1 Language Science

This course is about phonology, but it is valuable to begin with a broader sense of both the science of language and cognitive science to see how phonology fits into this enterprise.

The scientific study of language is an important part of understanding human cognition. As Chomsky (1965) explains, there are three fundamental goals of cognitive science.

1. One goal is to characterize the knowledge that humans possess in various cognitive domains such as perception, categorization, language, and reasoning. A theory which characterizes this knowledge is called a theory of human *competence*.

2. A second goal is to discover the methods by which knowledge is acquired, including a characterization of innate restrictions on the form and acquisition of knowledge. A theory achieving this goal is a theory of *learning*.

3. A third goal is to understand how knowledge is applied in particular behaviors, and what limitations prevent performance from being coextensive with competence. Achieving this goal entails construction of a theory of *performance*.

Chapter 1 of Chomsky (1965) explains what these goals mean for the science of language. Following Chomsky and Halle 1968, p. 3, it is useful to "think of a language as a set of sentences, each with an ideal phonetic form and an associated intrinsic semantic interpretation. The grammar of the language is the system of rules that specifies this sound-meaning correspondence."

Consequently, the *grammars* of languages constitute a theory of competence because they encapsulate the knowledge that humans have regarding their language (construed as a set of phonetic forms paired with semantic interpretations). Chomsky (1965, pp. 8–9) elaborates further.

> *...by a generative grammar I mean simply a system of rules that in some explicit and well-defined way assigns structural descriptions to sentences. Obviously, every speaker of language has mastered and internalized a generative grammar that expresses his knowledge of his language. This is not to say that he is aware of the rules of the grammar or even that he can become aware of them, or that his statements about his intuitive knowledge of the language are necessarily accurate .... Similarly, a theory of visual perception would attempt to account for what a person actually sees and the mechanisms that determine this rather than his statements about what he sees and why, though these statements may provide useful, in fact, compelling evidence for such a theory.*

Where do these grammars come from? To some extent, they must be learned because humans learn the language spoken in the community they are raised in. The learning theory for language science must explain how humans come to acquire a particular grammar based on their experience. Chomsky (1965, p. 7) considers the learning theory to be a centerpiece of language science.

> *...the main task of linguistic theory must be to develop an account of linguistic universals that, on the one hand, will not be falsified by the actual diversity of languages and,*

> *on the other, will be sufficiently rich and explicit to account for the rapidity and uniformity of language learning, and the remarkable complexity and range of the generative grammars that are the product of language learning.*

A correct theory of learning would provide a deep explanation for theories of competence. It would provide a single explanation of how humans acquire the various specific "system[s] of rules" which relates pronounced forms with semantic interpretations.

Theories of performance are another important part of language science. These theories seek to explain systematic facts about language use: its production, comprehension, and the behavior we observe every day.

With respect to performance, Chomsky (1965, p. 10) writes

> *There seems to be little reason to question the traditional view that investigation of performance will proceed only so far as understanding of underlying competence permits. ...To my knowledge, the only concrete results that have been achieved and the only clear suggestions that have been put forth concerning the theory of performance, outside of phonetics, have come from studies of performance models that incorporate generative grammars of specific kinds ....*

Chomsky is firmly stating that any correct theory of performance will depend on a correct theory of competence. A theory of performance is ultimately a theory of how many different factors interact to produce linguistic behavior. The grammar is but one of these factors. Chomsky and Halle (1968, p. 3) explain the distinction between competence and performance this way.

> Competence ...is not to be confused with performance. Performance, that is, what the speaker-hearer actually does, is based not only on his knowledge of the language, but on many other factors as well-factors such as memory restrictions, inattention, distraction, non-linguistic knowledge and beliefs, and so on. We may, if we like, think of the study of competence as the study of the potential performance of an idealized speaker-hearer who is unaffected by such grammatically irrelevant factors.

The distinction between competence and performance is a fundamental one in language science. It isolates the grammatical factors from non-grammatical ones.

