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Features and Contrast: The Universal Versus the Language Particular

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1. Introduction

Introduction: features and contrast

This talk is based on a chapter I have submitted to the second edition of the *Cambridge Handbook of Phonology*, edited by Paul de Lacy and Adam Jardine.

The chapter addresses two central and related phonological concepts: features and contrast.

I assume that distinctive features are the irreducible 'primes' of phonological representation. As such, they are inherently contrastive, as one of their main functions is to show how segments differ from each other.

Introduction: features and contrast

Nevertheless, there is a continuing tension between feature theory, which aims to be universal, and contrast, which is language particular.

I will review how this tension between the universal and the language particular has been addressed in phonological theory.

In this talk I will present the history of these concepts as a Hegelian dialectic, which according to one definition is:

> an interpretive method in which the contradiction between a proposition (thesis) and its antithesis is resolved at a higher level of truth (synthesis).

2. THESIS

Features as expressing
language-particular contrasts

Features express language-particular contrasts

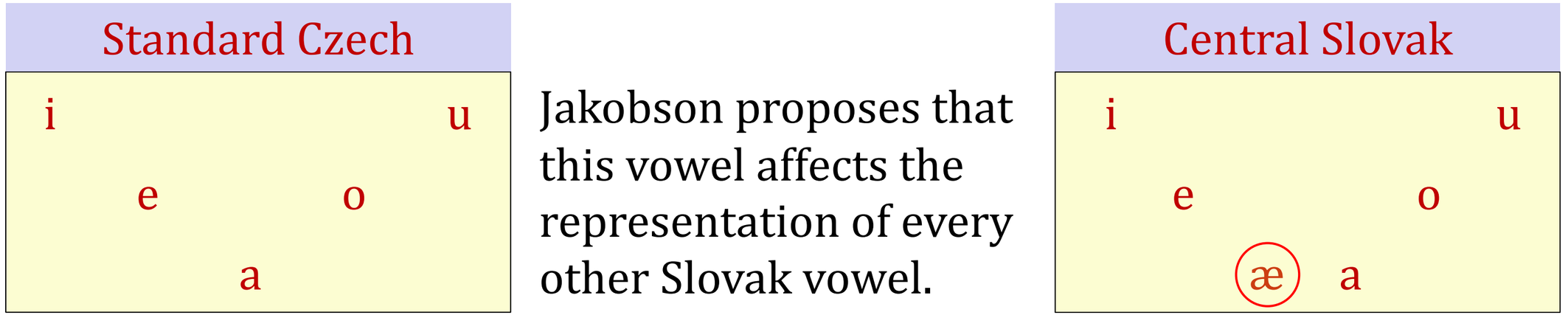
In their earliest manifestations in the work of Roman Jakobson and N. S. Trubetzkoy, distinctive features represent language-particular contrasts: segments that are phonetically ‘the same’ may receive different representations depending on what they contrast with.

Language-particular contrastive features in Czech and Slovak

An early example of this approach is the analysis of two similar Slavic vowel systems by Jakobson (1962 [1931]).

Jakobson observed that with one exception, the simple vowels of Central Slovak ‘correspond completely both in their production and in the auditive impression they produce to the vowels of Standard Czech’.

The exception is a vowel /æ/ in Central Slovak.

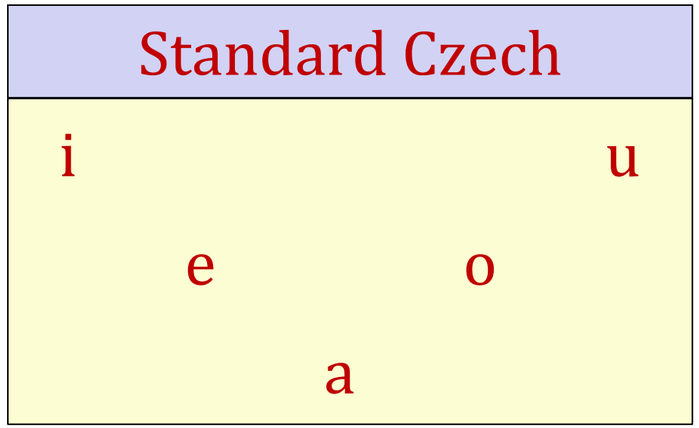


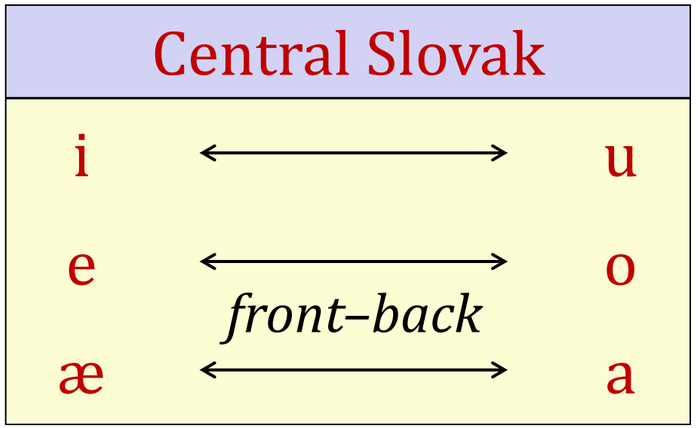
Language-particular contrastive features in Czech and Slovak

Jakobson diagrams the Czech and Slovak short vowels as shown.

