

The arch not the stones: Universal feature theory without universal features

B. Elan Dresher
*University of Toronto**

Abstract

There is a growing consensus that phonological features are not innate, but rather emerge in the course of acquisition. If features are emergent, we need to explain why they are required at all, and what principles account for the way they function in the phonology. I propose that the learners' task is to arrive at a set of features that account for the contrasts and the phonological activity in their language. For the content of the features, learners use the available materials relevant to the modality (spoken or signed). Formally, contrasts are governed by an ordered feature hierarchy. The concept of a contrastive hierarchy is an innate part of Universal Grammar, and is the glue that binds phonological representations and makes them appear similar across languages. Examples from the Classical Manchu vowel system show the connection between contrast and phonological activity. I then consider the implications of this approach for the acquisition of phonological representations. The relationship between formal contrastive hierarchies and phonetic substance is illustrated with examples drawn from tone systems in Chinese dialects. Finally, I propose that the contrastive hierarchy has a recursive digital character, like other aspects of the narrow faculty of language.

In *Invisible Cities*, Italo Calvino (1974) imagines an exchange between Marco Polo and Kublai Khan. Marco Polo describes a bridge, stone by stone.

"But which is the stone that supports the bridge?" Kublai Khan asks.

"The bridge is not supported by one stone or another," Marco answers, "but by the line of the arch that they form."

Kublai Khan remains silent, reflecting. Then he adds: "Why do you speak to me of the stones? It is only the arch that matters to me."

Polo answers: "Without stones there is no arch."

1. Introduction

I will propose that the phonological component of the grammar computes features, but these features are not innate.* Rather, they are created by the learner as part of the acquisition of phonology. Further, Universal Grammar (UG) requires that these features be organized into contrastive feature hierarchies that reflect phonological activity and the contrasts in the lexical inventory.

This article is organized as follows: In section 2, I review the objections that have been raised against innate distinctive features, and introduce the notion of contrastive feature hierarchies. In §3, I present an extended example, based on the Classical Manchu vowel system, illustrating the relation between contrast and phonological activity. In §4, I consider the implications of this approach for the acquisition of phonological representations. Section 5 takes up the relationship between contrastive hierarchies and phonetic 'substance', with examples drawn from tonal organization in Chinese dialects. Section 6 concludes with a brief discussion of the place of phonology in the Faculty of Language.

* For discussions, ideas, and analyses I would like to thank Elizabeth Cowper, Daniel Currie Hall, Paula Fikkert, Ross Godfrey, Christopher Harvey, Ross Krekoski, Will Oxford, Keren Rice, Christopher Spahr, and Zhang Xi, and other members of the project on Markedness and the Contrastive Hierarchy in Phonology at the University of Toronto. I am also grateful to two anonymous reviewers for comments on an earlier draft.

2. Phonological features: What is universal?

There is a growing consensus that phonological features are not innate, but rather ‘emerge’ in the course of acquisition. Most of the papers in a recent volume titled *Where do phonological features come from?* (Clements & Ridouane 2011) take an emergentist position; none argue for innate features. Mielke (2008) and Samuels (2011) summarize the arguments against innate features (1).

- (1) *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.

If features are emergent, we need to explain why they are required at all, and what UG principles account for the way they function in the phonology. I propose that features arise because it is the learners’ task to arrive at a set of features that account for the contrasts in the lexical inventory (the phonemes) of their language. I further assume that the contrastive features of a language are the ones that are phonologically active in that language, in a sense I will define below. The connection between feature contrast and feature activity imposes constraints on the number of features that can be posited for a given phonological inventory, and to a large extent accounts for why phonological systems tend to look similar even without a set of innate features.

To implement contrast in an explicit theory, Dresher (1998b; 2003; 2009) borrows an idea from Jakobson and his collaborators (Jakobson, Fant & Halle 1952; Jakobson & Halle 1956) that contrastive features are assigned hierarchically (depicted as ‘branching trees’ in the literature of the 1950s and 1960s). I call it the *Successive Division Algorithm*, given informally in (2) (see Dresher 2009: 16–17 for a more procedurally explicit version of this algorithm).

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

For the Successive Division Algorithm to operate, features must be *ordered*. I assume that the ordering of features is language particular (3).¹

- (3) *Variability of feature ordering*
Contrastive feature hierarchies are language particular.

If contrastive hierarchies vary from language to language, we need strategies for figuring out what the contrastive features are. As a first approximation, I assume that phonology computes *only* contrastive features, in keeping with the *Contrastivist Hypothesis*, which Hall (2007) formulates as in (4).

- (4) *The Contrastivist Hypothesis (Hall 2007)*
The phonological component of a language L operates only on those features which are necessary to distinguish the phonemes of L from one another.

¹I thus depart from Jakobson & Halle (1956) and Clements (2001; 2009), who proposed that there is a universal feature ordering, perhaps with some limited variations (see Dresher to appear for discussion). In addition to empirical evidence against this, the notion of a universal order becomes less plausible if features are not innate. Nevertheless, even emergent features might show tendencies to be ordered in certain ways if, as Clements (2001; 2009) suggests, ordering is related to how ‘accessible’ or ‘robust’ (perceptually salient or otherwise apparent to the learner) features are.

According to (4), only contrastive features can be *phonologically active*, where feature activity is defined as in (5), which adapts a formulation by Clements (2001: 77).

(5) *Feature 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.

If the Contrastivist Hypothesis is correct, it follows as a corollary that if a feature is phonologically active, then it must be contrastive (6). This, then, is the basis of a heuristic for discovering contrastive features: look for phonologically active features, and hypothesize that they are contrastive in those segments in which they are active.

(6) *Corollary to the Contrastivist Hypothesis*

If a feature is phonologically active, then it must be contrastive.

One final assumption is that features are *binary*, and that every feature has a *marked* and *unmarked* value (7). I assume that markedness is language particular (Rice 2003; 2007) and accounts for asymmetries between the two values of a feature, where these exist. I will designate the marked value of a feature F as '[F]', and the unmarked value as '(non-F)'.

(7) *Assumption about phonological primes*

Features are binary; every feature has a marked value, designated '[F]', and an unmarked value designated '(non-F)'.

It is a working assumption that the phonological primes are binary features and not other sorts of entities, such as privative elements or dependency structures of various kinds. As long as these other types of representations are compatible with the contrastive hierarchy and related assumptions as outlined above, we can consider them to be variations of the theory presented here.²

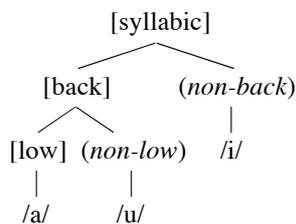
For the content of features (or whatever primes are assumed), I assume that learners make use of the available materials relevant to the modality: for spoken language, acoustic and articulatory properties of speech sounds; and for sign language, hand shapes and facial expressions.

