Uppsala: Uppsala Universitets Arsskrift.
Jakobson, Roman. 1968. *Child language, aphasia, and phonological universals*, translated from German by A. R. Keiler. The Hague: Mouton, 1968.
Jakobson, Roman. 1969. *Langage enfantin et aphasie*, translated from English and German by Jean-Paul Boons & Radmila Zygouris. Paris: Les Éditions de Minuit.
Jakobson, Roman, C. Gunnar M. Fant & Morris Halle. 1952. *Preliminaries to speech analysis.* MIT Acoustics Laboratory, Technical Report, No. 13. Reissued by MIT Press, Cambridge, Mass., Eleventh Printing, 1976.
Jakobson, Roman & Morris Halle. 1956. *Fundamentals of language.* The Hague: Mouton.
Jakobson, Roman & John Lotz. 1949. Notes on the French phonemic pattern. *Word* 5. 151–158.
Janda, Richard D. 2003. "Phonologization" as the start of dephoneticization – or, on sound change and its aftermath: Of extension, generalization, lexicalization, and morphologization. In Brian D. Joseph & Richard D. Janda, (eds.), *The handbook of historical linguistics*, 401–422. Oxford: Blackwell.
Kaplan, Lawrence D. 1981. *Phonological issues in North Alaskan Inupiaq*. Fairbanks: Alaska Native Language Center.
Kaplan, Lawrence D. 1990. The language of the Alaskan Inuit. In Dirmid R.F. Collis (ed.), *Arctic languages: An awakening*, 131–158. Paris: UNESCO.
Kaye, Jonathan, Jean Lowenstamm & Jean-Roger Vergnaud. 1985. The internal structure of phonological elements: a theory of charm and government. *Phonology Yearbook* 2. 305–328.
Kaye, Jonathan & Markus A. Pöchtrager. 2013. GP 2.0. *SOAS Working Papers in Linguistics* 16. 52–64.
Keyser, Samuel Jay & Kenneth N. Stevens. 2001. Enhancement revisited. In Michael J. Kenstowicz (ed.), *Ken Hale: A life in language*, 271–291. Cambridge, Mass.: MIT Press.
Keyser, Samuel Jay & Kenneth N. Stevens. 2006. Enhancement and overlap in the speech chain. *Language* 82. 33–63.
Kiparsky, Paul. 2015. Phonologization. In Patrick Honeybone & Joseph Salmons (eds.), *The handbook of historical phonology*, 563–579. Oxford: Oxford University Press.
Kiparsky, Valentin. 1932. Johdatusta fonologiaan. *Virittäjä* 36. 230–250.
Ko, Seongyeon. 2010. A contrastivist view on the evolution of the Korean vowel system. In Hiroki Maezawa & Azusa Yokogoshi (eds.), *MITWPL 61: Proceedings of the Sixth Workshop on Altaic Formal Linguistics*, 181—196.
Ko, Seongyeon. 2012. *Tongue root harmony and vowel contrast in Northeast Asian languages.* Ithaca, NY: Cornell University dissertation. [Published 2018, Wiesbaden: Harrassowitz Verlag.]
Lass, Roger. 1994. *Old English: A historical linguistic companion*. Cambridge: Cambridge University Press.
Levelt, Clara C. 1989. An essay on child phonology. M.A. thesis, Leiden University.
Liberman, Anatoly. 1991. Phonologization in Germanic: Umlauts and vowel shifts. In Elmer H. Antonsen & Hans Henrich Hock (eds.), *Stæfcræft: Studies in Germanic Linguistics*, 125–137. Amsterdam: John Benjamins.
Liljencrants, Johan & Björn Lindblom. 1972. Numerical simulation of vowel quality systems: The role of perceptual contrast. *Language* 48. 839–862.
Lindblom, Björn. 1986. Phonetic universals in vowel systems. In John J. Ohala & Jeri J. Jaeger (eds.), *Experimental phonology*, 13–44. New York: Academic Press.

