CHAPTER 1
What is phonology?

PREVIEW

This chapter introduces phonology, the study of the sound systems of language. Its key objectives are to:

- explain the difference between physical sound and "a sound" as a discrete element of language

- highlight the tradeoff between accuracy and usefulness in representing sound

- introduce the notion of "sound as cognitive symbol"

- present the phonetic underpinnings of phonology

- introduce the notion of phonological rule

KEY TERMS

sound

symbol

grammar

continuous nature of speech

Phonology is one of the core fields composing the discipline of linguistics, which is the scientific study of language structure. One way to understand the subject matter of phonology is to contrast it with other fields within linguistics. A very brief explanation is that phonology is usually considered to be the study of sound structure in language, which is different from the study of sentence structure (syntax), word structure (morphology), or how languages change over time (historical linguistics). But this is insufficient (it is only a first approximation). An important feature of the structure of a sentence *is* how it is pronounced – its sound structure. The pronunciation of a given word is also a fundamental aspect of the structure of the word. And certainly the principles of pronunciation in a language are subject to change over time. So phonology has a relationship to numerous domains of linguistics. Moreover, phonology is not directly about physical sound, it is about a mental faculty that only has a contingent connection to physical sound.

An important question that clarifies what phonology is, is the question of how phonology differs from the closely related discipline of phonetics. Making a principled separation between phonetics and phonology is difficult – just as it is difficult to make a principled separation between physics and chemistry, or sociology and anthropology. While phonetics and phonology both deal with language sound, they address different aspects of sound and serve different purposes. Phonetics deals with "actual" physical sounds as manifested in speech, and concentrates on acoustic waveforms, formant values, duration measured in milliseconds, or amplitude and frequency. Phonetics also deals with the physical principles underlying the production of sounds, such as vocal tract resonances, or the muscles and other articulatory structures used to produce those resonances. Phonology, on the other hand, is an abstract cognitive system dealing with rules in a mental grammar: principles of subconscious "thought" as they relate to the representational units of language, like sounds. Phonology is responsible for selecting the proper categories for the individual sounds in the morphemes of an utterance, given a certain context. Such rules are why we say "**il**legal", "**ir**regular", "**im**possible" and "**in**tolerable" in English. Phonetics is responsible for giving physical, perceivable form to those abstract cognitive sounds. Just as the phonological rules of a language are particular to that language, so too are the phonetic rules of a language.

1.1 Phonetics – the manifestation of language sound

From the phonetic perspective, "sound" refers to time-varying mechanical pressure waves and the sensations arising when a pressure wave strikes the ear. In physical sound, the wave changes continuously, which can be graphed as a waveform showing the amplitude on the vertical axis and time on the horizontal axis. Figure 1.1 displays the waveform of a pronunciation of the word "wall", with an expanded view of the details of the waveform at the center of the vowel between "w" and "ll".

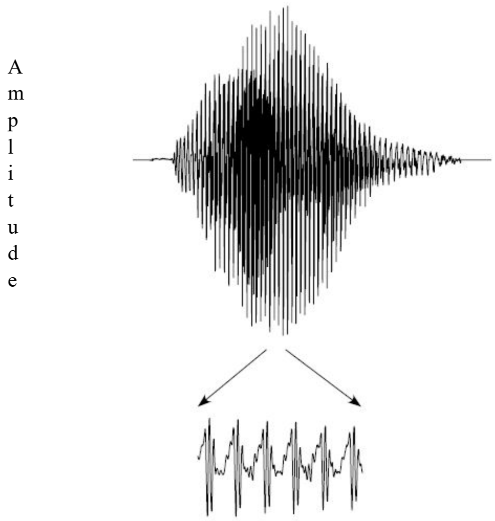


FIGURE 1.1

Figure 1.2 provides an analogous waveform of a pronunciation of the word "will", which differs from "wall" just in the choice of the vowel.

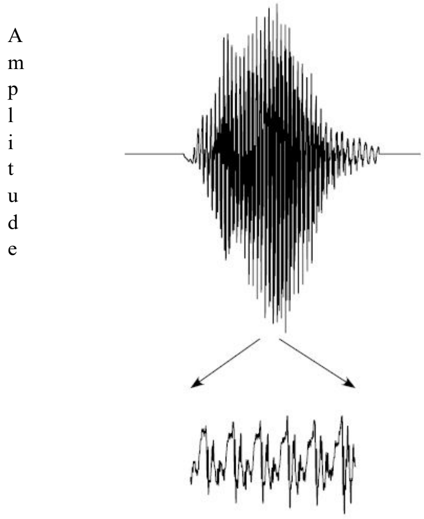


FIGURE 1.2

Inspection of the expanded view of the vowel part of these waveforms reveals subtle differences in the overall shape of the time-varying waveforms, which is what makes these words sound different.

It is difficult to characterize those physical differences directly from the waveform. An important analytical tool of phonetics, the **spectrogram**, provides a useful way to describe the differences, by reducing the absolute amplitude properties of a pressure wave at a sequence of ‘exact’ times to a set of (less precise) amplitude characteristics in different frequency and time regions. Although a spectrogram is less precise compared to a wavefr=orm, it is more useful for understanding properties of speech. In the spectrogram below, the vertical axis represents frequency in Hertz (Hz) and darkness represents amplitude on a coarser frequency-specific scale. Comparing the spectrograms of “wall” and “will” in Figure 1.3, you can see that there are darker bands in the lower part of the spectrogram, and the frequency at which these bands occur – known as **formants** – is essential to perceptually distinguishing the vowels of these two words. Formants are numbered from the bottom up, so the first formant is at the very bottom.

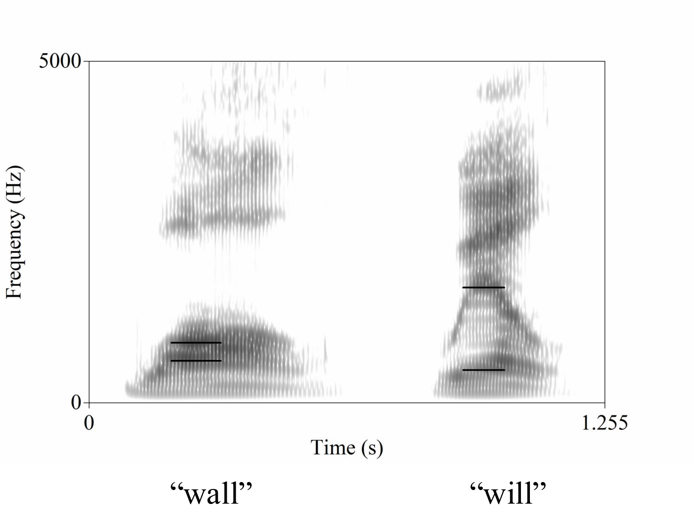


FIGURE 1.3

In "wall" the first two formants are very close together, occurring at 613 Hz and 875 Hz, whereas in "will" they are far apart, occurring at 476 Hz and 1691 Hz. In fact, in "wall", the formants are so close together that that they effectively merge into one blur in the picture, and we have to rely on another analytic method of LPC analysis to distinguish the formants. In "will", on the other hand, the spectrogram clearly shows the second formant rising then falling. The mechanical reason for the difference in these sound qualities is that the tongue is in a different position during the articulation of these two vowels. In the case of the vowel of "wall", the tongue is relatively low and retracted, and in the case of "will", the tongue is relatively fronted and raised. These differences in the shape of the vocal tract result in different physical sounds coming out of the mouth.

The physical sound of a word's pronunciation can be highly variable, as we see when we compare the spectrograms of three pronunciations of one word "wall" in Figure 1.4: the three spectrograms are obviously different, even though there is an overall similarity.

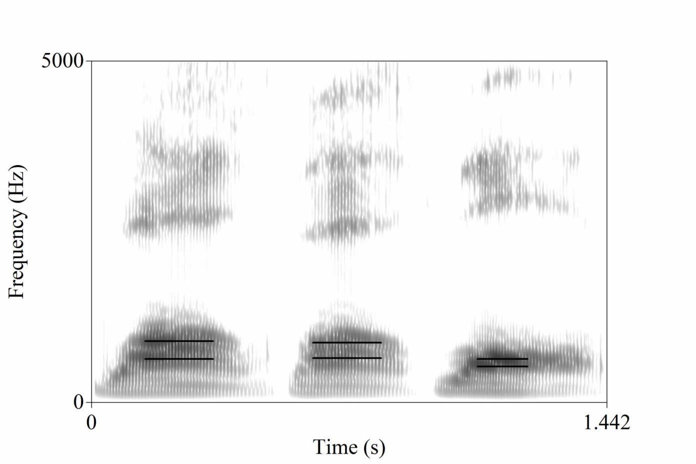


FIGURE 1.4

The first two pronunciations are produced at different times by the same speaker, differing slightly in where the first two formants occur (634 Hz and 895 Hz for the first token versus 647 Hz and 873 Hz for the second), and they differ in numerous other ways such as the greater amplitude of the lower formants in the first token. In the third token, produced by a second (male) speaker of the same dialect, the first two formants are noticeably lower and closer together, occurring at 524 Hz and 634 Hz.

Physical variation in sound also arises because of differences in surrounding context. Figure 1.5 gives spectrograms of the words "wall", "tall" and "lawn", with grid lines to identify the portion of each spectrogram in the middle which corresponds to the vowel.

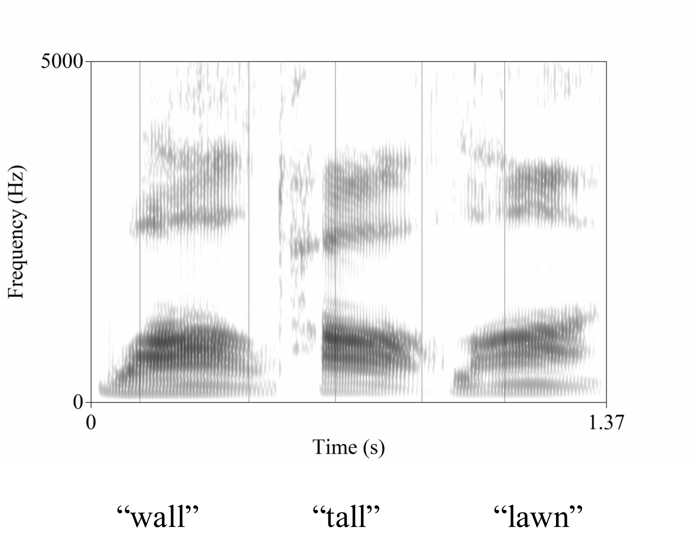


FIGURE 1.5

In "wall", the frequency of the first two formants rapidly rises at the beginning, and falls at the end. In "tall", the formant frequencies start higher and fall slowly. In "lawn", the formants rise slowly and do not fall at the end. A further important fact about physical sound is that it is continuous, so while "wall", "tall" and "lawn" are composed of three sounds where the middle sound (*qua* cognitive category) in each word is the same one, there are no sharp physical boundaries between the vowel and the surrounding consonants.

A common type of continuous phonetic process is **coarticulation**, where an aspect of the production of one sound overlaps the production of surrounding sounds. We see this in two English utterances 'I scream' and 'I scheme', which are the same except for the inclusion of *r* in 'scream'. In this dialect of English, the consonant *r* is strongly rounded. That lip rounding extends significantly before and after *r* itself. In the spectrogram of these utterances, we see the influence of this lip rounding on neighboring segments, by how *r* causes a lowering of resonance frequencies. The downward-sloping line towards the top of the spectrogram (where the arrow points) traces the lowering of the fricative formant of *s* in these two words, which differ under the influence of the rounding of *r*.

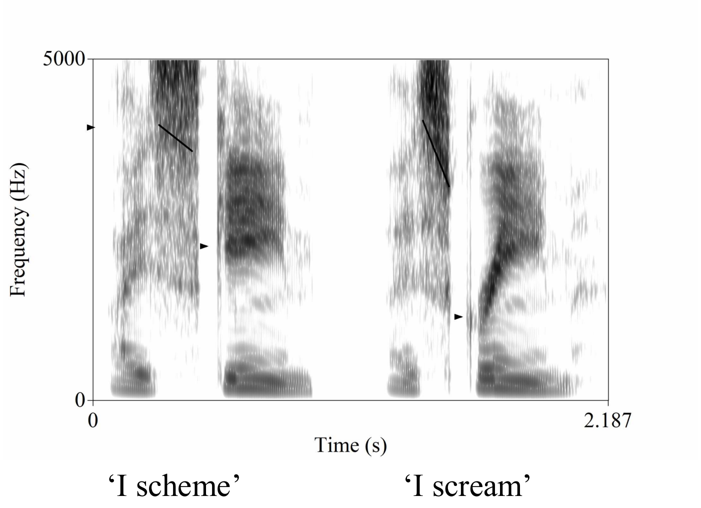


FIGURE 1.6

The mostly-blank part of each utterance roughly in the middle, after the fricative, is the consonant [k]. In 'scheme', what immediately follows *k* is the vowel [i]. The first two dark horizontal bands are F_1 and F_2, at 334 Hz and 2260 Hz (note the pointing arrow at different height for "scheme" and "scream"). You can see that these formants only rise slightly after *k*. In 'scream', what follows *k* is the phonetic consonant [ɹʷ], which is how *r* is pronounced in this dialect. Because [ɹʷ] has lip protrusion (rounding), it has low F_2 – its F_1 and F_2 start at 361 and 1222 Hz. This lip rounding causes significant coarticulatory lowering of the second formant of the following vowel *i*. F_2 then rises continuously to 2057 Hz in the following vowel [i].

We also see an influence of [ɹʷ] on the preceding [s], and more subtly on the lower frequency of energy when [k] is released before voicing commences. As indicated by the line through the fricative in 'scheme', the darker higher amplitude portion of [s] is relatively constant in frequency, reflecting the intrinsic resonance properties of [s]. But in 'scream', the resonance frequency of [s] falls sharply from the beginning to the ending of [s], because of the increasing anticipatory lip-rounding of [s] before [ɹʷ] (we cannot detect a lowering effect on [k] since it is essentially silence until its release). On the web page you can hear the full utterances, plus excised [s], where the falling frequency of [s] in 'scream' is very evident.

1.2 Phonology: the mental representation of sound

The goal of science is the discovery of principles which explain the nature of things, so we need to be able to organise things in the world into different types. In linguistics, we cannot directly inspect pressure waves produced by speakers of a language, we need to create a stable representation of that physical sound from which we can learn about the speech-related properties of language. A very common current way to do this is to make a digital recording: to use some simple hardware (for example a microphone and a computer) to reduce physical sound to a series of numbers. This way, we have potentially permanent captured a version of the sound, and can compare and classify utterances for similarities and differences. Aided by the companion web page https://languagedescriptions.github.io/IP3/Ch1.html, we will look at different ways of representing language sounds, with the goal of representing two words of Logoori (a Bantu language of Kenya) that translate to English ‘dog’ and ‘new’. The ultimate goal is to say how these two utterances are similar and how they are different, knowledge which will then inform us, a bit, about this language.

The web page provides the full set of numbers that are the digital representation of these two recordings. Any sound can be converted to and from a sequence of numbers at evenly-spaced intervals, the fact which underlies all digital sound recordings. Below is a fractional sample of the initial, middle and final 3 numbers of a digitized version of the recorded utterances.

‘dog’	‘new’
-34	-4
-36	-5
-29	-9
⋮	⋮
-2709	514
-2497	1111
-2079	2040
⋮	⋮
-472	681
-424	576
-349	443

TABLE 1.1

You could listen to these recordings, but I recommend first trying to understand what these words might be, based on the other evidence provided. The wall of numbers (9,183 numbers for ‘dog’, 9,191 for ‘new’), supplemented with the information that the data has a sampling rate of 22050 Hz, is almost completely uninformative, though you can determine that they both last 416.462 msc. Clearly, we need better visualization.

We can also graph these numbers, creating a waveform of the utterances. The x-axis represents time, and the y-axis is the digital version of sound pressure (related to but not the same as amplitude).

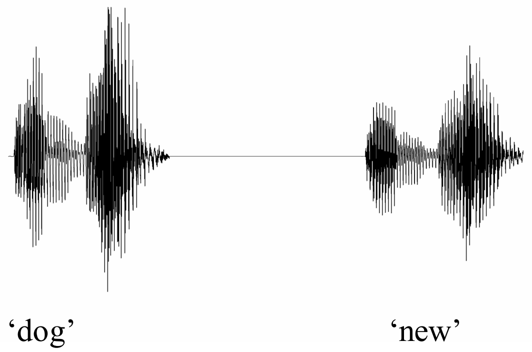
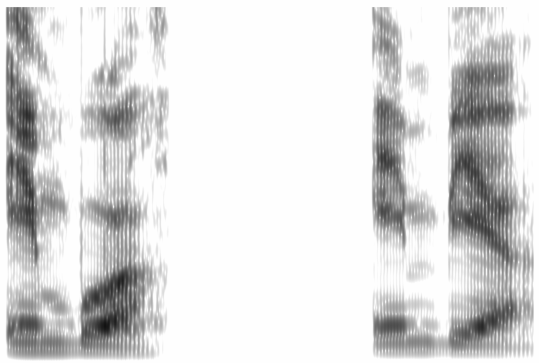


FIGURE 1.7

An expert phonetician could tell you a very little bit about these utterances from the pictures. While a waveform picture is more informative than a long table of numbers, it is rather imprecise. Time and amplitude information is very hard to extract from such picture, though it is much easier to perceive the whole representational object, compared to the big table of numbers. Given a lot of training in reading waveform pictures, it might be possible to surmise that the utterance is composed of a vowel-nasal-vowel sequence (because of the drop in amplitude in the middle), but which vowels and nasals?

A more informative display is a spectrogram, which transforms the table of numbers into another bunch of numbers, in this case a 116 × 204 matrix of (floating-point) numbers (23,664 numbers).



'dog' 'new'

FIGURE 1.8

An expert phonetician could tell you much more about these words from these pictures. The phonetician now knows that there is a consonant after the nasal, and knows other things. But how do we talk about the differences systematically, not using vague descriptions like "a bit darker", "a bit further up the picture" or "a bit further to the right"? Again, these pictures are more informative than waveform pictures or tables of numbers, but it is difficult to say exactly when something happens (the horizontal axis) or at what frequency it happens (the vertical axis), or at what amplitude (relative darkness).

Our next step is to compute formant values, giving yet another list of numbers. This type of analysis is much more informative and compact, ergo more useful. We can reduce each of these words to 228 numbers, which is 76 triples of formant numbers: F_1, F_2, F_3. As you can see on the web page, these utterances have been stripped to a more manageable size, plus we can be much more definite about the time and frequency properties that we are talking about. A portion of the table of formants is given below.

time	F_1	F_2	F_3	F_1	F_2	F_3
0.02	459	2198	2863	491	2151	2849
0.04	451	2174	2885	475	2155	2851
0.06	464	2156	2897	481	2139	2845
⋮	⋮	⋮	⋮	⋮	⋮	⋮
1.48	620	1556	3132	691	1415	2290

1.5	702	1530	2991		666	1437	2246
1.52	636	1598	3025		688	1429	2274
		‘dog’				‘new’	

TABLE 1.2

Unfortunately, in the course of throwing away information in order to compact the representation of these utterances and make the information more usable, we have significantly compromised the fidelity of the representation. Although this more compact set of formant values can be re-converted into a sound waveform, it is one that very poorly represents the original utterances (you can play the re-synthesized sounds from the web page).

The problem which we faced in seeking a phonologically-useful representation of the sounds of these words in terms of physical properties is that we were using the wrong tool for classification, namely physical analysis. Those computational and acoustic tools are good for understanding physical properties of speech or any other kind of sound, but that is not what phonology is about. Phonology is about how the mind organizes external sound into cognitive categories, and then performs categorial transformations on these individual units. Therefore we need symbolic representations of physical sound as they are used as cognitive building blocks of language. Instead of dealing with complex tables of numbers, we reduce these two recordings to a tiny set of technically-defined symbols specially developed for language, and represent these utterances as [ímbwá] ‘dog’ and [ímbjá] ‘new’. How we convert the continuous stream of speech sound into discrete data, a transcription, is the topic of Chapter 2. In a nutshell, we are trained in what to listen for, we listen to speech, and we write what we hear.

1.3 The concerns of phonology

You should now understand what distinguishes phonetics from phonology: phonology is the study of cognitive computations performed on mental categories derived from physical sound, whereas phonetics is the study of how those categories are physically realized. Now we consider some specific aspects of sound structure that would be part of a phonological analysis.

The sounds of a language. One aspect of phonology investigates what the individual sounds of a language are. We would take note in a description of the phonology of English that we have the sound [θ] as in ‘**th**ing’, which is lacking in German and French, and while English lacks the vowel [ø], that vowel exists in German in words like *schön* ‘beautiful,’ also in French (spelled *eu,* as in *jeune* ‘young’), or Norwegian (*øl* ‘beer’).

Sounds in languages are not just isolated atoms, they are part of a system. The systems of stops in Hindi and English are given in (1). The symbol ^{h} indicates that the consonant is aspirated, and ʈ, ɖ in the third column of Hindi indicates a retroflex stop, a sound type lacking in English – briefly touched on in Chapter 2.

(1)

Hindi stops			
p	t	ʈ	k
p^h	t^h	ʈ^h	k^h
b	d	ɖ	g
b^h	d^h	ɖ^h	g^h

English stops		
p	t	k
p^h	t^h	k^h
b	d	g

The stop systems of these languages differ in three ways. English does not have a series of voiced aspirated stops like Hindi [b^h d^h ɖ^h g^h], nor does it have a series of retroflex stops [ʈ ʈ^h ɖ ɖ^h]. Furthermore, the phonological status of the aspirated sounds [p^h t^h k^h] is different in the languages, as discussed in chapter 3, in that they are basic lexical facts of words in Hindi, but are the result of applying a rule in English.

Rules for combining sounds. Another aspect of language sound which a phonological analysis may take account of is that in any language, certain combinations of sounds are allowed, but other combinations are systematically impossible. The fact that English has the words [gɹ^{w}ik] 'Greek', [gɹ^{w}ejt] 'grate', [gɹ^{w}ʌd^ʒ] 'grudge', [bɹ^{w}ɛd] 'bread' is a clear indication that there is no rule against words beginning with the consonant sequence [gɹ^w]. Similarly, there are many words which begin with *gl*, such as [glu] 'glue', [glɪf] 'glyph', [glæns] 'glance', [glɪmɹ̩] 'glimmer' showing that there is no rule against words beginning with *gl*. It is also a fact that there is no word *[glɪk][1] in English. The question is, why is there no word **glick* in English? The best explanation for this is simply that it is an accidental gap. Not every logically possible combination of sounds following the rules of English phonology is found as an actual word of the language.

While the nonexistence of *glick* in English is accidental, the exclusion from English of certain other imaginable but nonexistent words is based on a rule of the language. There are words that begin with *sn* like *snake*, *snip* and *snort*, also numerous words beginning with [sm], for example *small, smite, smidgen, smell*, but no words words beginning with *gn* or *gm,* thus **gnick*, **gnark*, **gniddle, *gmelt, *gmite* are not words of English. While there are words spelled with *gn*, such as *gneiss, gnostic*, they are pronounced without [g] – [naɪs], [nɔstɪk]. Moreover, native speakers of English have a clear intuition that hypothetical **gnick*, **gnark*, **gniddle, *gmelt, *gmite* could not be words of English, whereas speakers have no such intuition about accidentally non-existent *glick*. A description of the phonology of English would provide a basis for characterizing the fact that English words can start with [gl, gɹ^w] but not [gn, gm].

Rule-governed variations in pronunciation. A phonological analysis especially explains variations in the pronunciation of word parts (morphemes). For example, there is a very general rule of English phonology which dictates that the plural suffix on nouns is pronounced as [ɨz], represented in spelling as *es*, when the preceding consonant is one of a certain set of consonants including [ʃ] (spelled *sh*) as in *bushes*, [t^ʃ] (spelled as *ch*) as in *churches*, and [d^ʒ] (spelled *j*, *ge*, *dge*) as in *cages*, *bridges*. This pattern of pronunciation is not limited to the plural, so despite the difference in spelling, the possessive suffix *s*[2] is also subject to the same rules of pronunciation: thus, plural *bushes* is pronounced the

[1] The asterisk is used to indicate that a given word is non-existent or wrong.

[2] This is the "apostrophe s" suffix found in *The child's shoe*, meaning 'the shoe owned by the child.'

same as the possessive *bush's*, and plural *churches* is pronounced the same as possessive *church's*.

This is the sense in which phonology is about the sounds (countable) of language. From the phonological perspective, a "sound" is a specific unit in a language which combines with other specific units according to rules, and which are realized as physical sound. What phonology is concerned with is how sounds behave in a grammar. A grammar is not the thing you were taught in elementary school or composition class. As set forth above, a grammar is an abstract cognitive system which specifies the subconscious rules that a speaker employs to relate sound and meaning. These rules are scientific idealizations, which do not take into consideration other factors that influence what actually comes out of the mouth of a speaker, or how a listener may end up interpreting physical sound. Phonological rules do not account for the effect on sound waves of having a cold or forgetting what you were talking about, nor do they account for how *sit* and *sin* might be confused in a noisy room. Speech perception and production is a very complex ability, which integrates grammatical and non-grammatical knowledge. A phonological grammar, which is the focus of this book, is a model of a specific kind of knowledge of how to relate morphological structure to speech. In terms of the theory of generative grammar, it is a model of computational competence, which is the abstract knowledge of an evaluative procedure identifying form-meaning pairs as being or not being "in" a particular language, and it is not a record of what was actually done (performance).

Whether or not it is important to have a theory of what the sounds of a language are, or how they might be hypothetically combined in speech, this last function of stating the rules of a language is indispensible. We don't need a rule to permit us to produce "sit" or "thing", we can just learn the particular word and then pronounce it (which does presuppose that we know how to move vocal tract muscles – which is not what phonology is about). Do we need a rule to be able to say "things" or "sits"? If we deny that there is a rule which we know and use to produce these words, then we must have previously memorized the plural or 3rd person words "things" and "sits" separate from "thing" and "sit". Maybe you have already heard and memorized these particular words, but if you do not know the word *sthondat*, are you able to form the plural (*sthondats* with *s*), and when you learn the name *Kurosh*, are you stumped that you don't know the plural (in English: *Kuroshes*, with an inserted vowel, and *z* rather than *s*)? You know these rules if you know English, and you use them to expand your knowledge of "what the words of English are". In English, learning one new word implies the ability to produce and understand a number of related word forms, which often involve changes in the sounds of this newly-learned words.

In English, that number of related words is relatively small because we do not have a lot of inflectional processes which create new words. Many languages have highly-active word-formation rules, for example in the Bantu language Shona, learning one new verb root implies the ability to produce on the order of 10^{33} related verb forms. Furthermore, the actual pronunciation of each subpart in this horde of new words can change, depending on what comes before or after, in a way that demands a system of rules. A person cannot have experienced 10^{33} words, much less done so for each of the thousands of roots in the language that they know, so “memorize words” is not a viable theory.

> Logoori examples are given here in spelling augmented with accents to indicate tone. Later on, you will find – and create – more data in Logoori, which are phonetically transcribed, and are tailored to actual pronunciation. Do not confuse the two!

Finally, the pronunciation of a particular fully-composed word is not necessarily invariant, it can depend on some phonological fact arbitrarily far from the word itself. Here is a brief example. The Logoori language of Kenya has tones: H and L, where unmarked vowels have L tone and vowels with acute accent have H tone. Some words have H, and you have to learn where the H is, but others words do not have H. There is a rule of the language that whenever you have a H tone in an utterance, and it is preceded by a L tone, the L tone becomes H. This happens to an entire sequence of L tones:

(2)	umuundu	‘person’	múláhi	‘good’
	vuza	‘only’	mwaangu	‘quick’
	umuundu vuza	‘only a person’		
	umuundu mwaangu	‘quick person’		
	úmúúndú múláhi	‘good person’		

The rule applies between words, which means that you have to know the pronunciation of the next word in order to decide whether the word ‘person’ is pronounced [umuundu] or [úmúúndú]. Clearly you need a rule, unless you can somehow memorize all word-pairs in the language. Although the morphology of Logoori is less prolific compared to Shona, a single root can still have around a billion morphological variants, see https://languagedescriptions.github.io/IP3/LogooriVerbs.html for an overview of this structure. The number of two-word pairs in Logoori is huge, and even then, memorizing two-word pairs is insufficient, one would have to memorize all sentences of the language – an impossibility. We see in (3) that the word which causes *umuundu* to be pronounced *úmúúndú* can be citation-pronounced *mwaangu*, but only if *mwaangu* is followed by *múláhi*.

(3)	umuundu mwaangu vuza	‘only a quick person’
	úmúúndú mwáángú múláhi	‘a good quick person’

The reason for this long-range dependency is that *múláhi* causes a change in *mwaangu* which becomes *mwáángú*, then *mwáángú* causes the same change in *umuundu*. But only if *múláhi* is at the end.

This dependency between the tone of one word and the sequence of somewhere-following words can be arbitrarily long. All the rule has to do is look for a H tone, make the L before it become H, and repeatedly do that throughout the sentence.

(4) valagavulanyila umuundu mwaangu vuza izing'oombe ngulu nditu
mumugela mululu mulla
'They will divide up the energetic heavy cows in one fierce river for only
the quick person'
válágávúlányílá úmúúndú mwáángú vúzá ízíng'óómbé ngúlú ndítú
múmúgélá múlúlú múllá dáave
'They will not divide up the energetic heavy cows in one fierce river for
only the quick person'

It is plainly untenable to maintain that Logoori speakers have experienced and memorized all of the sentences of their language. Rules eliminate the need for impossible memorization tasks.

Summary

Phonetics and phonology both study language sound. Phonology examines language sounds as mental units, encapsulated symbolically for example as [æ] or [g], and focuses on how these units function in grammars. Phonetics examines how symbolic sound is manifested as a continuous physical phenomenon. The conversion from the continuous external domain to mental representation requires focusing on the information that is important, which is possible because not all physical properties of speech sounds are cognitively important. One of the goals of phonology is then to discover exactly what these cognitively important properties are, and how they function in expressing regularities about languages.

Exercises

The first three exercises are intended to be a framework for discussion of the points made in this chapter, rather than being a test of knowledge and technical skills.

1. Examine the following true statements and decide if each best falls into the realm of phonetics or phonology, and why.

   a. Sound in the word *frame* changes continuously.

   b. The word *frame* is composed of four segments.

   c. Towards the end of the word *frame*, the velum is lowered.

d. The last consonant in the word *frame* is a bilabial nasal.

2. Explain what a “symbol” is; how is a symbol different from a letter?
3. Why would it be undesirable to use the most precise representation of the physical properties of a spoken word that can be created under current technology in discussing rules of phonology?

Further reading

Ashby & Maidment 2005; Isac & Reiss 2008, Johnson 1997; Ladefoged & Johnson 2010 Liberman 1983; Stevens 1998.