Du and Durvasula (2025) bolsters these ideas in a contemporary context.

2 Phonological Knowledge

The aspect of language that phonology addresses is the knowledge speakers have regarding the pronunciation of words and phrases in their language. Systematic facts about the pronunciation of words and phrases in a language are often referred to as *sound pattern* of a language.

It is a striking fact that natural languages have sound patterns. I will give examples of sound patterns in a moment in an effort to convince you that there are systematic aspects to your pronunciation, and that every human language exhibits sound patterns. But for now, assume that

there is something systematic about the way you pronounce words and phrases in your language. What then are the goals of phonology? It is precisely to find an explanation for this fact.

Not surprisingly, there are three dimensions this explanation, which match the goals expressed above. Understanding the sound patterns of languages means answering the following three questions.

1. (Competence) How can we characterize the knowledge speakers have about the sound patterns of their language?
2. (Learning) How do children come to acquire this knowledge about their language?
3. (Performance) How do humans produce and perceive speech?

In service to the above questions, the study of phonology tries to answer the following:

- What are the right linguistic generalizations regarding sound patterns? This can also be expressed as follows.
  - What are the sound patterns of the world's languages?
  - What are the principles underlying these patterns?
  - What are possible sound patterns?
- How could anything learn a sound pattern from the kinds of input
- How do language phonologies change over time?

In this course, we mainly address the questions in 2 above. Answers to these questions help us better understand the competence humans bring to bear on the sound patterns of their language.

With these questions in mind, I would like to now present a brief survey of different kinds of phonological knowledge. Speaking generally, there are three kinds of knowledge regarding the pronunciation of words and phrases in natural language: *phonotactic* knowledge, knowledge of *processes*, and knowledge of *contrasts*. These are all examples of sound patterns that humans have internalized. A fourth type of sound pattern comes from *typology*: are there recurring tendencies or patterns *across* languages? In this section, a brief introduction to each type of sound pattern is presented.

2.1 Phonotactics

Phonotactic patterns refer to the possible words in a language (Chomsky and Halle, 1965; Halle, 1978).

English speakers can coin new words. However, speakers are much more willing to coin new words with words on the left, and not with the words on the right. It is striking that many English native speakers agree with the division in 1 even though they have zero experience with *all* of those words. This is an example systematic, uniform linguistic behavior that requires an explanation.

possible new words	impossible new words
flump	flunp
blick	bnick
bist	bizt
slem	srem

Table 1: Possible and impossible English words.

Assuming agreement among the native English speakers, how did they learn to discriminate words they never heard before in the same way? The answer of course is that there is a system of rules or constraints—a grammar—that speakers have internalized that allow them to classify logically possible words into well- and ill-formed groups. This is knowledge that English speakers acquired and learned since for example words like [srem] are perfectly acceptable in other languages. But it is also knowledge which English speakers were never explicitly taught.

With respect to the above case, it would appear that this system of rules is sensitive to the sub-parts of words. All the sub-parts of the words on the left in 1 are well-formed, but that is not the case for the words on the right. English words cannot end with [np] or [zt] sequences, nor can they begin with [bn] or [sr] sequences.

This last sentence is an example of a *linguistic generalization*, which is a hypothesis about the character of our linguistic knowledge and competence. This hypothesis makes at least two predictions. First, existing English words should not begin or end with the aforementioned sequences. We can examine existing English words to see whether this prediction is true. Second, it predicts that English speakers should avoid coining new words with the aforementioned sequences. This can be is testable in principle with a behavioral experiment. Native speakers can also conduct this behavioral experiment on themselves with a little bit of introspection.

Here is another example of a sound pattern. Below are actual and hypothetical words below from Navajo (Sapir and Hojier, 1967).

