CHAPTER 4

Feature theory

PREVIEW

This chapter explores the theory for representing language sounds as symbolic units. You will:

• see that sounds can be defined in terms of a fixed set of features
• learn the phonetic definitions of features, and how to assign feature values to segments based on phonetic properties
• understand how phonological rules are formalized in terms of those features
• see how these features makes predictions about possible sounds and rules in human language

KEY TERMS
observation
predictions
features
natural classes

We have been casual about what sounds as cognitive units are made of, and just treated them as letters labeled by traditional articulatory descriptions. It is time now to raise a fundamental question: are segments further analyzed into "parts" which define them, or are they truly atomic – units which are not further divisible or analyzable?

4.1 Scientific questions about speech sounds

One of the scientific questions that needs to be be asked about language is: *what is a possible speech sound?* Humans can physically produce many more kinds of sounds than are used in language. No language employs hand-clapping, finger-snapping, or vibrations of air between the hand and cheek caused by release of air from the mouth when obstructed by the palm of the hand (though such a sound can easily communicate an attitude). A goal of a scientific theory of language is to systematize such facts and explain them, thus we have discovered one limitation on language sound and its modality – language sounds are produced exclusively within the mouth and nasal passages, in the area between the lips and larynx.

Even staying within the vocal tract, languages also do not, for example, use whistles or inhalation to form speech sounds, nor is a labiolingual trill (a.k.a. "the raspberry") a speech sound in any language. It is important to understand that even though these various odd sounds are not language sounds, they may still be used in communication. The "raspberry" in American culture communicates a contemptuous attitude; in parts of coastal East Africa and Scandinavia, inhaling with the tongue in the position for schwa expresses agreement. Such noises lie outside of language, and we never find plurality indicated with these sounds, nor are they surrounded by other sounds to form the word *dog*. General communication has no systematic limitations short of anatomical ones, but in language, only a restricted range of sounds are used.

The issue of possible speech sounds is complicated by manual languages such as American Sign Language. ASL is technically not a counterexample to a claim about modality framed in terms of “speech sounds.” But it is arbitrary to declare manual language to be outside of the theory of language, and facts from such languages are relevant in principle. Unfortunately, knowledge of the signed languages of the world is very restricted, especially in phonology. Signed languages clearly have syntax: what isn’t clear is what they have by way of phonologies or phonetic implementation. Researchers have only just begun to scratch the surface of sign language phonologies, so unfortunately we can say nothing more about them here.

The central question is: what is the basis for defining possible speech sounds? Do we use our “speech anatomy” in every imaginable way, or only in certain well-defined ways?

4.1.1 Possible differences in sounds

One way to approach the question is to collect samples of the sounds of all of the languages in the world. This search (which has never been conducted) would reveal massive repetition, and would probably reveal that the segment [m] in English is exactly the same as the segment [m] in French, German, Tübatülabal, Arabic, Swahili, Chinese and innumerable other languages. It would also reveal differences, some of them perhaps a bit surprising. Given the richness of our transcriptional resources for notating phonetic differences between segments, you might expect that if a collection of languages had the same vowels transcribed as [i] and [ɪ], then these vowels should sound the same. This is not so.

Varieties of phonetic [i] vs. [ɪ]. Many languages have this pair of vowels; for example, Matuumbi has [i] and [ɪ]. But the actual pronunciation of [i] vs. [ɪ] differs between English and Matuumbi. Matuumbi [i] is higher than in English, and Matuumbi [ɪ] is a bit lower than English [ɪ] – to some people it almost sounds like [e] (but is clearly different from [e], even the “pure” [e] found in Spanish). This might force us to introduce new symbols, so that we can accurately represent these distinctions. (This is done in publications on Matuumbi, where the difference is notated as “extreme” *į*, *ų* versus “regular” *i, u*.) Before we embark on a program of adding new symbols, we should be sure that we know how many symbols to add. It turns out that the pronunciation of [i] and [ɪ] differs in many languages: these vowels exist in English, Kamba, Lomwe, Matuumbi, Bari, Kipsigis, Didinga and Sotho, and their actual pronunciation differs in each language.

You do not have to go very far into exotic languages to find this phonetic difference, for the difference between English [i] and German [i] is also very noticeable, and is something that a language learner must master to develop a good German or English accent. Although the differences may be difficult for the untrained ear to perceive at first, they are consistent, physically measurable, and reproducible by speakers. If written symbols are to represent phonetic differences between languages, a totally accurate transcription should represent these differences. To represent just this range of vowel differences involving [i] and [ɪ], over a dozen new symbols would need to be introduced. Yet we do not introduce large numbers of new symbols to express these differences in pronunciations, because phonological symbols do *not* represent the precise phonetic properties of the sounds in a language, they only represent the essential contrast between sounds.

Other variants of sounds. Similar variation exists with other phonetic categories. The retroflex consonants of Telugu, Hindi and Koti are all pronounced differently. Hindi has what might be called “mild” retroflexion, where the tip of the tongue is placed just behind the alveolar ridge, while in Telugu, the tip of the tongue is further back and contact is made between the palate and the underside of the tongue (sublaminal); in Koti, the tongue is placed further forward, but is also sublaminal. Finnish, Norwegian, and English contrast the vowels [a] and [æ], but in each of these languages the vowels are pronounced in a slightly different way. The voiced velar fricative [γ] found in Arabic, Spanish and the Kurdish language Hawrami are all phonetically different in subtle but audible ways.

The important details of speech. Although languages can differ substantially in the details of how their sounds are pronounced, there are limits on the types of sound differences which can be exploited contrastively, i.e. can form the basis for making differences in meaning. Language can contrast tense [i] and lax [ɪ], but cannot further contrast a hypertense high vowel (like that found in Matuumbi) which we might write as [i^{+}] with plain tense [i] as in English, or hyper-lax [ɪ$^{-}$] as in Matuumbi with plain lax [ɪ] as found in English. Within a language, you find at most [i] vs. [ɪ]. Languages can have one series of retroflex consonants, and cannot contrast Hindi-style [ṭ] with a Telugu-style phoneme which we might notate as [ṭ$^{+}$]. The phonology simply has “retroflex,” and it is up to the phonetic component of a language to say exactly how a retroflex consonant is pronounced.

It is important to emphasize that such phonetic details are not too subtle to hear. The difference between various types of retroflex consonants is quite audible – otherwise, peple could not learn the typcal pronunciation of retroflex consonants in their language – and the difference between English and German [i] is appreciable. Children learning German can hear and reproduce German [i] accurately. Speakers can also tell when someone mispronounces a German [i] as an English [i], and bilingual German–English speakers can easily switch between the two phonetic vowels.

One thing that phonological theory wants to know is: *what is a possible phoneme?* How might we answer this? We could look at all languages and publish a list. A monumental difficulty with that is that there are nearly 7,000 languages, but useful information on around only 10 percent of these languages. Worse, this could only say what phonemic contrasts happen to exist at the present. A scientific account of language does not just ask what has been actually observed, it asks about the fundamental nature of language, including *potential* sounds which may have existed in a language spoken 1,000 years ago, or some future language which will be spoken 1,000 years hence. We are not just interested in passive *observation*, we are interested in active *prediction*.

In this connection, consider whether a “bilabial click” is a possible phoneme. We symbolize it as [ʘ] – it is like a kiss, but with the lips flat as for [m], not protruded as for [w]. Virtually all languages have bilabial consonants, and we know of dozens of languages with click consonants (Dahalo, Sotho, Zulu, Xhosa, Khoekhoe), so the question is whether the combination of concepts “bilabial” and “click” can define a phoneme. As it happens, we know that such a sound does exist, but only in two closely related languages, !Xoo and Eastern ≠Hoan, members of the

Khoisan language family. These languages have under 5,000 speakers combined, and given socio-economic factors where these languages are spoken (Namibia and Botswana), it is likely that the languages will no longer be spoken in 200 years. We are fortunate in this case that we have information of these languages which allows us to say that this *is* a phoneme, but things could have turned out differently. The languages could easily have died out without having been recorded, and then we would wrongly conclude that a bilabial click is not a possible phoneme because it has not been observed. We need a principled, theoretical basis for saying what we think might be observed.

Predictions versus observations. A list of observational facts is scientifically uninteresting. A basic goal of science is to have knowledge that goes beyond what has been observed, because we believe that the universe obeys general laws. A list might be helpful in building a theory, but we would not stop with a list, because it would give us no explanation why that particular list exists, as opposed to some other arbitrary list. The question "what is a possible phoneme" should thus be answered by reference to a general theory of what speech sounds are made of, just as a theory of physics of "possible atoms" is based on a general theory of what makes up atoms and rules for putting those bits together. Science is not simply the accumulation and sorting of facts, but rather the attempt to discover the laws that regulate the universe. Such laws make predictions about things that we have yet to observe: certain things should be found, other things should never be found.

The Law of Gravity predicts that a rock will fall to earth, which says what it will do and by implication what it will not do: it also won't go up or sideways. Physicists have observed that subatomic particles decay into other particles. Particles have an electrical charge – positive, negative or neutral – and there is a physical law that the charge of a particle is preserved when it decays (adding up the charges of the decay products). The particle known as a "kaon" (K) can be positive (K^+), negative (K^-) or neutral (K^0); a kaon can decay into other particles known as "pions" (π) which also can be positive (π^+), negative (π^-) or neutral (π^0). Thus a neutral kaon may become a positive pion and a negative pion ($K^0 \rightarrow \pi^+ + \pi^-$) or it may become one positive, one negative, and one neutral pion ($K^0 \rightarrow \pi^+ + \pi^- + \pi^0$), because in both cases the positives and negatives cancel out and the sum of charges is neutral (0). The Law of Conservation of Charge allows these patterns of decay, and prohibits a neutral kaon from becoming two positive pions ($K^0 \rightarrow \pi^+ + \pi^+$). In the myriad cases of particle decay which have been observed experimentally, none violates this law which predicts what can happen and what cannot. Analogously, phonological theory seeks to discover the laws for building phonemes, which predict what phonemes can be found in languages. We will see what that theory is, after considering a related question which defines phonology.

4.1.2 Possible rules

Previous chapters have focused on rules, but we haven't paid much attention to how they should be formulated. English has rules defining allowed clusters of two consonants at the beginning of the word. The first set of consonant sequences in (1) is allowed, whereas the second set of sequences is disallowed.

(1) pr pl br bl tr dr kr kl gr gl
*rp *lp *rb *lb *rt *rd *rk *lk *rg *lg

This is not the only rule governing consonant sequences at the beginning of the word in English, so for example the voiceless alveolar fricative [s] can be followed by any nonfricative.

This restriction is very natural and exists in many languages – but it is not inevitable, and does not reflect any insurmountable problems of physiology or perception. Russian allows many of these clusters, for example [rut^{j}] 'mercury' exemplifies the sequence [rt] which is impossible in English.

We could list the allowed and disallowed sequences of phonemes and leave it at that, but this does not explain why these particular sequences are allowed. Why don't we find a language which is like English, except that the specific sequence [lb] is allowed and the sequence [bl] is disallowed? An interesting generalization regarding sequencing has emerged after comparing such rules across languages. Some languages (e.g. Hawaiian) do not allow any clusters of consonants and some (Bella Coola a.k.a. Nuxalk, a Salishan language of British Columbia) allow any combination of two consonants, but *no* language allows initial [lb] without also allowing [bl]. This is a more interesting and suggestive observation, since it indicates that there is something about such sequences that is not accidental in English; but it is still just a random fact from a list of accumulated facts, if we have no basis for characterizing classes of sounds, and view the restrictions as restrictions on letters, as sounds with no structure.

There is a rule in English which requires that all vowels be nasalized when they appear before a nasal consonant, and thus we have a rule something like (2).

(2)	ɛ e ɪ i		ɛ̃ ẽ ɪ̃ ĩ	
	a ɔ o ʊ	→	ã ɔ̃ õ ʊ̃	/_m, n, ŋ
	u ə æ		ũ ə̃ æ̃	

If rules just replace one arbitrary list of sounds by another list when they stand in front of a third arbitrary list, we have to ask why these particular sets of symbols operate together. Could we replace the symbol [n] with the symbol [t^{ʃ}], or the symbol [õ] with the symbol [ø], and still have a rule in some language? It is not likely to be an accident that these particular symbols are found in the rule: a rule similar to this can be found in quite a number of languages, and we would not expect this particular collection of letters to assemble themselves into a rule in many languages, if these were just random collections of letters.

Were phonological rules properly stated in terms of randomly assembled symbols, there would be no reason to expect (3a) to have a different status from (3b).

(3) a. {p, t, t^{ʃ}, k} → {m, n, ɲ, ŋ}/ _ {m, n, ɲ, ŋ}
b. {b, p, d, q} → {d, q, b, p}/ _ {s, x, o, ɪ}

Rule (3a) – nasalization of stops before nasals – is quite common, but (3b) is never found in human language. This is not an accident, but rather reflects the fact that the latter process cannot be characterized in terms of a unified phonetic operation applying to a phonetically defined context. The insight which we have implicitly assumed, and make explicit here, is that rules operate not in terms of specific symbols, but in terms of definable classes. The basis for defining those classes is a set of phonetic properties.

As a final illustration of this point, rule (4a) is common in the world's languages but (4b) is completely unattested.

(4) a. k, g → tʃ, dʒ / _ i, e
b. p, r → i, b / _ o, n

The first rule refers to phonetically definable classes of segments (velar stops, alveopalatal affricates, front vowels), and the nature of the change is definable in terms of a phonetic difference (velars change place of articulation and become alveopalatals). The second rule cannot be characterized by phonetic properties: the sets {p, r}, {i, b}, and {o, n} are not defined by some phonetic property, and the change of [p] to [i] and [r] to [b] has no coherent phonetic characterization.

The lack of rules like (4b) is not just an isolated limitation of knowledge – it's not simply that we haven't found the specific rules (4b) but we have found (4a) – but rather these kinds of rules represent large, systematic classes. (3b) and (4b) represent a general kind of rule, where classes of segments are defined arbitrarily. Consider the constraint on clusters of two consonants in English. In terms of phonetic classes, this reduces to the simple rule that the first consonant must be a stop and the second consonant must be a liquid. The second rule changes vowels into nasalized vowels before nasal consonants. The basis for defining these classes will be considered now.

4.2 Distinctive feature theory

Just saying that rules are defined in terms of phonetic properties is too broad a claim, since it says nothing about the phonetic properties that are relevant. Consider a hypothetical rule, stated in terms of strictly phonetic properties:

> all vowels change place of articulation so that the original difference in formant frequency between F_1 and F_3 is reduced to half what it originally was, when the vowel appears before a consonant whose duration ranges from 100 to 135 ms.

What renders this rule implausible (no language has one vaguely resembling it) is that it refers to specific numerical durations, and to the difference in frequency between the first and third formant.

An acoustic description considers just physical sound, but a perceptual description factors in the question of how the ear and brain process sound. The difference between 100 Hz and 125 Hz is acoustically the same as that between 5,100 Hz and 5,125 Hz. The two sets are perceptually very different, the former being perceived as "more separate" and the latter as virtually indistinguishable.

The phonetic properties which are the basis of phonological systems are general and somewhat abstract, such as voicing or rounding, and are largely the categories which we have informally been using already: they are not the same, as we will see. The hypothesis of distinctive feature theory is that there is a small set, around two dozen, of phonetically based properties which phonological analysis uses. These properties, the **distinctive features**, not only define the possible phonemes of human languages, but also define phonological rules.

The classical statement of features derives from Chomsky and Halle (1968). We will use an adapted set of these features, which takes into consideration refinements. Each feature can have one of two values, plus and minus, so for each speech sound, the segment either *has* the property (is [$+F_i$]) or *lacks* the property (is [$-F_i$]). In this section, we follow Chomsky and Halle (1968) and present the generally accepted articulatory correlates of the features, that is, what aspects of production the feature relates to. There are also acoustic and perceptual correlates of features, pertaining to what the segment sounds like, which are discussed by Jakobson, Fant and Halle (1952) using a somewhat different system of features.

4.**2.1 Phonetic preliminaries**

By way of phonetic background to understanding certain features, two phonetic points need to be clarified. First, some features are characterized in terms of the "neutral position," which is a configuration that the vocal tract is assumed to have immediately prior to speaking. The neutral position, approximately that of the vowel [ɛ], defines relative movement of the tongue.

Second, you need to know a bit about how the vocal folds vibrate, since some feature definitions relate to the effect on vocal fold vibration (important because this provides most of the sound energy of speech). The vocal folds vibrate when there is enough air pressure below the glottis (the opening between the vocal folds) to force the vocal folds apart. This opening reduces subglottal pressure, which allows the folds to close, and this allows air pressure to rebuild to the level where the vocal folds are blown apart again. The factor that causes the folds to open is that the pressure below the vocal folds is enough higher than the pressure above that the vocal folds are moved.

Air flows from the lungs at a roughly constant rate. Whether there is enough drop in pressure for air to force the vocal folds open is thus determined by the positioning and tension of the vocal folds (how hard it is to force them apart), and the pressure above the glottis. The pressure above the glottis depends on how effectively pressure buildup can be relieved, and this is determined by the degree of constriction in the vocal tract. In short, the configuration of the vocal folds, and the degree and location of constriction above the glottis almost exclusively determine whether there will be voicing.

If the pressure above and below the glottis is nearly equal, air stops flowing and voicing is blocked. So if the vocal tract is completely obstructed (as for the production of a voiceless stop like [k]), air flowing through the glottis rapidly equalizes the pressure below and above the glottis, which stops voicing. On the other hand, if the obstruction in the vocal tract is negligible (as it is in the vowel [a]), the pressure differential needed for voicing is easily maintained, since air passing through the glottis is quickly vented from the vocal tract.

A voiced stop such as [g] is possible, even though it involves a total obstruction of the vocal tract analogous to that found in [k], because it takes time for pressure to build up in the oral cavity to the point that voicing ceases. Production of [g] involves ancillary actions to maintain voicing. The pharynx may be widened, which gives the air more room to escape, delaying the buildup of pressure. The larynx may be lowered, which also increases the volume of the oral cavity; the closure for the stop may be weakened slightly, allowing tiny amounts of air to flow through; the velum may be raised somewhat to increase the size of the air cavity, or it may be lowered somewhat to allow small (usually imperceptible) amounts of air to pass through the nose. The duration of the consonant can be reduced – generally, voiced stops are phonetically shorter than corresponding voiceless stops.

Certain sounds such as vowels lack a radical constriction in the vocal tract, so it is quite easy to maintain voicing during such sounds, whereas with other sounds, specifically obstruents, voicing is difficult to maintain. Some accounts of this distinction, especially that of Chomsky and Halle (1968), refer to "spontaneous voicing," which is grounded on the assumption that voicing occurs automatically simply by positioning the vocal folds in what we might call the "default" position. For sounds that involve a significant obstruction of the vocal tract, special actions are required for voicing. The features [sonorant] and [consonantal] directly relate to the obstruction in the vocal tract, which determines whether the vocal folds vibrate spontaneously.

Particularly in writing formal rules, feature names tend to be abbreviated to give the rule a more compact form. Common abbreviations are:

high = hi	coronal = cor	nasal = nas
low = lo	anterior = ant	lateral = lat
back = bk	strident = strid	spread glottis = s.g.
round = rd	distributed = dist	constricted glottis = c.g.
tense = tns	continuant = cont	voice = voi
advanced tongue root = ATR	delayed release = del. rel	

4.2.2 Major class features

One of the most intuitive distinctions which feature theory needs to capture is that between consonants and vowels. There are three features, the so-called major class features, which provide a rough first grouping of sounds into functional types that includes the consonant/vowel distinction.

syllabic: forms a syllable peak (and thus can be stressed).

sonorant: sounds produced with a vocal tract configuration in which spontaneous voicing is possible.

consonantal: sounds produced with a major obstruction in the oral cavity.

The feature [syllabic] is, unfortunately, simultaneously one of the most important features and one of the hardest to define physically. It corresponds intuitively to the notion "consonant" (where [h], [j], [m], [s], [t] are "consonants") versus "vowel" (such as [a], [i]): indeed the only difference between the vowels [i, u] and the corresponding glides [j, w] is that [i, u] are [+syllabic] and [j, w] are [−syllabic]. The feature [syllabic] goes beyond the intuitive vowel/consonant split. English has syllabic sonorants, such as [r̩], [l̩], [n̩]. The main distinction between the English words (American English pronunciation) *ear* [ɪr] and *your* [jr̩] resides in which segments are [+syllabic] versus [−syllabic]. In *ear*, the vowel [ɪ] is [+syllabic] and [r] is [−syllabic], whereas in *your*, [j] is [−syllabic] and [r̩] is [+syllabic]. The words *eel* [il] and the reduced form of *you'll* [jl̩] for many speakers of American English similarly differ in that [i] is the peak of the syllable (is [+syllabic]) in *eel*, but [l̩] is the syllable peak in *you'll.*

Other languages have syllabic sonorants which phonemically contrast with nonsyllabic sonorants, such as Serbo-Croatian which contrasts syllabic [r̩] with nonsyllabic [r] (cf. *groze* 'fear (gen)' versus *gr̩oce* 'little throat'). Swahili distinguishes [mbuni] 'ostrich' and [m̩buni] 'coffee plant' in the fact that [m̩buni] is a three-syllable word and [m̩] is the peak (the only segment) of that first syllable, but [mbuni] is a two-syllable word, whose first syllable peak is [u]. Although such segments may be thought of as "consonants" in one intuitive sense of the concept, they have the feature value [+syllabic]. This is a reminder that there is a difference between popular concepts about language and technical terms. "Consonant" is not strictly speaking a technical concept of phonological theory, even though it is a term quite frequently used by phonologists – almost always with the meaning "nonpeak" in the syllable, i.e. a [−syllabic] segment.

The definition of [sonorant] could be changed so that glottal configuration is also included, then the laryngeals would be [–sonorant]. There is little compelling evidence to show whether this would be correct; later, we discuss how to go about finding such evidence for revising feature definitions.

The feature [sonorant] captures the distinction between segments such as vowels and liquids where the constriction in the vocal tract is small enough that no special effort is required to maintain voicing, as opposed to sounds such as stops and fricatives which have enough constriction that effort is needed to maintain voicing. In an oral stop, air cannot flow through the vocal tract at all, so oral stops are [–sonorant]. In a fricative, even though there is some airflow, there is so much constriction that pressure builds up, with the result that spontaneous voicing is not possible, thus fricatives are [–sonorant]. In a vowel or glide, the vocal tract is only minimally constricted so air can flow without impedance: vowels and glides are therefore [+sonorant]. A nasal consonant like [n] has a complete obstruction of airflow through the oral cavity, but nevertheless the nasal passages are open which allows free flow of air. Air pressure does not build up during the production of nasals, so nasals are [+sonorant]. In the liquid [l], there is a complete obstruction formed by the tip of the tongue with the alveolar ridge, but nevertheless air flows freely over the sides of the tongue so [l] is [+sonorant].

The question whether *r* is [+sonorant] or [−sonorant] has no simple answer, since many phonetically different segments are transcribed as *r*; some are [−sonorant] and some are

[+sonorant], depending on their phonetic properties. The so-called fricative *r* of Czech (spelled *ř*) has a considerable constriction, so it is [−sonorant], but the English type [ɹ] is a sonorant since there is very little constriction. In other languages there may be more constriction, but it is so brief that it does not allow significant buildup of air pressure (this would be the case with "tapped" *r*'s). Even though spontaneous voicing is impossible for the laryngeal consonants [h, ʔ] because they are formed by positioning the vocal folds so that voicing is precluded, they are [+sonorant] since they have no constriction above the glottis, which is the essential property defining [+sonorant].

The feature [consonantal] is very similar to the feature [sonorant], but specifically addresses the question of whether there is any major constriction in the oral cavity. This feature groups together obstruents, liquids and nasals which are [+consonantal], versus vowels, glides and laryngeals ([h, ʔ]) which are [−consonantal]. Vowels and glides have a minor obstruction in the vocal tract, compared to that formed by a fricative or a stop. Glottal stop is formed with an obstruction at the glottis, but none in the vocal tract, hence it is [−consonantal]. In nasals and liquids, there is an obstruction in the oral cavity, even though the overall constriction of the whole vocal tract is not high enough to prevent spontaneous voicing. Recent research indicates that this feature may not be necessary, since its function is usually covered as well or better by other features.

The most important phonological use of features is that they identify classes of segments in rules. All speech sounds can be analyzed in terms of their values for the set of distinctive features, and the set of segments that have a particular value for some feature (or set of feature values) is a **natural class.** Thus the segments [a i r̩ m̩] are members of the [+syllabic] class, and [j h ʔ r m s p] are members of the [−syllabic] class; [a r̩ j ʔ r m] are in the [+sonorant] class and [s z p b] are in the [−sonorant] class; [a i w h ʔ] are in the [−consonantal] class and [r̩ m̩ r m s p] are in the [+consonantal] class. Natural classes are defined in terms of conjunctions of features, such as [+consonantal, −syllabic], which refers to the set of segments which are simultaneously [+consonantal] and [−syllabic].

When refering to segments defined by a combination of features, the features are written in a single set of brackets – [+cons,-syl] refers to a single segment which is both +*consonantal* and -*syllabic*, while [+cons][–syl] refers to a sequence of segments, the first being +*consonantal* and the second being -*syllabic*.

Accordingly, the three major class features combine to define five maximally differentiated classes, exemplified by the following segment groups.

(5)	a, i, u	r̩, l̩, m̩	j, w, h, ʔ	r, l, m	s, z, p, b
syllabic	+	+	−	−	−
sonorant	+	+	+	+	−
consonantal	−	+	−	+	+

Further classes are definable by omitting specifications of one or more of these features: for example, the class [−syllabic, +sonorant] includes {j, w, h, ʔ, r, l, m}.

One thing to note is that all [+syllabic] segments, i.e. all syllable peaks, are also [+sonorant]. It is unclear whether there are syllabic obstruents, i.e. [s̩], [k̩]. It has been claimed that such things exist in certain dialects of Berber, but their interpretation remains controversial, since the principles for detection of syllables are controversial. Another gap is the combination [−sonorant, −consonantal], which would be a physical impossibility. A [−sonorant] segment would require a major obstruction in the vocal tract, but the specification [−consonantal] entails that the obstruction could not be in the oral cavity. The only other possibility would be constriction of the nasal passages, and nostrils are not sufficiently constrictable without manual intervention.

4.**2.3 Place of articulation**

Features which define place of articulation are our next functional set. We begin with the features typically used by vowels, specifically the [+syllabic, −consonantal, +sonorant] segments, and then proceed to consonant features, ending with a discussion of the intersection of these features.

Vowel place features. The features which define place of articulation for vowels are the following.

high: the body of the tongue is raised from the neutral position.
low: the body of the tongue is lowered from the neutral position.
back: the body of the tongue is retracted from the neutral position.
round: the lips are protruded.
tense: sounds requiring deliberate, accurate, maximally distinct gestures that involve considerable muscular effort.
advanced tongue root: produced by drawing the root of the tongue forward.

The main features are [high], [low], [back], and [round]. Phonological analysis primarily distinguish just front and back vowels, governed by [back]: front vowels are [−back] since they do not involve retraction of the tongue body, and back vowels are [+back]. Phonetic central vowels are usually treated as phonological back vowels, since typically central vowels are unrounded but back vowels are rounded. Distinctions such as those between [ɨ] and [ɯ], [ɜ] and [ʌ], [y] and [ʉ], [ɘ] and [œ] or [a] and [ɑ] are usually considered to be phonologically unimportant over-differentiations of language-specific phonetic values of phonologically back unrounded vowels. The phonologically relevant question about a vowel pronounced as [ʉ] is not whether the tongue position is intermediate between that of [i] and [u], but whether it patterns with {i,e,y,ø} or with {u,ɯ,o,ʌ} – or does it pattern apart from either set? In lieu of clear examples of a contrast between central and back rounded vowels, or central and back unrounded vowels, we will not at the moment postulate any other feature for the front–back dimension: though, section 4.6 considers possible evidence for the phonological relevance of the concept “central vowel”. Given the phonologically questionable status of distinctive central vowels, no significance should be attributed to the use of the symbol [ɨ] versus [ɯ], and typographic convenience may determine that a [+back,-round] high vowel is typically transcribed as [ɨ].

Two main features are employed to represent vowel height. High vowels are [+high] and [−low], low vowels are [+low] and [−high]. No vowel can be simultaneously [+high] and [+low] since the tongue cannot be raised and lowered simultaneously; mid vowels are [−high, −low]. In addition, any vowel can be produced with lip rounding, using the feature [round]. These features allow us to characterize the following vowel contrasts.

(6)

	i	y	ɨ	u	e	ø	ə	o	æ	œ	ɑ	ɒ
high	+	+	+	+	−	−	−	−	−	−	−	−
low	−	−	−	−	−	−	−	−	+	+	+	+
back	−	−	+	+	−	−	+	+	−	−	+	+
round	−	+	−	+	−	+	−	+	−	+	−	+

Note that [ɑ] is a back low unrounded vowel, in contrast to the symbol [ɒ] for a back low rounded vowel.

Vowels with a laxer, "less deliberate" and lower articulation, such as [ɪ] in English *sit* or [ɛ] in English *set* would be specified as [−tense].

(7)

	ɪ	ʏ	ɨ	ʊ	ɛ	œ	ʌ	ɔ
high	+	+	+	+	−	−	−	−
low	−	−	−	−	−	−	−	−
back	−	−	+	+	−	−	+	+
round	−	+	−	+	−	+	−	+
tense	−	−	−	−	−	−	−	−

Korean has a set of so-called "tense" consonants but these are phonetically "glottal" consonants.

One question which has not been resolved is the status of low vowels in terms of this feature. Unlike high and mid vowels, there do not seem to be clear analogous contrasts in low vowels between tense and lax [æ]. Another important point about this feature is that while [back], [round], [high] and [low] will also play a role in defining consonants, [tense] plays no role in consonantal contrasts.

The difference between *i* and *ɪ*, or *e* and ɛ has also been considered to be one of vowel height (proposed in alternative models where vowel height is governed by a single scalar vowel height feature, rather than by the binary features [high] and [low]). This vowel contrast has also been described in terms of the features "Advanced Tongue Root" (ATR), especially in the vowel systems of languages of Africa and Siberia. There has been debate over the phonetic difference between [ATR] and [tense]. Typically, [+tense] front vowels are fronter than their lax counterparts, and [+tense] back vowels are backer than their lax counterparts. In comparison, [+ATR] vowels are supposed to be generally fronter than corresponding [−ATR] vowels, so that [+ATR] back vowels are phonetically fronter than their [−ATR] counterparts. However, some articulatory studies have shown that the physical basis for the tense/lax distinction in English is no different from that which ATR is based on. Unfortunately, the clearest examples of the feature [ATR] are found in languages of Africa, where insufficient comparative phonetic research has been done. Since no language contrasts both [ATR] and [tense] vowels, it is usually supposed that there is a single feature, whose precise phonetic realization varies somewhat from language to language.

Consonant place features. The main features used for defining consonantal place of articulation are the following.

coronal: produced with the blade or tip of the tongue raised from the neutral position.
anterior: produced with a major constriction located at or in front of the alveolar ridge.
strident: produced with greater noisiness.
distributed: produced with a constriction that extends for a considerable distance along the direction of air flow.

Place of articulation in consonants is primarily described with the features [coronal] and [anterior]. Labials, labiodentals, dentals and alveolars are [+anterior] since their primary constriction is at or in front of the alveolar ridge (either at the lips, the teeth, or just back of the teeth) whereas other consonants (including laryngeals) are [−anterior], since they lack this front constriction. The best way to understand this feature is to remember that it is the defining difference between [s] and [ʃ], where [s] is [+anterior] and [ʃ] is [−anterior]. Anything produced where [s] is produced, or in front of that position, is [+anterior]; anything produced where [ʃ] is, or behind [ʃ] is [−anterior].

(8)	[+anterior]	[−anterior]
	f ɸ p θ s t̪ t	ʃ $t^{ʃ}$ ʂ ʈ ç x k q ʕ h ʔ

Remember that the two IPA letters <$t^{ʃ}$> represent a single [-anterior] segment, not a combination of two segments, [+anterior] [t] and [-anterior] [ʃ].

Consonants which involve the blade or tip of the tongue are [+coronal], and this covers the dentals, alveolars, alveopalatals and retroflex consonants. Consonants at other places of articulation – labial, velar, uvular and laryngeal – are [−coronal]. Note that this feature does not encompass the body (back) of the tongue, so while velars and uvulars use the tongue, they use the body of the tongue rather than the blade or tip, and therefore are [−coronal]. The division of consonants into classes as defined by [coronal] is illustrated below.

(9)	[+coronal]	[−coronal]
	t̪ θ t s ʃ n l r ɲ ʈ	p ɸ f k q ʕ

Two other features are important in characterizing the traditional places of articulation. The feature [distributed] is used in coronal sounds to distinguish dental [t̪] from English alveolar [t], or alveopalatal [ʃ] from retroflex [ʂ]: the segments [t̪, ʃ] are [+distributed] and [t, ʈ, ʂ] are [−distributed]. The feature [distributed], as applied to coronal consonants, approximately corresponds to the traditional phonetic notion "apical" ([−distributed]) versus "laminal" ([+distributed]). This feature is not relevant for velar and labial sounds and we will not specify any value of [distributed] for noncoronal segments.

The feature [strident] distinguishes strident [f, s] from nonstrident [φ, θ]: otherwise, the consonants [f, φ] would have the same feature specifications. Note that the feature [strident] is defined in terms of the aerodynamic property of greater turbulence (which has the acoustic correlate of greater noise), not in terms of the movement of a particular articulator – this defining characteristic is accomplished by different articulatory configurations. In terms of contrastive usage, the feature [strident] only serves to distinguish bilabial and labiodentals, or interdentals and alveolars. A sound is [+strident] only if it has greater noisiness, and "greater" implies a comparison. In the case of [φ] vs. [f], [β] vs. [v], [θ] vs. [s], or [ð] vs. [z] the second sound in the pair is noisier. No specific degree of noisiness has been proposed which would allow you to determine in isolation whether a given sound meets the definition of strident or not. Thus it is impossible to determine whether [ʃ] is [+strident], since there is no contrast between strident and nonstrident alveopalatal sounds. The phoneme [ʃ] is certainly relatively noisy – noisier than [θ] – but then [θ] is noisier than [φ] is.

[Strident] is not strictly necessary for making a distinction between [s] and [θ], since [distributed] also distinguishes these phonemes. Since [strident] is therefore only crucial for distinguishing bilabial and labial fricatives, it seems questionable to postulate a feature with such broad implications solely to account for the contrast between labiodental and bilabial fricatives. Nonetheless, we need a way of representing this contrast. The main problem is that there are very few languages (such as Ewe, Venda and Shona) which have both [f] and [φ], or [v] and [β], and the phonological rules of these languages do not give us evidence as to how this distinction should be made in terms of features. We will therefore only invoke the feature [strident] in connection with the [φ, β] vs. [f, v] contrast.

Using these three features, consonantal places of articulation can be partially distinguished as follows.

(10)

	p	t̪	t	t^ʃ	ʈ	c, k, q, ʕ, ʔ
anterior	+	+	+	–	–	–
coronal	–	+	+	+	+	–
distributed		+	–	+	–	–

Vowel features on consonants. The features [high], [low], [back], and [round] are not reserved exclusively for vowels, and these typical vowel features can play a role in defining consonants as well. As we see in (10), velar, uvular, pharyngeal and glottal places of articulation are not yet distinguished; this is where the features [high], [low] and [back] become important. Velar, uvular and pharyngeal consonants are [+back] since they are produced with a retracted tongue body. The difference between velar and uvular consonants is that with velar consonants the tongue body is raised, whereas with uvular consonants it is not, and thus velars are [+high] where uvulars are [−high]. Pharyngeal consonants are distinguished from uvulars in that pharyngeals are [+low] and uvulars are [−low], indicating that the constriction for pharyngeals is even lower than that for uvulars.

One traditional phonetic place of articulation for consonants is that of "palatal" consonants. The term "palatal" is used in many ways, for example the postalveolar or alveopalatal (palatoalveolar) consonants [ʃ] and [t^ʃ] might be referred to as palatals. This is strictly speaking a misnomer, and the term "palatal" is best used only for the "true palatals," transcribed as [c ç ɟ].

Such consonants are found in Hungarian, and also in German in words like [iç] ‘I’ or in Norwegian [çø:per] ‘buys’. These consonants are produced with the body of the tongue raised and fronted, and therefore they have the feature values [+hi,−back]. The classical feature system presented here provides no way to distinguish such palatals from palatalized velars ([k^j]) either phonetically or phonologically. Palatalized (fronted) velars exist as allophonic variants of velars before front vowels in English, e.g. [k^jip] ‘keep’; they are articulatorily and acoustically extremely similar to the palatals of Hungarian. Very little phonological evidence is available regarding the treatment of “palatals” versus “palatalized velars”: it is quite possible that [c] and [k^j], or [ç] and [x^j], are simply different symbols, chosen on the basis of phonological patterning rather than systematic phonetic differences.

With the addition of these features, the traditional places of articulation for consonants can now be fully distinguished.

(11)

	p	t̪	t	$t^ʃ$	ʈ	c, k^j	k	q	ʕ	ʔ
anterior	+	+	+	−	−	−	−	−	−	−
coronal	−	+	+	+	+	−	−	−	−	−
distributed		+	−	+	−					
hi	−	−	−	−	−	+	+	−	−	−
back	−	−	−	−	−	−	+	+	+	−
low	−	−	−	−	−	−	−	−	+	−

The typical vowel features have an additional function as applied to consonants, namely that they define secondary articulations such as palatalization and rounding. Palatalization involves superimposing the raised and fronted tongue position of the glide [j] onto the canonical articulation of a consonant, thus the features [+high, −back] are added to the primary features that characterize a consonant (those being the features that typify [i, j]). So, for example, the essential feature characteristics of a bilabial are [+anterior, −coronal] and they are only incidentally [−hi,−back]. A palatalized bilabial would be [+anterior, −coronal, +hi −back]. Velarized consonants have the features [+high, +back] analogous to the features of velar consonants; pharyngealized consonants have the features [+back, +low]. Consonants may also bear the feature [round]. Applying various possible secondary articulations to labial consonants results in the following specifications.

(12)

	p	p^j	$p^ɣ$	p^w	$p^ɥ$	$p^ʕ$	p^q	p^o	$p^ø$
hi	−	+	+	+	+	−	−	−	−
back	−	−	+	+	−	+	+	+	−
low	−	−	−	−	−	+	−	−	−
round	−	−	−	+	+	−	−	+	+

Labialized (p^w), palatalized (p^j), velarized ($p^ɣ$) and pharyngealized ($p^ʕ$) variants are the most common categories of secondary articulation. Uvularized consonants, i.e. p^q, are rare: uvularized clicks are attested in Jun /’hoansi. It is unknown if there is a contrast between rounded consonants differing in secondary height, symbolized above as p^w vs. p^o or $p^ɥ$ vs. $p^ø$. Feature theory allows such a contrast, so eventually we ought to find examples. If, as seems likely after some decades of research, such contrasts do not exist where predicted, there should be a revision of the theory, so that the predictions of the theory better match observations.

This treatment of secondary articulations makes other predictions. One is that there cannot be palatalized uvulars or pharyngeals. This follows from the fact that the features for palatalization ([+high, −back]) conflict with the features for uvulars ([−hi, +back]) and pharyngeals ([−hi, +back, +low]). Since such segments do not appear to exist, this supports the theory: otherwise we expect – in lieu of a principle that prohibits them – that they will be found in some language. Second, in this theory a "pure" palatal consonant (such as Hungarian [ɟ]) is equivalent to a palatalized (i.e. fronted) velar. Again, since no language makes a contrast between a palatal and a palatalized velar, this is a good prediction of the theory (unless such a contrast is uncovered, in which case it becomes a bad prediction of the theory).

4.**2.4 Manner of articulation**

Other features relate to the manner in which a segment is produced, apart from the location of the segment's constriction. The manner features are:

continuant (cont): the primary constriction is not narrowed so much that airflow through the oral cavity is blocked.
delayed release (del. rel): release of a total constriction is slowed so that a fricative is formed after the stop portion.
nasal (nas): the velum is lowered which allows air to escape through the nose.
lateral (lat): the mid section of the tongue is lowered at the side.

The feature [continuant] groups together vowels, glides, fricatives, and [h] as [+continuant]. Note that [continuant] is a broader group than the traditional notion "fricative" which refers to segments such as [s], [ʃ] or [θ]. The term "fricative" generally refers to nonsonorant continuants, i.e. the class defined by the conjunction of features [+continuant, −sonorant]. Since continuants are defined as sounds where air can flow continuously through the oral cavity, nasals like [m n ŋ] are [−continuant], even though they allow continuous air flow (through the nose).

Affricates such as [$t^ʃ$, p^f] are characterized with the feature [+delayed release]. Necessarily, all affricates are [−continuant], since they involve complete constriction followed by a period of partial fricative-like constriction, and therefore they behave essentially as a kind of stop. This feature is in question, since [p^f $t^ʃ$ k^x] do not act as a unified phonological class; nevertheless, some feature is needed to characterize stops versus affricates. Various alternatives have been proposed, for example that [k^x] might just be the pronunciation of aspirated [k^h] since velar [k^x] and [k^h] never seem to contrast; perhaps the feature [strident] defines [t^s] vs. [t]. The proper representation of affricates is a currently unsolved issue in phonology.

The feature [+nasal] is assigned to sounds where air flows through the nasal passages, for example [n] as well as nasalized vowels like [ã]. Liquids and fricatives can be nasalized as well, but the latter especially are quite rare. L-like sounds are characterized with the feature [lateral]. Almost all [+lateral] sounds are coronal, though there are a few reports of velar laterals. Detailed information on the phonetics and phonology of these segments is not available.

Examples of the major manners of articulation are illustrated below, for coronal place of articulation.

(13)

	t	n	t^s	s	l	l̃	t^l
delayed release	−	−	+	−	−	−	+
continuant	−	−	−	+	+	+	+
lateral	−	−	−	−	+	+	+
nasal	−	+	−	−	−	+	−

4.2.5 Laryngeal features

Three features characterize the state of the glottis:

spread glottis: the vocal folds are spread far apart.
constricted glottis: the vocal folds are tightly constricted.
voice: the vocal folds vibrate.

Voiced sounds are [+voice]. The feature [spread glottis] describes aspirated obstruents ([p^h], [b^h]) and breathy sonorants ([m̤], [a̤]); [constricted glottis] describes implosives ([ɓ]), ejective obstruents ([p’]), and laryngealized sonorants ([m̰], [a̰]).

How to distinguish implosives from ejectives is not entirely obvious, but the standard answer is that ejectives are [−voice] and implosives are [+voice]. There are two problems with this. One is that implosives do not generally pattern with other [+voiced] consonants in phonological systems, especially in how consonants affect tone (voiced consonants, but typically not implosives, may lower following tones). The second is that Ngiti and Lendu have both voiced and voiceless implosives. The languages lack ejectives, which raises the possibility that voiceless implosives are phonologically [−voice,+c.g.], which is exactly the specification given to ejective consonants. You may wonder how [−voice,+c.g.] can be realized as an ejective in languages like Navajo, Tigre or Lushootseed, and as a voiceless implosive in Ngiti or Lendu. This is possible because feature values give approximate phonetic descriptions, not exact ones. The Korean “fortis” consonants, found in [k’ata] ‘peel (noun),’ [ak’i] ‘musical instrument’ or [alt’a] ‘be ill’ are often described as glottalized, and phonetic studies have shown that they are produced with glottal constrictions: thus they would be described as [−voice,+c.g.]. Nevertheless, they are not ejectives. Similarly, Khoekhoe (Nama) has a contrast between plain clicks ([!àm̋] ‘deep’) and glottalized ones ([!’ám̋] ‘kill’), but the glottalized clicks realize the feature [+c.g.] as a simple constriction of the glottis, not involving an ejective release.

The usual explanation for the difference between ejectives in Navajo and glottalized nonejective consonants in Korean or Khoekhoe is that they have the same phonological specifications, [−voice,+c.g.], but realize the features differently due to language-specific differences in principles of phonetic implementation. This is an area of feature theory where more research is required.

The representations of laryngeal contrasts in consonants are given below.

(14)

	p	b	ɓ	p’	p^h	$b^ɦ$
voice	−	+	+	−	−	+
c.g.	−	−	+	+	−	−
s.g.	−	−	−	−	+	+

4.2.6 Prosodic features

Finally, in order to account for the existence of length distinctions, and to represent stressed versus unstressed vowels, two other features were proposed:

long: has greater duration.
stress: has greater emphasis, higher amplitude and pitch, longer duration.

These are obvious: long segments are [+long] and stressed vowels are [+stress].

A major lacuna in the Chomsky and Halle (1968) account of features is a lack of features for tone. This is remedied in chapter 10 when we introduce nonlinear representations. For the moment, we can at least assume that tones are governed by a binary feature [±high tone] – this allows only two levels of tone, but we will not be concerned with languages having more than two tone levels until chapter 10.

4.2.7 Summary of feature values

Features combine quite freely, so we cannot give a complete list of segment symbols and their features. By learning some specific feature values and applying your knowledge of the meaning of features, it should be possible for you to arrive at the feature values of other segments. This is, of course, possible only if you know relevant phonetic details of the sound that you are considering. In order to know the feature values of [ɭ] (which you encountered in chapter 2, in Logoori), you need to know that this is the symbol for a retroflex lateral approximant, thus it has the features appropriate for [l], and it also has the features that characterize retroflex consonants, which are [−ant, −dist]. If you do not know the phonetic characteristics of the segment symbolized as [ʕ], it is necessary to first understand its phonetic properties – it is a voiced pharyngeal continuant – before trying to deduce its phonological feature values. In reading descriptions of languages, it is also important to understand that a symbol used in published data on a language is not always used according to a particular standard of phonetic transcription practices at the moment, so read the phonetic descriptions of letters in the grammar carefully!

The standard feature values for the consonants of (American) English are given in (15), to help you understand how the entire set of features is applied to the sound inventory of a language which you may be at least somewhat familiar with.

(15)

	p	t	tʃ	k	b	d	dʒ	g	f	v	θ	ð
syl	−	−	−	−	−	−	−	−	−	−	−	−
son	−	−	−	−	−	−	−	−	−	−	−	−
cons	+	+	+	+	+	+	+	+	+	+	+	+
cont	−	−	−	−	−	−	−	−	+	+	+	+
del.rel	−	−	+	−	−	−	+	−	−	−	−	−
lat	−	−	−	−	−	−	−	−	−	−	−	−
nas	−	−	−	−	−	−	−	−	−	−	−	−
voi	−	−	−	−	+	+	+	+	−	+	−	+
c.g.	−	−	−	−	−	−	−	−	−	−	−	−
s.g.	(−	−	−	−)	−	−	−	−	−	−	−	−
ant	+	+	−	−	+	+	−	−	+	+	+	+
cor	−	+	+	−	−	+	+	−	−	−	+	+
distr		−	+	−	+	+	+					
hi	−	−	−	+	−	−	−	+	−	−	−	−
lo	−	−	−	−	−	−	−	−	−	−	−	−
back	−	−	−	+	−	−	−	+	−	−	−	−
round	−	−	−	−	−	−	−	−	−	−	−	−

	s	z	ʃ	ʒ	h	ʔ	m	n	ŋ	ɹ	l	j	w
syl	−	−	−	−	−	−	−	−	−	−	−	−	−
son	−	−	−	−	+	+	+	+	+	+	+	+	+
cons	+	+	+	+	−	−	+	+	+	−	+	−	−
cont	+	+	+	+	+	−	−	−	−	+	+	+	+
del.rel	−	−	−	−	−	−	−	−	−	−	−	−	−
lat	−	−	−	−	−	−	−	−	−	−	+	−	−
nas	−	−	−	−	−	−	+	+	+	−	−	−	−
voi	−	+	−	+	−	−	+	+	+	+	+	+	+
c.g.	−	−	−	−	−	+	−	−	−	−	−	−	−
s.g.	−	−	−	−	+	−	−	−	−	−	−	−	−
ant	+	+	−	−	−	−	+	+	−	−	+	−	−
cor	+	+	+	+	−	−	−	+	−	+	+	−	−
distr	−	−	+	+	−	−	−						
hi	−	−	−	−	−	−	−	−	+	+	−	+	+
lo	−	−	−	−	−	−	−	−	−	−	−	−	−
back	−	−	−	−	−	−	−	−	+	+	−	−	+
round	−	−	−	−	−	−	−	−	−	+	−	−	+

The assignment of [spread glottis] – aspiration – in English stops varies according to context, so the value [−s.g.] is in parenthesis in the chart because both values of this feature are found on the surface, depending on context. The value [−s.g.] represents the underlying value.

Vowel feature summary. Certain feature values are uniform for all vowels: [+syl, −cons, +son, +cont, −del.rel, −ant, −lat, −dist.]. Typically, vowels are also [+voice, −s.g.,−c.g.]. There are languages such as Mazateco and !Xoo where breathy voicing and glottalization are used contrastively, so in these languages [+s.g.] and [+c.g.] are possible specifications. A number of languages have phonetic voiceless vowels, but the phonological status of voiceless vowels is not so clear, thus it may be that there are no phonologically [−voice] vowels. Values of the main features used to distinguish vowels are given in (16). (Recall that we are not certain whether [tense] applies to low vowels.)

(16)

	i	y	ɨ	u	e	ø	ə	o	æ	œ	ɑ	ɒ
high	+	+	+	+	−	−	−	−	−	−	−	−
low	−	−	−	−	−	−	−	−	+	+	+	+
back	−	−	+	+	−	−	+	+	−	−	+	+
round	−	+	−	+	−	+	−	+	−	+	−	+
tense	+	+	+	+	+	+	+	+				

	ɪ	ʏ	ᵻ	ʊ	ɛ	œ	ʌ	ɔ
high	+	+	+	+	−	−	−	−
low	−	−	−	−	−	−	−	−
back	−	−	+	+	−	−	+	+
round	−	+	−	+	−	+	−	+
tense	−	−	−	−	−	−	−	−

Nasality, length, breathiness and creaky voice are properties freely available to vowels, so any of these vowels can have ±nasal, ±long, ±s.g. or ±c.g. counterparts.

Consonant feature summary. Primary place of articulation for consonants is summarized in (17), using continuant consonants (voiceless in the first row, voiced in the second: numbers in the third row are keyed to traditional place of articulation terms). Continuant consonants are used here because they exhibit the maximum number of distinctions, for example there are bilabial and labiodental fricatives, but only bilabial stops. All of these consonants are [−syl, +cont, −del.rel, −nas, −lat, −c.g., −tense, −round].

(17)

1: bilabial
2: labiodental
3: (inter-)dental
4: alveolar
5: alveopalatal
6: retroflex
7: palatal
8: velar
9: uvular
10: pharyngeal
11: glottal/laryngeal

	ɸ	f	θ	s	ʃ	ʂ	ç	x	χ	ħ	h
	β	v	ð	z	ʒ	ʐ	j	ɣ	ʁ	ʕ	ɦ
	1	2	3	4	5	6	7	8	9	10	11
ant	+	+	+	+	−	−	−	−	−	−	−
cor	−	−	+	+	+	+	−	−	−	−	−
distr			+	−	+	−					
hi	−	−	−	−	−	−	+	+	−	−	−
lo	−	−	−	−	−	−	−	−	−	+	−
back	−	−	−	−	−	−	−	+	+	+	−

Secondary place of articulation is illustrated in (18), here restricted to secondary articulations on [p t]. All of these consonants are [−syl, −son, +cons, −cont, −del.rel, −lat, −nas, −voice, −s.g., −c.g., −tense].

(18)

	p	p^{w}	p^{γ}	p^{j}	$p^{ʕ}$	$p^{ɥ}$	t	t^{w}	t^{γ}	t^{j}	$t^{ʕ}$	$t^{ɥ}$
ant	+	+	+	+	+	+	+	+	+	+	+	+
cor	−	−	−	−	−	−	+	+	+	+	+	+
distr	−	−	−	−	−	−	−	−	−	−	−	−
hi	−	(+)	+	+	−	+	−	(+)	+	+	−	+
lo	−	−	−	−	+	−	−	−	−	−	+	−
back	−	+	+	−	+	−	−	+	+	−	+	−
round	−	+	−	−	−	+	−	+	−	−	−	+

Round consonants might simply have the specification [+round]. Tongue raising and backing is not necessary in order to achieve rounding, whereas tongue raising and backing is by definition necessary in order to have a velarized consonant.

A final important point must be made. The twenty-one features discussed here – syllabic, sonorant, consonantal, high, low, back, round, tense (advanced tongue root), coronal, anterior, strident, distributed, continuant, delayed release, nasal, lateral, spread glottis, constricted glottis, voice, long, stress – are specific empirical hypotheses. This means that they are subject to change in the face of evidence that a change is required, so they are not immutable. On the other hand, as scientific hypotheses, they must be taken seriously until good evidence is presented that another system of features is better (see section 4.6 and chapter 10 for discussion of such changes). Features should not be invented willy-nilly: using distinctive features is not the same as placing a plus sign in front of a traditional articulatory description, and thus describing sounds as [+mid], [+alveolar] or [+vowel] misconstrues the claim of the theory of distinctive features.

4.3 Features and classes of segments

Besides defining phonemes, features play a role in formalizing rules, since rules are stated in terms of features. Every specification, such as [+nasal] or [−voice], defines a class of segments. The generality of a class is inversely related to how many features are required to specify the class, as illustrated in (19).

(19)

[+syl]	[+syl,-nas]	[+syl,+rd]	[+syl,+hi,-nas]	[+syl,-hi,-lo,-nas,-tense]
ɛ e ɪ i ɛ̃ ẽ ɪ̃ □	ɛ e ɪ i	ɔ o ʊ ɔ̃	ɪ i	ʌ ɛ ɔ
a ɔ o ʊ ã ɔ̃ õ ʊ̃	a ɔ o ʊ	õ ʊ̃ u ũ	ʊ u	
u ə æ ũ ə̃ æ̃	u ə æ			

The most general class, defined by a single feature, is [+syllabic] which refers to all vowels. The size of that class is determined by the segments in the language: [+syllabic] in Spanish refers to [i e a o u], but in English refers to [i ɪ e ɛ æ a ɔ o ʊ u ə ʌ r̩ l̩]. As you add features to a description, you narrow down the class, making the class less general. The usual principle adopted in phonology is that simpler rules, which use fewer features, are preferable to rules which use more features.

One challenge in formalizing rules with features is recognizing the features which characterize classes. Discovering the features which define a class boils down to seeing which values are the same for all segments in the set, then checking that no other segment in the inventory also has that combination of values. The main obstacle is that you have to think of segments in terms of their feature properties, which takes practice to become second nature. As an exercise towards understanding the relation between classes of segments and feature descriptions, we will assume a language with the following segments:

(20) p t k b d g f s x v γ w j l m n a e i o u y

To assist in solving the problems which we will consider, feature matrices of these segments are given below in (21).

(21)

	cons	son	syl	voi	cont	nas	lat	ant	cor	hi	bk	low	rd
p	+	−	−	−	−	−	−	+	−	−	−	−	−
t	+	−	−	−	−	−	−	+	+	−	−	−	−
k	+	−	−	−	−	−	−	−	−	+	+	−	−
b	+	−	−	+	−	−	−	+	−	−	−	−	−
d	+	−	−	+	−	−	−	+	+	−	−	−	−
g	+	−	−	+	−	−	−	−	−	+	+	−	−
f	+	−	−	−	+	−	−	+	−	−	−	−	−
s	+	−	−	−	+	−	−	+	+	−	−	−	−
x	+	−	−	−	+	−	−	−	−	+	+	−	−
v	+	−	−	+	+	−	−	+	−	−	−	−	−
γ	+	−	−	+	+	−	−	−	−	+	+	−	−
w	−	+	−	+	+	−	−	−	−	+	+	−	+
j	−	+	−	+	+	−	−	−	−	+	−	−	−
l	+	+	−	+	+	−	+	+	+	−	−	−	−
m	+	+	−	+	−	+	−	+	−	−	−	−	−
n	+	+	−	+	−	+	−	+	+	−	−	−	−
a	−	+	+	+	+	−	−	−	−	−	+	+	−
e	−	+	+	+	+	−	−	−	−	−	−	−	−
i	−	+	+	+	+	−	−	−	−	+	−	−	−
o	−	+	+	+	+	−	−	−	−	−	+	−	+
u	−	+	+	+	+	−	−	−	−	+	+	−	+
y	−	+	+	+	+	−	−	−	−	+	−	−	+

Each of the following sets of segments can be defined in terms of some set of distinctive features.

(22) i. p t k f s x
ii. p t b d f s v l m n
iii. w j l m n a e i o u y
iv. p k b g f x v γ
v. j l m n a e i
vi. v γ w j a e i o u y

In the first set, each segment is a voiceless obstruent, and, equally importantly, every voiceless obstruent of the language is included in this first set. This set could be specified as [−sonorant,-voice] or as [−voice], since all voiceless segments in the language are [−sonorant]. Given that both specifications refer to exactly the same segments, there is no question of one solution being wrong in the technical sense (assuming the language has the segments of (20): if the language had [h], these two feature specifications would not describe the segments). However, unless there is a compelling reason to do otherwise, the simplest definition of the set of segments should be given, using only those features which are absolutely necessary. The features which are used to exactly define a set of segments depends very much on what the entire set of segments in the language is. If we were dealing with a language which had, in addition, the segments [p^h t^h k^h], then in specifying the set [p t k f s x], you would have to also mention [−s.g.] in order to achieve a definition of the set which excludes [p^h t^h k^h].

The set (22ii) contains only consonants (i.e. [−syllabic] segments), but it does not contain all of the [−syllabic] segments of the language. Compare the segments making up (22ii) with the full set of consonants:

(23)	p t b d f s v l m n	← Selected class of segments
	p t k b d g f s x v γ w j l m n	← Entire set of consonants

This set does not include glides: [consonantal] is the essential property which distinguishes glides (including *h* and ʔ, which are lacking here) from regular consonants. Thus, the segments in (ii) are [+consonantal]. But not all [+consonantal] segments are included in set (ii): the velars are not included, so we need a further restriction. The features typically used to specify velars are [+high, +back], so we can use one of those features. Thus, you can pick out the segments in (ii) as the class of [+consonantal,−high] segments, or the [+consonantal,−back] segments. Rather than refer to [consonantal], you could try to take advantage of the fact that all glides are [+high] and refer to (ii) as the set of [−high] segments, without mentioning [consonantal]. It is true that all segments in the set are [−high], but [−high] itself cannot be the entire description of this set since not all [−high] segments of the language are in the set: the vowels {aeo} is not in set (ii). We conclude that [+consonantal,−high] is the correct one for this class of segments.

This set can also be identified by reference to a single feature: what one feature makes this distinction?

Set (iii) contains a mixture of vowels and consonants: it includes all vowels, plus the nasals, the lateral [l], and the glides. This class is defined by [+sonorant]. Another feature which is constant in this group is [+voice], so you could define the class as [+sonorant, +voice]. But addition of [+voice] contributes nothing, so there is no point to mentioning that feature as well. Set (iv) on the other hand contains only obstruents, but not all obstruents. Of the whole set of obstruents, what is missing from (iv) is the group {tds}, which are [+coronal]. Therefore, we can refer to set (iv) by the combination [−sonorant, −coronal].

The fifth set, {jlmnaei}, includes a mixture of vowels and consonants. Some properties that members of this set have in common are that they are voiced, and they are sonorants. Given the phoneme inventory, all sonorants are voiced, but not all voiced segments are sonorants. Since the voiced obstruents {bdgvγ} are not included in this set, it would be less efficient to concentrate on the feature [+voice], thus we focus on the generalization that the segments are sonorants. Now compare this set to the total set of sonorants.

(24)   j l m n a e i
  w j l m n a e i o u y

We can see that this set of segments is composed of a subset of sonorants, namely the sonorants excluding {w, o, u, y}. But that set is the set of [+round] segments; therefore, the set is the set of [+sonorant, −round] segments.

The last set also contains a mixture of consonants and vowels: it includes all of the vowel and glides, plus the voiced obstruents {v, γ}. Therefore, the feature [sonorant] cannot be used to pick out this class of segments, since members of the class can have both values for that feature. However, all of the members of this class are voiced. Now compare set (vi) against the set of all voiced segments.

(25)   v γ w j   a e i o u y
  b d g v γ w j l m n a e i o u y

The fundamental difference between [b] and [v], or between [g] and [γ], is that {b, g} are stops while {v, γ} are continuants. This suggests using [+continuant] as one of the defining features for this class. Vowels and glides are all [+continuant], so we have passed the first test, namely that all segments in set (vi) are [+continuant,+voice]. We must also be sure that this is a sufficient specification for the class: are there any [+continuant,+voice] segments in the language which are not included in set (vi)? The segments to worry about in this case would be {l, m, n}, which are [+voice]. We exclude the nasals via [+continuant] and add [−lateral] to exclude *l*.

As a further exercise in understanding how sets of segments are grouped by the features, assume a language with the following segmental inventory.

(26) p p^{f} t t^{s} t^{ʃ} c k b b^{v} v β d^{z} d^{ʒ} ɟ g m n ŋ f θ s ʃ d ð z ʒ i y e ø ə o u a w j

For each group, determine what feature(s) define the particular set of segments.

(27) i. t^{ʃ} c k d^{ʒ} ɟ g ŋ ʃ ʒ i y e ø ə o u a w j
  ii. s i ʃ e f z v β a ʒ o u j ø θ y ə w ð
  iii. k j g c w i u y ɟ ŋ
  iv. k g a ə ŋ

4.**4 Possible phonemes and rules – an answer**

We now return to the theoretical questions raised at the beginning of this chapter: what is a possible phoneme and what is a possible phonological rule?

4.4.1 Possible phonemes

The theory of features answers the question of possible phonemes, saying that the segments which can be constructed using these features are all and the only possible phonemes. This gives a mathematical upper limit of 2^n segments, given *n* binary features, so if there are twenty features (a reasonable number), there are 1,048,576 logically possible feature specifications, which is quite a lot of segments. It also has to be physically possible to realize a segment, so the number of possible segments is smaller than this. Many segments can be imagined which are phonetically uninterpretable, such as one which is [+high,+low]. Such a segment is physically impossible since the tongue cannot be contradictorily raised and lowered at the same time, so the nonexistence of a large class of such segments is independently explained. Similarly, no segment can be [+cons, −hi, −back, −ant, −cor]. A segment which is [+cons] is not a vowel or glide. The feature [−back] tells us that the segment would have a place of articulation in front of the velar position. [−ant] tells us that it must have a place of articulation behind the alveolar ridge, and [−hi] tells us that it cannot be a palatal. Everything about this description suggests the vowel [e], *except* that it is [+consonantal], whereas vowels are [−consonantal]. No major constriction can be formed with the tongue in the position of [e]: hence this combination of features happens to be physically impossible. To be attested in a language, a segment must be both *combinatorially* possible, i.e. it must use just the features given by the theory, and *physically* possible.

Although the set of attested phonemes in human languages is quite large, there are significant limitations on what phonemes are possible. Retroflex consonants have the features [−anterior, +coronal, -distributed]. Recall the question whether a language could contrast two kinds of retroflex consonants, such as apical and sublaminal retroflex as found in Hindi versus Telugu. According to this theory of features, such a contrast is impossible, since no feature is available to describe such a difference within a language. Phonetic differences across languages are possible because phonetic interpretation is not subject to the limitations of phonological feature theory. Were we to discover such a contrast, the theory of features would be challenged, because it has no mechanism for expressing such a distinction. Similarly, the differences attested in the phonetics of [u] and [ʊ] across languages are never found within a single language. In a single language, the maximal contrast is between two such vowels, governed by the feature tense (or ATR). The fact that such differences exist at the phonetic level between languages, but are never exploited within a single language as a way to distinguish words, is an example of the difference between phonetic and phonological properties.

Thus one of the main goals of distinctive feature theory is providing a predictive framework for saying what contrasts will and will not be found in the phoneme systems of human languages. The above theory has done a rather good job of answering the “possible phoneme” question.

4.4.2 Rule formulation and features

The most important function of features is to form the basis for writing rules, which is crucial in understanding what defines a possible phonological rule. A typical rule of vowel nasalization, which nasalizes all vowels before a nasal, can be formulated very simply if stated in features:

(28) [+syllabic] → [+nasal]/ __ [+nasal]

Such a rule is common in the languages of the world. Very uncommon, if it exists at all, is one nasalizing only the lax vowel [ɪ], and only before [m]. Formulated with features, that rule looks as follows:

(29) $$\begin{bmatrix} +\text{syl} \\ -\text{ATR} \\ +\text{hi} \\ -\text{rd} \end{bmatrix} \rightarrow [+\text{nasal}] \;/\; \underline{\quad} \begin{bmatrix} +\text{nasal} \\ +\text{ant} \\ -\text{cor} \end{bmatrix}$$

This rule requires significantly more features than (28), since [ɪ] which undergoes the rule must be distinguished in features from other high vowels such as [i] or [ʊ] which (in this hypothetical case) do not undergo the rule, and [m] which triggers the rule must be distinguished from [n] or [ŋ] which do not.

Simplicity in rule writing. This relation between generality and simplicity on the one hand, and desirability or commonness on the other, has played a very important role in phonology: all things being equal, simpler rules are preferred, both for the intrinsic elegance of simple rules and because they correlate with more general classes of segments. Maximum generality is an essential desideratum of science.

The idea that rules are stated in terms of the simplest, most general classes of phonetically defined segments has an implication for rule formulation. Suppose we encounter a rule where high vowels (but not mid and low vowels) nasalize before nasal stops (*n, m, ŋ*), thus *in* → *ĩn, uŋ* → *ũŋ*, and so on. We would formulate such a rule as follows:

(30) $$\begin{bmatrix} +\text{syl} \\ +\text{hi} \end{bmatrix} \rightarrow [+\text{nasal}] \;/\; \_ \begin{bmatrix} +\text{nasal} \\ -\text{cont} \end{bmatrix}$$

However, we could equally well formalize the rule as

(31) $$\begin{bmatrix} +\text{syl} \\ +\text{hi} \\ -\text{low} \end{bmatrix} \rightarrow \begin{bmatrix} +\text{syl} \\ +\text{hi} \\ -\text{low} \\ +\text{nasal} \end{bmatrix} \;/\; \_ \begin{bmatrix} +\text{nasal} \\ -\text{cont} \\ -\text{low} \end{bmatrix}$$

We could freely add [−low] to the specification of the input segment (since no vowel can be [+hi, +low], thus high vowels automatically would pass that condition), and since the same class of vowels is referenced, inclusion of [−low] is empirically harmless. Saying that the vowel becomes [+syl, +hi, −low] is factually harmless, since the vowel that undergoes the change already has these specifications. At the same time, the additional features in (31) are useless complications, so on the theoretical grounds of simplicity, we formalize the rule as (30). In writing phonological rules, we specify only features which are mandatory. A formulation like

(32) $\left[+\text{syl}\right] \rightarrow \left[+\text{nasal}\right] / \_ \begin{bmatrix} +\text{nasal} \\ -\text{cont} \end{bmatrix}$

would mention fewer features, but it would be wrong given the facts which the rule is supposed to account for, since the rule should state that only *high* vowels nasalise, but this rule nasalises *all* vowels. Simplicity obviously is subordinate to accuracy.

Likewise, we could complicate the rule by adding the restriction that only non-nasal vowels are subject to (30): in (30), we allow the rule to vacuously apply to high vowels that are already nasal. There is (and could be) no direct evidence which tells us whether /ĩn/ undergoes (30) and surfaces as [ĩn], or /ĩn/ is immune to (30) and surfaces as [ĩn]; and there is no conceptual advantage to complicating the rule to prevent it from applying in a context where we do not have definitive proof that the rule applies. The standard approach to rule-formalization is, therefore, to write the rule in the simplest possible way, consistent with the facts.

Formalizability. The claim that rules are stated in terms of phonetically defined classes is essentially an axiom of phonological theory. What are the consequences of such a restriction? Suppose you encounter a language with a phonological rule of the type {p, r} → {i, b} _ {o, n}. Since the segments being changed (*p* and *r*) or conditioning the change (*o* and *n*) cannot be defined in terms of any combination of features, nor can the changes be expressed via any features, the foundation of phonological theory would be seriously disrupted. Such a rule would refute a fundamental claim of the theory that processes must be describable in terms of these (or similar) features. This is what it means to say that the theory makes a prediction: if that prediction is wrong, the theory itself is wrong.

Much more remains to be said about the notion of "possible rule" in phonology; nevertheless, we can see that distinctive feature theory plays a vital role in delimiting possible rules, especially in terms of characterizing the classes of segments that can function together for a rule. We now turn to a discussion of rule formalism, in the light of distinctive feature theory.

4.5 The formulation of phonological rules

Many aspects of rule theory were introduced in our informal approach to rule-writing in chapter 2, and they carry over in obvious ways to the formal theory that uses features. The general form of a phonological rule is:

$$(33) \quad \underset{\text{Focus}}{\begin{bmatrix} \alpha F_i \\ \beta F_j \\ \vdots \end{bmatrix}} \rightarrow \underset{\text{Structural change}}{\begin{bmatrix} \gamma F_k \\ \delta F_l \\ \vdots \end{bmatrix}} \; / \; \ldots \underset{\text{Trigger}}{\begin{bmatrix} \varepsilon F_{m_i} \\ \zeta F_n \\ \vdots \end{bmatrix}} \_\_ \begin{bmatrix} \eta F_o \\ \theta F_p \\ \vdots \end{bmatrix} \ldots$$

where F_i, F_j, F_k … are features and α, β, γ … are plus or minus values. The arrow means "becomes", slash means "when it is in the context" and the dash refers to the position of the focus in that context. The matrix to the left of the arrow is the segment changed by the rule; that segment is referred to as the **focus** or **target** of the rule. The matrix immediately to the right of the arrow is the **structural change**, and describes the way in which the target segment is changed. The remainder of the rule constitutes the **trigger** (also known as the **determinant** or **environment**), stating the conditions outside of the target segment which are necessary for application of the rule. Instead of the slash, a rule can be fomulated with the mirror-image symbol "%", which means "before or after", thus "X → Y % __Z" means "X becomes Y before or after Z".

Each element is given as a matrix, which expresses a conjunction of features. The matrices of the target and trigger mean "all segments of the language which have the features [αF_i] as well as [βF_j]…" The matrix of the structural change means that when a target segment undergoes a rule, it receives whatever feature values are specified in that matrix.

There are a few special symbols which often enter into rule formulation. One which we have encountered is the word boundary, symbolized as "#". A rule which lengthens a vowel before a word-final sonorant would be written as follows:

(34) [+syl] → [+long] / _ [+son] #

A rule which devoices a word-initial consonant would be written as:

(35) [−son] → [−voice] / # _

A word boundary can come between the target and the trigger segments, in which case it means "when the trigger segment is in the next word." Such processes are relatively infrequent, but, for example, there is a rule in Sanskrit which voices a consonant at the end of a word when it is followed by a sonorant in the next word, so /tat#aham/ becomes [tad#aham] 'that I'; voicing does not take place strictly within the word, and thus /pata:mi/ 'I fly' does not undergo voicing. This rule is formulated as in (36).

(36) [−son] → [+voice] / _ # [+son]

Another symbol is the null, Ø, used in the focus or structural change of a rule. As the focus, it means that the segment described to the right of the arrow is inserted in the stated context; and as the structural change, it means that the specified segment is deleted. Thus a rule that deletes a word-final short high vowel which is preceded by a sonorant would be written as follows:

(37) $$\begin{bmatrix} +\text{syl} \\ +\text{hi} \\ -\text{long} \end{bmatrix} \rightarrow \text{Ø} / [+\text{son}] \_\_\#$$

There are occasions where it is necessary to restrict a rule to apply only when a sequence occurs in different morphemes, but not within a morpheme. Suppose you find a rule that deletes a consonant after a consonant, but only when the consonants are in separate morphemes: thus the bimorphemic word /tap-ta/ with /p/ at the end of one morpheme and /t/ at the beginning of another becomes [tapa], but the monomorphemic word /tapta/ does not undergo deletion.

Analogous to the word boundary, there is also a morpheme boundary symbolized by "+," which can be used in writing rules. Thus the rule deleting the second of two consonants just in case the consonants are in diferent morphemes (hence a morpheme boundary comes between the consonants) is stated as:

(38) $[-\text{syl}] \rightarrow \text{Ø} / [-\text{syl}] + \_$

Interestingly, rules generally do not care if a specified sequence of segment are in the same morpheme or in different morphemes, and by convention we interpret rule as universally meaning "whether or not a morpheme bounday is present". But a rule may be explicitly stated as in (38), in case the rule *only* applies when a morpheme boundary is present.

You may encounter other conventions of formalism. One such notation is the brace notation. Whereas the standard matrix [...] refers to a conjunction of properties – segments which are A *and* B *and* C all at once – braces {...} express disjunctions, that is, segments which are A *or* B *or* C. One of the most frequent uses of braces is exemplified by a rule found in a number of languages which shortens a long vowel if it is followed by either two consonants or else one consonant plus a word boundary, i.e. followed by a consonant that is followed by an consonant or #. Such a rule can be written as (39).

(39) $[+\text{syl}] \rightarrow [-\text{long}] / \_[-\text{syl}]\begin{Bmatrix} -\text{syl} \\ \# \end{Bmatrix}$

Most such rules use the notation to encode syllable-related properties, so in this case the generalization can be restated as "shorten a long vowel followed by a syllable-final consonant." Using [.] as the symbol for a syllable boundary, this rule could then be reformulated as:

(40) $[+\text{syl}] \rightarrow [-\text{long}] / \_ [-\text{syl}].$

Although the brace notation has been a part of phonological theory, it has been viewed with considerable skepticism, partly because it is not well motivated for more than a handful of phenomena that may have better explanations (e.g. the syllable), and partly because it is a powerful device that undermines the central claim that rules operate in terms of natural classes (conjunctions of properties).

Some rules need to refer to a variably sized sequence of elements. A typical example is vowel harmony, where one vowel assimilates a feature from another vowel, and ignores any consonants that come between. Suppose we have a rule where a vowel becomes round after a round vowel, ignoring any consonants. We could not just write the rule as (41), since that incorrectly states that only vowels strictly next to round vowels harmonize.

(41) $[+\text{syl}] \rightarrow [+\text{rd}] / \begin{bmatrix} +\text{syl} \\ +\text{rd} \end{bmatrix} \_$

We can use the subscript-zero notation, and formalize the rule as in (42).

(42) $[+\text{syl}] \rightarrow [+\text{rd}] \;/\; \begin{bmatrix}+\text{syl}\\+\text{rd}\end{bmatrix}[-\text{syl}]_0$ ___

The expression "$[-\text{syl}]_0$" means "any number of [−syl] segments," from none to an infinite sequence of them.

A related notation is the parenthesis, which surrounds elements that may be present, but are not required. A rule of the form X → Y / _ (WZ)Q means that X becomes Y before Q or before WZQ, that is, before Q ignoring WZ. The parenthesis notation essentially serves to group elements together. This notation is used most often for certain kinds of stress-assignment rules and advancements in the theory of stress have rendered parenthesis unnecessary in many cases.

One other very useful bit of notation is the feature variable notation. So far, it has actually been impossible to formalize one of the most common phonological rules in languages, the rule which assimilates a nasal in place of articulation to the following consonant, where /mk/ → [ŋk], /np/ → [mp] and so on. While we can write a rule which makes any nasal become [+ant,+cor] before a [+ant,+cor] consonant – any nasal becomes [n] before /t/ – and we can write a rule to make any nasal [+ant,−cor] before a [+ant,−cor] consonant – nasals become [m] before [p] – we cannot express both changes in one rule.

(43)

a. $[+\text{nas}] \rightarrow \begin{bmatrix}+\text{ant}\\+\text{cor}\end{bmatrix} / \_ \begin{bmatrix}+\text{ant}\\+\text{cor}\end{bmatrix}$

b. $[+\text{nas}] \rightarrow \begin{bmatrix}+\text{ant}\\-\text{cor}\end{bmatrix} / \_ \begin{bmatrix}+\text{ant}\\-\text{cor}\end{bmatrix}$

The structural change cannot be "→[+cor]" because when a nasal becomes [m] it becomes [−cor]. For the same reason the change cannot be " → [−cor]" since making a nasal becomes [n] makes it become [+cor]. One solution is the introduction of feature variables, notated with Greek letters α, β, γ, etc. whose meaning is "the same value." Thus a rule which makes a nasal take on whatever values the following consonant has for place of articulation would be written as follows:

(44) $[+\text{nasal}] \rightarrow \begin{bmatrix}\alpha\text{ant}\\\beta\text{cor}\end{bmatrix} / \_\_ \begin{bmatrix}\alpha\text{ant}\\\beta\text{cor}\end{bmatrix}$

Thus when the following consonant has the value [+cor] the nasal becomes [+cor] and when the following consonant has the value [−cor] the nasal becomes [−cor]. We will return to issues surrounding this notation in chapter 10.

While rules are usually written in the format "[X] → [Y] / [W]__[Z]", this limits theoretically possible rules to ones that only change a single segment, the one to the left of the arrow standing between [W] and [Z]. How would one formalize a rule that deletes a nasal conconant before a fricative and simultaneously nasalizing the preceding vowel? This question is especially relevant to the development of autosegmental phonology, discussed in chapter 10, where attention is directed to explaining "compensatory" actions especially where a feature of one segment is transferred to another segment. For now, in case the issue arises, there is a simple alternative rule formulation to can cover simultaneous changes on multiple segments. Very simply, if the sequence [X] [Y] changes to [A] [B] in the context [W]__[Z], one can write the rule as [X] [Y] → [A] [B] / [W]__[Z]. This of course raises the question whether we should allow a rule of the form [X] [Y] [Z]→ [A] [B] [C] / [W]__[Z], since such a process is so far not observed to exist. We will leave this as a matter for future theoretical contemplation, because in fact we *will* encounter cases of two segments affecting each other, and you will need a way to write such a rule.

There are some other commonly used informal shorthand practices which you need to recognize. Many rules refer to "consonants" versus "vowels," meaning [−syllabic] and [+syllabic] segments, and the shorthand "C" and "V" are often used in place of [−syllabic] and [+syllabic]. Also, related to the feature variable notation, it is sometimes necessary to write rules which refer to the entire set of features. A typical example would be in a rule "insert a vowel which is a copy of the preceding vowel into a word-final cluster." Rather that explicitly listing every feature with an associated variable, such a rule might be written as:

(45) $\emptyset \rightarrow V_i$ / V_i C_C#

meaning "insert a copy of the preceding vowel".
As a practical matter, it has frequently been necessary for analysts to include plain-English conditions on rules, because there is no obvious formalism for expressing some generalization. While you should always aim to exploit the standard resources of the theory in expressing rules, a temporary inability to do so should not prevent you from writing a particular rule. Taking note of such problems of formalism can eventually lead to improvements in the theory.

4.6 Changing the theory

The theory of features is an empirical hypothesis, and is subject to revision in the face of appropriate data. It is not handed down by a higher authority, nor is it arbitrarily picked at the whim of the analyst. It is important to give critical thought to how the set of distinctive features can be tested empirically, and revised. One prediction of the theory which we have discussed in section 4.1 is that the two kinds of phonetic retroflex consonants found in Hindi and Telugu cannot contrast within a language. What would happen if a language were discovered which distinguished two degrees of retroflexion? Would we discard features altogether?

This situation has already arisen: the theory presented here evolved from earlier, similar theories. In an earlier theory proposed by Jakobson and Halle, retroflex consonants were described with the feature [flat]. This feature was also used to describe rounding, pharyngealization, and uvularization. While it may seem strange to describe so many different articulatory characteristics with a single feature, the decision was justified by the fact that these articulations share an acoustic consequence, a downward shift or weakening of higher frequencies. The assumption at that point was that no language could minimally contrast retroflexion, rounding, and pharyngealization. If a language has both [ʈ] and [kʷ], the surface differences in the realization of [flat], as retroflexion versus rounding, would be due to language-specific spell-out rules.

The theory would be falsified if you could show that rounding and pharyngealization are independent, and counterexamples were found. Arabic has the vowels [i a u] as well as pharyngealized vowels [iˤ aˤ uˤ], which derive by assimilation from a pharyngealized consonant. If rounding and pharyngealization are both described by the feature [flat], it is impossible to phonologically distinguish [u] and [uˤ]. But this is not at all inappropriate, since the goal is to represent phonological contrasts, not phonetic differences, because the difference between [u] and [uˤ] is a low-level phonetic one. The relevance of Arabic – whether it falsifies the feature [flat] – depends on what you consider to be the purpose of features.

Badaga's three-way vowel contrast challenges the standard theory as well. Little is known about this language: the contrast was originally reported by Emeneau (1961), and Ladefoged and Maddieson (1996) report that few speakers have a three-way contrast. The problem posed by this contrast has been acknowledged, but so far no studies have explored its nature.

Another prediction is that since uvular and round consonants are both [+flat], there should be no contrast between round and nonround uvulars, or between round velars and nonround uvulars, within a language. But a number of languages of the Pacific Northwest, including Lushootseed, have the contrast [k kʷ q qʷ]: this is a fact which is undeniably in the domain of phonology. The Dravidian language Badaga is reported to contrast plain and retroflex vowels, where any of the vowels [i e a o u] can be plain, half-retroflex, or fully retroflex. If [flat] indicates both retroflexion and rounding, it would be impossible to contrast [u] and [u˞]. Such languages forced the abandonment of the feature [flat] in favor of the system now used.

The specific feature [flat] was wrong, not the theory of features itself. Particular features may be incorrect, which will cause us to revise or replace them, but revisions should be undertaken only when strong evidence is presented which forces a revision. Features form the foundation of phonology, and revision of those features may lead to considerable changes in the predictions of the theory. Such changes should be undertaken with caution, taking note of unexpected consequences. If the theory changes frequently, with new features constantly being added, this would rightly be taken as evidence that the underlying theory is wrong.

Suppose we find a language with a contrast between regular and sublingual retroflex consonants. We could accommodate this hypothetical language into the theory by adding a new feature [sublingual], defined as forming an obstruction with the underside of the tongue. This theory makes a new set of predictions: it predicts other contrasts distinguished by sublinguality. We can presumably restrict the feature to the [+coronal] segments on physical grounds. The features which distinguish coronals subclasses are [anterior] and [distributed], which alone can combine to describe four varieties of coronal – which actually exist in a number of Australian languages. With a new feature [sublingual], eight coronal classes can be distinguished: regular and sublingual alveolars, regular and sublingual dentals, regular and sublingual alveopalatals, and regular and sublingual retroflex consonants. Yet no such segments have been found. Such predictions need to be considered, when contemplating a change to the theory.

Similarly, recall the problem of "hyper-tense," "plain tense," "plain lax" and "hyper-lax" high vowels across languages: we noted that no more than two such vowels exist in a language, governed by the feature [tense]. If a language were discovered with three or four such high vowels, we could add a feature "hyper." But this makes the prediction that there could also be four-way contrasts among mid and low vowels. If these implications are not correct, the modification to the theory is not likely to be the correct solution to the problem. In general, addition of new features should be undertaken only when there is compelling evidence for doing so. The limited number of features actually in use is an indication of the caution with which features are added to the theory.

The case for labial. A classical case in point of a feature which was added in response to significant problems with the existing feature system is the feature [labial]. It is now accepted that feature theory should include this feature:

[labial]: sound produced with the lips

This feature was not part of the set of features proposed in Chomsky and Halle (1968). However, problems were noticed in the theory without [labial].

The argument for adding [labial] is that it makes rules better formalizable. It was noticed that the following types of rules, inter alia, are frequently attested (see Campbell 1974, Anderson 1974).

(46) a. b → w / _ C
b. w → b / [+nasal] _
c. w → v
d. i → u / {p, b, m, w, u, o} _

In the first three rules, the change from bilabial obstruent to rounded glide or rounded glide to labiodental obstruent is a seemingly arbitrary change, when written according to the then-prevailing system of features. Under the traditional features for labials, there is so little in common between [b] and [w] that a change of [b] to [r] would be simpler to formulate as in (47b), and yet the change [b] → [r] is unattested.

(47) a. $\begin{bmatrix} +\text{ant} \\ -\text{cor} \\ -\text{voi} \end{bmatrix} \rightarrow \begin{bmatrix} +\text{ant} \\ -\text{cons} \\ +\text{hi} \\ +\text{bk} \\ +\text{rd} \end{bmatrix} / \_\_\text{C}$ b. $\begin{bmatrix} +\text{ant} \\ -\text{cor} \\ -\text{voi} \end{bmatrix} \rightarrow \begin{bmatrix} +\text{cor} \\ +\text{son} \end{bmatrix} / \_\_\text{C}$

In the last rule of (46), no expression covers the class {p, b, m, w, u, o}: rather they correspond to the disjunction [+ant,−cor] or [+round].

These rules can be expressed quite simply with the feature [labial].

(48) a. $\begin{bmatrix}+\text{labial}\\+\text{voi}\end{bmatrix} \rightarrow$ [–cons] / __ C

b. $\begin{bmatrix}+\text{labial}\\-\text{cons}\end{bmatrix} \rightarrow$ [+cons] / [+nasal]__

c. $\begin{bmatrix}+\text{labial}\\+\text{rd}\end{bmatrix} \rightarrow \begin{bmatrix}+\text{cons}\\-\text{rd}\end{bmatrix}$

d. i → [+labial] / [+labial] __

Feature redefinition. Even modifying definitions of existing features must be done with caution, and should be based on substantial evidence that existing definitions fail to allow classes or changes to be expressed adequately. One feature which might be redefined is [continuant]. The standard definition states that a segment is [+continuant] if it is produced with air continuously flowing through the *oral cavity*. An alternative definition is that a segment is [+continuant] if air flows continuously through the *vocal tract*. How do we decide which definition is correct? The difference is that under the first definition, nasals are [−continuant] and under the second definition, nasals are [+continuant].

If the first definition is correct, we expect to find a language where {p, t, t^ʃ, k, m, n, ŋ, b, d, d^ʒ, g} undergo or trigger a rule, and {f, s, θ, x, v, z, ð, γ} do not: under the "oral cavity" definition, [−continuant] refers to the class of segments {p, t, t^ʃ, k, m, n, ŋ, b, d, d^ʒ, g}. On the other hand, if the second hypothesis is correct, we should find a language where {m, n, ŋ, f, s, x, v, x, γ} undergo or trigger a rule, and the remaining consonants {p, t, t^ʃ, k, b, d, d^ʒ, g} do not: under the "vocal tract" definition of [continuant], the feature specification [+continuant] would refer to the set {m, n, ŋ, f, s, x, v, x, γ}.

Just as important as knowing what sets of segments can be referred to by one theory or another, you need to consider what groupings of segments *cannot* be expressed in a theory. Under either definition of [continuant], finding a process which refers to {p, t, k, b, d, g} proves nothing, since either theory can refer to this class, either as [−continuant] in the "oral cavity" theory or as [−continuant,−nasal] in the "vocal tract" theory. The additional feature needed in the "vocal tract" theory does complicate the rule, but that does not in itself disprove the theory. If you find a process referring to {m, n, ŋ, f, s, x, v, x, γ}, excluding {p, t, k, b, d, g}, this would definitively argue for the "oral cavity" theory. Such a class can be referred to with the specification [+continuant] in the "oral cavity" theory, but there is no way to refer to that set under the "vocal tract" theory. As it stands, we have not found such clear cases: but, at least we can identify the type of evidence needed to definitively choose between the theories. The implicit claim of feature theory is that it would be impossible for both kinds of rules to exist in human languages. There can only be one definition of any feature, if the theory is to be coherent.

Central vowels. We will consider another case where the features face a problem with expressing a natural class, relating to the treatment of central versus back vowels. In chapter 2 we saw that Kenyang [k] and [q] are in complementary distribution, with [q] appearing word-finally after the vowels [o], [ɔ] and [ɑ] and [k] appearing elsewhere. Representative examples are reproduced here.

(49)	enɔ**q**	'tree'	eno**q**	'drum'
	ŋgɑ**q**	'knife'	e**k**ɑ**q**	'leg'
	mə**k**	'dirt'	nde**k**	'European'
	pɔbri**k**	'work project'	ɑyu**k**	(person's name)

Phonetic descriptions of vowels are not usually based on physiological data such as x-ray studies. Tongue positions are often deduced by matching sound quality with that of a standardly defined vowel: we assume that Kenyang schwa is central because it sounds like schwa, which is phonetically defined as being central.

Schwa does not cause lowering of *k* to *q*. In the standard account of vowels, [ə] differs from [ɔ] only in rounding, though phonetic tradition claims that these vowels also differ in being back ([ɔ]) versus central ([ə]). As previously discussed, this difference is attributed to a low level, phonologically insignificant phonetic factor.

The problem which Kenyang poses is that it is impossible to formulate the rule of k-lowering if schwa is phonologically a mid back unrounded vowel. A simple attempt at formalizing the rule would be:

(50) $$\begin{bmatrix} +\text{hi} \\ +\text{back} \end{bmatrix} \rightarrow \begin{bmatrix} -\text{hi} \\ +\text{back} \end{bmatrix} / \begin{bmatrix} -\text{hi} \\ +\text{back} \end{bmatrix} \_\_\#$$

If schwa is [+back, −hi, −round] it would satisfy the requirements of the rule so should cause lowering of /k/, but it does not: therefore this formulation cannot be correct. Since schwa differs from [ɔ] in being [−round], we might try to exclude [ə] by requiring the trigger vowel to be [+round].

(51) $$\begin{bmatrix} +\text{hi} \\ +\text{back} \end{bmatrix} \rightarrow \begin{bmatrix} -\text{hi} \\ +\text{back} \end{bmatrix} / \begin{bmatrix} -\text{hi} \\ +\text{back} \\ +\text{round} \end{bmatrix} \_\_\#$$

But this formulation is not correct either, since it would prevent the nonround low vowel [ɑ] from triggering uvularization, which in fact it does do.

These data are a problem for the theory that there is only a two-way distinction between front and back vowels, not a three-way distinction between front, central, and back vowels. The uvularization rule of Kenyang can be formulated if we assume an additional feature, [±front], which characterizes front vowels. Under that theory, back vowels would be [+back, −front], front vowels would be [+front, −back], and central vowels would be [−back, −front]. Since we must account for this fact about Kenyang, the theory must be changed. But before adding anything to the theory, it is important to consider all of the consequences of the proposal.

A positive consequence is that it allows us to account for Kenyang. Another possible example of the relevance of central vowels to phonology comes from Norwegian (and Swedish). There are three high, round vowels in Norwegian, whereas the standard feature theory countenances the existence of only two high rounded vowels, one front and one back. Examples in Norwegian spelling are *do* ‘outhouse,’ *du* ‘you sg.’ and *dy* ‘forbear!’. The vowel *o* is phonetically [u], and *u* and *y* are distinct nonback round vowels. In many transcriptions of Norwegian, these are transcribed as [dʉ] ‘you sg’ and [dy] ‘forbear!’, implying a contrast between front, central and back round vowels. This is exactly what the standard view of central vowels has claimed should not happen, and it would appear that Norwegian falsifies the theory.

The matter is not so simple. The vowels spelled *u* versus *y* also differ in lip configuration. The vowel *u* is “in-rounded,” with an inward narrowing of the lips, whereas *y* is “out-rounded,” with an outward-flanging protrusion of the lips. This lip difference is hidden by the selection of the IPA symbols [ʉ] versus [y]. While it is clear that the standard theory does not handle the contrast, we cannot tell what the correct basis for maintaining the contrast is. We could treat the difference as a front ~ central ~ back distinction and disregard the difference in lip configuration (leaving that to phonetic implementation); or, we could treat the labial distinction as primary and leave the presumed tongue position to phonetic implementation.

Given that the theory of features has also accepted the feature [labial], it is possible that the distinction lies in [labial] versus [round], where the out-rounded vowel <y> is [+round, +labial] and in-rounded <u> is [−round, +labial] – or vice versa. Unfortunately, nothing in the phonological behavior of these vowels gives any clue as to the natural class groupings of the vowels, so the problem of representing these differences in Norwegian remains unresolved. Thus the case for positing a distinct phonological category of central vowel does not receive very strong support from the vowel contrasts of Norwegian.

A negative consequence of adding [front], which would allow the phonological definition of a class of central vowels, is that it defines unattested classes and segments outside of the realm of vowels. The classical features could distinguish just [k] and [k^j], using [±back]. With the addition of [front], we would have a three-way distinction between k-like consonants which are [+front, −back], [−front, −back] and [−front, +back]. But no evidence at all has emerged for such a contrast in any language. Finally, the addition of the feature [front] defines a natural class [−back] containing front and central vowels, but not back vowels: such a class is not possible in the classical theory, and also seems to be unattested in phonological rules. This may indicate that the feature [front] is the wrong feature – at any rate it indicates that further research is necessary, in order to understand all of the ramifications of various possible changes to the theory.

Thus the evidence for a change to feature theory, made to handle the problematic status of [ə] in Kenyang phonology, would not be sufficiently strong to warrant complete acceptance of the new feature. We will suspend further discussion of this proposal until later, when nonlinear theories of representation are introduced and answers to some of the problems such as the unattested three-way contrast in velars can be considered. The central point is that changes in the theory are not made at will: they are made only after considerable argumentation and evidence that the existing theory is fundamentally inadequate.

Summary

Language sounds can be defined in terms of a small set of universal phonetically based features, which not only define the basic atoms of phonological representations, but also play a central role in the formal expression of rules. An important theme of this chapter is the nature of scientific theories, such as the theory of features, which make predictions both about what can happen and what cannot happen. The fundamental role of feature theory is to make specific predictions about the kinds of segments and rules that we should find in human languages. One of the main concerns of phonological theory is finding the correct set of features that define the sounds and rule systems of all human languages.

Exercises

1. Assume a segmental inventory composed of: [ʕ k t d s z n p f b i u e o a w h]. Indicate what feature or features characterize the following classes of sounds.
i. ʕ k u o a w
ii. f p k h
iii. f p b t s d z n
iv. ʕ u o w a b d z n i e

2. Given the segments [w j h ʔ i ɛ a o ɔ u m̩ l r m ŋ p t kʲ k q b ð d dʲ g ɣ], describe the following segment classes, being as economical as you can with your use of features.
i. m̩ l r m ŋ p t kʲ k q b ð d dʲ g ɣ
ii. w j i ɛ a o ɔ u m̩ l r m ŋ
iii. w a o ɔ u ŋ k q g ɣ
iv. w j h i ɛ a o ɔ u l r ð ɣ
v. y i kʲ dʲ
vi. i ɛ a o ɔ u m̩

3. Assume the following segmental inventory: p t tᶴ q b ɖ g s ʂ β ʒ ɣ n ŋ l j i ɨ e o ɛ ɔ æ

Give the minimal feature description which identifies exactly the following subsets of the inventory

i. p t b s β n l
ii. t tᶴ ɖ s ʂ ʒ n l
iii. p t tᶴ q b ɖ s ʂ β ʒ n l e o ɛ ɔ æ
iv. q g ɣ ŋ ɨ o ɔ
v. tᶴ ɖ ʂ ʒ j i e ɛ æ

5. State **all** of the features which are changed in each of the following rules:
i. p → f
ii. t → ŋ
iii. o → w
iv. k → s
v. s → t

vi. a → i

6. Formalize the following rules using distinctive features (segmental inventories to be assumed for each language are given after the rule in brackets). In each case, if the inventory includes segments [w x y z] and the rule is stated as changing [w] and [x], assume that /y,z/ can appear in the specified context and appear as [y,z] after the rule applies.

i. b, d, g → β, ð, γ / V _	[p t k b d g β ð γ m n ŋ r i u a ə]
iii. Ø → j / i, e _ o, u, a	[p t k b d n j w i y e æ o u a]
iv. t → s / _i	[p t k h v d s r l m n j i y e ø a o u]
v. s → r / V_V	[p t k b d g s r l m n h w j e i o u a]
p, t → [t^ʃ]/ __ i, e, a, o, u, k, t^ʃ, ŋ	[p t t^ʃ k n ŋ i e a o u]

p, t̪, t, k →φ, θ, r̥, x / i e a o w j h ___ i e a o r̩ l̩ [p t̪ t k b d g φ θ r̥ x r l w j h r̩ l̩ i e a o]
p, t^ʃ, k, q → t / __ p, b, m, t, d, n [p t t^ʃ k q b d g ð l r m n i u a ɛ]
k, g, ŋ → k^j, g^j, ŋ^j / p p^j m b t t^j n d t^ʃ d^ʒ ɲ k^j g^j ŋ^j f s ʃ x^j j ___
[p p^j m b t t^j n d t^ʃ d^ʒ ɲ k^j g^j ŋ^j k g ŋ q f s ʃ x^j j w i u e o a æ]

7. Mixtec (San Miguel el Grande)

The causative form of the verb in Mixteco has a prefix, underlying /s/, which changes before certain consonants. Formalize a rule which accounts for these changes.

s-kaka	'make walk'	s-haa	'make sprout'
ʃ-dɨbɨ	'make enter'	s-taka	'gather'
s-t^{ʃ}aku	'make live'	ʃ-lili	'tighten'
s-kunu	'make run'	ʃ-ndata	'crack'
ʃ-d^{ʒ}aʔa	'overthrow'		

8. Review previous solutions to exercises which you have done in the preceding chapter, and state the rules according to the features given here: discuss any problems which you may encounter in reformalizing these rules.

Further reading
Campbell 1974; Chomsky and Halle 1968; Jakobson and Halle 1956; Jakobson, Fant and Halle 1952; Trubetzkoy 1939.