Lindblom, Björn, Randy Diehl, Sang-Hoon Park & Giampiero Salvi. 2011. Sound systems are shaped by their users: The recombination of phonetic substance. In Clements & Ridouane, 67–97.

Mackenzie, Sara. 2009. *Contrast and similarity in consonant harmony processes.* Toronto, ON: University of Toronto dissertation.

Mackenzie, Sara. 2011. Contrast and the evaluation of similarity: Evidence from consonant harmony. *Lingua* 121. 1401–1423.

Mackenzie, Sara. 2013. Laryngeal co-occurrence restrictions in Aymara: Contrastive representations and constraint interaction. *Phonology* 30. 297–345.

Mackie, Scott & Jeff Mielke. 2011. Feature economy in natural, random, and synthetic inventories. In Clements & Ridouane, 43–63.

Martinet, Andre (1955). *Économie des changements phonétiques*. Berne: Francke.

Mesgarani, Nima, Stephen V. David, Jonathan B. Fritz & Shihab A. Shamma. 2008. Phoneme representation and classification in primary auditory cortex. *Journal of the Acoustical Society of America* 123. 899–909.

Mielke, Jeff. 2008. *The emergence of distinctive features*. Oxford: Oxford University Press.

Moulton, Keir. 2003. Deep allophones in the Old English laryngeal system. *Toronto Working Papers in Linguistics* 20. 157–173.

Nevins, Andrew. 2012. Vowel lenition and fortition in Brazilian Portuguese. *Letras de Hoje*, Porto Alegre 47 (3). 228–233.

Newman, Paul. 2000. *The Hausa language: An encyclopedic reference grammar*. New Haven: Yale University Press.

Odden, David. 2006. Phonology ex nihilo. Presented at the Phonology Get-Together, Universitetet i Tromsø, December 2006. Handout available online at http://www.ling.ohio-state.edu/~odden/Phonology_ex_Nihilo.pdf.

Ohala, John J. 1980. Introduction to the symposium on phonetic universals in phonological systems and their explanation. In *Proceedings of the 9th International Congress of Phonetic Sciences*. Vol. 3, 181–185. University of Copenhagen: Institute of Phonetics.

Oxford, Will. 2015. Patterns of contrast in phonological change: Evidence from Algonquian vowel systems. *Language* 91. 308–357.

Penzl, Herbert. 1972. Methods of comparative Germanic linguistics. In Frans van Coetsem & Herbert L. Kufner (eds.), *Toward a grammar of Proto-Germanic*, 1–43. Tübingen: Max Niemeyer.

Pöchtrager, Markus A. 2006. *The structure of length.* Vienna: University of Vienna dissertation.

Pöchtrager, Markus A. 2016. Vowel reduction: Sawing off the branch you're sitting on. Séminaire P3, Laboratoire de Linguistique de Nantes, Juin 2016.

Purnell, Thomas & Eric Raimy. 2015. Distinctive features, levels of representation and historical phonology. In Patrick Honeybone & Joseph Salmons (eds.), *The handbook of historical phonology*, 522–544. Oxford: Oxford University Press.

Pye, Clifton, David Ingram & Helen List. 1987. A comparison of initial consonant acquisition in English and Quiché. In Keith E. Nelson & Ann Van Kleeck (eds.), *Children's language (vol. 6)*, 175–190. Hillsdale, NJ: Erlbaum.

Reiss, Charles. 2017. Substance-free phonology. In S. J. Hannahs & Anna Bosch (eds.), *The Routledge handbook of phonological theory*, 425–452. New York, NY: Routledge.

Rice, Keren. 2003. Featural markedness in phonology: Variation. In Lisa Cheng & Rint Sybesma (eds.), *The second Glot International state-of-the-article book: The latest in linguistics*, 387–427. Berlin: Mouton de Gruyter.