On this view, the concept of a contrastive hierarchy is an innate part of UG, and is the glue that binds phonological representations and makes them appear similar from language to language.

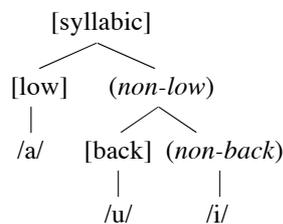
For example, if a language has three vowel phonemes /i, a, u/, and if the vowels are split off from the rest of the inventory so that they form a sub-inventory, then they must be assigned a contrastive hierarchy with two vowel features. Though the features and their ordering vary, the limit of two features constrains what the hierarchies can be. Two possible contrastive hierarchies using the features [back] and [low] are shown in (8).

(8) *Contrastive hierarchies for /i, a, u/ with [back] and [low]*

a. [back] > [low]



b. [low] > [back]



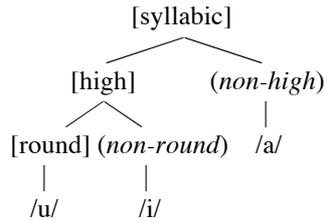
²This theory arises out of Modified Contrastive Specification (Dresher, Piggott & Rice 1994; Dresher & Rice 2007); see Dresher 2009: 163f. for a review.

UNIVERSAL FEATURE THEORY WITHOUT UNIVERSAL FEATURES

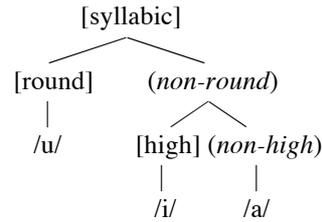
Here are two more hierarchies, using [high] and [round].

(9) *Contrastive hierarchies for /i, a, u/ with [high] and [round]*

a. [high] > [round]



b. [round] > [high]



The contrastive hierarchies in (8) and (9) constrain phonological activity. If only contrastive features can be phonologically active, it follows that both /a/ and /u/ can potentially trigger backing in (8a), only /u/ is a potential backing trigger in (8b), and no vowel is expected to trigger backing in (9). By the same token, the languages in (8) could have a lowering rule triggered by /a/, whereas the languages in (9) might have raising, triggered by both /u/ and /i/ in (9a), and by only /i/ in (9b). Spahr (2014) proposes that the intermediate nodes in contrastive trees can also be referred to by the phonology in ‘archiphonemic’ fashion. Thus, we might find that /a/ and /u/ in (8a) merge in vowel reduction, suspending the [low] contrast and deriving a vowel that is contrastively just [back]; whereas in (9b) vowel reduction might merge /i/ and /a/.

If the contrastive hierarchy governs phonological organization, we might also expect it to influence phonological change, as has been proposed by Harvey (2012), Ko (2012), Oxford (2015), and Drescher (to appear b). In particular, we might expect the hierarchy to constrain neutralization and merger, on the assumption that mergers affect phonemes that are contrastive sisters. In (8a), for example, we might expect /u/ to merge with /a/, whereas in (8b) and (9a) it is more likely to merge with /i/.

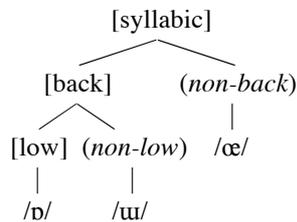
Typological generalizations can thus not be found by looking at inventories alone (say, /i, a, u/), or at individual phonemes (say, /a/), or phones ([a]), without also considering the relevant contrastive feature hierarchies.

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. Thus, the contrasts indicated by [back] and [low] may be cross-linguistically common because our auditory perception is sensitive to formant transitions. The same is true, it appears, of ferrets, who have been shown to have individual neurons that are sensitive to acoustic properties relevant to speech, including formant transitions (Mesgarani et al. 2008). But ferrets do not necessarily have our kind of phonological representations.

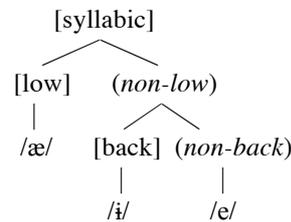
Notice also that, on this view, lexical specifications are limited to contrastive features, so are not pronounceable. In (8a), for example, the phoneme designated /u/ has only two features: [back] and (non-low). Why, then, is it designated /u/ and not /ʊ/, /ʌ/, /ɯ/, /ɨ/ or /o/, among other choices? As far as its contrastive status goes, any of these alternatives would be equally appropriate. We could indicate the phonemes as in (10), for example, though these symbols are typographically less convenient.

(10) *Underspecification of contrastive hierarchies for /i, a, u/*

a. [back] > [low]



b. [low] > [back]



Unless the vowels are further specified in the phonology by other contrastive features (originating in the consonants, for example), they are made more specific only in a post-phonological component. Stevens, Keyser & Kawasaki (1986) proposed that feature contrasts can be *enhanced* by other features that have similar acoustic effects.³ Hall (2011) shows how the enhancement of contrastive features can result in configurations predicted by Dispersion Theory (Liljencrants & Lindblom 1972; Lindblom 1986; Flemming 2002). Thus, a contrastively non-low back vowel can enhance its features by being round and high, that is, [u]. These enhancements are not necessary, however, and other realizations are possible.⁴

It is thus the contrastive hierarchy, not the features, that is native to UG, the thing that ‘matters’ to us (Kublai Khan, *op. cit.*). In the words of Jakobson, Fant & Halle (1952: 9): “The dichotomous scale is the pivotal principle of the linguistic structure. The code imposes it upon the sound”. But just as there is no arch without the stones that constitute it, there is no contrastive hierarchy without features.

3. The connection between contrast and activity

In this section I will illustrate the connection between contrast and phonological activity, taking as an extended example the Classical Manchu vowel system, following the analysis of Zhang (1996) and Drescher & Zhang (2005). Classical Manchu has six vowel phonemes, as shown in (11).

(11) *Classical Manchu vowel system (Zhang 1996)*

/i/	/u/
	/ʊ/
/ə/	/ɔ/
/a/	

Even if there were innate universal features, there would be considerable ambiguity as to how they apply to this system. For example, where is the boundary between the low vowel(s) and the non-low vowels? How many heights should we distinguish: two, three, five?⁵ For further insight, we need to look at how the vowels pattern, that is, at the types of phonological activity they exhibit.

The three most notable kinds of phonological activity involving vowels are ATR harmony, labial (rounding) harmony, and palatalization. I will briefly discuss each in turn.