In Central Slovak there is a front–back contrast between /æ/ and /a/.

Jakobson assumes, presumably by symmetry, that this contrast holds also of the other vowels in Central Slovak, thereby creating a front /i, e, æ/ and a back /u, o, a/ series.

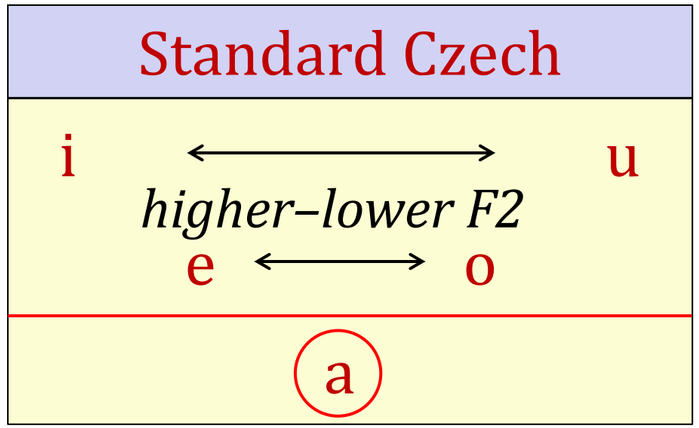


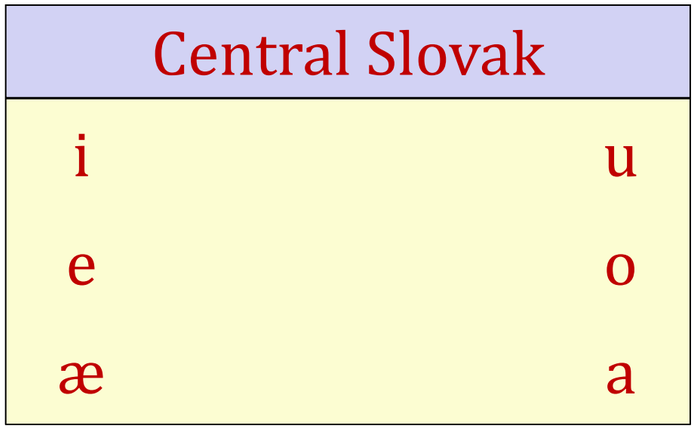


Language-particular contrastive features in Czech and Slovak

In Standard Czech, the low vowel /a/ is not opposed to another low vowel, and Jakobson considers it to be neutral with respect to tonality (frontness/backness or rounding), having no contrastive value except for its height.

This has consequences for the analysis of the other Czech short vowels. Jakobson proposes that for those vowels, the two dimensions of frontness/backness and roundness/non-roundness cannot be separated.





Language-particular contrastive features in Czech and Slovak

If we were to (anachronistically) assign contemporary binary distinctive features to the vowels in these languages based on Jakobson's analysis, we might arrive at the tables below.

The Czech /a/ has different feature specifications than the phonetically identical Slovak /a/.

Standard Czech

	i	e	a	o	u
[low]	–	–	+	–	–
[bk/rd]	–	–		+	+
[high]	+	–		–	+

Central Slovak

	i	e	æ	a	o	u
[low]	–	–	+	+	–	–
[back]	–	–	–	+	+	+
[high]	+	–			–	+

Language-particular contrastive features in Czech and Slovak

Also, whereas the Slovak non-low vowels have specifications for the feature [±back], in Czech there is no such feature;

rather, Czech vowels have a value for the feature [±back/round], which we could also call [±low F2].

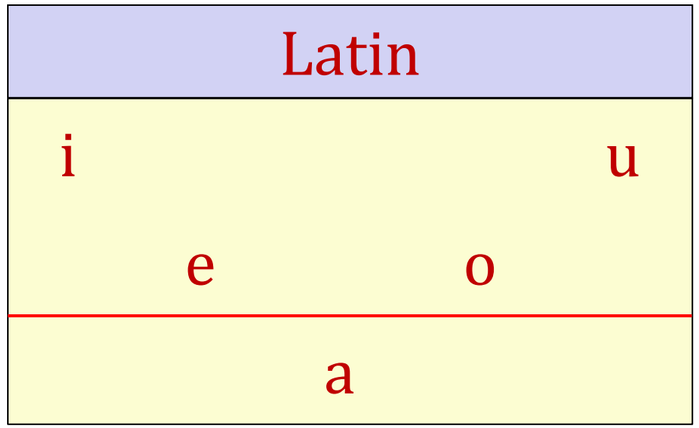
Standard Czech					
	i	e	a	o	u
[low]	–	–	+	–	–
[bk/rd]	–	–		+	+
[high]	+	–		–	+

Central Slovak						
	i	e	æ	a	o	u
[low]	–	–	+	+	–	–
[back]	–	–	–	+	+	+
[high]	+	–			–	+

Language-particular contrastive features in five-vowel systems

In his discussion of five-vowel systems, Trubetzkoy (1939: 90–91) observes that the low vowel in Latin is contrastive only with respect to height.

This is the same as Jakobson's analysis of Standard Czech



Language-particular contrastive features in five-vowel systems

But, according to Trubetzkoy, this is not true of all five-vowel systems.

He observes that in Archi (East Caucasian, Central Dagestan), a consonantal rounding contrast is neutralized before and after the rounded vowels /u, o/.