Rice, Keren. 2007. Markedness in phonology. In Paul de Lacy (ed.), *The Cambridge handbook of phonology*, 79–97. Cambridge: Cambridge University Press.

Ringe, Donald. 2006. *A history of English: From Proto-Indo-European to Proto-Germanic (A linguistic history of English, Vol. 1)*. Oxford: Oxford University Press. Oxford Scholarship Online (www.oxfordscholarship.com).

Ringe, Donald & Ann Taylor. 2014. *The development of Old English (A linguistic history of English, Vol. 2).* Oxford: Oxford University Press.

Samuels, Bridget D. 2011. *Phonological architecture : A biolinguistic perspective*. Oxford: Oxford University Press.

Sandler, Wendy. 1993. Sign language and modularity. *Lingua* 89. 315–351.

Sapir, Edward. 1925. Sound patterns in language. *Language* 1. 37–51.

Scheer, Tobias. 2010. How to marry (structuralist) contrast and (generative) processing (review of Dresher 2009). *Lingua* 120 (10). 2522–2534.

Schuh, Russell G. 1997. Changes in obstruent voicing in Bade/Ngizim. Ms., University of California, Los Angeles.

Spahr, Christopher. 2012. Positional neutralization in the Contrastive Hierarchy: The case of phonological vowel reduction. Ms., University of Toronto, available at http://individual.utoronto.ca/spahr/.

Spahr, Christopher. 2014. A contrastive hierarchical account of positional neutralization. *The Linguistic Review* 31 (3–4). 551–585.

Steriade, Donca. 2001. Directional asymmetries in place assimilation: A perceptual account. In Elizabeth V. Hume & Keith Johnson (eds.), *The role of speech perception in phonology*, 219–250. San Diego, CA: Academic Press.

Stevens, Kenneth N. & Samuel Jay Keyser. 1989. Primary features and their enhancement in consonants. *Language* 65. 81–106.

Stevens, Kenneth N., Samuel Jay Keyser & Haruko Kawasaki. 1986. Toward a phonetic and phonological theory of redundant features. In Joseph S. Perkell & Dennis H. Klatt (eds.), *Symposium on invariance and variability of speech processes*, 432–469. Hillsdale, NJ: Lawrence Erlbaum.

Trubetzkoy, N. S. 1939. *Grundzüge der Phonologie*. Göttingen: Vandenhoek & Ruprecht.

Trubetzkoy, N. S. 1949. *Principes de phonologie,* translated from German by J. Cantineau. Paris: Klincksieck.

Trubetzkoy, N. S. 1969. *Principles of phonology*, translated from German by Christiane A. M. Baltaxe. Berkeley: University of California Press.

Trubetzkoy, N. S. 2019. *Principios de fonología*. New translation and critical edition by Esther Herrera Zendeyas & Michael Herbert Knapp. Mexico City: El Colegio de México, Centro de Estudios Lingüísticos y Literarios.

Twaddell, W. Freeman. 1938. A note on OHG umlaut. *Monatshefte für deutschen Unterricht* 30. 177–181.

Twaddell, W. Freeman. 1948. The prehistoric Germanic short syllabics. *Language* 24(2). 139–151.

Voeltzel, Laurence. 2016. *Morphophonologie des langues scandinaves. Hiérarchie segmentale et complexité syllabique.* Nantes: Université de Nantes dissertation.

Voeltzel, Laurence & Ali Tifrit. 2013. From binary features to elements: The case of Scandinavian. Paper presented at Features in Phonology, Morphology, Syntax and Semantics: What are they? CASTL, University of Tromsø, Oct.-Nov. 2013.

Zhang, Xi. 1996. *Vowel systems of the Manchu-Tungus languages of China.* Toronto, ON: University of Toronto dissertation.

Živanović, Sašo & Markus A. Pöchtrager. 2010. GP 2, and Putonghua too. *Acta Linguistica Hungarica* 57 (4). 357–380.