Possible Navajo Words		Impossible Navajo Words
ʃiːteːʒ	'we (dual) are lying'	ʃiːteːz
dasdoːlis	'he (4th) has his foot raised'	dasdoːliʃ
sokos	(hypothetical)	sokoʃ
ʃokoʃ	(hypothetical)	ʃokos
kiːteːp	(hypothetical)	
piːteːk	(hypothetical)	

Note [ʃ] is like *sh* in *shoe* and [ʒ] is like *ge* in *beige*. Can you determine what grammar speakers of Navajo have internalized that allow them to distinguish between these two groups of words?

It clearly has to do with the sounds [s,ʃ,z,ʒ], which are examples of sibilant sounds. In Navajo, words can contain either [s,z] sounds or [ʃ,ʒ] sounds, but not both. As the examples indicate, it is not necessary that the sibilants be adjacent to each other. In fact, they can be separated by many other speech sounds as evidenced by the word [dasdoːlis] 'he (4th) has his foot raised.'

The above examples have established one kind of sound pattern: phonotactic knowledge. There are rules and constraints which govern the possible words in languages. Speakers can coin new words, but they cannot coin any arbitrarily sequence of speech sounds as a new word. Speakers distinguish logically possible words with which they have had no prior experience. This is the expected behavior of individuals who have internalized a productive and generative system of rules and constraints.

The above examples made a binary distinction between "possible" and "impossible" words. Some question whether this is just a convenient abstraction (Albright and Hayes, 2003). It has been argued that there are well-formedness is gradient. For example, it has been argued that since native English speakers rate [kɪp] as more well-formed than [θwiːks], which they rate as more well-formed than [bzɑrʃk, that the phonotactic grammar must likewise be gradient (Hayes and Wilson, 2008). This argument has been criticized for mistakenly conflating competence with performance (Gorman, 2013; Heinz and Idsardi, 2017; Durvasula, 2025).

Whatever the details may be, the central fact of phonotactic knowledge is that speaker-hearers of the same language community uniformly distinguish logically possible words in the same way, at least more or less. What is the nature of this knowledge—what are the rules and constraints that govern this system—and how do children come to learn it?

2.2 Processes

Another aspect of phonological knowledge comes from phonological *processes*. Evidence for phonological processes comes from *morphological alternations*. Morphemes are the smallest sequences of speech sounds with a particular meaning. Therefore, unlike phonotactic patterns, the semantic meanings or morphemes play an important role in understanding the evidence for phonological processes.

A morphological alternation is the observation that the same morpheme is pronounced differently in different contexts. The English plural provides a familiar example.

	singular	plural
cat	kʰæ t	kʰæ t**s**
sack	sæ k	sæ k**s**
dog	dɔg	dɔg**z**
grub	gɹʌ b	gɹʌ b**z**
dish	dɪʃ	dɪʃ**əz**
lodge	lɔd͡ʒ	lɔd͡ʒ**əz**
pea	pʰi	pʰi**z**
cow	kʰaU	kʰaU**z**
man	mæ n	m**ɛn**
foot	fʊt	f**i**t
wife	waɪf	waɪ**vz**
whiff	wɪf	wɪf**s**
...		

Ignoring irregular forms like *men* and *feet*, it is clear that regular plural morpheme has three forms [-s, -z, -əz]. These do not appear to be assigned arbitrarily to nouns. One way to see this is to conduct the following experiment. Which pronunciation goes with which of the following made-up words?

[lɛp]
[rɑg]
[nɪz]

As with the phonotactic patterns above, the fact that English speakers answer this question uniformly is strong evidence that they have internalized a system of rules and/or constraints.

There are several ways these facts can be analyzed. Below I provide two analyses to illustrate.

Analysis 1

1. If the word end with a sibilant, use [-əz] for words
2. Else if the word ends with a voiceless consonant, use [-s].
3. Else use [-z].

Analysis 2

1. Add the suffix [-z] to the noun. Consider the resulting word.
2. If there are two adjacent sibilants, *epenthesize* (insert) a schwa [ə] between them.
3. Then if there is a voiceless consonant before the [-z] *change* the [-z] to [s].