'As a result, these vowels are placed in opposition with…unrounded *a*, *e*, and *i*'.

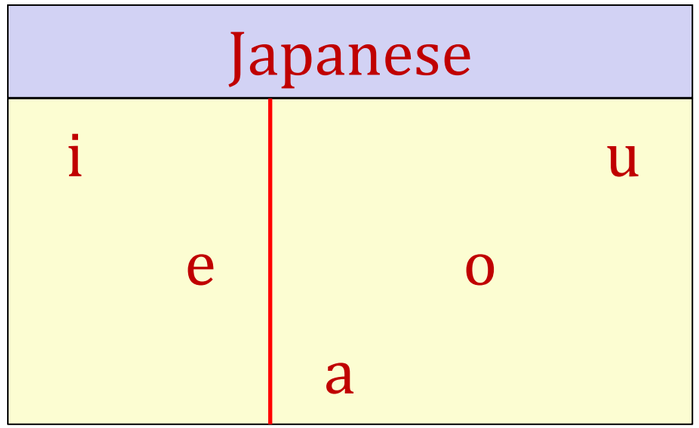
Archi	
i	u
e	o
a	

Here, /a/ is contrastively [–round] as well as [+low].

Language-particular contrastive features in five-vowel systems

In Japanese, Trubetzkoy argues that neutralization of the opposition between palatalized and non-palatalized consonants before /i/ and /e/ shows that these vowels are put into opposition with the other vowels /a, o, u/.

Thus, Japanese /a/ is contrastively [–front] as well as [+low].



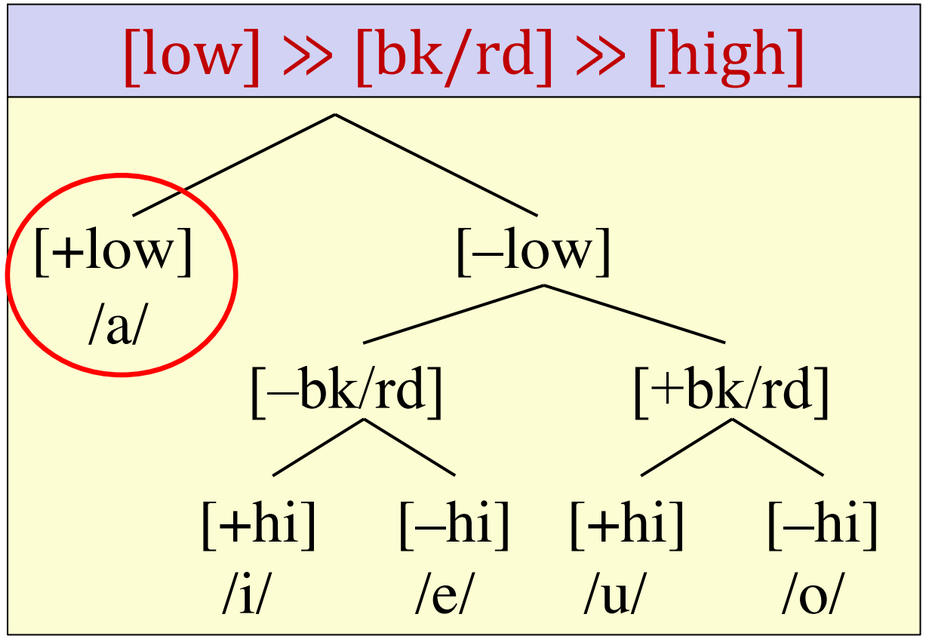
Language-particular contrastive feature hierarchies

Building on later work by Jakobson and his colleagues (Jakobson 1941; Jakobson & Lotz 1949; Jakobson, Fant, & Halle 1952; Cherry, Halle, & Jakobson 1953; Jakobson & Halle 1956; Halle 1959; see Dresher 2016 for a history),

these differing contrastive relations can be generated by branching trees, where features are assigned in a language-particular order until every segment has a unique representation ('≫' means 'is assigned before').

Language-particular contrastive feature hierarchies

Czech/Latin features					
	i	e	a	o	u
[low]	–	–	+	–	–
[bk/rd]	–	–		+	+
[high]	+	–		–	+

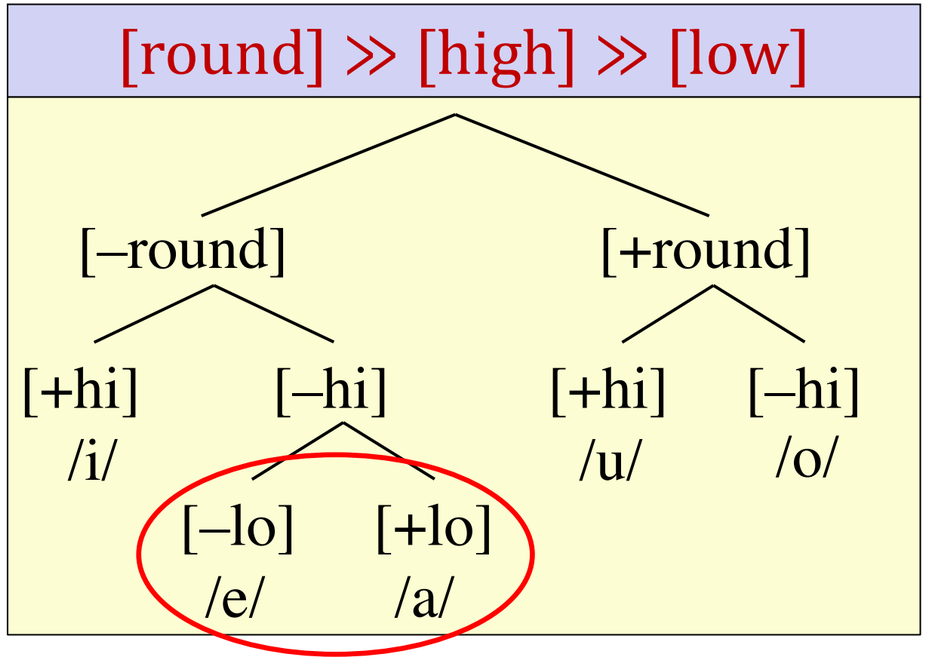


For /a/ to be assigned only [+low], as in Czech or Latin, [low] is assigned first.

Now, /a/ is uniquely specified and receives no further features.

Language-particular contrastive feature hierarchies

Archi features	i	e	a	o	u
[low]		–	+		
[round]	–	–	–	+	+
[high]	+	–	–	–	+

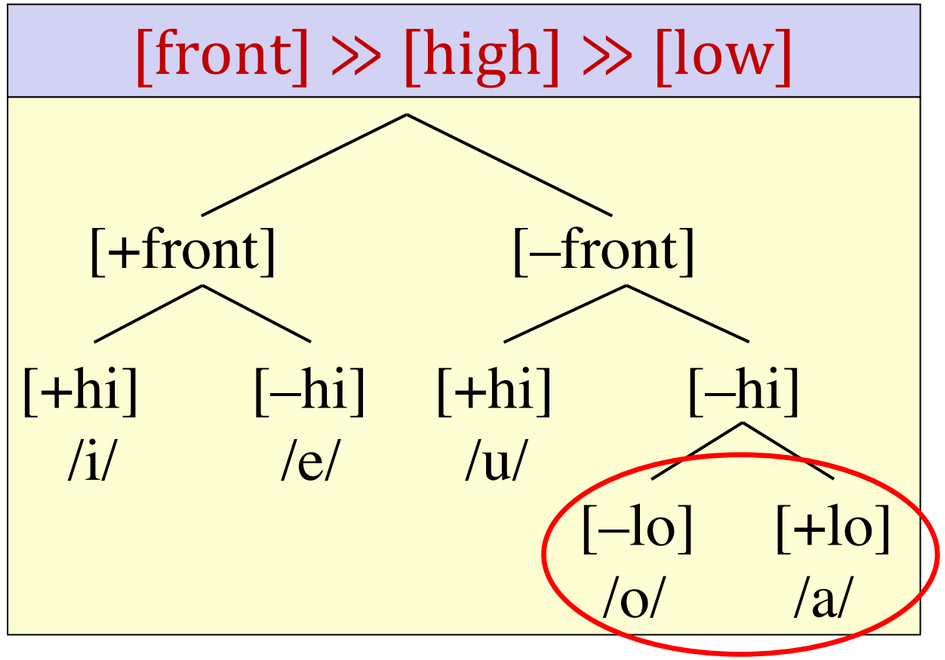


To get the Archi features, [round] is assigned first.

Then [low] is contrastive only in the [–round, –high] vowels.

Language-particular contrastive feature hierarchies

Japanese features	i	e	a	o	u
[low]			+	–	
[front]	+	+	–	–	–
[high]	+	–	–	–	+



In Japanese, [front] goes first.

[low] is contrastive only in the [–front, –high] vowels.

Problems with language-specific feature hierarchies

For a brief period, branching trees became the preferred approach to feature specification in early generative grammar.

However, they were omitted from Chomsky & Halle's *The Sound Pattern of English* (SPE), and disappeared from mainstream generative phonology.

Branching trees fell out of favour for several reasons:

- They give rise to underspecification, which Lightner (1963) and Stanley (1967) claimed increase the expressive power of the grammar in improper ways.
- It wasn't obvious that the difference between contrastive and non-contrastive features really mattered (see Dresher & Hall 2021 for discussion).

Problems with language-specific feature hierarchies

- Most important with respect to our theme is that the approach that gave rise to branching trees is rooted in language-particular differences, and thus was out of step with efforts to develop a theory that aspired to universality.

3. ANTITHESIS
Features as expressing universal contrasts

Features express universal contrasts

SPE (Chomsky & Halle 1968: 4) writes that the goal of linguistics is to discover linguistic universals, which are 'the essential properties of any human language':

> 'The search for essential linguistic universals is, in effect, the study of the a priori *faculté de langage* that makes language acquisition possible'

SPE proposes that among the linguistic universals are the phonological features, which are innate and have relatively fixed phonetic correlates.

Features express universal contrasts

In the SPE theory, language-particular contrasts do not influence the assignment of feature specifications to segments, and the vowels of all the languages discussed above would be fully specified for the same universal set of features.

Czech/Latin/Archi/Japanese					
	i	e	a	o	u
[low]	–	–	+	–	–
[back]	–	–	+	+	+
[round]	–	–	–	+	+
[high]	+	–	–	–	+

CentralSlovak						
	i	e	æ	a	o	u
[low]	–	–	+	+	–	–
[back]	–	–	–	+	+	+
[round]	–	–	–	–	+	+
[high]	+	–	–	–	–	+

Features express universal contrasts: Duanmu (2016)

A more recent universal feature theory is proposed by Duanmu (2016).

In his theory, all five-vowel systems would be represented as below.

All five-vowel systems					
	i	e	a	o	u
[ATR]	+	+	–	+	+
[back]	–	–	+	+	+
[round]	–	–	–	+	+
[high]	+	–	–	–	+

Universal features in Optimality Theory

The most influential approach within generative grammar in the last decades has been Optimality Theory (OT; Prince & Smolensky 1993/2004).

For various reasons (see Iosad 2018), OT analyses have also tended to favour universal features and to avoid underspecification.

Problems with disregarding language-particular contrast

There were already indications in SPE that there is a price to be paid for disregarding language-particular contrasts, though SPE does not put it that way.

Chomsky & Halle (1968: 400) open Chapter 9 with a dramatic statement:

> 'The entire discussion of phonology in this book suffers from a fundamental theoretical inadequacy.'

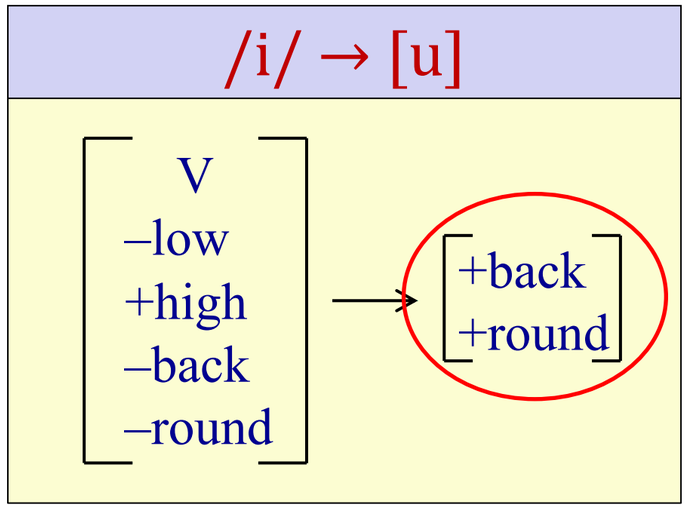
This inadequacy consists of SPE's 'overly formal' approach to features, which does not take into account their intrinsic content.

Problems with disregarding language-particular contrast

One example concerns the pair of rules shown below:

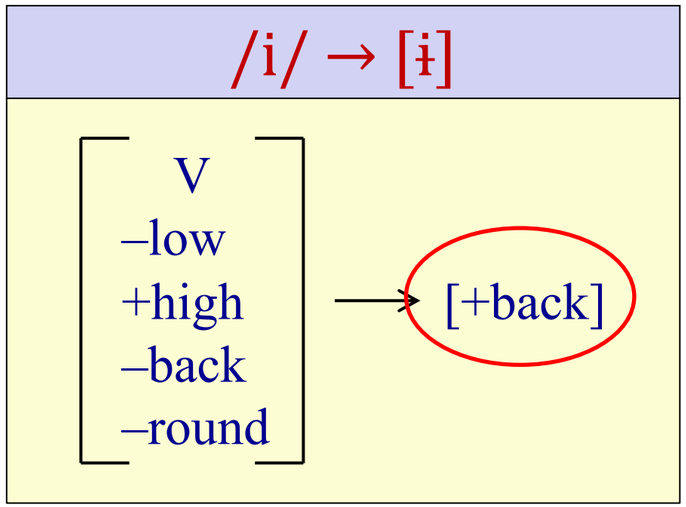
Chomsky & Halle observe that a rule changing /i/ to [u] is cross-linguistically more common than a rule changing /i/ to [ɨ].

However, their evaluation measure, which assigns higher values to rules that utilize fewer features, makes the wrong prediction:



A rule changing /i/ to [u] must change two features,

whereas /i/ to [ɨ] requires a change of only one.



Universal markedness to supplement universal features

To remedy this shortcoming in the theory, SPE introduces a version of markedness theory which assigns universal markedness values to segments.

These values are arrived at by a series of conventions that stipulate what the unmarked values of features are in various contexts.

These conventions follow a universal hierarchy whereby the markedness value of [back] is sensitive to [low], and the markedness values of [round] depend on [back] as well as [low].

Universal markedness to supplement universal features

The relevant markedness convention we need to know is Convention XIa:

Convention XIa:	In the context [–low], the unmarked value of [round] is the same as the value of [back].

The markedness conventions play a role in the rule system by means of linking.

The basic idea is that when a feature is changed by a rule, all the features below it in the hierarchy revert to their unmarked value.

Linking of the markedness conventions

In the case of the rule changing /i/ to [u], it suffices to change only [back].

Then, linking forces [round] to take on its unmarked value in the new context [–low, +back], which is [+round] according to convention (XIa).

/i/ → [u]	
Target	[V, –low, +high, –back, –round]
Change	[+back]
Linking	[round] becomes [+round]
Result	[u]

Linking of the markedness conventions

Conversely, if we want /i/ to change to [ɨ], we must *prevent* linking by explicitly specifying that the output must be [–round].

Now the rule changing /i/ to [u] is less costly than the one changing /i/ to [ɨ].

/i/ → [u]	
Target	[V, –low, +high, –back, –round]
Change	[+back]
Linking	[round] becomes [+round]
Result	[u]

/i/ → [ɨ]	
Target	[V, –low, +high, –back, –round]
Change	[+back, –round]
Linking	*Does not apply*
Result	[ɨ]

Problems with a universal markedness hierarchy

The SPE solution is based on the idea that [u] is universally less marked than [ɨ] because [u] is much more common than [ɨ].

An apparently paradoxical fact has been observed, however: when /u/ and /ɨ/ occur together in an inventory, /ɨ/ acts as if it is less marked than /u/ by many common criteria (Rice 2003, 2007).

Thus, the claim that [u] is universally less marked than [ɨ] needs rethinking.

De Lacy (2006) proposes that there are many different markedness hierarchies, and that not all markedness diagnostics work all the time.

Problems with a universal markedness hierarchy

I would like to pursue a different perspective that suggests that contrast is a crucial piece of the [u/ɨ] problem.

While adding [+back] to /i/ does more commonly result in [u] than in [ɨ], this is true only when the inventory contains a /u/ and no distinct /ɨ/.

When a language has a phoneme /ɨ/ in contrast with /u/ and /i/, adding [+back] to /i/ results in [ɨ], not [u].

An example can be found in Tuvan (Turkic; Anderson & Harrison 1999; Rose & Walker 2011).

Problems with a universal markedness hierarchy

The Tuvan back counterpart of /i/ is transcribed as /ɯ/, which plays the same role as /ɨ/ for most purposes.

In Tuvan backness harmony, [e] alternates with [a] and [i] alternates with [ɯ].

Linking does not intervene here to turn [ɯ] into [u].

Tuvan vowel system

	front		back	
	non-round	round	non-round	round
high	i	y	ɯ	u
non-high	e	ø	a	o

SPE (433 n20) simply observes: 'The phenomenon of vowel harmony in the Ural-Altaic languages provides a further example of the nonapplication of convention (XIa) [...]'.

Arguments against universal features

In the 2000s, arguments against universal features became influential.

Mielke (2008), Samuels (2011), and others argue that features are emergent and language particular:

- No one set of features has been discovered that works for all languages.
- Phonetically-based features exclude sign languages, which have important parallels with spoken phonology (van der Hulst 1993, 2022; Sandler 1993).
- If some features have to be acquired based on language-specific evidence, a prespecified list of features becomes less useful in learning.

What accounts for emergent features?

But if features are not innate, we need to explain why they inevitably emerge, and why they have the properties that they do.

Let's look again at feature theories that allow for language-specific contrast.

4. SYNTHESIS
Language-particular contrasts in a universal theory of features

Contrastive Hierarchy Theory

Underspecification began to make its way back into generative phonology in the 1980s, and a version of the hierarchical branching trees was revived by Clements (2001; 2003; 2009) and independently at the University of Toronto (Dresher, Piggott, & Rice 1994; Dyck 1995; Zhang 1996; Dresher 1998; Dresher & Rice 2007; Hall 2007, 2011; Dresher 2009; Mackenzie 2013; etc.).

At U of T, it first went under the name Modified Contrastive Specification (MCS) and has since gone under other names—I will refer to it as Contrastive Hierarchy Theory (CHT).

Contrastive Hierarchy Theory

Some principles of CHT are the following:

The Successive Division Algorithm (Dresher 2009): Assign contrastive features by successively dividing the inventory until every phoneme has been distinguished.

Variability of feature ordering: Feature hierarchies are language particular.

The Contrastivist Hypothesis (Hall 2007): The phonological component operates only on contrastive features.

If feature ordering is variable, then we need criteria for how to order the features in any given language.

Contrastive Hierarchy Theory

In CHT, feature hierarchies must account for phonological activity, that is, the way sounds pattern in a particular language:

> Phonological activity (adapted from Clements 2001: 77): 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.

I have argued (Dresher 2014, 2019) that CHT is a 'universal feature theory without universal features' that structures the features that learners must create.

The necessity of organizing contrastive phonological features into hierarchies that account for phonological activity puts constraints on how many features may be posited and how much phonetic detail they may contain.

The [u/ɨ/] problem in Contrastive Hierarchy Theory

Consider again the [u/ɨ] problem: Why is it that the result of changing /i/ to [+back] tends to be [u], except in languages with a contrastive /ɨ/ or /ɯ/?

Let's start with Tuvan; the contrastive features of the high vowels are shown.

When we change /i/ to [+back], the result is the features [+high, +back, –round], which is the same as /ɯ/.

Tuvan high vowels				
	i	y	ɯ	u
[high]	+	+	+	+
[back]	–	–	+	+
[round]	–	+	–	+

Change /i/ to [+back]			
	i	=	ɯ
[high]	+		+
[back]	+		+
[round]	–		–

The [u/ɨ/] problem in Contrastive Hierarchy Theory

Now consider a language like Central Slovak, which has no distinct /ɨ/ or /ɯ/.

If we assume that the feature hierarchy is [low] ≫ [back] ≫ [high], then the contrastive specifications are as shown.

Now, changing /i/ to [+back] results in [–low, +back, +high], the same as /u/.

like Central Slovak						
	i	e	æ	a	o	u
[low]	–	–	+	+	–	–
[back]	–	–	–	+	+	+
[high]	+	–			–	+

Change /i/ to [+back]			
	i	=	u
[low]	–		–
[back]	+		+
[high]	+		+

The [u/ɨ/] problem in Contrastive Hierarchy Theory

The key to this result is that the segments are underspecified.

The specification of /u/ does not indicate that it is round; this specification is compatible not just with [u], but also with other vowels, such as [ɨ], [ɯ], and [ʊ].

Rather, changing /i/ to [+back] results in a vowel that is not featurally different from /u/.

like Central Slovak						
	i	e	æ	a	o	u
[low]	–	–	+	+	–	–
[back]	–	–	–	+	+	+
[high]	+	–			–	+

Change /i/ to [+back]			
	i	=	{ɨ/ɯ/u/ʊ}
[low]	–		–
[back]	+		+
[high]	+		+

Dispersion Theory

What, then, explains why [u] is cross-linguistically more common than /ɨ/?

An influential account is Dispersion Theory, proposed by Liljencrants & Lindblom (1972), elaborated by Lindblom (1986), and adapted to Optimality Theory by Flemming (2002), Padgett (2003a,b), and Sanders (2003).

The basic idea is that phonological inventories exhibit a tendency to maximize auditory distinctiveness.

Thus, a three-vowel system [i, a, u] is maximally dispersed to the corners of the auditory space; the unattested [ɨ, ə, ʉ] is very poorly dispersed.

Enhancement Theory

Hall (2011) argues, however, that Dispersion Theory wrongly predicts some implausible inventories.

He demonstrates that common vowel systems result from phonologically under-specified features combined with the Enhancement Theory of Stevens, Keyser, & Kawasaki (1986) (also Stevens & Keyser 1989; Keyser & Stevens 2001, 2006).

They propose that feature contrasts can be enhanced by other features with similar acoustic effects.

Thus, [+back] (low F2) can be enhanced by {+round}, which further lowers F2; [–low] can be enhanced by {+high}, etc. I indicate enhancement by { }.

Contrastive underspecification plus Enhancement Theory

Returning to our Slovak-like language, a vowel specified as [–low, +back, +high] can potentially be realized by any of [ɨ, ɯ, u, ʊ].

As noted, [+back] can be enhanced by {+round}.

Adding {+round} eliminates the non-round candidates [ɨ, ɯ].

like Central Slovak						
	i	e	æ	a	o	?
[low]	–	–	+	+	–	–
[back]	–	–	–	+	+	+
[high]	+	–			–	+

Enhancements					
Candidates		ɨ	ɯ	u	ʊ
[–low]					
[+back]	{+round}				
[+high]					

Contrastive underspecification plus Enhancement Theory

The feature [+high] can be enhanced by {+ATR}.

Adding {+ATR} eliminates [ʊ], leaving [u] as the most likely realization.

QED.

like Central Slovak						
	i	e	æ	a	o	?
[low]	–	–	+	+	–	–
[back]	–	–	–	+	+	+
[high]	+	–			–	+

Enhancements			
Candidates		u	ʊ
[–low]			
[+back]	{+round}		
[+high]	{+ATR}		

5. Conclusion

Conclusion

To sum up:

THESIS:	Features are language particular and express language-particular contrasts.
Reason to reject:	Does not provide a universal theory that can account for language acquisition.

ANTITHESIS:	Features (and markedness) are universal and express universal contrasts.
Reason to reject:	Individual features (and markedness) are not universal, and the theory does not account for language-particular contrasts.

Conclusion

SYNTHESIS:	Emergent features express language-particular contrasts within a universal theory (CHT) that structures and constrains the features that learners must create.
Reason to reject:	None! We have attained a higher level of truth.

(for now)

For very helpful comments I would like to thank Paul de Lacy, Norbert Hornstein, Bill Idsardi, Adam Jardine, and Jeff Mielke.

and

THANK YOU!

References

Anderson, Gregory & K. David Harrison. 1999. *Tyvan* (Languages of the World: Materials, 257). Munich: LINCOM Europa.

Cherry, E. Colin, Morris Halle, & Roman Jakobson. 1953. Toward the logical description of languages in their phonemic aspect. *Language* 29(1): 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 phonological inventories. In Eric Raimy &Charles Cairns (eds.) *Contemporary views on architecture and representations in phonological theory,* 19–68.. Cambridge, MA: MIT Press.

de Lacy, Paul. 2006. *Markedness: Reduction and preservation in phonology.* Cambridge: Cambridge University Press.

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

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

Dresher, B. Elan. 2014. The arch not the stones: Universal feature theory without universal features. *Nordlyd* 4: 165–81. Special issue on Features ed. by Martin Krämer, Sandra Ronai, & Peter Svenonius. University of Tromsø — The Arctic University of Norway.
Dresher, B. Elan. 2016. Contrast in phonology 1867–1967: History and development. *Annual Review of Linguistics* 2: 53–73.
Dresher, B. Elan. 2019. Contrastive feature hierarchies in phonology: Variation and universality. In David W. Lightfoot & Jonathan Havenhill (eds.) *Variable properties in language: Their nature and acquisition,* 13–25. Washington, DC: Georgetown University Press.
Dresher, B. Elan & Daniel Currie Hall. 2021. The road not taken: *The Sound Pattern of Russian* and the history of contrast in phonology. *Journal of Linguistics* 57(2), 405–44. doi:10.1017/S002222672000377
Dresher, B. Elan & Keren Rice. 2007. Markedness and the contrastive hierarchy in phonology. https://dresher.artsci.utoronto.ca/contrast/
Dresher, B. Elan, Glyne Piggott, & Keren Rice. 1994. Contrast in phonology: Overview. *Toronto Working Papers in Linguistics* 13: iii–xvii.
Duanmu, San. 2016. *A theory of phonological features*. Oxford: Oxford University Press.
Dyck, Carrie. 1995. *Constraining the phonology-phonetics interface, with exemplification from Spanish and Italian dialects*. PhD dissertation, University of Toronto.
Flemming, Edward S. 2002. *Auditory representations in phonology*. New York, NY: Routledge.

Hall, Daniel Currie. 2007. *The role and representation of contrast in phonological theory.* PhD dissertation, University of Toronto.
Hall, Daniel Currie. 2011. Phonological contrast and its phonetic enhancement: Dispersedness without dispersion. *Phonology* 28(1): 1–54.
Halle, Morris. 1959. *The sound pattern of Russian: A linguistic and acoustical investigation*. The Hague: Mouton. Second printing, 1971.
Hulst, Harry van der. 1993. Units in the analysis of signs. *Phonology* 10: 209–41.
Hulst, Harry van der. 2022. The (early) history of sign language phonology. In B. Elan Dresher & Harry van der Hulst (eds.), *The Oxford history of phonology,* 284–305. Oxford: Oxford University Press.
Iosad, Pavel. 2018. Optimality Theory: Motivations and perspectives. In S. J. Hannahs & Anna Bosch (eds.) *The Routledge handbook of phonological theory,* 13–36. Abingdon & New York, NY: Routledge.
Jakobson, Roman. 1941. *Kindersprache, Aphasie, und allgemeine Lautgesetze.* Uppsala: Uppsala Universitets Arsskrift.
Jakobson, Roman. 1962 [1931]. Phonemic notes on Standard Slovak. In *Selected writings I. Phonological studies*, 221–30. The Hague: Mouton. [In Czech in *Slovenská miscellanea (Studies presented to Albert Pražak)*. Bratislava, 1931.]
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: 151–58.
Keyser, Samuel Jay & Kenneth N. Stevens. 2001. Enhancement revisited. In Michael J. Kenstowicz (ed.), *Ken Hale: A life in language*, 271–91. Cambridge, Mass.: MIT Press.
Keyser, Samuel Jay & Kenneth N. Stevens. 2006. Enhancement and overlap in the speech chain. *Language* 82(1): 33–63.
Lightner, Theodore McGraw. 1963. A note on the formation of phonological rules. In *Quarterly progress report* 68, 187–189. Cambridge, MA: Research Laboratory of Electronics, MIT.
Liljencrants, Johan & Björn Lindblom. 1972. Numerical simulation of vowel quality systems: The role of perceptual contrast. *Language* 48: 839–62.
Lindblom, Björn. 1986. Phonetic universals in vowel systems. In John J. Ohala & Jeri J. Jaeger (eds.), *Experimental phonology,* 13–44. New York: Academic Press.
Mackenzie, Sara. 2013. Laryngeal co-occurrence restrictions in Aymara: Contrastive representations and constraint interaction. *Phonology* 30(2): 297–345.
Mielke, Jeff. 2008. *The emergence of distinctive features*. Oxford: Oxford University Press.
Padgett, Jaye. 2003a. Contrast and post-velar fronting in Russian. *Natural Language & Linguistic Theory* 21: 39–87.
Padgett, Jaye. 2003b. The emergence of contrastive palatalization in Russian. In D. Eric Holt (ed.) *Optimality Theory and language change,* 307–335. Dordrecht: Kluwer.

Prince, Alan & Paul Smolensky. 1993/2004. *Optimality Theory: Constraint interaction in generative grammar.* London: Blackwell.
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.
Rose, Sharon & Rachel Walker. 2011. Harmony systems. In John A. Goldsmith, Jason Riggle, & Alan C. L. Yu (eds.) *The handbook of phonological theory*, second edition, 240–90. Malden, MA & Oxford: Wiley-Blackwell.
Samuels, Bridget D. 2011. *Phonological architecture : A biolinguistic perspective.* Oxford: Oxford University Press.
Sanders, Nathan. 2003. *Opacity and sound change in the Polish lexicon*. PhD dissertation, University of California, Santa Cruz.
Sandler, Wendy. 1993. Sign language and modularity. *Lingua* 89: 315–51.
Stanley, Richard. 1967. Redundancy rules in phonology. *Language* 43(2): 393–436.
Stevens, Kenneth N. & Samuel Jay Keyser. 1989. Primary features and their enhancement in consonants. *Language* 65(1): 81–106.

Stevens, Kenneth N. & Samuel Jay Keyser. 1989. Primary features and their enhancement in consonants. *Language* 65(1): 81–106.
Stevens, Kenneth N., Samuel Jay Keyser, & Haruko Kawasaki. 1986. Toward a phonetic and phonological theory of redundant features. In J. S. Perkell and D. H. Klatt (eds.), *Invariance and variability in speech processes*, 426–49. Hillsdale, NJ: Lawrence Erlbaum.
Trubetzkoy, N. S. 1939. *Grundzüge der Phonologie*. Göttingen: Vandenhoek & Ruprecht.
Zhang, Xi. 1996. *Vowel systems of the Manchu-Tungus languages of China.* PhD dissertation, University of Toronto.