3.1 ATR harmony

The vowels /ə/ and /u/ trigger ATR harmony within a word: in suffixes, /ə/ alternates with /a/ (12a) and /u/ alternates with /ʊ/ (12b).

(12) *ATR harmony: Stems with [ATR] vowels*

a. /ə/ alternates with /a/ in suffix

[ATR]	xəxə	‘woman’	xəxə-ŋgə	‘female’
	ujun	‘nine’	ujun-ŋgə	‘of nine’
(non-ATR)	aga	‘rain’	aga-ŋga	‘of rain’
	malχun	‘frugal’	malχu-ŋga	‘frugal’

³See also Stevens & Keyser 1989 and Keyser & Stevens 2001, 2006.

⁴See Dyck 1995 for a detailed study of the effects of enhancement and other processes on phonetic variation in the realization of vowels in Asturian and Montañés dialects.

⁵That is, even theories that posit innate universal features must allow for variability in how the features apply; there are no fixed phonetic boundaries that demarcate the range of features like [low], [high], or [back], for example.

UNIVERSAL FEATURE THEORY WITHOUT UNIVERSAL FEATURES

b. /u/ alternates with /ʊ/ in suffix

	[ATR]	xərə-	‘ladle out’		xərə-ku	‘ladle’
		səxəxun	‘vertical’		səxə-xuri	‘towering high’
	(non-ATR)	paqt’a-	‘contain’		paqt’a-qu	‘internal organs’
		laqtaχun	‘drooping’		laqta-χuri	‘fully drooping’

An apparent exception is caused by the fact that /ʊ/ changes to [u] everywhere except after dorsal (velar ~ uvular) consonants; however, the underlying contrast between /ʊ/ and /u/ emerges in the way they participate in ATR harmony (13).

(13) *ATR harmony and the neutralization of /u/ and /ʊ/*

a. *Underlying /u/: ATR harmony*

	[ATR]	susə	‘coarse’		susə-tə-	‘make coarsely’
	[ATR]	gulu	‘plain’		gulu-kən	‘somewhat plain’

b. *Underlying /ʊ/: non-ATR vowels*

	(non-ATR)	tulpa	‘careless’		tulpa-ta-	‘act carelessly’
	(non-ATR)	χutun	‘fast’		χutu-qan	‘somewhat fast’

The vowel /i/ is neutral and co-occurs with both ATR and non-ATR vowels (14).

(14) */i/ is neutral with respect to ATR harmony*

a. */ə/ ~ /a/ suffix*

	[ATR]	pəki	‘firm’		pəki-lə	‘make firm’
	(non-ATR)	paqtʃ’in	‘opponent’		paqtʃ’i-la-	‘oppose’

b. */u/ ~ /ʊ/ suffix*

	[ATR]	sitərə-	‘hobble’		sitərə-sxun	‘hobbled/lame’
	(non-ATR)	panjin	‘appearance’		panji-sχun	‘having money’

c. */i/ suffix*

	[ATR]	əmt’ə	‘one each’		əmt’ə-li	‘alone; sole’
	(non-ATR)	taχa-	‘follow’		taχa-li	‘the second’

When /i/ is in a position to trigger harmony, it occurs only with non-ATR vowels (15).

(15) *Stems with only /i/ co-occur with non-ATR vowels*

a. */ə/ ~ /a/ suffix*

	(non-ATR)	ili-	‘stand’		ili-χa	‘stood’
	(non-ATR)	fili	‘solid’		fili-qan	‘somewhat solid’

b. */u/ ~ /ʊ/ suffix*

	(non-ATR)	tʃ’ili-	‘to choke’		tʃ’ili-qu	‘choking’
	(non-ATR)	sifi-	‘stick in the hair’		sifi-qu	‘hairpin’

The evidence from activity, therefore, is that /ə/ and /u/ have an active feature in common that is not shared by the other vowels; by hypothesis, this feature must be contrastive. What feature could this be? I have already given away that it is [ATR]. But this is not obvious right away, because though /ə/ and /u/ are phonetically ATR (= {ATR}), so is /i/. But there is no obvious alternative, so we can designate the feature as [ATR]. The learner will have to find a feature ordering in which the feature applies to /ə/ and /u/, but not /i/.

3.2 Labial (rounding) harmony

Two successive /ɔ/ vowels cause a suffix /a/ to become /ɔ/ (16a); a single /ɔ/, short or long, does not trigger rounding (16b).

(16) *Labial (rounding) harmony*

a. *Two successive /ɔ/ vowels trigger labial harmony*

ᠵ...ᠵ	ᠮᠣᠲᠤᠰᠤᠨ	‘colour’	ᠮᠣᠲᠤᠰᠤᠨ-ᠬᠡᠭᠠ	‘coloured’
Compare	aga	‘rain’	aga-ᠬᠡᠭᠠ	‘of rain’

b. *A single /ɔ/, short or long, does not trigger rounding*

Single ᠵ	ᠲᠤ-	‘alight (birds)’	ᠲᠤ-na-	‘alight in swarm’
Single ᠵᠤ	ᠲᠤᠵ-	‘cross (river)’	ᠲᠤᠵ-na-	‘go to cross’

Note that /u/ and /ʊ/ do not trigger labial harmony (17).

(17) *No labial harmony triggered by high vowels*

a. *After /u/*

gulu	‘plain’	gulu-kən	‘somewhat plain’
kumun	‘music’	kumu-ᠬᠡᠭᠠ	‘noisy’

b. *After /ʊ/ (/ʊ/ becomes [u] except after a back consonant)*

χʊtun	‘fast’	χʊtu-qan	‘somewhat fast’
tursun	‘form’	tursu-ᠬᠡᠭᠠ	‘having form’

The evidence from activity here, then, is that /ɔ/ must have an active, therefore contrastive, feature that causes rounding. [labial] is an obvious candidate. But /u/ and /ʊ/ are also phonetically {labial}, though there is no evidence that they have an active [labial] feature. Here, the preferred analysis is one where contrastive [labial] is restricted to /ɔ/, and excludes /u/ and /ʊ/.

3.3 *Palatalization*

The vowel /i/ uniquely causes palatalization of a preceding consonant, which suggests that it alone has a contrastive triggering feature we call [coronal]. In this case /i/ is the only vowel that falls in the space of the phonetic percept {coronal}.

