Features in Phonology[1]

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1 What are features?

When we talk about sounds in a phonetics or phonology class, we usually use phonetic terms to describe them: *alveolar, palatal, interdental, trill*. In many cases, you can characterize a phonological pattern by using just these terms, or even by just referring to sounds using their IPA symbols. For example, in English, [t] is in complementary distribution with [ɾ]; it doesn't necessarily help to use the category descriptions "alveolar plosive" and "flap/tap". But there are other situations in which you have to refer to a group of sounds that pattern together as a NATURAL CLASS in a rule. To refer to such natural classes, we use segmental features—the basic language of phonological rules. The goal of this review is to discuss the goals of feature theory and the types of evidence that phonologists use to argue for phonological features. Along the way, we will survey the most commonly used phonological features in approximate order of their importance and practical usefulness.[1]

Evidence for features. Features are mainly used to characterize (i) phonological contrasts, and (ii) natural classes defined by constraints and rules. For example, English contrasts [s] and [ʃ] in words like "sin" and "shin". In languages such as Kikongo, there are no words that differ only in [s] and [ʃ], but speakers must know which one is which to speak the language: [ʃ] occurs only before [i], whereas [s] occurs in all other environments. One could, of course, simply refer to the symbols that stand for the acoustic events that we call [s] and [ʃ] in characterizing these contrasts and patterns, but that would fail to capture the observation that the same feature that distinguishes [s] and [ʃ] in English also distinguishes [z] ∼ [ʒ], and [ʧ] ∼ [ʤ] in the language, and that the sounds [t, s, z] and [ʧ, ʃ, ʒ] have identical and predictable distributions in Kikongo:

(1) Kikongo palatalization: compare the distribution of [t, s, z] and [ʧ, ʃ, ʒ]

tobola	'to bore a hole'	nselele	'termite'
ʧina	'to cut'	lolonʒi	'to wash'
kesoka	'to be cut'	zevo	'then'
ŋkoʃi	'lion'	aʒimola	'alms'
zeŋga	'to cut'	nzwetu	'our house'
ʒima	'to stretch'	kunezulu	'to heaven'
kasu	'emaciation'	tanu	'five'
ʧiba	'banana'		

Thus, features allow us to state phonological generalizations over abstract, symbolic features that are hypothesized to be the basic unit of mental phonological representations.

Acoustic or articulatory? The earliest influential theory of features is that of Jakobson et al. (1952), though it was supplanted by the theory outlined in the book The Sound Pattern of English (Chomsky and Halle 1968), most of whose features have stuck around to this day. (Phonologists affectionately refer to the Sound Pattern of English as the SPE.) The main difference between these two feature theories is that the Jakobson, Fant and Halle theory refers to acoustic characteristics of sounds, whereas the SPE feature set mostly refers to articulatory characteristics. In practice, it is possible to characterize many features in either acoustic or articulatory terms, although it is harder for some of them than for others. You will see examples of such characterizations throughout the following discussion.

[1] If you would like more background, a good place to start is to read chapters on features in recent and classic phonology textbooks such as Kenstowicz and Kisseberth (1979), Kenstowicz (1994), Spencer (1995),Odden (2005), Hayes (2009), and Zsiga (2012). There are also targeted survey chapters in the first volume of Blackwell Companion to Phonology (van Oostendorp et al. 2011). If your memory of phonetic symbols is rusty, I recommend (re-)reading a good phonetics textbook such as Ladefoged and Johnson (2014), or at least an introductory chapter on phonetics in one of the phonology textbooks. Those of you with more background will benefit from reading about more modern approaches to the theory of features (Mielke 2008, Dresher 2014).

Innate or learned? The main sources of controversy in discussing features are (i) whether they are universal, and (ii) whether the main goal should be to characterize both contrasts and natural classes.

On the universality issue, the strongest view is that features are universal and innate; this is meant to explain why there are certain patterns that could be defined acoustically or articulatorily but are not attested in phonological typologies. My impression is that this view has been weakening over the past couple of decades—in part, this is because there appear to be some rare patterns or contrasts that are attested in one or two languages, and it seems unlikely that the features that define them could be universal. The other reason for this is that phonologists have made strides in understanding how certain phonological universals could arise as a result of learning from data and experience. This has been debated in phonology for some time, but similar questions arise in morphosyntax. For example, are the distinctions in number (singular vs. plural, or singular vs. dual vs. plural) innate and universal, or are they learned? What about the various distinctions in gender, tense, evidentiality, etc.? If it is possible to learn a feature, then the argument for its innateness is rather weak. So the middle ground view between the all-innate and all-learned positions is that there is a basic set of features that most languages will use and learners will be likely to discover, but any distinction that can be acoustically discriminated by the human ear can be encoded by a feature on a language-specific basis.

As far as the contrasts/natural classes issue goes, you will see in the examples to come that not all features capture both contrasts and natural classes. Some of the features distinguish sounds that contrast in many languages and group them into natural classes that pattern together in constraints and rules. There are other features, however, that seem to be useful mainly for characterizing contrasts—they define odd natural classes that are not supported by evidence from rules or constraints.

2 The main features

We start with the most basic features, slicing up the space of speech sounds into the largest classes, and gradually move on towards finer and finer distinctions.

2.1 Manner features

2.1.1 Consonantal

The feature [±consonantal] divides sounds into two large natural classes: consonants and vowels. All languages have sounds from both of these categories, and evidence for their distinct patterning is not difficult to find. For example, in languages such as Spanish and Polish, there are as many syllables in a word as there are vowels, and consonants are not syllabic. Many rules refer to consonants and vowels in their context, too: for example, in languages such as Yoruba, a vowel is inserted after any consonant that is not already followed by a vowel.

(2) Example of a rule referring to [consonantal]: Yoruba loanwords

dikiri:	‘decree’	si:ki	‘sick’
gase:ti	‘gazette’	risi:ti	‘receipt’
adire:si	‘address’	pailoti	‘pilot’

We can encode this in a rule that specifies that a vowel is inserted (in SPE notation, you turn a zero into a segment) when a [+consonantal] segment is followed by another [+consonantal] segment or a word boundary (#); the rule specifies that the vowel is [i] by giving it the features [high] and [−back] (discussed later, when we get to vowels):

(3) SPE-style rule: $\varnothing \rightarrow \begin{bmatrix} -\text{consonantal} \\ +\text{high} \\ -\text{back} \end{bmatrix} / [+\text{consonantal}] \_\_ \begin{Bmatrix} \# \\ +\text{consonantal} \end{Bmatrix}$

The distinction between consonants and vowels is so basic that the feature [±consonantal] is not even usually written out in full—we use C for [+consonantal] segments and V for [−consonantal] ones instead.

In terms of acoustic and articulatory correlates, the distinction between vowels and consonants is not binary but forms continuum: the most vowel-like segments are articulated with an open vocal tract and periodic vibration of the vocal folds, and the most consonant-like ones are articulated with closure in the vocal tract, and the acoustic signal is aperiodic. While the feature [consonantal] is basic and uncontroversial, the analysis of specific languages sometimes makes it difficult to decide whether individual sounds are consonants or vowels. The segments that are most ambiguous in their consonant/vowel status are glides, sometimes called "semivowels" (see §5.1.1); another example would be the 'apical vowels' of Mandarin, which resembles English [ɻ] (see Lee-Kim 2014).

2.1.2 Sonorant

The feature [±sonorant] is used to distinguish sonorants from obstruents. The class of sonorants includes vowels, glides, liquids, and nasals. The class of obstruents includes affricates, fricatives, and stops. All known languages distinguish at least some sonorant consonants from obstruents produced at the same place of articulation. For example, [b] is [−sonorant], and [m] is [+sonorant]. It is difficult to come up with a contrast in [sonorant] alone, however, since it is usually accompanied by differences in some other features, such as voicing, nasality, laterality, or stridency.

There is lots of evidence for the natural classes of sonorants and obstruents from patterning in constraints. For example, in English, sonorants may be syllabic but obstruents cannot be (e.g., [bʌʔn̩] 'button', [bɑrm̩] 'bottom', [bɻ̩d] 'bird', [bɑɾl̩] 'bottle'. In Spanish, a word can only begin in a consonant cluster if the first consonant is an obstruent and the second consonant is a sonorant.

(4) Spanish word-initial consonant clusters

[−sonorant]	[+sonorant]	
f	l	flaxelar
b	r	braka
p	j	pjamos
d	w	duoðena

Likewise, in many languages, the class of obstruents can exhibit special behaviors. For example, in Russian, only obstruents can contrast for voice. By the same token, in Russian, obstruents but not sonorants devoice in word-final position, and obstruents but not sonorants trigger voicing assimilation:

(5) Russian obstruents: contrast and patterning in rules

g̲ol	'goal'	zg̲olom	'with (a) goal'
k̲ol	'spike'	sk̲olom	'with (a) spike'
mul	'mule'	sm̲ulom	'with (a) mule'
koz̲a	'she-goat (nom sg)'	kos̲	'she-goat (gen pl)'
kos̲a	'scythe (nom sg)'	kos̲	'scythe (gen pl)'

The natural class of sonorants is easy to define either articulatorily or acoustically. Sonorants are articulated with a relatively open vocal tract, whereas for obstruents, some obstruction of airflow—either total or partial, as in fricatives—is necessary. This obstruction is the source of the name "obstruents". Acoustically, sonorants have a higher intensity compared to obstruents, and they have periodic waveforms, whereas obstruents tend to be characterized by aperiodic noise. (There are exceptions to this—for example, voiced stops can be periodic during closure in languages with true prevoicing). Just like [consonantal], this feature is not controversial, but the status of individual segments as sonorants or obstruents is sometimes debated; the sound transcribed as [v] is often ambiguous between the two (see 7).

2.1.3 Nasal

The feature [nasal] defines the class of sounds such as [m, ɱ, n, ɲ, ɳ, ŋ, ɴ]. The nasal natural class also includes nasalized vowels such as [ẽ]; other sounds (typically sonorants) may be nasalized as well, though rarely contrastively. Most languages have at least some nasals, but several languages of Northwestern North America, such as Ditidaht, lack nasals in their inventory.

Both vowels and consonants can contrast for nasality. In English, the initial segments of [bʌt] and [mʌt] contrast for nasality (and also for [sonorant]). Perhaps the cleanest kind of example of a purely [±nasal] contrast is in vowel systems. In a language like French, nonhigh vowels may be either nasal or oral: e.g., [mɔ̃d] 'world' vs. [mɔd] 'fashion', or [tabl] 'table' vs. [tãpl] 'temple'.

In rules, [+nasal] consonants are often targets for place assimilation; for example, in Japanese and many other languages, a nasal always has the same place of articulation as the following stop: [mb], [nd], [ŋg] are allowed, but [md], [ng], etc. are not. Nasal consonants are also special in Japanese in that they are the only consonants that can occur in word-final position or before other consonants.

Articulatorily, nasals are easy to define—they are sounds produced with air coming out of the nose. This requires the velum to be lowered, so that the nasal cavity is open for air to enter.

Acoustically, nasals sometimes look quite similar to other sonorants, but they can be recognized by the somewhat lower intensity than liquids and vowels. Nasals also have formants with areas that are darker ("poles") and lighter ("zeroes") on a spectrogram. These arise because some of the resonances in the nasal cavity cancel out the ones in the mouth, and others amplify them. You can see this pole/zero effect in nasalized vowels, as well, which messes with the perception of their height—compare the diphthong [aɪ] before an oral fricative and a nasal stop. The poles and zeroes can be seen in the nasal as well as in the vowel:

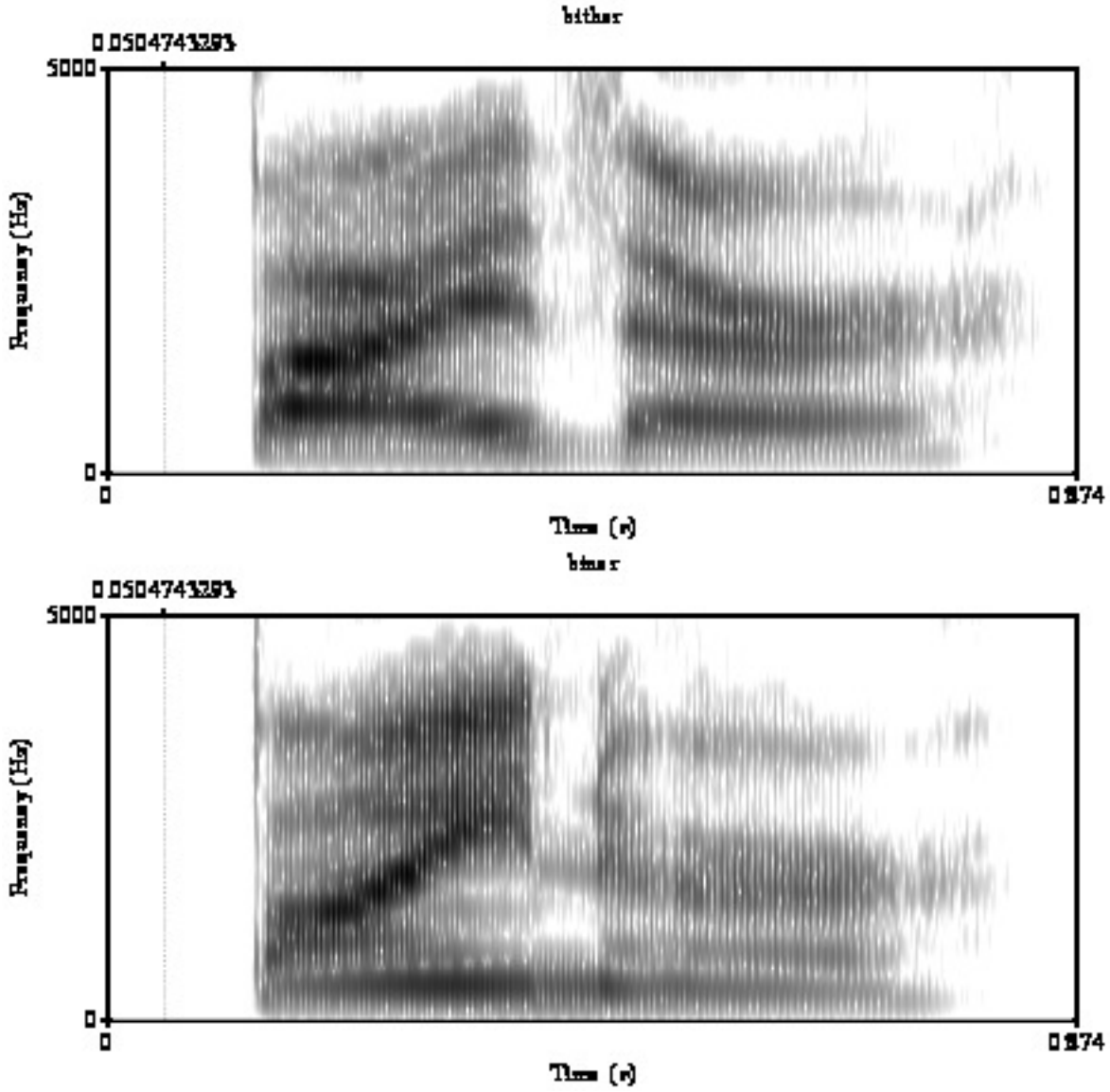


Figure 1: Nasal poles and zeroes: [baiðɚ] vs. [bãĩnɚ] (nonce words pronounced by an American English speaker)

2.1.4 Continuant

The feature [continuant] refers to sounds that have a continuous oral airflow, such as fricatives [f, s, ʃ, h, x], [l], [r], and glides. Non-continuant sounds include oral and nasal stops. In practice, this feature is most often used to distinguish fricatives, which are [+continuant], from plosive oral stops, which are [−continuant]. Many languages contrast stop and fricative sounds that are otherwise the same; for example, Russian and Greek have a velar stop, [k], but also a velar fricative, [x], and they differ only in the value of [continuant]. In Russian, there are plenty of minimal pairs for this contrast: [sok] 'juice' vs. [sox] 'dried', or [kor] 'bark (gen pl)' vs. [xor] 'choir (nom sg)'.

The feature [continuant] often figures in rules of lenition, where stops become fricatives in certain environments. For example, in Gascon, voiced stops are allowed word-initially, but between vowels, only voiced fricatives are allowed; e.g., [d̲uso] 'sweet' cannot be pronounced *[ð̲uso], and [puð̲e] 'to be

able' is not *[pud̲e]. In English, fricatives sometimes assimilate to following nasals in continuancy (e.g., "bus̲iness" and "does̲n't" pronounced with a [d] instead of [z]).

In terms of articulatory correlates, [+continuant] requires the air to come out of the mouth, whereas [−continuant] means oral closure. It is harder to define [−continuant] acoustically—while for voiceless stops, there is an actual discontinuity on the waveform, voiced stops can involve vocal fold vibration throughout the duration of closure in some languages. Nasals and liquids also look similar acoustically, even though they differ in their [continuant] values based on the articulatory definition of the feature.

2.2 Laryngeal features

As the name suggests, laryngeal features characterize the state of the larynx during articulation, and most of the distinctions concern the class of obstruents. The phonology of laryngeal contrasts is rather rich, and there is a lot of controversy among phonologists about the precise nature of laryngeal features, too, so we focus on the basics here—see §§5.1.7, 6, and 7 for more.

2.2.1 Voice

The feature [voice] separates sounds into [−voiced] and [+voiced]; the voiceless[2] group includes [s, f, p, t, k], and the voiced group includes [z, v, b, d, g]. The Russian example in §2.1.2 demonstrates both the contrast in this feature and its role in rules: there is a contrast for voicing, but in certain environments, obstruents are obligatorily voiced or obligatorily voiceless.

Articulatorily, [−voiced] sounds are pronounced with an open glottis, whereas [+voiced] ones are produced with vibration of the vocal folds. In Russian, this is actually true even of word-initial stops, which are noticeably prevoiced. Here is a waveform of the word [bərebán] "drum", which shows about 6 ms of voicing during closure for the first [b] and voicing throughout the entire closure for the second [b]:

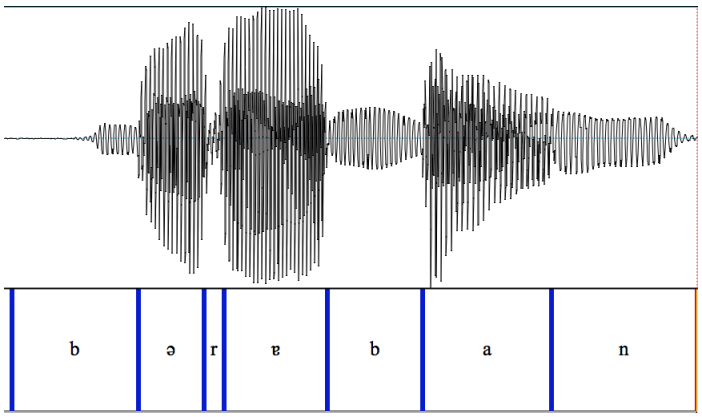


Figure 2: A waveform of obstruent voicing in Russian

Acoustically, voicing is energy at the fundamental frequency level—the direct result of vocal fold vibration. You can even see this energy as a dark band at the bottom of the spectrogram of aperiodic fricatives—look at the [ð] in [baɪðɚ], Fig. 1.

The status of the [voice] feature in sonorants is controversial (see 5.1.7). One of the debates is about whether the feature is even specified for sonorants, since they so rarely (if ever) contrast for it. The other area of controversy is whether it is appropriate to use the feature [voice] to analyze languages like English, which really contrast stops for aspiration rather than prevoicing (see 7).

[2]The term is "voiceless". Real phonologists do not use "unvoiced".

2.2.2 Spread glottis

The feature [spread glottis], or [sg] for short, defines the class of aspirated consonants such as [pʰ, tʰ, kʰ]. Languages such as Thai have a three-way laryngeal distinction in their obstruents: some consonants are voiced, some are aspirated, and some are neither:

(6) Thai near-minimal pairs for voicing and aspiration:

t̲it 'get stuck' d̲ii 'good' t̲ʰee 'pour'

Just like voicing, [sg] distinctions are often neutralized positionally. Thus, in Thai, aspirates and voiced stops can occur word-initially, but only plain stops occur word-finally—there are no words such as *[titʰ] or *[tid].

The feature's name derives from its articulatory definition: just like voiceless sounds, aspirated consonants are pronounced with an open glottis. The main acoustic difference between plain voiceless and aspirated consonants is in the timing of voicing with respect to closure: after the release of a voiceless stop into a vowel, voicing starts right away, whereas for aspirated consonants, there is a delay in the onset of voicing. Acoustically, therefore, this long Voice Onset Time (VOT) is the main property that spread glottis consonants have in common.

2.2.3 Constricted glottis

Constricted glottis, or [cg], is the third feature in the laryngeal set. It is used to characterize ejective consonants such as [p', t', k'], as well as implosive consonants such as [ɓ, ɗ, ɠ]. Languages such as Quechua have both ejectives and aspirates alongside "plain" stops, which are neither:

(7) Quechua ejectives and aspirates:

p̲'uɲu 'jug' p̲ʰiri 'type of food' p̲uka 'red'

Languages that have such contrasts often restrict them to certain environments. Georgian distinguishes voicing, aspiration, and ejection in its consonant inventory, and consonants can be combined into some unusual clusters word-initially (much as in Russian), but all the consonants have to have the same [sg], [cg], or [voice] feature:

(8) Georgian aspiration, voicing and ejection in clusters (Chitoran 1998)

p̲'k'ureba	'to sprinkle'	b̲g̲era	'sound'
t̲ʰk̲ʰma	'to say'	d̲y̲veba	'to spread butter'

Just like [spread glottis], [constricted glottis] takes its name after the feature's articulatory definition; whether the sound is implosive or ejective, it is pronounced by initiating the airflow by moving the constricted glottis rather than by exhaling from the lungs. Acoustically, ejectives vary a lot between languages, but they usually have a fairly loud visible burst and a longer VOT than plain stops. The feature has a different phonetic expression, however, when used for sonorants (see §5.1.7).

(9) A chart summarizing contrasts and specifications for laryngeal features

	voice	spread glottis	constricted glottis
p	-	-	-
p^h	-	+	-
p'	-	-	+
b	+	-	-
ɓ	+	-	+

2.3 Place features

The number of distinctions that languages make in consonantal place of articulation is great, but most languages require at least some way to differentiate the three major places: *labial*, for sounds made with the lips, vs. *coronal*, for sounds made with the front part of the tongue, vs. *dorsal*, for sounds made in the posterior part of the vocal tract using the body of the tongue. These are discussed in turn, with further distinctions within these groups taken up after vowel features.

An interesting aspect of this grouping is that it is much easier to characterize these groups in articulatory terms than in acoustic ones. Jakobson et al. (1952) define coronals as having an acoustic spectrum that is tilted like the acute diacritic (á), whereas dorsals and labials have a spectrum that is tilted like a grave diacritic (à). This is true of some consonants in some contexts, but it does not generalize. Thus, the search for acoustic cues for major place of articulation in phonetic research has turned up some context-specific cues, but it has been difficult to identify cues that do not depend on the context in which the sound occurs. This is an advanced topic in phonetics, so we will focus on the phonological arguments for the feature groupings and their articulatory definitions.

2.3.1 Labial

Sounds defined by the feature [labial] include bilabials and labiodentals such as [p, b, f, v, m, ɱ, ɸ, ɓ, β, w, ʍ]—the commonality is that all of them are articulated with active involvement of the lower lip. The evidence for this natural class is plentiful, both from patterning in rules/constraints and from contrasts.

As mentioned above, most languages contrast some labials and non-labials. For English, [m] contrasts with [n] in [mæp] and [næp], for example; [m] also contrasts with [ŋ] in [hæm] vs. [hæŋ]. Such examples are easily multiplied for stops, fricatives, and so on in most languages. To my knowledge, no spoken language lacks labials. The reasons for this are interesting to ponder. One possible explanation is that lips are such an obvious articulator that children almost cannot fail to acquire labial sounds in their language; they certainly appear very early in infant speech (Jakobson 1941 et seq.). Labials also have the advantage of requiring little refined motor control; even the questionable 1950's "experiments" attempting to teach Vicky the Chimp speech succeeded in teaching her to approximate articulations for "mama" and "papa" (as well as "cup", which sounded more like a cough than [kʌp]).

Back to phonology: labials pattern as a natural class in English phonotactics. Two labial consonants tend to not occur in word-initial position: words beginning with [bw], [pw], [mw], and [fw] are underattested in Engish. Labials sometimes dissimilate over longer distances, as well: some languages restrict how freely labials can combine in adjacent syllables.[3]

[3]Somewhat surprisingly, it is fairly rare to find a phonotactic pattern where labials pattern to the exclusion of dorsals (e.g., bans on these place specifications in coda position tend to go hand-in-hand), although this is usually taken to be an argument for the class of coronals—labials and dorsals may pattern together simply because the relevant condition is on coronals, and not because labials and dorsals are a natural class.

A different type of argument for the class, however, comes from preservation of labiality in rules. When a phonological rule applies to a labial and affects its manner of articulation, it is going to stay a labial, even if its minor place of articulation (bilabial vs. labiodental) changes. In Irish, there is a rule of mutation that changes stops to fricatives and nasals to corresponding glides. When labials are thus affected, they may alternate between bilabial and labiodental and labiovelar, but they still stay labial:

(10) Irish mutation: a labial stays a labial (Ni Chiosain 1991)

po:stə	'married'	inʲfo:stə	'marriageable'
bʲaləx	'a way'	mo:rvʲaləx	'a highway'
ma:lə	'a bag'	məwa:lə	'my bag'

Patterns like this are difficult to characterize using a single rule if all you have is phonetic terminology. Armed with the feature [labial], we can say that a [−continuant] becomes [+continuant], and nothing happens to labial place of articulation, voicing, or the value for [sonorant]. If all we have are phonetic terms, however, we have to list that bilabial stops become labiodental fricatives and bilabial nasals become labiovelar glides. Here, having features such as [labial] allows us to abstract away from minute phonetic distinctions and add analytical insight and generality.

2.3.2 Coronal

Sounds that are [coronal] are named after the "corona" (crown) of the tongue—made with the front part of the organ (tip or blade) rather than its body (dorsum). The word is pronounced ['koɹənl̩], not [kə'ɹoʊnl̩]. Coronal sounds include [t, d, s, z, ʧ, ʤ, ʦ, ʣ, ʃ, ʒ, ʂ, ʐ, n, l, ɬ, ʎ, r, ɻ] and many others; this is indeed a crowded area of the IPA chart and many languages have multiple coronals but only a couple each of labials and dorsals, if any.

The evidence from contrast for this feature is robust, and it is easy to find minimal pairs for contrasts for place of articulation between coronals and non-coronals of the same manner of articulation in English. It should be noted, however, that some languages lack certain common coronals. Hawaiian famously does not have a [t] but has [p, k, ʔ]. But even Hawaiian has the coronals [n] and [l], and there is a contrast between [m] and [n].

Evidence for the natural class [coronal] abounds in rules and constraints. In Arabic, the definite determiner is [ʔal]. You have encountered it in "Al Qaeda" and various borrowings from Arabic into English, such as "algebra", "alchemy", "alcohol", and "algorithm". Before coronals, however, the determiner is realized as [ʔa] plus a lengthened consonant; thus, the [l] in "Al Jazeera" is not actually pronounced in Arabic—just ask any Arabic speaker. As the next batch of examples show, then, the coronal [l] completely assimilates to the following coronals, but not to the following labials or dorsals or pharyngeals:

(11) Arabic "Sun and Moon" pattern

Arabic	*Gloss*	*Arabic*	*Gloss*
ʔaʃʃams	'the sun'	ʔalqamar	'the moon'
ʔattiʤa:ra	'the commerce'	ʔalbadw	'the Bedouin'
ʔaθθaqa:fa	'the culture'	ʔalfilfil	'the pepper'
ʔaddi:n	'the religion'	ʔalħaðˤ	'the luck'
ʔaððahab	'the gold'	ʔalxardal	'the mustard'
ʔarrab	'the lord'	ʔalɣarb	'the west'
ʔazzuhu:r	'the flowers'	ʔalkanz	'the treasure'

In many languages, word-final consonants can be coronal but not labial or dorsal. This is true of Finnish, where [t, s, n, l, r] can occur in word-final position, but [p, k, ʋ, m, ŋ, h, ʔ, j] cannot.

(12) Finnish final consonants

saajan	'beneficiary'	raadit	'panel, jury'
taival	'leg'	laulajatar	'songstress'
pæætøs	'decision'		

Patterns that affect all coronals provide some the clearest arguments that we need phonological features and that phonetic descriptions alone will not do. In terms of acoustic and articulatory detail, coronals are quite diverse; what makes them a natural class is an abstract feature.

2.3.3 Dorsal

Dorsal consonants include velars and uvulars, such as [k, g, x, q, χ, ɠ, ɣ, ʁ, ŋ]. The dorsal class is defined as being articulated with the dorsum, or the tongue body. As with labials and coronals, the evidence for [dorsal] from phonological contrasts is easy to find, since most languages have at least some consonants made in the dorsal region. Acoustically, dorsals are characterized by formant "pinching" in the transitions into and out of vowels.

When dorsals are targeted as a class by phonological rules, they are often undergoers of a rule that other consonants do not undergo. For example, word-final dorsals are replaced with glottal stops in Malay, while no other consonants are affected.

(13) Malay final consonants

Word-final /k/ becomes [ʔ]:	Gloss	With V-initial suffix:	Other consonants	
baiʔ	'good'	kə-baik-an	atap	'roof'
didiʔ	'educate'	didik-an	ikat	'to tie'
pendeʔ	'short'	kə-pəndek-an	sakat	'parasitic plant'

The dorsal class includes velars and uvulars, but it is less clear whether other consonants (such as palatals and pharyngeals) belong to it; the boundaries of the class and the evidence for them are controversial. In this class, we will treat palatals such as [j] as coronals; it is fairly standard to do so.

3 Vocalic features

Vowels are mainly distinguished articulatorily by rounding, backness, and height; some additional distinctions that the IPA chart casts in terms of height are handled by appealing to tongue root position.

3.1 Round

Round vowels involve lips as an active articulator. If lips are rounded, as in the articulation of [u, o, œ, ø, y, ʏ] and so on, then the vowel is classified as [+round]; all other vowels are [−round]. In acoustic terms, rounding correlates with a lower third formant, although rounding tends to depress all three formants.

In English, all rounded vowels are non-low and back, and all non-low and back vowels are rounded (just about—with the exception of [ʌ]). In order to have a contrast in rounding alone, a language must have front rounded vowels or back unrounded ones. Hungarian is such a language, with minimal pairs such as [bø:r] 'skin, leather' and [be:r] 'wage'. Both of these vowels are front, but [ø] is rounded and

[e] is not. For a contrast in rounding for back vowels, any language that has both [ɯ] and [u] (such as Mongolian) would be an example.

Rounded vowels often pattern together phonologically in languages that have rounding harmony. In Kyrgyz words, all the vowels have to be either rounded or unrounded.

(14) Kyrgyz vowel harmony for [round]

bir	'one'	birinʧi	'first'
eki	'two'	ekinʧi	'second'
yʧ	'three'	yʧynʧy	'third'
tørt	'four'	tørtynʧy	'fourth'
beʃ	'five'	beʃinʧi	'fifth'
altɯ	'six'	altɯnʧɯ	'sixth'
ʒeti	'seven'	ʒetinʧi	'seventh'
on	'ten'	onunʧu	'tenth'

3.2 Back

Backness is determined by the position of the tongue when the vowel is articulated. Vowels that are [+back] include [u, ɯ, o, ʊ, ɔ, ɑ, ʌ]. Vowels that are [−back] include [i, y, ɪ, e, ɛ, æ]). By convention that goes back to the *Sound Pattern of English*, the name of the feature is [back] rather than [front]. The latter term is used only descriptively. Acoustically, backness is correlated with the distance between the second formant and the first: the bigger the difference, the fronter the vowel.

A simple example of a backness distinction would be from a language that has both back and front rounded vowels, such as Hungarian. Along with [be:r] and [bø:r] (previous section), Hungarian also has [bo:r] 'boron (the chemical element)'. The feature [back] is phonologically active in the Kyrgyz vowel harmony example in the previous section; look at the vowels again, and you'll see that all of them are either back or front depending on the word.

On the IPA chart, there is a three-way distinction in backness between front (e.g., [i]), central (e.g., [ɨ]), and back vowels (e.g., [u] and [ɯ]), but phonologists for the most part agree that only one backness feature is needed to capture the contrasts and the natural patterns. In most languages that have central vowels, they pattern with back vowels or else pattern as a separate natural class; thus, the vowels [ɨ] and [ə] are often singled out for their low sonority, correlated with their short duration. In the vast majority of languages, it is possible to make all the contrastive distinctions with some combination of [±back] and [±round] as well as the height features. See §5.2.2 for more on central vowels and rare backness contrasts.

3.3 Height

Vowel height is a function of the position of the jaw and the tongue. To make a three-way distinction in height between high vowels such as [i, u] and mid vowels such as [e, o] and low vowels such as [æ, ɑ, a], only two binary features are needed; [±high] vs. [±low]. Mid vowels then have minus values for both high and low, and high vowels are [+high, −low], whereas low vowels are [+low, −high]. The combination [+low, +high] is not used in human speech because the tongue can only be in one position at a time. (This is in contrast to doubly articulated consonants such as [w] or [k͡p], which involve simultaneous constriction at the lips and the tongue body.) Acoustically, height is inversely correlated the first formant: the higher the first formant, the lower the vowel.

Three-way height contrasts between vowels are common—as in the English triplet [bɪt], [bɛt], [bæt]. It is also commonplace for height to play a role in phonological rules and constraints. For example, in

Cairene Arabic, the high vowels [i, u] delete in certain contexts but the low vowel [a] is unaffected:

(15) Lebanese high vowel syncope (Broselow 1976)

saaħib	'friend (m)'	taakul	'you (m) eat'	katab	'he wrote'	fihim	'he understood'
saħba	'friend (f)'	takli	'you (f) eat'	katabu	'they wrote'	fihmu	'they understood'
saħbiin	'friends'	taklu	'you (pl) eat'	katabit	'she wrote'	fihmit	'she understood'

It is also common for mid vowels to pattern differently from the non-mid ones; in Belarusian, for example, mid vowels are not allowed in unstressed syllables:

(16) Belarusian unstressed vowel reduction (Crosswhite 1999)

nóɣi	'legs'	naɣá	'leg'
kól	'pole (nom)'	kalá	'pole (gen)'
vʲósnɨ	'spring (gen)'	vʲasná	'spring (nom)'
mʲót	'honey (n)'	mʲadóvɨ	'honey (adj)'
ʃépt	'whisper'	ʃaptátsʲ	'to whisper'
réki	'rivers'	raká	'river'

3.4 ATR

The IPA chart makes a multivalued distinction in height among close (e.g., [i, u, y]), close-mid (e.g., [e, o]), open-mid (e.g., ɛ, ʌ, ɔ), and open vowels (ɑ, æ), with some vowels floating somewhere between these levels (e.g, [ə] is between close-mid and open-mid, and [ɪ, ʊ] are betwen close and close-mid). To make distinctions beyond the three-way height cut-up established by [high] and [low], we use the feature [ATR], which stands for "Advanced Tongue Root".

The set of [+ATR] vowels includes [i, u, e, o]; their [-ATR], or retracted tongue root counterparts are [ɪ, ʊ, ɛ, ɔ]. In the IPA chart, the [-ATR] vowels appear lower than the [+ATR] vowels; the easiest mnemonic for it is to remember that the tongue is a bag of water. When you push the bag, I mean the tongue, down to make a slightly lower vowel, it will squish down and push out at the tongue root—because it has a constant volume. Thus, in higher vowels, the tongue is advanced forward, and in lower vowels, the tongue is retracted. The acoustic counterpart of this distinction is formant structure, though since this feature is used to cut up the height continuum into non-contiguous areas, formants alone cannot be used to isolate just the [-ATR] vowels.

In languages that do have an ATR contrast, it sometimes goes hand-in-hand with a rule that requires all vowels to be [+ATR] or [−ATR]. For example, in African languages such as Wolof and Pulaar, there is a contrast between the vowels [o]∼[ɔ] and [e]∼[ɛ], but there is also a rule that refers to them: they cannot co-occur in the same word. The feature [ATR] is not controversial for these languages, but it is controversial for English, for reasons explained in §5.2.1.

Many languages have only five vowels, often drawn from the set [i, u, e, o, a]. In such systems, it is normal for high vowels to be [+ATR] and for low vowels to be [-ATR] (much the same way that rounding and backness often go hand-in-hand). Mid vowels can be pronounced as either [ɛ] and [ɔ] or [e] and [o]—Russian and Polish are sometimes transcribed with either sets of symbols. In practice, if there is no contrast for [ATR] in a language, the feature is not used in the language's phonology.

4 Minor features

The next set of features is used to make further distinctions within natural classes defined by the major features.

4.1 Minor consonantal features

4.1.1 Lateral

The feature [lateral] separates the class of liquids into l-like sounds such as [l, ʎ, ʟ], which are [+lateral], and rhotics such as [r, ɾ, ɹ, ɻ, ɺ], which are [−lateral]. Some obstruents, such as the fricatives [ɬ, ɮ], are also [+lateral]. Lateral sounds are articulated with one or both sides of the tongue lowered and the middle raised. For rhotics and non-lateral fricatives, the articulations vary quite a bit, so it is difficult to define them by any positive articulatory common feature; it is really the opposition to laterals that defines them. Normally, the feature [lateral] is understood as being specified only to coronals, because it is difficult to impossible to articulate labials and dorsals with lateral airflow. We treat the other sounds as neither [+lateral] nor [−lateral]—you could say they are [0 lateral].

The feature [lateral] is necessary to characterize alternations such as the following, from Ganda. In this language, [l] and [r] are in complementary distribution, determined by the preceding vowel:

(17) Ganda liquid alternations

kola	'do'	wulira	'hear'	oluganda	'Ganda language'
wawa:bira	'accuse'	olulimi	'tongue'	lagira	'command'
ebendera	'flag'	lu:la	'ruler'	le:rwe	'railway'
sa:fali	'safari'	lwana	'lwana'	be:ra	'help'
bu:lira	'tell'	ʤukira	'remember'	lja	'eat'
erjato	'canoe'	lu:la	'sit'	omuliro	'fire'
omugole	'bride'	effirimbi	'whistle'	lumonde	'sweet potato'
emme:ri	'ship'	eddwaliro	'hospital'	eraddu	'lightning'

You might expect lateral fricatives and affricates to pattern with lateral liquids in a natural class, but lateral fricatives are relatively unusual cross-linguistically, so the evidence for the natural class that includes [l, ɬ] to the exclusion of other sonorants and fricatives is hard to come by.

Acoustically, lateral sonorants can resemble nasals, but they are louder and have more defined formant structure. English [l] and [ɹ] are differentiated by the third formant value; trills in other languages have distinct periodicity in the waveform as a result of the tongue flapping in the wind. There is no common acoustic correlate that would group liquid laterals and obstruent ones, however.

4.1.2 Strident

Stridents, or sibilants, include sounds such as [s, z, ʃ, ʒ, ʂ, ʐ, ʦ, ʣ, ʧ, ʤ, ɕ ʑ]. Acoustically, stridents have in common a concentration of aperiodic energy at high frequencies. This was the only feature in the SPE that had a primarily acoustic rather than articulatory definition. Articulatorily, these sounds involve creating a double obstruction to airflow, sometimes referred to as the "jets-and-baffles" articulation pattern—for [s], for example, airflow speed increases after passing the first obstruction (jet) created by the tongue and the alveolar ridge, and turbulence is created when the airflow hits the secondary obstruction (baffle) created by the front upper teeth. Teeth are indeed instrumental in creating all coronal stridents.

Stridents are often special in phonotactic patterning, and they pattern as a natural class that excludes all other sounds. A simple example from English that illustrates the natural class status of stridents is the

possessive suffix [s/z/əz]: it is [-əz] whenever the base ends in a strident [ʧ, ʤ, s, z, ʃ, ʒ]. Compare the possessives of "bus", "fish", "garage", "buzz", "latch", "bridge" and "ship", "back", "bat", "chef", "bun", etc. English also has enough coronal fricatives to demonstrate a contrast between strident and non-strident fricatives such as [θ] and [s], or [ð] and [z] (in "bathe" vs. "bays").

For the most part, this feature is uncontroversial when used for coronal stridents, but there is some disagreement as to whether it should be used for distinctions between non-coronals, such as [f, v] and [ɸ, β], or [x] and [h]. Under the articulatory definition of [strident], [f] and [v] fit in with the class: the "jet" is formed with the lower lip and upper teeth, and the upper lip creates the "baffle". But [f] and [v] do not have the high energy acoustic characteristics of stridents, and it would be hard to find convincing arguments that they form a natural class with stridents to the exclusion of other fricatives. See §5.1.5 for a practical suggestion.

4.1.3 Anterior

The feature [anterior] divides coronals into those articulated forward of the midpoint of the hard palate, [+anterior], vs. those articulated to the back of this midpoint, [−anterior]. The [+anterior] set includes alveolars and dentals such as [t, d, θ, ð, s, z], whereas [−anterior] includes palato-alveolars and palatals [c, ɟ, ʃ, ʒ, ʧ, ʤ] and retroflex consonants such as [ʈ, ɖ, ʂ, ʐ]. English contrasts fricatives for anteriority; in some languages, such as Navajo, all stridents in a word are required to be [+anterior] or [-anterior], but no word can contain [+anterior] and [-anterior] stridents at the same time. An example of the anteriority feature being manipulated comes from Kikongo, repeated below:

(18) Kikongo palatalization

tobola	'to bore a hole'	nselele	'termite'
tʃina	'to cut'	lolonʒi	'to wash'
kesoka	'to be cut'	zevo	'then'
ŋkoʃi	'lion'	aʒimola	'alms'
zeŋga	'to cut'	nzwetu	'our house'
ʒima	'to stretch'	kunezulu	'to heaven'
kasu	'emaciation'	tanu	'five'
tʃiba	'banana'		

The feature [anterior] had a different meaning in the *Sound Pattern of English* than it does today: it used to divide all consonants into two classes, one of which included labials and anterior coronals, and the other of which included dorsals and the rest of the coronals. It is now understood more narrowly as referring to coronals only; in part, this is because there is not much evidence for a natural class that includes labials and [+anterior] coronals but not [−anterior] coronals and dorsals.

Anteriority is acoustically correlated with some subtle characteristics of burst resonances in stops; for strident fricatives, it is straightforwardly correlated with the Center of Gravity (the average of the highest frequencies present in the signal). The more anterior a strident, the higher its CoG; you can hear this in [s] vs. [ʃ], where the first consonant sounds higher-pitched. It would be difficult to find an acoustic correlate of this minor place distinction that would distinguish the [+anterior] consonants [θ, s, t] from the [−anterior] consonants [ʃ, c, ʎ], however.

4.1.4 Secondary articulations on consonants

Secondary articulations on consonants involve the action of a non-primary articulator at the same time as some primary constriction is happening. For example, the lips can be rounded while the tongue is at

the alveolar ridge for a [t^{w}], yielding labialization. Other secondary articulations include palatalization (tongue body forward), velarization (tongue body towards the velum), and pharyngealization (pharynx constricted by retracting the tongue root). Secondary articulations can be robustly contrastive: thus, Russian contrasts palatalized and velarized consonants at most places of articulation. (Velarization is often not transcribed in discussions of Russian, but it is easy enough to hear as velarized consonants sound quite different from their neutral counterparts in other languages.)[4]

(19) Russian velarization-palatalization contrast

m^{j}at^{j}	m^{j}at^{ɣ}	m^{ɣ}at^{j}	m^{ɣ}at^{ɣ}
'to squash'	'mint (gen pl)'	'mother'	'swearword vocabulary'

Other languages have robust contrasts in labialization/rounding or pharyngealization. In many cases, the distinctions are thought to derive from vowels that were historically lost in the vicinity of the affected consonants: the loss of [u] leads to rounding on the preceding consonant; the loss of [i]—to palatalization, the loss of a back high vowel such as [ɨ]—to velarization, and the loss of [a]—to pharyngealization. Thus, the simplest way to analyze these distinctions using features is to allow consonants to bear the vocalic place features [round], [back], [high], and [low]. Palatalized consonants are [−back], and velarized ones are [+back]; pharyngealized consonants are [+low], and labialized ones are [+round].

This makes certain predictions about the affinity between such consonants and correponding vowels. In Russian linguistics, there is some debate about the status of high unrounded vowels [i] and [ɨ]. These are written with different letters and heard in words such as [m^{ɣ}ɨt^{j}] 'to wash', [m^{j}it^{j}] 'Mitya (vocative)' and [m^{ɣ}ɨt^{ɣ}] 'is washed', but is this a vowel contrast between [i] and [ɨ], or are the vowels different because the consonants preceding them are different? The consonants can contrast even word-finally, but [ɨ] does not occur except after velarization, which suggests [ɨ] is just an allophonic variant of [i]; the vowel assimilates to the preceding consonant in backness (see Padgett 2003). In fact, even the vowel transcribed as [a] in the minimal quadruplet above is actually closer to [æ] in the first two words, consistent with this pattern.

Extending vowel features to consonants allows us to capture further contrasts and patterns that we have neglected so far, such as distinctions within the dorsal class, including velars [k, x, g, ŋ] and uvulars [q, χ, ɢ, ɴ]. Based on the rather common pattern of vowel lowering near uvulars, they are usually treated as [−high], whereas velars are [+high]. In Quechua, for example, there is a three-way contrast between vowels [i, u, a], but [e] and [o] are found on either side of the uvulars [q, q', q^{h}]: [kiru] not *[keru] 'tooth', and [qeru] 'vase' not *[qiru].

5 Controversial distinctions

For the distinctions and features discussed in the remaining sections, phonologists disagree either about the need for the feature or about the proper feature to use for characterizing a contrast or a pattern. Some of these controversial features are needed for contrasts but not for phonological patterning; this is usually the case with the rarest contrasts. Another source of disagreement is the treatment of sounds that are articulatorily or acoustically similar but pattern differently from language to language, such as [ə]. I'll make practical suggestions for what features to use, but really you have to use your judgment. Remember that features are a theory about the content of people's heads, and we can't look inside—so when we disagree about features, we are debating different theories about phonological knowledge. A

[4] Yes, Russian really does have a monomorphemic word for "swearword vocabulary". This word is historically related to "mother", since swearing in Russian often involves saying unkind words about people's moms; this gives you [m^{ɣ}ət^{j}ir^{j}ítsə] 'to swear', from which [m^{ɣ}at^{ɣ}] is backformed.

good theory obeys Occam's Razor,[5] is supported by evidence, explains the existing facts, and makes predictions about facts not yet seen. A good set of features is also all of these things.

5.1 Consonantal distinctions

5.1.1 Glides vs. vowels

The distinction between glides such as [j, w] and corresponding vowels such as [i, u] is usually cast either in terms of syllable position or in terms of the feature [syllabic]. The [syllabic] treatment goes back to the SPE, where the feature was used to cross-classify vowels, glides, and true consonants as follows:

(20) The feature [syllabic] in the Sound Pattern of English

	[+syllabic]	[−syllabic]
[+consonantal]	syllabic consonants	non-syllabic consonants
[−consonantal]	vowels	glides

The problem with this approach is that syllabification varies by language; thus, the SPE feature [syllabic] had an awkward status where it had a cross-linguistically fixed meaning for glides and vowels but a language-specific and even context-specific meaning for true consonants. In English, the rhotic can be syllabic or not depending on its position: cf. [hɑɻm] and [hæ.mɻ]. This suggests that syllabic status is determined by rule rather being an inherent property of the sound, which is strikingly different from how other features work in the theory.

This approach was eventually replaced by redefining [syllabic] (and some people discard it altogether). The feature was needed in the SPE because syllables did not play a role in the theory, whose rule language did not even have a way to refer to syllables or their boundaries. This changed with the advent of more elaborate hierarchical representations in phonological theory (Kahn (1976) et seq.). For languages in which glides and high vowels alternate based on syllable position, as in Swahili below, the representational analysis treats them as featurally identical; the differences arise because vocoids are pronounced as vowels in syllabic nuclei and as glides in non-nuclei:

(21) Swahili glide-vowel alternations

Class 2 prefix /wa-/	Class 8 prefix /vi-/	
wazuri	vizuri	'nice'
wadogo	vidogo	'little'
warefu	virefu	'long'
waororo	vjororo	'soft'

[5] Occam's Razor is the reasoning principle that takes the simplest explanation to be correct. It is named after William of Ockham, who was born before the advent of consistent spelling of place names. The "razor" part is supposed to invite you to imagine slicing off unnecessary parts of a theory. "Occamite" is the adjective describing reasoning that is consistent with the principle.

(22) The glide-vowel distinction as a consequence of syllabification into the onset vs. the nucleus of a syllable

Some languages do distinguish vowels and glides contrastively: in Russian, [vójn] 'wars (gen pl) is monosyllabic, whereas vs. [vó.in] 'warrior (nom sg)' is disyllabic. To treat this contrast, syllabification would have to be posited underlyingly, but there are theoretical arguments for treating the distinction in terms of segmental features rather than underlying prosodic structure. One of the problems with specifying syllabicity underlyingly is that it is not clear why vocoids are apparently the only types of segments that can be so contrastively syllabified (see Levin 1985, Rosenthall 1994, 1997, Levi 2004, Padgett 2008).

Another issue with the feature [syllabic] is that it is difficult to define in either articulatory or acoustic terms, unsurprisingly so given the somewhat circular phonological logic behind its use in the SPE. In languages that have a contrast between glides and vowels, they are distinguished by constriction degree: glides are more constricted, shorter in duration, and have a different dynamic pattern of articulation (a shorter steady state in the formant structure). There is some indication that in languages that have a predictable glide-vowel alternation, the sounds are more similar, and the glides are more vowel-like.

For practical purposes, the feature [syllabic] can be convenient for analyzing glide-vowel alternations or contrasts, with the understanding that there is a lot more to this than the simple feature treatment would suggest.

5.1.2 Approximants as a class

The feature [approximant] is marginal in the theory because it is unnecessary for singling out the natural class of approximants (vowels, glides, and liquids). Approximants are just as easily captured with a combination of features, [+son, −nasal]. Thus, the feature seems to be redundant by Occamite reasoning. The feature is useful in talking about levels of the sonority hierarchy, however. The sonority hierarchy arranges sounds by manner of articulation approximately by most airflow to least, and when recast in terms of distinctive features, greater sonority can be understood as having more positive specifications for certain manner features. If [approximant] is available as a feature, then many sonority distinctions emerge without positing a sonority hierarchy as a primitive; the features define all the patterns and the implicational universals concerning sonority. This approach also requires replacing [consonantal] with its inverse, [vocalic]—and once that switch is made, there is a generalization: the more sonorous a sound, the more pluses it has for the big manner features.

(23) Sonority hierarchy derived as natural classes defined by features (Clements 1990)

	most airflow				least airflow
	vowels	glides	liquids	nasals	obstruents
[syllabic]	+	-	-	-	-
[vocalic]	+	+	-	-	-
[approximant]	+	+	+	-	-
[sonorant]	+	+	+	+	-

The specification of some approximants for the feature [continuant] is also worth mentioning here as controversial. If [continuant] is defined articulatorily, then laterals should pattern with continuants—there is airflow through the mouth. But depending on the diagnostic, they do not always pattern with continuants in all languages. This either means that the specification for this feature is done on a language-specific basis or perhaps that [continuant] is not the right feature to capture the patterns in question (see Mielke 2005a).

5.1.3 Exotic distinctions among coronals

Some features have been called upon to analyze fine-grained contrasts within the class of coronals. For example, some languages distinguish dental and alveolar stops: Bengali contrasts [t̪] and [t], and Hindi distinguishes [t̪] and [ʈ]. For the dental-retroflex contrast, the feature [anterior] can be used, but for dentals and alveolars, another feature is necessary, since they are both [+anterior]. The dental-alveolar contrast has been captured with the feature [distributed], which distinguishes sounds articulated with the tip vs. the blade of the tongue. The name of this feature refers to the area of contact between articulators: in a [+distributed] segment, the area is large, whereas in a [−distributed] segment, it is small and compact. If you can articulate a dental and an alveolar stop and have the requisite degree of proprioception to feel the difference, you can ascertain this for yourself; a more scientific method would use palatography or another imaging technique.

The [distributed] feature is not so much controversial as arcane, since it is primarily used for such contrasts and rarely (if ever) captures phonological class behavior. The natural classes it defines are somewhat odd: based on the articulatory definition, [+distributed] includes dentals and palato-alveolars [θ, t̪, ʃ, ʒ, ʧ], whereas [−distributed] includes alveolars and retroflexes [s, z, ʈ, ʂ, ɖ]. Even if a language has some sounds from each category, it may be hard to come up with an example in which these groups of sounds pattern as natural classes. It is also unlikely that this feature has clear acoustic correlates that would group these sounds correctly.

5.1.4 Affricates

The featural characterization of affricates was the topic of some debate in the late 1980's, when the quest for a universal theory of the representation of affricates ran up against inconsistent evidence of their natural class behavior. Articulatorily, affricates are contour segments: they start out as stops and end up as fricatives, so they cannot be unambiguously classed as either [+continuant] or [−continuant] based on oral airflow alone. Acoustically, they combine some characteristics of stops (period of silence or near-silence) and strident fricatives in the burst. Phonologically, affricates sometimes pattern with the class of stridents, which includes fricatives, and sometimes with the class of stops. In English, affricates differ from stops and fricatives in that they cannot freely combine in word-initial consonant clusters: there are no words beginning with [ʧl] or [ʤw], for example (compare [ʃl] and [dw]).[6] The question for any natural class theory of these phonotactic generalizations is whether affricates pattern differently because of a special feature they bear or whether they are subject to additional restrictions because they are complex segments.

Multiple positions on this question have been argued for. Some proposals treat affricates as having both [+continuant] and [−continuant] values, ordered sequentially or unordered. Others introduce a special feature just for affricates, [delayed release]. Still others extend [delayed release] to fricatives. Another proposal is that affricates are strident stops: they are defined by the combination of features

[6] The argument that [ʧ] and [ʤ] are affricates and not sequences is that they can occur word-initially in English, whereas [ts] and [dz] cannot, suggesting they are sequences of two segments. Words such as "tsunami" and "tsetse" are pronounced with a word-initial [s].

[−sonorant, −continuant, +strident]. Most of these approaches are supported by arguments from individual languages but run into difficulty when applied cross-linguistically (see Lin 2011 for a thorough review of this debate).

The strident stop treatment is fairly standard today, and it should suffice for most practical purposes. But if one is trying to generate all the contrasts and patterns with a single feature set, the strident stop analysis requires some special extensions to handle affricates that are non-coronal. For example, if a language has [p͡f] and [k͡x] and they are affricates rather than sequences of stops and fricatives, then [f] and [x] must be strident, and they should be expected to pattern with other stridents in rules and phonotactic constraints. Thus, there is a trade-off: economizing on the number of features used to define contrasts is aesthetically appealing, but it comes with potentially problematic predictions about natural class behavior. But one could argue that it is equally problematic to proliferate features for the purpose of characterizing contrasts that do not come with any analytical pay-off or predictions regarding natural class behavior.

5.1.5 Labials and trills

Another contrast that presents a puzzle for a universalist approach to features is the contrast between bilabials and labiodentals. Most languages that have a labial fricative choose one of these or the other, but the language Ewe is unusual in having both. To handle this contrast, familiar approaches have been pursued: proposing a feature just for this contrast, or repurposing another feature. In the second category of approaches, we have proposals to extend [distributed], such that [ɸ] is [+distributed] and [f] is [-distributed], or [strident], such that [ɸ] is [−strident] and [f] is [+strident]. We saw that [distributed] is already somewhat problematic as a natural class feature (as opposed to a way to describe contrasts), so its extension to the bilabial-labiodental contrast inherits the same problems. Classing [f] as [strident] again predicts that it should pattern with stridents to the exclusion of other fricatives, and this kind of evidence is hard to come by.

Some languages, such as Spanish, contrast [ɾ] and [r]. There is a length difference between these consonants, and possibly one of constriction (with [r] requiring a more active constriction to create the trill action). Some handle this distinction as one of length (see §5.2.3), and others posit the feature [trill] just for this contrast. Again, the evidence is not clear or uncontroversial.

5.1.6 Pharyngeals and glottals

A theme emerging by this point of the discussion is that there is more controversy and less clear evidence in classifying relatively rare segments and contrasts. This is definitely true for pharyngeal consonants, which are robust in just a few geographic areas. These sounds include the voiceless [ħ] and voiced [ʕ] fricatives as well as the rather rare epiglottal stop [ʡ], the voiced epiglottal fricative [ʢ], and the voiceless epiglottal fricative [ʜ]. Pharyngeal consonants are also called "gutturals", though this term is imprecise and sometimes used to refer to velars, uvulars, pharyngeals, and glottals together.

Pharyngeals pattern as a natural class with glottals in Arabic dialects such as Syrian, where the feminine suffix is realized as [-e] except after pharyngeals, where it lowers to [a]:

(24) Vowel lowering after pharyngeal consonants in Syrian

daraʒe	'step'	sˤanʕa	'handwork'
madrase	'school'	tˤabχa	'cooking'
χafi:fe	'light'	mni:ħa	'good'
kbi:re	'large'	wa:ʒha	'display'
ʃərke	'society'	χərʔa	'rag'

The affinity of pharyngeals and the vowel [a] is not surprising from an articulatory standpoint, since [a] also involves pharyngeal constriction, with the body tongue depressed and the root retracted. Somewhat more surprising here is that the glottal consonants [ʔ] and [h] cause lowering, too, and it would be an argument for a [pharyngeal] feature that is borne by both pharyngeals and glottals. Thus, the arguments for the natural class of pharyngeals are pretty clear for languages that have them, but the boundaries of the class are somewhat less clear, especially when other languages are considered.

The featural status of [h] and [ʔ] has been extremely controversial, even though these sounds are quite common cross-linguistically. They do appear to be special, however, patterning apart from other consonants. In English, for example, [h] is extremely limited in its distribution: it does not form clusters with other consonants, and it only occurs before stressed vowels. But [h] and [ʔ] are also very popular epenthetic consonants in other languages.

A popular approach characterizes these glottal sounds as placeless: they are defined by being non-labial, non-coronal, and non-dorsal. But they do pattern with pharyngeals in Arabic, which would be difficult to explain if they are placeless. Even their status as stops or fricatives has been challenged—there are some arguments for treating them as sonorants. Not all of these arguments withstand scrutiny, since what some try to analyze as an effect of manner could be the effect of place, for example. The alternative to the null specification approach is to give glottals their own feature, such as [glottal] or [laryngeal]. It may be a lost cause to try to characterize all glottals in a uniform way cross-linguistically using a single set of features, however, since they seem to pattern differently (much as glides are more consonant-like in some languages than in others).

5.1.7 Laryngeal controversies

One of the issues not addressed in the discussion of laryngeal features above is the status of [voice] in sonorants. In most languages, sonorants are "redundantly" voiced—this means that they do not contrast for voicing. But some languages are reported to have voiceless sonorants. English is, or used to be, such a language—in a few dialects, the words "witch" and "which" are pronounced differently, with the "wh" either aspirated [hʷ] or actually voiceless [ʍ]. This could be a vestige of a time where [h] could form clusters with other consonants in English. Languages such as Siberian Yupik have nasals that are pronounced without voicing (alongside regular voiced nasals), but phonologists and phoneticians disagree as to whether these sounds truly contrast for voice. In practice, many phonologists assume that sonorants are not specified for voice—i.e., they do not have a voicing feature at all. Obviously, this won't work if you are analyzing a problem like sonorant devoicing in Angas, where you had to make sonorants voiceless. They need to have a voicing feature to devoice, so you write the rule as follows:

(25) Angas word-final sonorant devoicing:

$$\begin{bmatrix} +\text{son} \\ +\text{cons} \end{bmatrix} \rightarrow [-\text{voice}] \; / \; \_\_]$$

Distinctions such as modal voice vs. creaky voice, which contrast in some languages, can be treated using the feature [constricted glottis], especially if it is treated as a spreading feature that is linked to a span of segments rather than just one consonant at a time. Glottalized sonorants are also usually assumed to be [constricted glottis], although extending this feature to sonorants requires redefining its acoustic and articulatory correlates. Whereas glottalized/ejective stops are primarily characterized acoustically by their burst properties, glottalized sonorants affect the vowels that precede them, and this can influence their phonotactic distribution (see Steriade 1999).

This raises the larger question of whether both acoustic or articulatory correlates are necessary or even sufficient for defining natural class behavior. Certain patterns become difficult to characterize in theories that have only articulatory definitions for features and no place for acoustically defined features.

For example, in languages such as Quechua, no root can have two ejectives or two aspirated stops: there are no words like *[pʰakʰa] or *[t'ak'a], but either [pʰaka] or [tak'a] are possible. This suggests some restriction on [spread glottis] or [constricted glottis], except there is a further restriction: these groups of sounds cannot cooccur with each other, either, so there are no [pʰak'a] type roots. Ejectives and aspirates do not have much in common articulatorily, but they do share an acoustic property: both are produced with a long VOT, so the vowel onset lags after closure is released. An acoustic feature such as [Long VOT] would be motivated for this language (Gallagher 2011) and makes certain predictions about how [ʔ] and [h] should pattern, which are borne out (Gallagher 2015).

5.2 Vocalic distinctions

5.2.1 Does English have an ATR distinction?

In English, there is a contrast between [bit] and [bɪt], and [bet] and [bɛt] (though the long vowels are sometimes transcribed to reflect their diphthongal quality, as in [bijt] and [bejt] or [beɪt], since the contrast is not just one of quality but also of duration). Regardless of transcription, we have a contrast to explain, but also some differences in phonological patterning: the vowels [ɪ], [ɛ], [ʊ] and [ʌ] cannot occur in open monosyllables, whereas the vowels [i], [e], [o], [u] can. There are words like [bi] but no words like *[bɪ]. There are also irregular alternations in tensing/laxing, like "obsc[i]ne/obsc[ɛ]nity" and "verb[oʊ]se/verb[ɑ]sity".

Tempting as it might be to use [+ATR] to class the tense vowels of English together, their phonological patterning does not lend itself to this easy analysis, since some vowels pattern with [i, e, o, u] even though they are transcribed with [-ATR] symbols. The vowel [ɔ] can carry a monosyllable in those dialects that have it, as in [pɔ] 'Pa' vs. [pɑ] 'paw'. Languages with ATR harmony that have a schwa treat it as [+ATR], but in English it does not pattern with [i, e, o, u]. A universalist approach would not allow us to connect the articulation of these vowels with their phonological patterning. (Their acoustic characteristics, such as length, also do not fully align with their phonology, since lower vowels such as [æ] tend to be longer regardless of their phonotactic patterning.) Because of this, phonologists sometimes use a language-specific feature for English, [±tense], to characterize the contrasts and phonotactic patterns/alternations.

5.2.2 The featural status of central vowels

In most languages, [back] and [round] can be used to make all the distinctions between front, central, and back vowels, since central vowels are normally unrounded. There is one example of a language that has a three-way distinction among its high vowels that cannot be captured using just [back] and [round]: Norwegian is said to have a contrast between [y, ʉ, u], all of which are rounded. This is a good case for a language-specific feature—[front] and [back] are needed just for Norwegian, to make a three-way cut in backness/frontness.

The featural status of central vowels such as [ɨ] and [ə] has been controversial in the same way that the featural status of [ʔ] and [h] has been controversial, with similar problems and solutions. The unrounded central vowels are often given the status of "featureless" vowels in phonological systems, because they are the ones that get inserted when a vowel is needed, and the ones that get deleted as well. The analysis would then posit that a vowel is inserted but is not given any features (as that would require an extra rule). To explain why the vowels are so readily deleted, one could formulate a rule that deletes only featureless vowels or invoke constraints on preserving vowel place features. The Salish language Lillooet, known to its speakers as St'át'imcets, demonstrates this pattern. In this language, any two consonants that can be adjacent given the phonotactics of the language are adjacent; schwas are inserted and deleted whenever necessary to ensure this outcome. Thus, a sonorant in this language has to be adjacent to a

vowel and every word must have at least one vowel, but two obstruents are never separated by a schwa if it could be deleted without violating these constraints. Another way of putting this is that schwa does not contrast with zero in Lillooet, but other vowels do (cf. *p̲ala?* and *plan*, or *s̲utik* 'winter' and *stut* 'cricket').

(26) St'át'imcets Salish schwa

təq	'to touch'	tq-alk'əm	'to drive, steer'
x^wəm	'fast'	x^wm-aka?	'to do something fast'
nəq^w	'warm'	nəq^w-alc	'warm in the house'
sutik	'winter'	sutik-aka?	'north wind'
pala?	'one'	plan	'already'

The 'featureless vowel' approach to schwa is appealing for the same reason that the "featureless consonant" approach is appealing in explaining the frequent epenthesis of [h] and [ʔ]. But the featureless approach is problematic for languages in which schwa and glottal consonants pattern with natural classes that are in line with how they are articulated. Thus, as mentioned in the discussion of ATR, schwa patterns with [+ATR] vowels in some languages; it cannot be featureless if it is [+ATR]. Coronal consonants were also sometimes treated as featureless because of epenthesis and deletion, which runs into various paradoxes when extended beyond specific languages. For a general discussion and critique of underspecification approaches to markedness, see Steriade 1995, McCarthy and Taub 1992, McCarthy 1994.

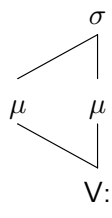
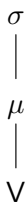
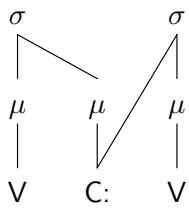
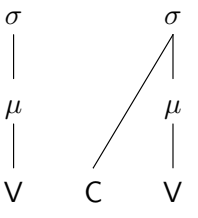
In transcriptions of English, a distinction is made between [ə] and [ʌ], demonstrated by words like "abut" [əbʌt] (which of course does not prove a contrast for [ə] and [ʌ], since the [ʌ] is stressed and the [ə] is not). If we want to capture the distinction between these vowels, both of which are [−high, +back, −round, −tense] in most analyses, then we need an additional feature. But some might argue that this distinction is just a matter of transcription, and that [ʌ] is really just a stressed schwa. Then "cut" is transcribed as [kət]. This transcriptional and analytic decision simplifies the treatment of English, and it also relieves us of the need to worry about a [ə]∼[ʌ] contrast that is likely unattested. Of course this is only a worry if we want our features to define both contrasts and natural classes universally, which may be an unreasonable goal.

5.2.3 How to characterize length contrasts

Many languages do not have contrastive vowel or consonant length, but some do have length contrasts, and length can also be assigned by phonological rule. As a shorthand, we often use [±long] for length distinctions, but there is a better way to do this that we'll talk about later in the semester. In modern phonology, length distinctions are normally handled representationally: long vowels get two time slots, or morae, and short vowels just one; consonants are either linked to one syllable (short) or two (long).

For consonants, length comes from morae as well: long consonants are linked to a mora and the onset of the following syllable. In the case of initial or final geminates, the consonant is assumed to be linked to a mora and some higher level such as the foot or the prosodic word (see Davis 1994, 1999, 2003).

(27) Moraic representations for consonant and vowel length

Long V:	Short V	Long C:	Short C
			
a:	a	ap:a	apa

This solution captures the observation that V: and VC often pattern together as heavy in languages that have weight-sensitive stress; in these cases, the common pattern follows because both V: and VC have two morae in their syllable structures—not from a distinctive feature they share. One advantage of the moraic theory of length is that it allows for a straightforward treatment of three-way length distinctions and three-way weight distinctions; if three morae can be linked to a syllable (as in a superheavy CV:C syllable of the kind found in Arabic dialects), then a three-way length distinction is predicted, and languages such as Estonian do indeed have them (Prince 1980).

There are some technical complexities for the moraic analysis in a framework where deletion and insertion incur faithfulness violations (see Bermudez-Otero 2001, Campos-Astorkiza 2004), so it is common to see [long] used as a shorthand feature when analyzing lengthening or shortening. It is usually understood that a more sophisticated theory of length and weight is available.

6 Are features privative, binary, or multivalued?

For most features, it is sensible to talk about the plus and the minus value. Both [+sonorant] and [−sonorant] define solid natural classes, as do [+nasal] and [−nasal]. For some features, however, not having the positive value does not appear to define a natural class. For example, being "non-labial" is not all that phonologically meaningful, and neither is being "non-dorsal". Thus, some features, such as consonantal place [LAB, COR, DOR, PHAR], and [strident], are commonly understood as *privative* rather than binary—a segment can bear a feature and be defined as part of the natural class, but lacking the feature does not carry a meaning. Writing the place features with all caps is supposed to highlight this.

There are some theories of features that treat all of them as binary or even multi-valued, with more than one degree of marking for a segment. Others treat all features as privative. Some features' binary vs. privative status is debated—this is the case for [voice], for example, which is sometimes assumed to be defined only for obstruents, or even only for voiced obstruents(see Lombardi 1991, 2001, 1999). In this view, plain stops such as [p t k] lack any sort of laryngeal features, and sonorants also lack a specification for [voice]—they can neither contrast for this feature nor participate in rules that refer to it. This allows for an analysis of devoicing, deaspiration, and deejectivization as the removal of features; the consonants become plain. This captures the inert status of sonorants in languages such as Polish, German, and Russian, but it does raise some issues for the universalist approach to features that wants to account for those rare languages that have devoiced sonorants.

As for multivalued features, they have been sometimes proposed as a theory of place distinctions (Maddieson and Ladefoged 1988). The SPE theory of stress treated it as a matter of degree and had the feature come in more than [±]. There are also proposals to treat sonority as a multivalued feature (de Lacy 2002, Parker 2002). Many mainstream proposals treat some features as binary and others as privative; it is most common to treat consonantal place as privative and most other features as binary. For features that are sensibly binary but seem to only be necessary for a subset of segments (for example,

[strident] is probably only necessary for coronals), we reserve the three-way specification of [+F, −F, 0F]. Thus, [θ] is [−strident], [ʃ] is [+strident], but [f] does not have a value for strident—i.e., it is [0 strident].

7 Same pattern, different sound?

Occasionally, a sound in one language patterns in a way that is inconsistent with its acoustic or articulatory characteristics. A famous example of this is the so-called "schwa" in French, which is actually a front rounded vowel (Selkirk 1978, Tranel 1987, and many others). This vowel is inserted and deleted freely in French, much as the schwa in Lillooet, but nobody listening to it would ever describe it as "featureless". Its schwa monicker is bestowed based on what schwas normally do in other languages, even though this vowel sounds nothing like a schwa. Another example of this type is the behavior of [v] in languages like Icelandic, Russian, and Hungarian; the consonant patterns for all intents and purposes like the glide [w], from which it descended. It is common in reading about these languages to see the [v] characterized as a glide, despite its articulatory and acoustic characteristics (though some studies do argue that there are phonetic differences between [v] in languages whose phonologies treat them as glide-like and [v] in languages that treat them as consonant-like; see especially Padgett 2002).

The question arises also for laryngeal features, which often pattern similarly in rules even though the contrasts are rather diverse phonetically. For example, some languages make an aspirated-plain contrast, and others a pre-voiced/plain contrast in their obstruents—and yet they have very similar neutralization patterns, where only one type of consonant is allowed word-finally but there is a contrast before sonorants (Steriade 1999). One approach to this is to treat the distinction as abstract and symbolic, and leave the details of aspiration/prevoicing/etc. to the phonetics. The other, phonetic realism, would say that there are some similarities between these systems but there are also phonological differences that go hand in hand with phonetics (for discussion, see Petrova et al. 2006, Vaux and Samuels 2005).

An approach that allows features to be posited in the process of learning a system of contrasts and natural classes can reconcile these contradictions to some extent, since in such a system, there is no requirement that a language's phonetics completely line up with a universal feature theory. The existence of such inconsistencies indeed suggests that some features need to be defined on a language-specific basis.

8 Are features innate or learned?

Some of the features in phonological theory have a stronger claim to universality than others. An innatist, universalist approach to phonological features has to address marginal contrasts and inconsistent patterning of similar segments across languages. An entirely inductive approach in which features are learned on a language-specific basis must explain why some featural distinctions are for all intents and purposes universal. I suspect that the latter approach will be more successful in the long run, since major, cross-linguistically robust features also tend to have strong articulatory and acoustic correlates. For this approach to be fully successful, we need a theory of how features are learned from articulatory and acoustic/perceptual experience. There are theories of this sort in the works(Mielke, 2005b, 2008, Cristià et al., 2013, Dresher, 2014), but we are a long way still from a fully explicit and explanatory theory.

A middle ground between innatism and inductivism is to assume that some features are innate and others are learned from data, or, alternatively, that there is a bias toward discovering features in a certain order. All these options will no doubt be developed in ongoing research.

9 How to write rules, SPE-style

The SPE introduced the idea that a speech sound is represented as a collection of features. Thus, the IPA symbol for the alveolar nasal, [n], really stands for the following:

(28) The feature matrix for [n]

$$\begin{bmatrix} \text{-syll} \\ \text{+cons} \\ \text{+son} \\ \text{+nas} \\ \text{COR} \\ \text{+ant} \\ \text{-cont} \end{bmatrix}$$

What rules do, then, is scan feature matrices and change features; some rules can also reorder, delete, or insert a segment. Here is how you write a deletion rule for English [t] deletion, as in "can't" pronounced as [kæn]:

(29) Deletion rule in SPE notation: word-final [t] deletion in consonant clusters

$$\begin{bmatrix} \text{-son} \\ \text{COR} \\ \text{-cont} \\ \text{-str} \\ \text{-voice} \end{bmatrix} \rightarrow \varnothing / \text{ C } \_\_ \#$$

This feature matrix specifies [t] uniquely in English phonology, and it omits some of the features that are implied by others' values: for example, a sound that's [−son] must also be [-syll, +cons]. It is, however, necessary to specify either [+anterior] or [−strident] to zero in on [t] among the set of voiceless coronal obstruents. It wouldn't be wrong to specify all the features that apply to [t], but we usually only specify the minimum number of features that's needed to single out the relevant segment.

When a rule assimilates one feature to match the value of another, you would have to write something pretty awkward to capture all the possibilities sometimes. For example, suppose a language has voicing assimilation in sequences of obstruents, and it has both voiceless obstruents becoming voiced and voiced ones becoming voiceless. Instead of writing two rules that capture the same assimilation pattern, the SPE introduces the *alpha notation*. For example, this rule uses the alpha notation to say that an obstruent takes on the same value of voice as the following obstruent; both are plus or minus:[7]

(30) A rule for obstruent voicing assimilation

$$[-\text{son}] \rightarrow [\alpha\text{voice}] / \_\_ \begin{bmatrix} \text{-son} \\ \alpha\text{voice} \end{bmatrix}$$

Finally, another useful shortcut is for rules that affect a group of features in the same way. For example, nasals often assimilate with following stops in all the place features: LAB, COR, DOR and all the minor place distinctions such as bilabial/labiodental and the various flavors of coronal. One could write a rule that matches [αLAB, βCOR, γDOR], and so on, until you run out of Greek letters. The more modern approach is to agree that the features are all part of a class, which we'll call [place], and write the rule just for that class—treating it as a feature:

[7] The alpha notation can also be used to write dissimilation rules: if you add a minus before the alpha, the value of the segment undergoing the rule will be the opposite of the context's feature. We won't write dissimilation rules this way.

(31) Place assimilation: a feature class rule

$$\begin{bmatrix} +\text{cons} \\ +\text{nas} \end{bmatrix} \rightarrow [\alpha\text{place}] \;/\; \_\_\_\; [\alpha\text{place}]$$

As an exercise, think about what you would have to say to capture the requirement for [cg], [sg], and [voice] in Georgian (see (8)).

10 Conclusion

Features are used in phonological theory to capture the observation that acoustically and articulatorily similar sounds pattern together, and to characterize contrasts and natural class patterning in rules and constraints. The contrast function of features is best served by a rich constraint set with some features that are needed for only a few languages, and others that have inconsistent acoustic and articulatory correlates. The natural class diagnostic is a more stringent test for features, and one that sometimes reveals significant discrepancies in how phonetically similar sounds pattern in different languages. This suggests that there may be some common tendencies in how feature systems are shaped in different phonological systems, but their exact details likely vary in individual languages.

Notes

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References

Bermudez-Otero, Ricardo. 2001. Underlyingly nonmoraic coda consonants, faithfulness, and sympathy. University of Manchester. http://myweb.tiscali.co.uk/bermudez/DEP-mora.pdf (accessed on 02 February 2007).

Broselow, Ellen. 1976. The Phonology of Egyptian Arabic. Doctoral Dissertation, University of Massachusetts, Amherst.

Campos-Astorkiza, Rebeka. 2004. Faith in moras: A revised approach to prosodic faithfulness. In *Proceedings of NELS 34*, ed. Keir Moulton and Matthew Wolf, 164–174. UMass Amherst: GLSA.

Chitoran, Ioana. 1998. Georgian harmonic clusters: Phonetic cues to phonological representation. *Phonology* 15:121–141.

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

Clements, George N. 1990. The role of the sonority cycle in core syllabification. In *Papers in Laboratory Phonology 1: Between the grammar and physics of speech*, ed. John Kingston and Mary Beckman, 283–333. New York: Cambridge University Press.

Cristià, Alejandrina, Jeff Mielke, Robert Daland, and Sharon Peperkamp. 2013. Similarity in the generalization of implicitly learned sound patterns. *Laboratory Phonology* 4:259–286.

Crosswhite, Katherine. 1999. Vowel reduction in Optimality Theory. Doctoral Dissertation, UCLA, Los Angeles, CA.

Davis, Stuart. 1994. Geminate consonants in moraic phonology. In *Proceedings of WCCFL 13*, ed. Raul Aranovich, William Byrne, Susanne Preuss, and Martha Senturia, 32–45. Stanford, CA: CSLI.

Davis, Stuart. 1999. On the moraic representation of underlying geminates: evidence from Prosodic Morphology. In *The prosody-morphology interface*, ed. René Kager, Harry van der Hulst, and Wim Zonneveld, 39–61. Cambridge: Cambridge University Press.

Davis, Stuart. 2003. The controversy over geminates and syllable weight. In *The Syllable in Optimality Theory*, ed. Caroline Féry and Ruben van de Vijver, 77–98. Cambridge: Cambridge University Press.

Dresher, B. Elan. 2014. The arch not the stones: Universal feature theory without universal features. *Nordlyd* 41:165–181. Special issue on features.

Gallagher, Gillian. 2011. Acoustic and articulatory features in phonology–the case for [long VOT]. *The Linguistic Review* 28:281–313.

Gallagher, Gillian. 2015. Natural classes in cooccurrence constraints. *Lingua* 166:80–98.

Hayes, Bruce. 2009. *Introductory phonology*. Malden, MA, and Oxford, UK: Wiley-Blackwell.

Jakobson, Roman. 1941. *Kindersprache, Aphasie, und Allgemeine Lautgesetze*. Uppsala: Almqvist & Wiksell [tr. Child Language, Aphasia and Phonological Universals, Mouton]. Translated into English by A. Keiler, 1968.

Jakobson, Roman, Gunnar Fant, and Morris Halle. 1952. *Preliminaries to Speech Analysis*. Cambridge, MA: MIT Press.

Kahn, Daniel. 1976. Syllable-based Generalizations in English Phonology. Doctoral Dissertation, MIT, Cambridge, MA. Published by Garland Press, New York, 1980.

Kenstowicz, Michael. 1994. *Phonology in Generative Grammar*. Oxford: Blackwell.

Kenstowicz, Michael, and Charles Kisseberth. 1979. *Generative phonology: Description and theory*. New York: Academic Press.

de Lacy, Paul. 2002. The formal expression of markedness. Doctoral Dissertation, University of Massachusetts, Amherst, Amherst, MA.

Ladefoged, Peter, and Keith Johnson. 2014. *A course in phonetics*. Cengage learning.

Lee-Kim, Sang-Im. 2014. Revisiting Mandarin 'apical vowels': An articulatory and acoustic study. *Journal of the International Phonetic Association* 44:261–282.

Levi, Susannah V. 2004. The representation of underlying glides: a cross-linguistic study. Doctoral Dissertation, University of Washington, Seattle, WA.

Levin, Juliette. 1985. A Metrical Theory of Syllabicity. Doctoral Dissertation, MIT, Cambridge, MA.

Lin, Yen-Hwei. 2011. Affricates. In *Blackwell companion to phonology*, ed. Marc van Oostendorp, Colin Ewen, Elizabeth Hume, and Keren Rice, volume I, 367–390. Wiley-Blackwell.

Lombardi, Linda. 1991. Laryngeal Features and Laryngeal Neutralization. Doctoral Dissertation, University of Massachusetts, Amherst.

Lombardi, Linda. 1999. Positional faithfulness and voicing assimilation in Optimality Theory. *Natural Language and Linguistic Theory* 17:267–302.

Lombardi, Linda. 2001. Why place and voice are different: Constraint-specific alternations and Optimality Theory. In *Segmental phonology in optimality theory: Constraints and representations*, ed. Linda Lombardi, 13–45. Cambrdige: Cambridge University Press.

Maddieson, Ian, and Peter Ladefoged. 1988. Multiply articulated segments and the feature hierarchy. Expanded version of a the 63rd Annual Meeting of the LSA, New Orleans, December 1988.

McCarthy, John J. 1994. On coronal 'transparency'. Santa Cruz, CA. TREND.

McCarthy, John J., and Alison Taub. 1992. Review of C. Paradis and J.-F. Prunet, eds., The special status of coronals: Internal and external evidence. *Phonology* 9:363–70.

Mielke, Jeff. 2005a. Ambivalence and ambiguity in laterals and nasals. *Phonology* 22:169–203.

Mielke, Jeff. 2005b. Modeling distinctive feature emergence. In *Proceedings of the West Coast Conference on Formal Linguistics*, ed. John Alderete, Chung-hye Han, and Alexei Kochetov, volume 24, 281–289. Somerville, MA: Cascadilla Press.

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

Ni Chiosain, Maire. 1991. Topics in the Phonology of Irish. Doctoral Dissertation, University of Massachusetts, Amherst.

Odden, David. 2005. *Introducing phonology*. Cambridge: Cambridge University Press.

van Oostendorp, Marc, Colin J Ewen, Elizabeth Hume, and Keren Rice. 2011. *The Blackwell companion to phonology*. John Wiley & Sons.

Padgett, Jaye. 2002. Russian voicing assimilation, final devoicing, and the problem of [v] (or, The mouse that squeaked). Ms. Santa Cruz.

Padgett, Jaye. 2003. Contrast and postvelar fronting in Russian. *Natural Language and Linguistic Theory* 21:39–87.

Padgett, Jaye. 2008. Glides, vowels, and features. *Lingua* 118:1937–1955.

Parker, Steve. 2002. Quantifying the sonority hierarchy. Doctoral Dissertation, University of Massachusetts, Amherst, Amherst, MA.

Petrova, Olga, Rosemary Plapp, Catherine O. Ringen, and Szilárd Szentgyörgyi. 2006. Voice and aspiration: Evidence from Russian, Hungarian, German, Swedish, and Turkish. *The Linguistic Review* 23:1–35.

Prince, Alan. 1980. A metrical theory for Estonian quantity. *Linguistic Inquiry* 11:511–562.

Rosenthall, Sam. 1994. Vowel/glide alternation in a theory of constraint interaction. Doctoral Dissertation, University of Massachusetts, Amherst, Amherst, MA.

Rosenthall, Sam. 1997. The distribution of prevocalic vowels. *Natural Language and Linguistic Theory* 15:139–180.

Selkirk, Elisabeth. 1978. The French foot: On the status of "mute" e. *Studies in French Linguistics* 1:141–150.

Spencer, Andrew. 1995. *Phonology: theory and description*. Malden, MA, and Oxford, UK: Wiley-Blackwell.

Steriade, Donca. 1995. Underspecification and markedness. In *Handbook of phonological theory*, ed. John Goldsmith, 114–174. Cambridge, MA: Blackwell.

Steriade, Donca. 1999. Phonetics in phonology: the case of laryngeal neutralization. In *Papers in phonology 3 (UCLA working papers in linguistics 2)*, ed. Matthew Gordon, 25–145. Los Angeles: Department of Linguistics, University of California.

Tranel, Bernard. 1987. French schwa and non-linear phonology. *Linguistics* 25:845–866.

Vaux, Bert, and Bridget Samuels. 2005. Laryngeal markedness and aspiration. *Phonology* 22:395–436.

Zsiga, Elizabeth C. 2012. *The sounds of language: an introduction to phonetics and phonology*. John Wiley & Sons.