Both analyses can account for the facts of regular plural formation in English. In the first one, which I will refer to as the *morphological analysis*, a choice is made among variants based on the

pronunciation of the noun. In the second one, which I will refer to as the *phonological analysis*, the plural morpheme is fixed as [-z] and the resulting word may undergo *transformations* if the proper conditions are met. These transformations are insertion of schwa (called schwa-epenthesis) or devoicing of the [z]. Such transformations are called *phonological processes*.

Generative phonologists argue that in general the phonological analysis (Analysis 2) is the better scientific explanation than the morphological explanation (Analysis 1) for the various pronunciations of the plural morpheme. The primary argument comes from the fact that multiple morphemes with the same kind of underlying form show the *same* patterns of allomorphy. This is the case in language after language.

On the basis of such arguments, we will conclude that morphological alternations constitute evidence for phonological transformations. Indeed, these arguments are so important they provide what I call the Fundamental Principle of Phonology:

- The best explanation of morpheme's alternations is to posit a single abstract lexical representation of the morpheme and one or more phonological processes which transform this abstract lexical representation to its concrete surface pronunciations.

From this principle (and the arguments for it), the rest of the field of phonology follows.

Let's provide another example, this time from Georgian (Aronson, 1982). Consider the form of the adjectival suffix below:

Georgian	gloss
phizik-uri	'physical'
kimi-uri	'chemical'
akti-uri	'active'
phrang-uli	'French'
german-uli	'German'
reakti-uli	'reactive'
real-uri	'real'
terminal-uri	'terminal'

What form of the suffix do you think would go on to a hypothetical words like

1. misato
2. pita
3. badurpi
4. ramuto
5. ralako

As with the example from the English plural, it is possible to state two analyses. One selects the correct pronunciation of the morpheme based on qualities of the root. The other fixes the phonetic form of the morpheme, affixes it to the root, and then subjects the resulting word to a series of phonological processes, or transformations.

Nepai	gloss	Nepai	gloss
pir	anxiety, pain	bar	fence
p^hir	Turn on!	b^har	burden
tal	lake	dar	a kind of tree
t^hal	plate	d^har	edge
kal	time, death	gol	circle, charcoal
k^hal	kind, skin	g^hol	Mix! Stir!

Table 2: Minimal pairs for aspiration as contrastive in Nepali.

Also, it is useful to ask ourselves: How did English and Georgian speakers learn these patterns? What possible purpose could such patterns serve?

2.3 Contrasts

A third kind of sound pattern has to do with what is called *contrast*. As with phonological processes, meaning plays a role here too.

Speech sounds are *contrastive* if they can be used to signal different meanings. For instance consider the words shown below from Nepali.

Here there are pairs of words which establish that aspiration [^{h}] is contrastive in Nepali. In each pair, the words are identical except for the presence or absence of aspiration in the first consonant. Therefore, in order to know what meaning is being conveyed, it is necessary to know whether aspiration is a present or absent property of these sounds. This is why aspiration is said to be contrastive in Nepali.

The relations that exist between contrastive units of speech are an important part of the study of contrast. In Nepali it is clear that the relation between [p] and [p^h] is the same as the relation between [g] and [g^h]. However, it is not always straightforward to determine the system of contrast present in a language. For instance what are the relations that are present in a language with a three-way contrast between the vowels [i,u,a]? As we will see, there is evidence that part of the knowledge that speakers have of the system of contrast of their language includes these relations. This evidence partly comes from the fact that languages with the same speech sounds, even the same contrastive speech sounds, organize the relations between these sounds *differently*, as was famously pointed out by Sapir (Sapir, 1925).

Furthermore, we will see, some languages may allow certain speech sounds to be contrastive in all positions in a word and others may allow certain speech sounds to be contrastive in only some positions. The lexicon of some languages may show that many words make use of particular contrastive features, but other contrastive features are only present in a small portion of the lexicon. Marginal and limited cases like these are of interest because it raises the question: why should a language make use of a contrast in only a limited number of circumstances?

2.4 Cross-linguistic patterns

A fourth type of sound pattern refers to the patterns that emerge when multiple languages are considered. Typological generalizations are especially interesting because they exist despite the considerable variation observed across languages. They therefore can lead to hypotheses about the *linguistic universals*. These in turn help distinguish the *humanly possible* phonological grammars from the *logically possible* ones.

Here are some examples of typological generalizations that have been presented in the phonological literature.

- If a language has phonemes {b,d,g}, it tends to have {p,t,k} (Maddieson, 1984).
- The word-initial triple consonant clusters a language allows is a subset of the double consonant clusters it allows (Greenberg, 1978).

  Let me explain with an example from English. In this language, every initial triple consonant cluster (like *str*) is decomposable into clusters of length two; in this case, *st* and *tr*. This generalization does not claim the converse. In fact, not all legal initial clusters of length two can be combined to form legal initial triple clusters. While English words can begin with both though *st* and *tw*, the general consensus appears to be they cannot begin with *stw* (as in *[stwɛk]).
- If a language palatalizes consonants before [e], they also do before [i] but not vice versa (and people generalize this way in experimental conditions) (Wilson, 2006). This was understood to be exceptionless, until Oxford (2014).

2.5 Summary

Phonological patterns are the sound patterns of language. Phonotactic patterns, phonological processes, and systems of contrast are facets of a phonological system that govern the knowledge speakers have about the pronunciation of words and phrases in their language. When these phonological systems are studied around the world, typological sound patterns emerge as well. Each kind of sound pattern provides some insight into the nature of the underlying system, and consequently into the nature of how the language faculties of human minds work.

As we will see, different phonological theories intertwine systems of contrast, phonotactic patterns, and phonological processes to different degrees and in different ways. In this course, we will develop an awareness of the empirical facts and will concentrate on developing principles for phonological analysis and for evaluating theories.

3 The fundamental principle of phonological analysis

We thus state the fundamental principle of phonological analysis of phonological analysis as follows.

The systematic variation of pronunciation in morphological paradigms is best explained by positing

1. a *single* abstract lexical representation ('the underlyings form') for each morpheme, and
2. phonological processes which transform these abstract representations to surface phonetic representations.

Consequently, there is a phonological module between the the output of the morphological component of the grammar and the phonetics component. The output of morphology is the input to the phonological component. The output of the phonological component is the input to the phonetics module.

$$\boxed{\text{Syntax}} \rightarrow \boxed{\text{Morphology}} \rightarrow \boxed{\text{Phonology}} \rightarrow \boxed{\text{Phonetics}}$$

Consequently, phonology, as a field itself is primarily concerned with three questions.

1. **What is the nature of the abstract, lexical ('underlying') representations?**
2. **What is the nature of the more concrete ('surface') forms?**
3. **What is the nature of the transformation from underlying forms to surface forms?**

To emphasize the different levels of representation that are entailed by a phonological analysis, they are distinguished by different kinds of delimiters. Slashes are standardly used to represent sequences at the abstract, underlying level and braces are used at more concrete surface level. We will refer to representations at the abstract and more concrete levels as *underlying representations* and *surface representations*, respectively.

People have tried to derive the fundamental principle from other principles. For example, a principle on economy of description (Chomsky and Halle, 1968). It may very well derive from such a principle. However, trying to establish this depends on the descriptive formalism. So the devil, as always, is in the details.

4 Formal Theories of Phonology

Next we turn to different formalizations of phonological theory. Broadly speaking, there are two influential ones. They differ fundamentally in the way they answer the key questions in phonology, which are repeated here.

1. What is the nature of the abstract, lexical ('underlying') representations?
2. What is the nature of the more concrete ('surface') forms?
3. What is the nature of the transformation from underlying forms to surface forms?

These two theories are:

1. Rule-based (for instance, SPE and LPs Chomsky and Halle, 1968; Bale and Reiss, 2018)

2. Constraint-based (for instance, OT Prince and Smolensky, 1993, 2004)

SPE and LP differ in key respects, but both adopt the position that the formal grammar is an ordered sequence of rules that change underlying forms step by step into surface forms. Constraint-based theories come in many variations, but Optimality Theory and its derivatives (Harmonic Grammar, Harmonic Serialism, and Maximum Entropy Goldwater and Johnson, 2003; McCarthy, 2008; Pater, 2009) centralize global optimization. Not all constraint-based theories are like that, however, and there are theories, both historically and today, that utilize constraint *satisfaction* instead of *optimization*.

Broadly speaking, rule-based and optimization, constraint-based theoroes have different *ontologies*. According to Wikipedia, the principle questions of ontology include "What can be said to exist?", and "Into what categories, if any, can we sort existing things?" In phonology, the existing things we are interested in is our phonological *knowledge*—our knowledge of the lexical representations, the surface forms, and the mapping—and how this knowledge is manifest in our minds (what is psychologically real).

For example take SPE and OT as specific examples. The difference between these theories can be stated as follows.

1. In SPE, the rules—which describe transformations from underlying forms to surface forms—are the primary psychological objects. These rules apply in some order. Additionally, there are statements on the well-formedness of abstract, lexical representations. The rules, their ordering, and these statements are language-specific. The surface phonotactic knowledge *emerges* as a consequence of these constraints on underlying representations and the rules themselves.

2. In OT, there are no rules, only *constraints*. In mosts exponents of the theory, these constraints come in two forms: some constraint the well-formedness of surface representations and others constraint directly and simply how underlying forms may relate to surface forms. Transformations between underlying and surface forms *emerge* via the interaction of these constraints. The constraints are universal to all languages, but their relative importance in any given language is language-specific.

Of course, these are not the only two theories that have been studied. Especially in the 1980s, prior to the advent of OT in the early 1990s, there were many theories which mixed rules and constraints. The grammatical model called Harmonic Serialism (McCarthy, 2008) also synthesizes aspects of these two earlier approaches, broadly construed. However, we will focus on the aforementioned two theories, and only mention these others as needed.

Finally, while the theories do differ, it is important to realize they all admit that the phonological component of a grammar includes underlying forms, surface forms, and a mapping between them. In other words, the common base for these two theories is the fundamental principle discussed earlier.

References

Albright, Adam, and Bruce Hayes. 2003. Rules vs. analogy in English past tenses: A computational/experimental study. *Cognition* 90:119–161.

Aronson, Howard. 1982. *Georgian, A Reading Grammar*. Slavica Publishers, Inc.

Bale, Alan, and Charles Reiss. 2018. *Phonology: A Formal Introduction*. The MIT Press.

Chomsky, Noam. 1965. *Aspects of the theory of syntax*. Cambridge, MA: MIT Press.

Chomsky, Noam, and Morris Halle. 1965. Some controversial questions in phonological theory. *Journal of Linguistics* 1:97–138.

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

Du, Naiyan, and Karthik Durvasula. 2025. *Psycholinguistics and Phonology: The Forgotten Foundations of Generative Phonology*. Cambridge University Press.

Durvasula, Karthik. 2025. A closer look at what/how we can learn from computational modelling of phonotactics. Under review with Phonology.
URL `https://ling.auf.net/lingbuzz/009051`

Goldwater, Sharon, and Mark Johnson. 2003. Learning OT constraint rankings using a maximum entropy model. In *Proceedings of the Stockholm Workshop on Variation within Optimality Theory*, edited by Jennifer Spenader, Anders Eriksson, and Osten Dahl, 111–120.

Gorman, Kyle. 2013. Generative phonotactics. Doctoral dissertation, University of Pennsylvania.

Greenberg, