In this section, you will learn the following important phonological notions, and get a first understanding of them:

- phonological feature, natural class
- phonological rule, derivation, UR, PR
- inventory, phoneme, allophone.

1 Chamorro vowels

The discussion of Chamorro vowels and natural classes in what follows is closely oriented with that of Kenstowicz 1994.

1.1 Chamorro vowel harmony: first generalization

The vowels in (1) from the Chamorro vowel-inventory are relevant in the following discussion. They can be distinguished along the front-back dimension, and along three dimensions of height that we have discussed in the section on articulation. [u] and [o] are also distinguished in rounding from the other vowels, but that is not relevant to what follows, and will be ignored here.

(1) Chamorro

<table>
<thead>
<tr>
<th></th>
<th>front</th>
<th>back</th>
</tr>
</thead>
<tbody>
<tr>
<td>high</td>
<td>[i]</td>
<td>[u]</td>
</tr>
<tr>
<td>mid</td>
<td>[e]</td>
<td>[o]</td>
</tr>
<tr>
<td>low</td>
<td>[æ]</td>
<td>[a]</td>
</tr>
</tbody>
</table>

The crucial data are shown in (2). Isolated nouns are shown on the left; for each noun, the definite form, that includes the definite determiner [i], is shown on the right.

(2) noun without determiner | same noun with definite determiner [i]
---|---
a. gumɔ | 'house' | a'. i gĩmɔ | 'the house'  
b. tomɔ | 'knee' | b'. i temɔ | 'the knee'  
c. lahr | 'male' | c'. i læh r | 'the male'  
d. gwihɔn | 'fish' | d'. i gwihɔn | 'the fish'  
e. pecɔ | 'chest' | e'. i pecɔ | 'the chest'  

Observe that the first vowel of the noun 'changes' in the forms on the right in a', b', and c'. For example, while we have the vowel [u] in [gumɔ] in a. on the left, we have the vowel [i] in [i gĩmɔ] in a'. on the right. Similarly in b'/b' and c'/c'. The generalization is that each of the back vowels [u, o, a] turns into a corresponding front vowel [i, e, æ]. 'Corresponding front vowel' here means 'a front
vowel of the same height'. For example, [u] in (2a) is a high vowel, and the vowel [i] that it turns into in (2a') on the right is also a high vowel, but it is front (compare (1)).

If it was not for phenomena of this kind, we could have a very simple theory of the pronunciation of languages. Recall that words and morphemes have (mental) lexical entries, which contain information about the meaning of these words/morphemes, about their syntactic category (N, V, etc.), and also about their pronunciation. A very simple theory about how the pronunciation works would have been to add the pronunciation of a word to this lexical entry, for example [gumə] for 'house' in a lexical entry of a Chamorro speaker. Then, when the word is spoken, this lexical entry is used, and the phonological part of this entry, [gumə], would define how the word is pronounced. However, this very simple theory cannot be right, since the word [gumə] is sometimes pronounced [gimə], as in (2a), and sometimes [gimə], as in (2b).

What is illustrated in (2) is an instance of vowel harmony (vowels leading to changes in other vowels). Many languages have vowel harmony systems of various kinds, and most languages have phenomena of this general kind, where sounds change, depending on the environment in which they occur. Such changes of sounds (sounds are also called phonological segments), are studied in one branch of phonology, segmental phonology. For an analysis of them, we have to expand the simple picture above in a number of ways.

For one thing, we would like to say that the pronunciations [gumə] and [gimə], which are still very similar, use the same lexical entry. Let us say, for now, that this lexical entry has the pronunciation [gumə] listed. Then we have to distinguish the lexical entry from what is actually said. In an expansion of the simple model, phonologists distinguish between the 'underlying representation' (UR) and the 'phonetic representation (PR). The underlying representation contains the information from lexical entries. The phonetic representation contains the information that is actually said. The following picture helps you see how that can be the beginning of a way of making sense of these two ways of pronouncing 'house' in Chamorro.

(3)  

\[
\text{UR} \quad /\text{i}/ \quad \text{gumə} / \\
\text{PR} \quad \text{[gumə]} \quad \text{[i gimə]}
\]

We will return to this picture below.

What we also need, of course, is a way of capturing what changes take place in such alternations as between [gumə] and [gimə]. Why does [u] change to [i] here, and not to [e] or [o]? Why does it change at all? Why does not some other sound of the word change? And why does the change take place after the definite determiner [i], but not in the isolated form?

A general characterization of the process is given in (4), based on what we observed above.

(4) The first vowel of a word turns into a front vowel of the same height if the word is preceded by the definite determiner [i].

Systematically: changes in the first vowel of the word following the definite determiner [i]:

\[
\begin{array}{c|c|c}
\text{front} & \text{back} \\
\hline
\text{high} & [i] & [u] \\
\text{mid} & [e] & [o] \\
\text{low} & [æ] & [a] \\
\end{array}
\]

Notice that nothing changes if the first vowel is already a front vowel, as in (2d,e). Let us assume that this is covered by the formulation in (4).
But how can a vowel just change into another vowel? And how can there be a generalization across all three vowels [u, o, a]? How does [u] know that it is supposed to change to [i], rather than to [e], which is also a front vowel?

In the section on articulation, we said that the vowels can be distinguished in their articulation in terms of whether they are articulated further front or further back, in terms of their height, and otherwise. The Chamorro vowel change, captured in the formulation in (4), suggests that there is something very systematic about such properties. It is an important property of [u, o, a] that they are back vowels, since they change in this process. Furthermore, they lose this property as being back vowels, and trade it in for the property of being front vowels. Likewise, it seems to be an important systematic property of the sound [u], for example, that it is a high vowel, since this property is crucially retained in the change to [i]. Similarly, the crucial property of [o] as being a mid vowel is retained in its change to [e], and likewise for low [a], which becomes [æ].

The Chamorro change seems to show that these systematic properties of the vowels should be isolated, and be looked upon separately. Thus, in the change in (4), the backness property of [u, o, a] is changed, while the height properties of these sounds are retained in the change.

1.2 Vowel features and natural classes

Phonologists capture these systematic properties of sounds (properties which can act separately) by postulating phonological features. Thus let us define the features in (5).

(5) Vowel features:

[+high] the highest point of the tongue is high in the oral cavity;
(F1 is low and other acoustic consequences)
[-high] the highest point of the tongue is not high in the oral cavity;
[+low] the highest point of the tongue is low in the oral cavity;
[-low] the highest point of the tongue is not low in the oral cavity;
[+back] the highest point of the tongue is back in the oral cavity
[-back] the highest point of the tongue is not back in the oral cavity

There is one feature, [+/-back] for capturing the distinction between front and back vowels. Front vowels are [-back] and back vowels are [+back]. There are two features, [+/-high] and [+/-low] for capturing the three-way distinction in height. These features are used as shown in (6): Only the high vowels are [+high]. Only the low vowels are [+low]. The mid vowels are [-high] and [-low]. That makes sense: the mid-vowels are neither really high, nor really low.

(6) [-back]  [+back]

[+high]  [i]  [u]  [-low]

[-high]  [æ]  [a]  [+low]

If we use these features as labels in a table, like in (6), they don't do much for us that the original classification, as in (1), would not also have done for us. Importantly, these features are now put to use in a different way. In a first step, we say that each sound has, inherently, certain features. In particular, [i] has the features [+high] and [-back], [u] has the features [+high] and [+back], etc. This is shown in (7) by writing the features that inherently belong to each sound below that sound. The feature backness is boldfaced, so that the result can be read more easily.
Now we don't really need the table any more: Each sound 'carries its properties with it', so to speak.

Before going on to illustrate the usefulness of these features in understanding the Chamorro vowel change, let us pause so you can learn an important notion in phonology, that is also sometimes applied in other areas of linguistics. This is the notion of the natural class.

(8) Natural class of sounds of a given language:
A natural class is the sets of sounds picked out by a feature or a combination of features. This set must include all and only the sounds picked out by this feature or combination of features.

Thus, we may informally speak about the natural class of back vowels in Chamorro. What we mean by this more formally is: the set of those vowels that have the feature [+back]. In (7), these are the vowels \([u, o, a] \). Thus (ignoring other vowel of Chamorro in the present discussion), the feature [+back] defines the natural class \([u, o, a] \). A combination of two features also defines a class, which is likewise called a natural class. For example, the two features [-back, -low] together define the class of vowels that have both of these features. As you can see in (7), these are the vowels \([i, e] \). Informally, we can call these the non-low front vowels. More natural classes are shown in (9).

(9) Natural classes relative to the inventory in (4):

a. [+high] [i, u] 'high vowels'
b. [-high] [e, o, æ, a] 'non-high vowels'
c. [-high, -back] [e, æ] 'non-high front vowels'
d. [-high, -low] [e, o] 'mid vowels'
e. [+low] [æ, a] 'low vowels'
f. [-low] [i, u, e, o] 'non-low vowels'
g. [-low, -back] [i, e] 'non-low front vowels'
h. [+back] [u, o, a] 'back vowels'
i. [+low, +back] [a] 'low back vowel'
j. [+high, +low] <not a class>
k. [-low, +back] [o, u] 'non-low back vowels'
l. [-back, -high, -low] [e] 'front mid vowel'
m. [e, o, u] <not a natural class in (7)>
n. [a, u] <not a natural class in (7)>

Observe in particular the following points. [+high, +low] in (9j) is not a class of sound. This combination of features results in a contradiction: the tongue cannot at the same time be high (for
[+high]) and low (for [+low]). That is a good result: We have the two features for vowel-height [high] and [low]. All cross-classifications of values for these features give us four possibilities, but we only want three vowel-heights: high, mid, and low. We get these three heights: 'high' is [+high, -low], 'mid' is [-high, -low], and 'low' is [-high, +low]. The fourth combination is [+high, +low], which is precisely the contradictory combination we have just seen.

Observe also in (9m,n) that some combinations of vowels are not natural classes. There is no feature combination that chooses [e, o, u] in (7) but no other vowel. A possibility that one might think of is [-low]. However, this chooses a set of vowels in (7) that also include [i], namely: [i, e, o, u]. This latter set is a natural class, the set of non-low vowels. However, the set [e, o, u], without [a], cannot be chosen by a feature or by a combination of features, and is thus not a natural class.

Finally, observe that when we use enough features, we end up with natural classes of just a single vowel sound. In (9i), for example, the combination [+low, +back] narrows things down to the single vowel [a], the only low back vowel in (7). Similarly in (9l), where [-high, -low, -back] leaves only the vowel [e] in (7). Technically, then, these single sounds are also natural classes. In practice, however, people don't normally say 'natural class' when they mean a single sound.

However, there is a very important point to notice in this connection, which will bring us to the next step in understanding the use of features in phonological theory. Notice that all the sounds in (7) are natural classes in this (odd) sense: Each of them can be picked out by a combination of features. The features we have to choose, for a given sound, are the ones written below that sound in (7): the properties of that sound. We can say, therefore, that the features of a sound, its properties, define the identity of the sound.

At this point, let us kick away the ladder! Phonologists assume that (the transcription) [i] is not really a sound, but only a short-hand for writing the sound. You can also think of it as a helpful name for writing the sound. You can also think of it as a helpful name for a person. What the sound [i] really is, then, is the set of the features that define its identity, the set of its properties. Thus, [i] is really [-back, +high, -low]. (Some additional features must be added in the full theory, so that this sound is also sufficiently distinct from the lax vowels and from the consonants, but we will ignore this here.) Similarly, [e] is really [-back, -high, -low], and more generally, (7) is really a picture of the names of the sounds, followed by what the set of features that, together, make up the identity of the sound.

Now we can understand what it means that one sound 'turns into another one', and we can get an understanding of the Chamorro vowel change.

1.3 Phonological rule and phonological derivation

The description of the Chamorro vowel change is repeated in (10), from (4), but this time with the features that characterize each sound.
The first vowel of a word turns into a front vowel of the same height if the word is preceded by the definite determiner [i].

Changes in the first vowel of the word following the definite determiner [i]:

<table>
<thead>
<tr>
<th>[i]</th>
<th>[u]</th>
</tr>
</thead>
<tbody>
<tr>
<td>[-back]</td>
<td>[+back]</td>
</tr>
<tr>
<td>[+high]</td>
<td>[+high]</td>
</tr>
<tr>
<td>[-low]</td>
<td>[-low]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>[e]</th>
<th>[o]</th>
</tr>
</thead>
<tbody>
<tr>
<td>[-back]</td>
<td>[+back]</td>
</tr>
<tr>
<td>[-high]</td>
<td>[-high]</td>
</tr>
<tr>
<td>[-low]</td>
<td>[-low]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>[æ]</th>
<th>[a]</th>
</tr>
</thead>
<tbody>
<tr>
<td>[-back]</td>
<td>[+back]</td>
</tr>
<tr>
<td>[-high]</td>
<td>[-high]</td>
</tr>
<tr>
<td>[+low]</td>
<td>[+low]</td>
</tr>
</tbody>
</table>

Now we get an understanding of what it means that one vowel turns into another vowel. The vowel [u], for example, is really [+back, +high, -low]. The change into another vowel is a change in one of its features: if [+back] is replaced with [-back] in this combination, we get the vowel [-back, +high, -low]. This is the vowel [i]. By the same mechanisms of replacing [+back] with [-back], [o] becomes [e], and [a] becomes [æ].

In this way, we now also get a more general understanding of the Chamorro vowel change: In a word that follows the definite determiner [i], the change replaces [+back] with [-back] in the first vowel of that word. If the change only replaces [+back] with [-back], it is then automatic that the vowel thus changed retains its height: the feature-values for [high] and [low] are not affected. This, then, is how [u] 'knows' that it changes to [i], rather than to [e]: It retains its features other than backness. And this is how the properties of the sound can act independently: the value of [+back] can be changed to [-back], but the values of the other features remain unchanged.

Consider then also the examples in (11). These demonstrate that the vowel change is not limited to the definite determiner [i]. Instead, it seems that more generally, words that themselves have a front vowel ([i, e, æ]) can trigger this process in the first vowel of the following word. For example, in (11a), the pronunciation of the verb 'to know' is [tonu?]. However, as shown in (11a'), after the pronoun 'you' [en], with the front vowel [e], 'to know' is pronounced [tenu?], with front [e] instead of back [o] (again retaining the height: both [o] and [e] are mid vowels).

(11)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>tonu? 'to know' a'. en tenu? 'you know'</td>
</tr>
<tr>
<td>b.</td>
<td>hulo? 'up' b'. sæn hilo? 'upward'</td>
</tr>
<tr>
<td>c.</td>
<td>otdot 'ant' c'. mi etdot 'lots of ants'</td>
</tr>
<tr>
<td>d.</td>
<td>oksu? 'hill' d'. gi eksu? 'the chest'</td>
</tr>
<tr>
<td>e.</td>
<td>lægo 'north' e'. sæn lægo 'toward north'</td>
</tr>
</tbody>
</table>

We therefore formulate this change more generally as in (12).

(12) The first vowel of the word becomes [-back] when the preceding vowel is [-back].

The theory of phonology formalizes such changes in a more precise format: that of the phonological rule. Such a rule is shown in (13). Phonological rules are usually given names (here: Backness harmony), so it's easier to refer to them later on.
(13)  (Phonological) rule

Backness harmony
V -> [-back] / [-back] C₀ ___ C₀; 0 or more consonants

The rule should be read as: "a vowel becomes [-back] when it stands in the environment [-back] C₀ ___." In the characterization of the environment, "___" indicates where the changing sound stands, [-back] stands for the earlier [-back] vowel, giving its the feature [-back] that is crucial for the rule to apply, and C₀ ("0 or more consonants") indicates that the changing sound ("___") and the preceding vowel ("[-back]") can be separated by consonants (but not by other vowels).

This rule turns the phonological representation in (14) into the representation in (15). As said each sound is now understood to be a set of features. A word, and more generally, any expression, is a sequence of sounds, and thus a sequence of such sets of features. (14) is the input representation to the rule (it includes other features that you don't yet know, but you don't need to worry about this here). The crucial aspects of the representation in (14) are highlighted: the feature [+back] in the vowel [u], and the feature [-back] in the earlier vowel [i]. The rule 'sees' this [-back] vowel of [i], and 'sees' the first vowel of the next word. It then turns this first vowel of the next word to [-back], as shown in (15), the output representation of the rule.

(14)  i  g  u  m  o
    -consonantal  +consonantal  -consonantal  +consonantal  -consonantal
    +sonorant    -sonorant    +sonorant    +sonorant    +sonorant
    +high       dorsal      +high      labial     ...
    -low        +voiced-low ...
    -back       ...
    ...         ...

(15)  i  g  i  m  o
    -consonantal  +consonantal  -consonantal  +consonantal  -consonantal
    +sonorant    -sonorant    +sonorant    +sonorant    +sonorant
    +high       dorsal      +high      labial     ...
    -low        +voiced-low ...
    -back       ...
    ...         ...

The rule will only change [+back] to [-back] in the relevant sound, under the relevant circumstances. The effect of this is that [u] becomes [i], [o] becomes [ɛ], and [a] becomes [æ] in this environment.

Let us then return to the little model of phonology laid out earlier. (3) is repeated in (16). We said that the lexical entry of the noun 'house' in Chamorro should contain the pronunciation /guma/, and that we want to relate the two different actual pronunciations to this.

(16)     UR    /i guma/
         /
PR     [guma]  [i gima]

We now have all the pieces for completing this picture. First, the lexical entry of the word 'house' contains the pronunciation in the form sketched in (14): with the pronunciation as a sequence of feature-bundles. The underlying representation (UR) more generally will be the sequence of pronunciations from lexical entries that an expression is composed of. To these, we apply the phonological rules of the language, in our case: the rule of Backness harmony. We assume that the rule tries to apply to all underlying forms. However, it will change only certain vowels: those in...
which the conditions required by the rule are met (in particular, the preceding vowel must be a [-back] vowel. The result of the rule application is then the actual pronunciation of the word, PR. PR is also a sequence of feature-bundles. (17) schematically shows two such derivations, one for 'house', and one for 'the house'. In the derivation of 'house', Backness harmony does not apply: There is no front vowel that could change a following vowel. Therefore, the UR does not change, and the PR ends up identical to the UR. In the case of 'the house', on the other hand, Backness harmony applies to the UR and changes the first vowel of /gəmə/ to [i], by changing its backness specification. The rule thus derives the PR, the actual pronunciation of the expression for 'the house'.

(17) (Phonological) derivations

<table>
<thead>
<tr>
<th></th>
<th>'house'</th>
<th>'the house'</th>
</tr>
</thead>
<tbody>
<tr>
<td>UR</td>
<td>/g u m ə/ [+back]</td>
<td>/i g u m ə/ [-back]</td>
</tr>
<tr>
<td>Backness harmony:</td>
<td>-- [unchanged]</td>
<td>/i g i m ə/ [-back]</td>
</tr>
<tr>
<td>PR:</td>
<td>/g u m ə/ [+back]</td>
<td>/i g i m ə/ [-back]</td>
</tr>
</tbody>
</table>

UR and PR are thus crucially separated by the application of our phonological rule. For completeness, definitions of UR and PR are given in the following.

**underlying representation (UR)** [G. zugrundeliegende Form]: 'what we memorize'; in phonology, the pronunciation as specified in the lexical entries of morphemes or words. In a standard cognitive understanding of the grammar, this is the way speakers memorize the pronunciation; part of the postulated entries in the mental lexicon.

**phonetic representation (PR)** [G. phonetische Form]: 'what we hear or say'; a form that is either identical to the underlying representation or derived from it by the application of phonological rules. This form is the input to the phonetic implementation: it may be thought of as the form that defines what instructions are given to the articulators in articulation, and the form that is recovered from the phonetic input in the perception.

Importantly, the pronunciation does not seem to be as simple as memorizing the pronunciation of a word or morpheme, and speaking out this memorized pronunciation. Instead, it seems that the sounds act as a system, where sounds can change other sounds in systematic ways. We capture the systematicity of such changes by conceiving of sounds as set of phonological features. We capture the fact that such changes take place in the more complex model, in which the underlying representation can be transformed by phonological rules, before we arrive at the representation that defines how something is actually said.
2 'Ich-Laut' and 'ach-Laut' in German

Let us turn to a German example that also involves vowel-features. This concerns the distribution of ich-Laut [ç] and ach-Laut [x]. The examples in (18) exemplify a very general fact about the distribution of these two sounds in German: [ç] occurs after front vowels as in (16a), and [x] occurs after back vowels as in (18b).

(18) a. kriechen [kʁiçøn] b. Buch [bu:x]
    Licht [løːt] Spruch [ʃpɔux]
    Bücher [byçɛ]} hoch [ho:x]
    Gerücht [ɡɔʁɡøt] doch [ðɔx]
    mechanisch [mɛçɑnɪf] nach [na:x]
    rühen [ʁœçøn] Bach [bax]
    Recht [ʁeçt]
    Lücher [løçɛn]

The classification of German vowels that we arrived at is repeated in (19), and the generalization about the distribution of [ç] and [x] is repeated in (20).

(19) Vowel classification in German

<table>
<thead>
<tr>
<th></th>
<th>-tense</th>
<th>+tense</th>
<th>-round</th>
<th>+round</th>
<th>-round</th>
<th>+round</th>
</tr>
</thead>
<tbody>
<tr>
<td>+high</td>
<td>i</td>
<td>y</td>
<td></td>
<td>u</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-low</td>
<td>+tense</td>
<td>i</td>
<td>y</td>
<td></td>
<td>o</td>
<td></td>
</tr>
<tr>
<td>-high</td>
<td></td>
<td>e</td>
<td>ø</td>
<td></td>
<td>o</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-tense</td>
<td>e</td>
<td>ø</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+low</td>
<td></td>
<td></td>
<td></td>
<td>a</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(20) Generalization about the distribution of [ç] and [x]:
[ç] is found following front vowels
[x] is found following back vowels

When two sounds occur in different environments like this, they are said to be in complementary distribution. (The name has to do with the fact that the set of environments that one sound occurs in is mathematically the complement of the set of environments that the other sound occurs in.)

complementary distribution [G. komplementäre Verteilung]: two sounds A and B are in complementary distribution if they do not occur in the same environment. Often, this means that one of the two sounds occurs in one environment only, while the other sound occurs in all other possible environments.

Example: [ç] and [x] are in complementary distribution in German

We will return to the 'all other possible environments' part of the definition.
For now, notice that there is a useful tool for establishing complementary distribution, and for finding the generalization what sound occurs in which environment. I will demonstrate this tool using (18), repeated here, but it can also be used when the examples are not already sorted in this way.

(18) a. kriechen [kʁiçɔn] b. Buch [buç]
Licht [lɪçt] Spruch [ʃpruç]
Gerücht [ɡɔʁççɛt] Docht [dɔxt]
mechanisch [mɛçaçɛʃ] nach [naχ]
richten [ɾɛççɔn] sachte [saxtə]
Recht [ɾɛççɛt] nach [naχ]
Löcher [lœçɛɾ]

Here is the tool: Make yourself a table. In one column, you write the environments of one sound, in the other column, you write the environments of the other sound. In (22), we write the environments of [ç] in the column on the left, and the environments of [x] in the column on the right. Now, working through your data ((18) in our case), you make a list of environments in which [ç] occurs, and a list of environments in which [x] occurs. You can write the environment for [ç] in 'kriechen' in (18a) as follows: [i__œ]. Thus, you take the part of the pronunciation of this word, in which [ç] occurs, replace [ç] with "__", and you add to this the sound that occurs just before [ç] and the sound that occurs just after [ç] in the pronunciation of this word. For 'Licht' in (18a), you similarly get the environment [t__t] for the sound [ç]. Then, for the occurrences of [ç] and for the occurrences of [x] in your data, you enter these environments into your table, as shown in (22).

(22) [ç] [x]
[i__œ] [u__#]
[t__t] [u__#]
[y__œ] [œ__œ]
[y__œt] [œ__œ]
[e__œt] [a__œt]
[e__œ] [a__œt]
[œ__œ] [œ__œ]

front vowels back vowels

Now it’s easier to see where there is or is not a generalization. For example, there is no generalization in the right context of these sounds (in the sound that follows). As can be seen in (22), [ç] is sometimes followed by Schwa [œ], and [x] is also sometimes followed by Schwa. Also, [ç] is sometimes followed by [t], and [x] is also sometimes followed by [t]. However, the regularity in regard to the left context does not have an exception: there is always a front vowel preceding [ç], and there is always a back vowel preceding [x].

The standard explanation for complementary distribution in phonology is this: First, only one of the two sounds is allowed in the underlying representation of words in the entire language. For example: [ç] may be used in underlying representations, but not [x]. Second, the other sound is derived from the first sound by a phonological rule, in a specific environment. For example: [x] is then derived from [ç] by a phonological rule.
How do we know which sound is underlying, and which one is derived? Consider the additional data in (23). [ç] also occurs after consonants such as [l] and [n], while [x] is never found after consonants. Furthermore, some speakers can also use [ç] in initial position. [x], on the other hand, never occurs word-initially.

(23) [ç] but not [x] after consonants (where possible)
    [...ɔç...]: Molch, Strolch
    [...ɔnç...]: Poncho
[ç] but not [x] initially (for some speakers)
    China [çìna] (other speakers: [kìna], yet others: [jìna])
    Chemie [çemi:] (other speakers: [kemi:], yet others: [jemi:]

Thus, a more complete description of the distribution of these two sounds is as in (24).

(24) [x] occurs after [+back] vowels
    [ç] occurs elsewhere (after front vowels, after consonants, word-initially (for some speakers))

This is the most useful kind of description of the distribution of two sounds, and one that is typically found: one of them is found in a specific environment (here: [x] after [+back] vowels), the other one is found in other environments (here: [ç]). In this kind of situation, we know that the 'elsewhere'-sound (here: [ç]) is the underlying sound, and that a rule creates the other sound (here: [x]) under the specific conditions in which this sound is found (here: after back vowels). Our phonological explanation thus takes the form in (25). First, we postulate that words can contain [ç] in the lexical entries of German, but not [x]. Second, we derive [x] from [ç] using the phonological rule of Fricative Backing. The example derivation illustrates how this works, using 'ich' (front vowel before the sound in question) and 'ach' (back vowel before the sound in question) as examples. Importantly, the underlying representation of both words now contain only /ç/, the only underlying sound allowed by this little theory. Following the back vowel in 'ach', underlying [ç] is changed to [x] in the derivation of 'ach' by the rule of Fricative Backing (abbreviated FB in this illustration). FB does not change [ç] in 'ich', since it does not occur after a back vowel here. In this way, the two correct pronunciations are derived.

(25) • underlying: always /ç/
    • rule: Fricative Backing
    [ç] -> [x] / [+back] ___
    • example derivations:
      "ich"    "ach"
      UR /çı/   /açı/
      FB --     [ax]
      PR [ç]    [ax]

The situation in which there is complementary distribution among two sounds is quite frequent in the languages of the world, and the explanation always follows the schema illustrated here: the 'elsewhere'-case is taken to be underlying; the other sound is not allowed underlyingly, but is created by a rule in the specific environment in which it is found.

Here is some more important terminology in connection with what we have seen:

inventory [G. (Laut)inventar]: the set of sounds used in underlying representations.

p. 11, Intro Ling, Phonology 3: Core elements of phonological theory
Examples: The inventory of English: \{p, t, k, \ldots, \&\, \ldots, \i, \ldots\} includes /\emptyset/,
but not /x/ or /\&/. The inventory of German: \{p, t, k, \ldots, \&, \ldots, \i, \ldots\} does not include /\emptyset/.
We adopt the little theory above, and say: it includes /\&/ but not /x/.

**phoneme** [G. *Phonem*]: (traditionally defined as the smallest unit that can make a difference in meaning; here also:) a sound that is in the inventory of the language.

**allophones** [G. *Allophone*]: two allophones of a phoneme are two sounds that are in complementary distribution, and are both derived from the same underlying phoneme.

Example: in German, /\&/ is a phoneme, with the allophones [\&] and [x].

Here is some more explanation of the format of phonological rules

Backness harmony
\[ V \rightarrow [-\text{back}] / [-\text{back}] C_0 \]

affected sound
one or few features:
the one that is that the sound has
features:
the opposite feature value is eliminated to have in order for the rule to apply
'change'
only one feature:
the one that is added; the opposite
features
'in the sound'
that the feature value is eliminated
'environment'
the sounds that have to surround the sound in question, in order for the rule to apply; the 'environment bar' indicates the position of the sound that changes.

Notice: A rule of the form \[ A \rightarrow B / X \_ Y \]
could also be written: \[ X A Y \rightarrow X B Y \]

Notation used in writing rules:

\[ V \] any vowel
\[ C \] any consonant
\[ C_0 \] 0 or more consonants

(...) an optional element; for example:
\[ A \rightarrow B / C (D) \_ \_ \_ \]
is a unification of the two rules:
\[ A \rightarrow B / C \_ \_ \_ \]
\[ A \rightarrow B / C D \_ \_ \_ \]

+ a morpheme boundary
# a word boundary; for example:
\[ A \rightarrow B / # \_ \_ \_ \]
'A becomes B at the beginning of a word.'
3 [ç] and [x] in Greek

Modern Greek also has the two sounds [ç] and [x]. In Greek, as in German, these two sounds are in complementary distribution, and are thus allophones of a single phoneme. As shown in (1a), [ç] occurs in Greek preceding front vowels, and [x] occurs preceding back vowels and consonants.

(26)  a. [çino] 'pour'  
     [çeli] 'eel'  
     [çeri] 'hand'  
     [oçi] 'no'

     b. [xano] 'lose'  
     [xali] 'plight'  
     [xori] 'dances'  
     [xufa] 'handful'

(27)  [ç] occurs preceding front vowels  
 [x] occurs elsewhere (preceding back vowels and consonants)

What is similar to German here is that [ç] goes with front vowels while [x] goes with back vowels. However, while in German, the preceding vowel determines whether [ç] or [x] occurs, in Greek, the following vowel determines the choice. A further difference is that [ç] is the 'elsewhere'-case, and thus the underlying sound in German, while [x] is the 'elsewhere'-case, and thus the underlying sound, in Greek (see (26) and (27)).

We explain the complementary distribution in Greek by postulating (28) for the phonology of Greek.

(28)  a. inventory: /x/ is in the Greek inventory, but not [ç]
     b. Fricative Fronting  
        [x] -> [ç]  / ___ [-back]

(29) illustrates how this little theory works. Both allophones [x] and [ç] are underlingly a single phoneme, [ç]. In UR, therefore, we have /xino/ and /xano/. Fricative Fronting then changes /xino/ to [çino], since [x] here occurs before a front vowel. More generally, Fricative Fronting creates the sound [ç] from [x] before front vowels, in this little theory about Greek. Fricative Fronting does not affect /xano/, since [x] here occurs before a back vowels, where Fricative Fronting (28b) does not apply. Therefore /xano/ surfaces unchanged as [xano]. This results in the two correct pronunciations that we first saw in (26).

(29) Derivations
     'pour'  
     'lose'  
     /xino/  
     /xano/  
     [çino]  
     -- [unchanged]
     [çino]  
     [xano]

The distribution of [ç] and [x] in German and Greek, in its dependency on the backness of the adjacent vowels, confirm a point that we originally made for Chamorro: Whether the tongue is further front or further back is not just a good way of describing how different vowels are articulated. It is, in addition, a systematic distinction that is important in capturing how sounds can affect each other. In the theory of phonology, this is captured by using the feature [+/-back] as part of the theory. In
Chamorro, back vowels were changed to corresponding front vowels. In that case, [+back] is changed to [-back]. In German and Greek, this same feature is relevant to triggering the creation of alloglyphs: In German, a [+back] vowel triggers the creation of a following [x] from [ç]. In Greek, a [-back] vowel triggers the creation of a preceding [ç] from [x].

Here, then, we get a first glimpse of what is universal, and what is language-specific in the theory of phonology that you are learning about.

(30) Universal: • The features and their phonetic content.
    For example, the vowels of all languages are specified in terms of the same set of features, which includes [+/-back], [+/-high], etc.
    • The model in which UR, composed of pronunciation entries of mental lexical entries, can be transformed by rules to PR, which defines the pronunciation.
    • The fact that each language has an inventory, a set of underlying sounds.

Language-specific:
• Rules are language-specific. Each language has different phonological rules.
• Each language has its specific inventory, the set of underlying sounds allowed in that language.

3 Contrastive distribution and minimal pairs: English [s] and [ʃ]

The opposite of complementary distribution is contrastive distribution: if two sounds can occur in the same environment. The best way of demonstrating this is by way of minimal pairs. For example:

(31) English: [s] vs. [ʃ]
    
    see [sɪ]        sew Am. [sɔu] Br. [sɔu]
    she [ʃɪ]       show Am. [ʃou] Br. [ʃou]

Here we want to say that [s] and [ʃ] are both phonemes of English, are both in the inventory of English, and can thus both be used in the lexical entries of words (‘underlying forms): /sɪ/ for the verb 'see', and [ʃɪ] for the pronoun 'she'.

A minimal pair like 'see' and 'she' demonstrates in a very clear way that these two sounds cannot be alloglyphs. If they were alloglyphs, they would have to occur in different environments, but never in the same environment. However, in a minimal pair like 'see'/she', these two sounds occur in exactly the same environment, namely: [#__i].

We can also put this differently, in terms of the explanation for alloglyphs that we have seen: We said when there are two alloglyphs, they are derived from the same underlying sound (phoneme) in such a way that a rule leaves certain occurrences of the sound unchanged, but changes other occurrences of the sound. For example, from the discussion of German:

    "ich"    "ach"
    UR /ɪç/ /aç/
    FB -- [ax]
    PR [ɪç] [ax]

Here the rule is written to change [ç] after back vowels. It therefore leaves [ç] in 'ich' alone, but changes [ç] to [x] in 'ach'.

Now, if there is a minimal pair, with the two sounds in the same environment, it is impossible to formulate a rule that similarly derives the two sounds from a single underlying sound:

    "see" "she" (wrong theory!)
    UR /sɪs/ /sɪs/ (assumed underlying forms with a single phoneme [s]

    rule ??? -- [ʃɪ]
    PR [sɪ] [ʃɪ]
But there cannot be such a rule, because the URs would have to be identical, and no rule could distinguish them, and apply in one case, but not in the other.

Therefore, when we have a minimal pair involving two sounds like [s] and [ʃ], we have good evidence that [s] and [ʃ] are different phonemes in the language in question. For example, [s] and [ʃ] are different phonemes in English.

They are also different phonemes in German, compare 'sein' [sam] and 'Schein' [ʃam].

4 Korean [s] and [ʃ]

Since languages have different inventories and different rules, it often happens that two sounds that are different phonemes in one language occur as allophones of a single phoneme in another language. The two sounds [s] and [ʃ] that are different phonemes in English, for example, are allophones of a single phoneme in Korean. (32) illustrates the complementary distribution between these two sounds in Korean. (Note: [ʃ] is an affricate, and thus a different sound from [ʃ]. When we consider the distribution of [s] and [ʃ], the affricate [ʃ] is not directly relevant.)

(32)   a. [s]    b. [ʃ]

| [sal] | 'flesh' |
| [tʃasal] | 'suicide' |
| [kasu] | 'singer' |
| [sanmun] | 'prose' |
| [kasʊ] | 'hypothesis' |
| [tʃɒsonʊnʊ] | 'adolescents' |
| [miso] | 'smile' |
| [susek] | 'search' |
| [tapsa] | 'exploration' |
| [so] | 'cow' |

It can be seen that [ʃ], on the right, occurs before the vowel [i], while [s] occurs before other vowels.

(33)    [ʃ] occurs before [i]

We therefore postulate (34) for the phonology of Korean. [s], which is the 'elsewhere'-case, is taken to be underlying. [ʃ] is created from [s] before [i] by the rule of Palatalization (34b).

(34)   a. /s/ but not /ʃ/ in the inventory

b. Palatalization: [s] -> [ʃ] / __ [i]

(35) illustrates. When [s] occurs before a vowel different from [i], it remains unchanged, as in the derivation of 'flesh'. [ʃ], which also derives from underlying [s] in this account, is created from [s] before [i] in the derivation of 'poem'.

(35) Example derivations:

| "flesh" | "poem"
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>UR</td>
<td>/sal/</td>
</tr>
<tr>
<td>Palatalization</td>
<td>--</td>
</tr>
<tr>
<td>PR</td>
<td>sal</td>
</tr>
</tbody>
</table>
Thus, [s] and [ʃ] are different phonemes in English and in German, but they are allophones of the phoneme [s] in Korean. This illustrates how languages can differ in their phonemes, even in cases where they have the same sounds (here: [s] and [ʃ]) on the surface. This is possible, since Korean and English can have different inventories (only [s] in Korean, but both [s] and [ʃ] in English and in German), and different rules (the rule of Palatalization in Korean; notice that English and German don't have this rule; otherwise there could not be a word like [sɪʃ], because such an underlying form would be automatically changed into the phonetic form [ʃɪː] by such a rule).

5 English aspiration

When we transcribe more precisely, we can distinguish [p, t, k] from their aspirated versions [pʰ, tʰ, kʰ]. The following examples show that [pʰ] occurs at the beginning of a word, while [p] occurs when removed from the beginning of the word by an initial [s].

(36) a. [pʰm] pin [spm] spin
    [pʰat] pie [spers] space
    [pʰuf] push [spitʃ] speech
    [pʰiːs] piece [splæʃ] splash

If you are a native speaker of English or German (German is similar in this respect), you can feel the difference by saying the words on the left with your hand close to your mouth. You will feel a puff of air coming from your mouth at the release of the [p]. When you try the same thing with the words on the right, there may be a very weak puff of air, or none at all. The difference between the two relates to what we transcribe as aspiration in the examples on the left.

The complete situation of English aspiration is more complex, and word-internally, it also involves whether the following vowel is stressed or not. For now, we will work with a simplified picture, and with the examples in (36). [p] and [pʰ] are in complementary distribution (even in the more complete picture). For our purposes here, we may state the distribution as in (37).

(37) [pʰ] occurs word-initially
    [p] occurs elsewhere (here: after initial [s])

These two sound are allophones of a phoneme, which is normally taken to be [p]. We thus postulate that [p] is part of the inventory, while [pʰ] is not, and that [pʰ] is derived by the rule of Aspiration in (38). This rule makes use of the word-boundary symbol # (see p.12). Thus, the environment "#__" means 'immediately following a word-boundary', which is the same as 'at the beginning of a word'. Thus, this rule aspirates [p] at the beginning of a word.

(38) Aspiration: [p] -> [pʰ] / # __

Derivations for two examples are given in (39). Underlying [p] is aspirated word-initially in [pʰm], but is not aspirated by the rules where [s] separates it from the initial word-boundary in [spm].

(39) "pin" /pɪn/ "spin" /spɪn/
    Aspiration [pʰm] Aspiration --
    PR [pʰm] PR [spm]
Notice, then, that a similar relation holds between [t] and [tʰ], and between [k] and [kʰ]:

\[
\begin{array}{lll}
\text{a.} & \text{b.} \\
[tʰn] & \text{tin} & [stŋ] & \text{sting} \\
[tʰi:] & \text{tea} & [sti:m] & \text{steam} \\
[tʰɔl] & \text{tall} & [stɔl] & \text{stall} \\
[kʰŋ] & \text{king} & [skŋ] & \text{sky} \\
[kʰul] & \text{cool} & [ski:] & \text{ski} \\
[kʰeik] & \text{cake} & [skip] & \text{skip} \\
\end{array}
\]

Thus, there are the three phonemes \{p, t, k\} with the allophones \{p, t, k\} and \{pʰ, tʰ, kʰ\}. We can state their distribution across all three pairs of allophones by generalizing (37) as in (41).

\[
(pʰ, tʰ, kʰ) \text{ occur word-initially} \\
[p, t, k] \text{ occur elsewhere (here: after initial } s) \\
\]

The explanation postulates the (underlying) phonemes \{p, t, k\}, but does not allow underlying aspirated stops in English. Importantly, because of the parallel between the three pairs of allophones, we can create the allomorphs of all three phonemes with a single (generalized) phonological rule:

\[
\text{voiceless stops } \rightarrow \text{ aspirated } / #___
\]

The rule is given somewhat informally here, since we have not yet introduced the features that make up consonants. There are, however, features that define the natural class of stops, and there is a feature for voicing, and so the voiceless stops \{p, t, k\} form a natural class. The rule in (42) determines that any member of this class becomes aspirated word-initially. This is similar to the first rule we discussed, for the Chamorro vowel change, where we wrote "V -> [-back] / ...", and this rule also applies to different sounds (in that case: to different vowel sounds).

English aspiration and the German alternation between [ç] and [x] are not reflected in the orthography. Both [p] and [pʰ] are spelled 'p' in English orthography, and both [ç] and [x] are spelled 'ch' in German orthography. This is typical of allophones. Since they don't distinguish words (no minimal pairs), and since it is predictable from the environment which one occurs, a writing system that does not reflect allophones is still precise enough to capture the distinctions among words.

The distinction between \{p, t, k\} and their aspirated version \{pʰ, tʰ, kʰ\} in English (and in German) is furthermore a distinction that speakers are normally not aware of, unless they learn about it in linguistics classes. This is also typical of allophones. The German distinction between [ç] and [x] is a bit untypical in this respect, since it is very easy to become aware of this allophonic distinction.

Even if allophonic distinctions are often hidden from the awareness of native speakers, they are nevertheless real. This can often be established by comparison with a language in which the same distinction exists, but in which the sounds in question are phonemes, rather than allophones.

For the distinction between plain and aspirated voiceless stops, we may compare English with Hindi. All the following sounds are different phonemes in Hindi:

\[
/p, pʰ, b, bʰ, j, jʰ, d, dʰ, k, kʰ, g, gʰ/ \text{ (the series in the middle are dental; the constriction is made further front than the alveolar ridge, in contact with the teeth).}
\]

Thus there are not only voiced and voiceless stops phonemes, but in addition a voiceless aspirated stop like [pʰ] (which exists as an allophone of [p] in English), and a voiced aspirated (also called 'murmured') stop [bʰ] (with no counterpart in English). Similarly for other places of articulation. The minimal pairs in (43) show that the sounds that differ in voicing or only in aspiration are separate phonemes. (The examples are from Ladefoged and Maddieson 1996.)
(43) Minimal pairs in Hindi

[pal] 'take care of'  [t[al]] 'beat'  [kan] 'ear'
[pʰal] 'knife blade'  [tʰ[al]] 'plate'  [kʰan] 'mine'
[bal] 'hair'  [d[al]] 'lentil'  [gan] 'song'
[bʰal] 'forehead'  [dʰ[ar]] 'knife'  [gʰan] 'bundle'

English and German have many other allophonic distinctions, which we are normally not aware of. The rules that derive the allophones in these cases are nevertheless part of the phonology, the system of sounds, of these languages.

PROBLEM SET

In Mohawk, a Native American language ('Indianersprache'), [t] and [d] are in complementary distribution. Examine the data in (i) to see whether the left or the right context of these sounds allows you to state a generalization that predicts whether [t] or [d] occurs in each case.

(i)  
[t]  [d]
[zahset] 'hide it!'  [olide?] 'dove'
[ohjotsah] 'chin'  [odahsa] 'tail'
[labahbet] 'catfish'  [sdu:ha] 'a little'
[degeni] 'two'
[desda?] 'get up!'

a. Generalization:
   [d] occurs ______  [t] occurs ______

b. Postulate an underlying sound (/d/ or /t/) and write a rule to derive the other sound. The rule should be based on your result in a.

c. Demonstrate how the account in b. works with derivations for [zahset] and for [olide?]?

d. Are [d] and [t] both phonemes in Mohawk, or are they allophones of the same phoneme? Give your reasoning.

e. [k] and [g] are also in complementary distribution in Mohawk, as are [p] and [b]. The data in (ii) illustrate.
(ii)

[k]  [g]
[wisk]  'five'  [ojagala]  'shirt'
[dʒiks]  'fly'  [gadis]  'sock'
[degeni]  'two'

[p]  [b]
[aplam]'Abraham'  [labahbet]  'catfish'

Find a generalization across all three pairs of allophones. Do this by writing a more general version of a. above:

Generalization: [voiced stops] occur ______
[voiceless stops] occur ______

Illustrate with a word with [k] and a word with [g].

f. Now consider English. In English, [t] and [d] are not allophones, nor are [k] and [g] allophones, nor are [p] and [b] allophones. For each of these pairs of sounds, demonstrate this by giving two minimal pairs that show that these are each separate phonemes. You may want to use a dictionary for this. Be sure to give both the pronunciation and the spelling of your words, and make sure that the minimal contrast is in the pronunciation in each case.

References