3.4 *Height contrast*

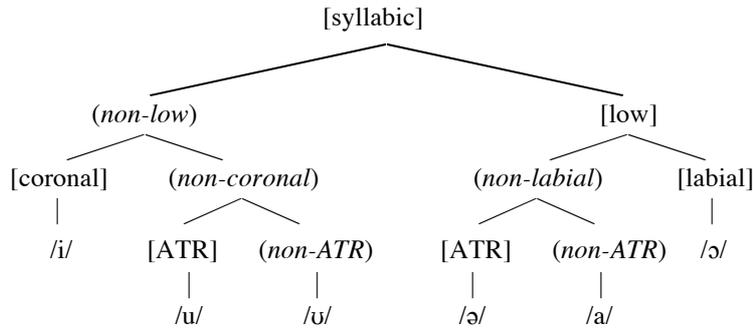
The alternations /ɔ/ ~ /a/ ~ /ɔ/ and /u/ ~ /ʊ/ are limited to a height class, and we still need to distinguish /ɔ/ from /u/ and /a/ from /ʊ/. It is simplest to assume one height contrast, which we call [low]. Since height is a relative property, it is not a problem to base the contrastive feature on a perceptible phonetic difference based on relative height or sonority. As there are only two height classes, [high] would also be possible here.⁶

3.5 *Contrastive feature hierarchy for Classical Manchu*

Putting together the evidence of phonological activity surveyed to here, we need to arrive at a feature hierarchy that yields the values identified above. Zhang (1996) proposes the hierarchy: [low] > [coronal] > [labial] > [ATR], illustrated by the tree in (18), and yielding the representations in (19). Though /i/ is phonetically {ATR}, it lacks a contrastive [ATR] feature, so does not participate in ATR harmony. Similarly, /u/ and /ʊ/ are phonetically {labial}, but lack a contrastive [labial] feature and do not participate in rounding harmony.

⁶Whether we label the height feature [low] or [high] reflects our sense as to which pole of the contrast is marked, as reflected in phonological processes. Other evidence bearing on this choice could come from the phonetic ranges of the two sets of vowels: we might expect the marked set to be more restricted than the unmarked set (Hall 2011). Though the evidence from Classical Manchu is not clear-cut, I follow Zhang (1995) in choosing [low]; nothing crucial with respect to the present discussion turns on this choice.

(18) *Contrastive hierarchy for Classical Manchu vowels*



(19) *Classical Manchu vowels: Contrastive featural representations*

/i/	/u/	/ʊ/	/ə/	/a/	/ɔ/
(non-low)	(non-low)	(non-low)	[low]	[low]	[low]
[coronal]	(non-coronal)	(non-coronal)	(non-labial)	(non-labial)	[labial]
	[ATR]	(non-ATR)	[ATR]	(non-ATR)	

4. The contrastive hierarchy and the acquisition of phonological representations

The phonological contrastive features that must be acquired are not identical to the acoustic percepts that can be detected in the signal by an early learner. We have already seen that the phonetic ranges of the acoustic percepts on which the Manchu features are based are not coextensive with the phonological representations of the vowels. Percepts are not *phonological representations*. The early learner can perceive and distinguish speech sounds, but has not yet identified any contrasts in the vowel system.

Assume that contrastive features are determined in order. Assuming that vowels are differentiated early from consonants, at the outset the learner posits one undifferentiated vowel phoneme /V/. At some point the learner discovers a contrast between a [low] vowel /A/ and a non-low vowel /I/ (the symbols are for convenience only). The non-low vowels split into a [coronal] vowel /i/ and a non-coronal vowel /U/. The low vowels split into a [labial] vowel /ɔ/ and a non-labial vowel /A/. [labial] has nothing to do in the non-low vowels, where [coronal] has arrived first. Finally, [ATR] makes the final set of contrasts. [ATR] cannot apply to the [coronal] vowel which is already uniquely specified. Nor can it apply to the unique [labial] vowel. At this point there are no further contrasts to find, and the hierarchy is complete.

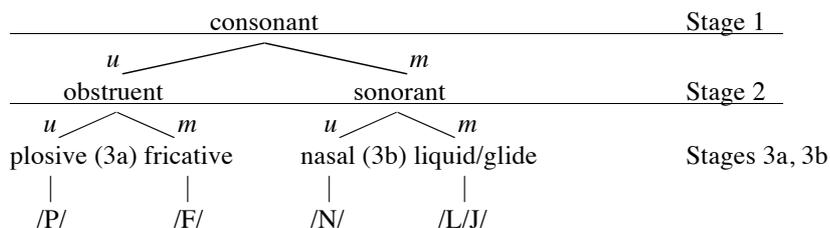
The preceding is a hypothetical sequence showing the order that contrasts in Manchu vowels would be acquired, if the order of acquisition mirrors the feature hierarchy of the adult system. This assumption may not be correct: we may have to allow for false starts and revisions, particularly at early stages, when learners presumably do not have all the relevant evidence concerning alternations and lexical representations. It might be best to consider the above acquisition sequence as being an idealization that abstracts away from various kinds of errors and misapprehensions.

Consider, for example, the first contrast in the vowel system, that between low and non-low vowels. How does the learner know to include [ə] with the low vowels rather than with the non-low vowels? Part of the answer must be that [ə] alternates with [a] as its ATR counterpart. This suggests that even at the first step in the idealized acquisition sequence there must be a certain amount of look-ahead that makes use of information about contrasts later on in the sequence.

The idea that stages of acquisition can be represented as contrastive feature hierarchies stems from Jakobson (1941), and is 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). In the formulation of Rice and Avery (1995), phonological representations are built into systems of increasing complexity, based on the input from phonetic perception together with evidence from the grammar, which itself becomes more complex and removed from the initial percepts.

Fikkert (1994) presents observed acquisition sequences in the development of Dutch onsets that follow this general scheme. At Stage 1 in (20) there are no contrasts. The value of the consonant defaults to the least marked onset, namely an obstruent plosive. At Stage 2, the first contrast is made, between obstruents and sonorants. The former remains the unmarked option (designated as *u*. The marked option (*m*), sonorant, defaults to nasal. Following this stage, children differ. Some expand the obstruent branch first, bringing in marked fricatives in contrast with plosives (Stage 3a). Others expand the sonorant branch, introducing marked sonorants, either liquids or glides (Stage 3b). Continuing in this way we will eventually have a tree that gives all and only the contrasting features in the language.

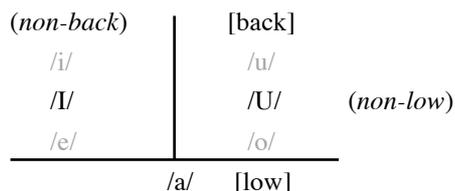
(20) *Development of Dutch onset consonants (Fikkert 1994)*



The scenario presented here has been criticized by Hale & Reiss (2008) and Samuels (2009). Hale & Reiss (2008: 39–42) argue that the “traditional model” set out by Rice & Avery (1995), and adopted here, cannot be accepted: “We believe that such a learning path is not possible given standard assumptions about the language faculty...Rice and Avery’s theory, and those like it, must be rejected as unparsimonious, incompatible with the generative program, and incapable of modeling a successful learning path.”

To illustrate their argument, imagine a five-vowel language /i, e, a, o, u/, and suppose that a learner has reached a stage that distinguishes only three vowels with the features shown in (21).

(21) *Acquiring a five-vowel language, only three vowels distinguished*



The learner has not yet made a distinction between /i/ ~ /e/ and /u/ ~ /o/; that is, the feature [high] has not yet been acquired. Thus, words like [pit] and [pet] are both represented /pIt/; for the child, the vowels in both have the identical representation (*non-low, non-back*). How do learners get to the five-vowel stage? Hale & Reiss (2008) argue that they can’t get there from here: “[A]ny vowel that the child is presented with must be parsed as one of the three, or else it will not be parsed at all... A representation can only be assigned using the available representational apparatus.” Thus, a learner that can distinguish [i] from [e] must already have access to the feature [high], contrary to what is assumed here.

One can answer that learners can discriminate sounds for which they have no phonological representations using their innate perceptual system, but Hale & Reiss do not accept this explanation, either. They argue that the grammar should not make use of two types of representation, “a phonological representation, which starts out with access to a minimal set of features, and a phonetic or acoustic representation, which makes use of fully specified phonetic feature matrices.” But I do not assume that what I have called ‘acoustic percepts’ are part of the grammar, or make use of feature matrices. Hale & Reiss, however, reject the notion that learners can make use of “raw acoustic images” that are outside the grammar. They assert that any discrimination of speech sounds must be in terms of innate phonological

UNIVERSAL FEATURE THEORY WITHOUT UNIVERSAL FEATURES

features. But recall the evidence that ferrets have neurons that can discriminate fine details of speech sounds. Presumably we have them, too, before and after we acquire phonological representations.

Hale & Reiss's view is that phonological representations begin as very detailed and become simpler in the course of acquisition. This theory requires that phonological features are innate, universal, and unambiguous, an untenable position. In support of their view, they cite evidence that infants begin by attending to many potential sources of contrasts, and are more able than adults to discriminate sounds not used in the ambient language (Eimas et al. 1971; Werker et al. 1981). That is, acquisition of the native language requires that learners 'tune' their perceptual system to the contrasts used in their language, while learning to disregard contrasts that are not used (Werker & Tees 1984; Kuhl et al. 1992).⁷ However, there is no evidence that this 'tuning' applies to phonological *representations*. The observations about infants apply to *phones*, not to phonemes. Learning to ignore sounds and distinctions that are not relevant to their native language is obviously helpful in eventually acquiring phonological features, but it is not the same process.

Counting against the notion that infants have phonological representations in place from the beginning are studies showing that they are unable to utilize fine phonetic differences in word recognition tasks (Stager & Werker 1997; Werker et al. 2002; Pater, Stager & Werker 2004). For example, the 14-month-old children studied by Stager & Werker (1997) could not distinguish minimally different nonce words such as *bin* and *din* in a word recognition task (when the 'words' were associated with objects), though they could distinguish them in a pure discrimination task. It follows that purely phonetic perception does not translate immediately into phonological representation.

In their review of the evidence, Cristià, Seidl & Francis (2011) propose that what underlies toddlers' ability to discriminate two sounds may not be the same units that enable them to use this contrast in a phonologically relevant manner. They side with the view that "features emerge over the course of language acquisition". More importantly, they distinguish between the acoustic and motor properties on which features may be based, and "the abstract mental representations, the *phonological* features" that the child has to construct.

Thus, studies of infant speech perception portray a learner going in two contrary directions simultaneously: the perceptual system is learning to ignore irrelevant contrasts, while phonological representations are becoming more complex. This picture is consistent with the view taken here.

In sum, the learning path proposed by Hale & Reiss (2008) is untenable because it requires an innate and universal set of features, and it further assumes that learners can immediately assign the correct featural representations to any surface sound they hear (that is, features must also be unambiguous). None of these prerequisites are met by phonological features, given the problems with assuming innate features, and the ambiguity of many features: How low qualifies as [low]? What height differences can be tolerated in segments of the same height? Where is the boundary between [back] and (*non-back*)?

It appears that there is no alternative but to suppose that learners must be able to perceive distinctions that are not yet encoded in their grammar. It follows that perception is not limited by the learner's current grammar. For that matter, adults are able to perceive unfamiliar phonetic distinctions in a foreign language if they focus on them. I conclude that Hale & Reiss's (2008) arguments against Rice & Avery (1995), and by implication the account presented here, do not go through, and that the alternative acquisition path they propose is not tenable. Thus there is no obstacle to adopting the 'traditional' view that phonological representations become more complex in the course of acquisition, and that learners acquire the contrasts of their language in stages. The contrastive hierarchy provides a way of connecting accounts in the acquisition literature of developing inventories with synchronic and diachronic phonology.

⁷There are also studies showing that certain phonetic contrasts are not as well-discriminated by infants as by adult native speakers (Aslin et al. 1981; Polka, Colantonio & Sundara 2001; see also Weiss & Maye 2008).

5. The contrastive hierarchy and phonetic ‘substance’

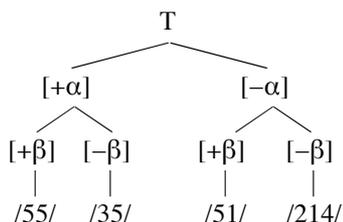
Krekoski (2013) constructs contrastive trees for the tone systems of a number of languages that descend from Middle Chinese. He bases the trees not on the phonetics of the tones, but on the patterns of activity they display in the form of tone sandhi. Thus, Beijing Mandarin has the four tones in (22), which participate in two robust sandhi rules (23). Rule (23a), also known as ‘third tone sandhi’, is obligatory, and states that a 214 tone becomes 35 before another 214. The rule in (23b) is optional, and states that a lexical 35 tone becomes 55 when it immediately follows either 35 or 55, and precedes any other tone.

- (22) *Beijing Mandarin tones*
- | | | | |
|---------|------------|----------|--------------|
| a. /55/ | high level | c. /214/ | low concave |
| b. /35/ | rising | d. /51/ | high falling |

- (23) *Beijing Mandarin tone sandhi*
- a. /214/ → 35/_____/214/
 b. /35/ → 55/{/35/, /55/}____T where (T = any tone)

Krekoski (2013) assumes that, where possible, tones related by a sandhi rule differ minimally, that is by only one feature.⁸ Thus, tone /35/ differs by one feature from /214/ and from /55/. A tree satisfying these constraints is given in (24). The labels [α] and [β] are placeholders for features which will be given a phonetic interpretation; similarly, + and – are placeholders indicating opposite values of a feature, and are not meant to indicate relative markedness.

- (24) *Beijing Mandarin contrastive hierarchy*



Pingyao is a Jin language with four underlying tones (25). Though two of them have merged at the surface, they can be distinguished by the way they participate in tonal alternations (Chen 2000). Krekoski identifies nine tone sandhi rules in Pingyao. Their inputs and outputs are summarized in (26); I omit the contexts of these sandhi rules, as well as alternations that are purely allotonic. When an input has more than one output, they are due to different rules with different contexts.

- (25) *Pingyao tones*
- | | | | |
|----------|------------|---------|--------------|
| a. /13a/ | low rising | c. /53/ | high falling |
| b. /13b/ | low rising | d. /35/ | high rising |

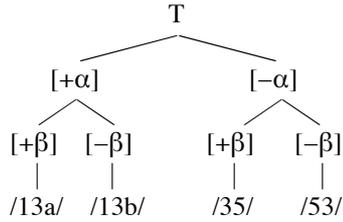
- (26) *Pingyao tone sandhi*
- | Input | Outputs |
|----------|----------------|
| a. /13a/ | 35 |
| b. /35/ | 13 [= 13a], 53 |
| c. /53/ | 35, 13 [= 13b] |

⁸This assumption is based on general simplicity and naturalness considerations. While phonological theory does not rule out more complex formulations in which processes require changes of more than one feature, one would have to have evidence that a more complex rule is required.

UNIVERSAL FEATURE THEORY WITHOUT UNIVERSAL FEATURES

Following the same procedure as for Beijing, Krekoski arrives at a tree for Pingyao whereby each of the tonal alternations involves a change of only one feature.

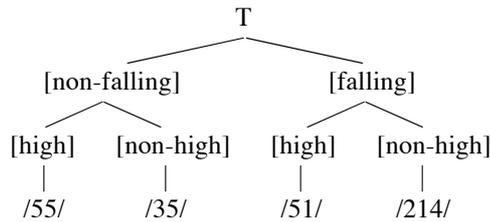
(27) *Pingyao (Jin) contrastive hierarchy*



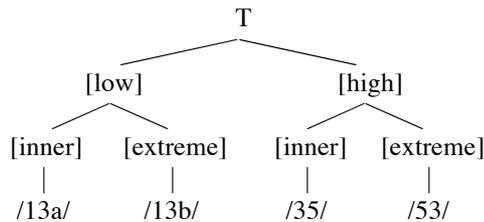
Krekoski observes that Beijing and Pingyao tones in corresponding positions in the trees in (24) and (27) are cognates, and descend from the same Middle Chinese tone. That is, despite extensive changes in their phonetics, the tones retain the same relative positions in their feature hierarchies.

Up to here we have not tried to give the features phonetic interpretations; however, features are not purely abstract entities. Krekoski (2013) suggests correlates for the features as in (28) and (29) (I do not attempt to assign markedness to them). The feature [extreme] in (29) refers to the periphery of a tonal space, and [inner] designates a more central region of the space.

(28) *Beijing Mandarin tone features*

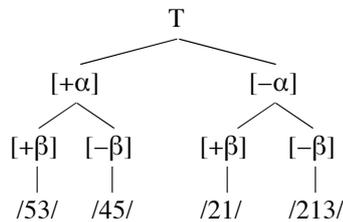


(29) *Pingyao (Jin) tone features*



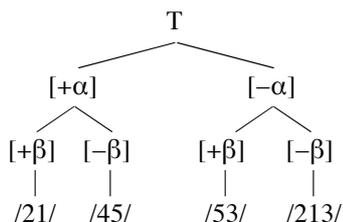
Following the same methodology, Krekoski posits the tree in (30) for Tianjin Mandarin. Surprisingly, these tones do *not* correspond as expected with their cognates in Beijing and Pingyao. Tones /21/ and /53/ are in the ‘wrong place’ relative to the other dialects that descend from Middle Chinese.

(30) *Tianjin Mandarin contrastive hierarchy*



Tracing the tones from Middle Chinese, Krekoski proposes that an earlier stage of Tianjin (*Proto-Tianjin) must have had the hierarchy in (31).

(31) *Proto-Tianjin Mandarin contrastive hierarchy



Why did a contrastive shift occur in the history of Tianjin? An answer can be found in the phonetics of the tones. Krekoski observes that it is difficult to find plausible phonetic correlates for the features in *Proto-Tianjin, whereas the current Tianjin system clearly groups the tones by height. He proposes: “Tonal drift likely accreted changes in height values until the system of contrasts reached some critical inflection point which precipitated the reanalysis of specifications.”

What this example illustrates is that features may be suggested by patterns of phonological activity, but that phonetic substance also has a say. Contrastive trees for tonal features can remain stable even as the phonetic realizations of the tones change; but the feature tree is restructured when it gets too out of sync with the phonetics. Without such a mechanism, we would expect a much greater proliferation of ‘crazy rules’ (rules that cannot be formulated in phonetically natural terms) than we actually find.

While phonetic substance influences the contrastive feature hierarchy, the influence is not all in this direction. I argued above that the contrastive hierarchy serves as an organizing principle for synchronic phonology, and influences the direction of diachronic changes, such as mergers. The conclusion is that influence runs in *both* directions.

6. Conclusion: Phonology and the Faculty of Language

The approach presented here shares with ‘substance-free’ theories the idea that the phonetic content of features is not part of the phonological computational system (Hale & Reiss 2000a; 2000b; 2008; Morén 2003; 2006; 2007; Odden 2006; Blaho 2008; Samuels 2009; 2011; 2012; Iosad 2012; see Hall 2014 for discussion). Some of these theories go too far, in my view, in shifting the explanation for phonological patterning to external factors; in this way they resemble phonetics-driven approaches to phonology (Boersma 1998; Pierrehumbert, Beckman & Ladd 2000; Hayes, Kirchner & Steriade 2004; Steriade 2009) that they otherwise oppose. In his review of Samuels (2011), Hall (2012: 738) comments: “the substance-free and the substance-based views are alike in that they both posit functional phonetic explanations for substantive phonological patterns...the two lines of thought, in their different ways, both turn away from the practice of constructing formal explanations for substantive patterns.” The contrastive feature hierarchy restores the balance between functional and formal explanations, to the extent that it serves as a formal organizing principle of the phonology.

More generally, it has been suggested that only syntactic recursion is part of the narrow faculty of language (FLN; Hauser, Chomsky & Fitch 2002), and that phonology is outside FLN. However, the contrastive hierarchy has a recursive digital character, like other aspects of FLN. Like syntax, phonology takes substance from outside FLN and converts it to objects that can be manipulated by the linguistic computational system. The parallels between phonology and syntax may go even further, if it turns out that syntax, too, is in the business of creating contrastive hierarchies of morphosyntactic features, as suggested by Cowper & Hall (2014).

UNIVERSAL FEATURE THEORY WITHOUT UNIVERSAL FEATURES

References

- Aslin, Richard N., David B. Pisoni, Beth L. Hennessy and Alan J. Perey. 1981. Discrimination of voice onset time by human infants: new findings and implications for the effects of early experience. *Child Development* 52: 1135–1145.
- Blaho, Sylvia. 2008. *The Syntax of Phonology: A Radically Substance-Free Approach*. Doctoral dissertation, University of Tromsø.
- Boersma, Paul. 1998. *Functional Phonology: Formalizing The Interactions Between Articulatory And Perceptual Drives*. The Hague: Holland Academic Graphics.
- Calvino, Italo. 1974. *Invisible Cities*. Translated from the Italian by William Weaver. New York: Harcourt Brace Jovanovich.
- Chen, Matthew. 2000. *Tone Sandhi*. Cambridge: CUP.
- 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. 2009. The role of features in phonological inventories. In Eric Raimy and Charles Cairns (eds.), *Contemporary Views on Architecture and Representations in Phonological Theory*, 19–68. Cambridge, MA: MIT Press.
- Clements, G. N. and Rachid Ridouane (eds.). 2011. *Where Do Features Come From? Cognitive, Physical and Developmental Bases of Distinctive Speech Categories*. Amsterdam: John Benjamins.
- Cowper, Elizabeth and Daniel Currie Hall. 2014. Reductiō ad discrīmen: Where features come from. *Nordlyd* 41.2: 145–164.
- Cristià, Alejandrina, Amanda Seidl and Alexander Francis. 2011. Phonological features in infancy. In Clements and Ridouane, 303–326.
- Dinnsen, Daniel A. 1992. Variation in developing and fully developed phonetic inventories. In Charles A. Ferguson, Lisa Menn and 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 and Thomas W. Powell. 1990. Some constraints on functionally disordered phonologies: Phonetic inventories and phonotactics. *Journal of Speech and Hearing Research* 33: 28–37.
- Dresher, B. Elan. 1998a. Child phonology, learnability, and phonological theory. In Tej Bhatia and William C. Ritchie (eds.), *Handbook of Language Acquisition*, 299–346. New York: Academic Press.
- Dresher, B. Elan. 1998b. On contrast and redundancy. Paper 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*, 239–57. Amsterdam: John Benjamins.
- Dresher, B. Elan. 2009. *The contrastive Hierarchy in Phonology*. Cambridge: CUP.
- Dresher, B. Elan. To appear a. The Motivation for contrastive feature hierarchies in phonology. *Linguistic Variation*.
- Dresher, B. Elan. To appear b. Phonologization of predictable allophones in West Germanic. *Lingua* (special issue on contrast in phonology).

B. ELAN DRESHER

- Dresher, B. Elan, Glyne Piggott and Keren Rice. 1994. Contrast in phonology: Overview. In Carrie Dyck (ed.), *Toronto Working Papers in Linguistics (Proceedings of the Montréal-Ottawa-Toronto Phonology Workshop)* 13,1: iii-xvii. Toronto, ON: Department of Linguistics, University of Toronto.
- Dresher, B. Elan and Keren Rice. 2007. Markedness and the contrastive hierarchy in phonology. <http://homes.chass.utoronto.ca/~contrast/>.
- Dresher, B. Elan and Xi Zhang. 2005. Contrast and phonological activity in Manchu vowel systems. *Canadian Journal of Linguistics/Revue canadienne de linguistique* 50: 45–82.
- Dyck, Carrie. 1995. *Constraining the Phonology–Phonetics Interface, with Exemplification from Spanish and Italian Dialects*. Doctoral dissertation, University of Toronto.
- Eimas, Peter D., Einar R. Siqueland, Peter Jusczyk and James Vigorito. 1971. Speech perception in infants. *Science* 171: 303–306.
- Fikkert, Paula. 1994. *On the Acquisition of Prosodic Structure (HIL Dissertations 6)*. Dordrecht: ICG Printing.
- Flemming, Edward S. 2002. *Auditory Representations in Phonology*. London: Routledge.
- Hale, Mark and Charles Reiss. 2000a. “Substance abuse” and “dysfunctionalism”: Current trends in phonology. *Linguistic Inquiry* 31: 157–169.
- Hale, Mark and Charles Reiss. 2000b. Phonological theory without substance. In Noel Burton-Roberts, Philip Carr and Gerard Docherty (eds.), *Phonological Knowledge: Conceptual and Empirical Foundations*, 161–184. Oxford: OUP.
- Hale, Mark and Charles Reiss. 2008. *The Phonological Enterprise*. Oxford: OUP.
- Hall, Daniel Currie. 2007. *The Role and Representation of Contrast in Phonological Theory*. Doctoral dissertation, University of Toronto.
- Hall, Daniel Currie. 2011. Phonological contrast and its phonetic enhancement: Dispersedness without dispersion. *Phonology* 28: 1–54.
- Hall, Daniel Currie. 2012. Review of Bridget D. Samuels, *Phonological Architecture: A Bilingual Perspective*. *Journal of Linguistics* 48: 736–741.
- Hall, Daniel Currie. 2014. On substance in phonology. In Laura Teddeman (ed.), *Proceedings of the 2014 Annual Conference of the Canadian Linguistic Association*. 14 pages. <http://cla-acl.ca/wp-content/uploads/Hall-2014.pdf>.
- Harvey, Christopher. 2012. Contrastive shift in Ob-Ugric vowel systems. Ms., Department of Linguistics, University of Toronto.
- Hauser, Marc D., Noam Chomsky and W. Tecumseh Fitch. 2002. The faculty of language: What is it, who has it, and how did it evolve? *Science* 298: 1569–1579.
- Hayes, Bruce, Robert Kirchner and Donca Steriade (eds.). 2004. *Phonetically Based Phonology*. Cambridge: CUP.
- Hulst, Harry van der. 1993. Units in the analysis of signs. *Phonology* 10: 209–241.
- Hyman, Larry M. 2011. Do tones have features? In John A. Goldsmith, Elizabeth Hume and 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: CUP.
- Iosad, Pavel. 2012. Representation and variation in substance-free phonology: A case study in Celtic. Doctoral dissertation, University of Tromsø.

UNIVERSAL FEATURE THEORY WITHOUT UNIVERSAL FEATURES

- Jakobson, Roman. 1941. *Kindersprache, Aphasie, und allgemeine Lautgesetze*. Uppsala: Uppsala Universitets Arsskrift. Translated by A. R. Keiler as *Child Language, Aphasia, and Phonological Universals*. The Hague: Mouton, 1968.
- Jakobson, Roman, C. Gunnar M. Fant and Morris Halle. 1952. *Preliminaries to Speech Analysis*. MIT Acoustics Laboratory, Technical Report, No. 13. Reissued by MIT Press, Cambridge, MA, Eleventh Printing, 1976.
- Jakobson, Roman and Morris Halle. 1956. *Fundamentals of Language*. The Hague: Mouton.
- Keyser, Samuel Jay and Kenneth N. Stevens. 2001. Enhancement revisited. In Michael J. Kenstowicz (ed.), *Ken Hale: A life in Language*, 271–291. Cambridge, MA: MIT Press.
- Keyser, Samuel Jay and Kenneth N. Stevens. 2006. Enhancement and overlap in the speech chain. *Language* 82: 33–63.
- Ko, Seongyeon. 2012. *Tongue Root Harmony and Vowel Contrast in Northeast Asian Languages*. Doctoral dissertation, Cornell University.
- Krekoski, Ross. 2013. On tone and the nature of features. Ms., Department of Linguistics, University of Toronto.
- Kuhl, Patricia, K. A. Williams, Francisco Lacerda, Kenneth N. Stevens and Björn Lindblom. 1992. Linguistic experience alters phonetic perception in infants by 6 months of age. *Science* 255: 606–608.
- Levelt, Clara C. 1989. *An Essay on Child Phonology*. M.A. thesis, Leiden University.
- Liljencrants, Johan and 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 and Jeri J. Jaeger (eds.), *Experimental Phonology*, 13–44. New York: Academic Press.
- Mesgarani, Nima, Stephen V. David, Jonathan B. Fritz and 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: OUP.
- Morén, Bruce. 2003. The Parallel Structures Model of feature geometry. *Working Papers of the Cornell Phonetics Laboratory* 15: 194–270. Ithaca, NY.
- Morén, Bruce. 2006. Consonant-vowel interactions in Serbian: Features, representations and constraint interactions. *Lingua* 116: 1198–1244.
- Morén, Bruce. 2007. Minimalist/substance-free feature theory: Why and how. Ms., Center for Advanced Study in Theoretical Linguistics, University of Tromsø.
- 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.
- Oxford, Will. 2015. Patterns of contrast in phonological change: Evidence from Algonquian vowel systems. *Language* 91,1.
- Pater, Joe, Christine L. Stager and Janet F. Werker. 2004. The perceptual acquisition of phonological contrasts. *Language* 80: 384–402.
- Pierrehumbert, Janet, Mary E. Beckman and D. R. Ladd. 2000. Conceptual foundations of phonology as a laboratory science. In Noel Burton-Roberts, Philip Carr and Gerard Docherty (eds.), *Phonological Knowledge: Conceptual and Empirical Issues*, 273–303. Oxford: OUP.
- Polka, Linda, Connie Colantonio and Megha Sundara. 2001. A cross-language comparison of /d/ – /ð/ perception: evidence for a new developmental pattern. *Journal of the Acoustical Society of America* 109: 2190–2201.

B. ELAN DRESHER

- Pye, Clifton, David Ingram and Helen List. 1987. A comparison of initial consonant acquisition in English and Quiché. In Keith E. Nelson and Ann Van Kleeck (eds.), *Children's Language* (vol. 6), 175–190. Hillsdale, NJ: Erlbaum.
- Rice, Keren. 2003. Featural markedness in phonology: Variation. In Lisa Cheng and 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: CUP.
- Rice, Keren and Peter Avery. 1995. Variability in a deterministic model of language acquisition: A theory of segmental elaboration. In John Archibald (ed.), *Phonological Acquisition and Phonological Theory*, 23–42. Hillsdale, NJ: Lawrence Erlbaum.
- Samuels, Bridget D. 2009. *The Structure of Phonological Theory*. Doctoral dissertation, Harvard University.
- Samuels, Bridget D. 2011. *Phonological Architecture : A Biolinguistic Perspective*. Oxford: OUP.
- Samuels, Bridget. 2012. The emergence of phonological forms. In Anna Maria Di Sciullo (ed.), *Towards a Biolinguistic Understanding of Grammar: Essays on Interfaces*, 193–213. Amsterdam: John Benjamins.
- Sandler, Wendy. 1993. Sign language and modularity. *Lingua* 89: 315–351.
- Spahr, Christopher. 2014. A contrastive hierarchical account of positional neutralization. *The Linguistic Review* 31: 551–585.
- Stager, Christine L. and Janet F. Werker. 1997. Infants listen for more phonetic detail in speech perception than in word learning tasks. *Nature* 388: 381–382.
- Steriade, Donca. 2009. The phonology of perceptibility effects: The P-map and its consequences for constraint organization. In Kristin Hanson and Sharon Inkelas (eds.), *The Nature of the Word: Studies in Honor of Paul Kiparsky*, 151–179. Cambridge, MA: MIT Press.
- Stevens, Kenneth N. and Samuel Jay Keyser. 1989. Primary features and their enhancement in consonants. *Language* 65: 81–106.
- Stevens, Kenneth N., Samuel Jay Keyser and Haruko Kawasaki. 1986. Toward a phonetic and phonological theory of redundant features. In Joseph S. Perkell and Dennis H. Klatt (eds.), *Symposium on Invariance and Variability of Speech Processes*, 432–469. Hillsdale, NJ: Lawrence Erlbaum.
- Weiss, Daniel J. and Jessica Maye. 2008. The role of contrast in the acquisition of phonetic systems. In Peter Avery, B. Elan Dresher and Keren Rice (eds.), *Contrast in Phonology: Theory, Perception, Acquisition*, 219–229. Berlin: Mouton de Gruyter.
- Werker, Janet F., Christopher T. Fennell, Kathleen M. Corcoran and Christine L. Stager. 2002. Age and vocabulary size influences on the phonological representation of newly learned words in infants aged 14 to 20 months. *Infancy* 3: 1–30.
- Werker, Janet F., John H. V. Gilbert, Keith Humphrey and Richard C. Tees. 1981. Developmental aspects of cross-language speech perception. *Child Development* 52: 349–355.
- Werker, Janet F. and Richard C. Tees. 1984. Cross-language speech perception: Evidence for perceptual reorganization during the first year of life. *Infant Behavior and Development* 7: 49–63.
- Zhang, Xi. 1996. *Vowel Systems of the Manchu-Tungus Languages of China*. Doctoral dissertation, University of Toronto.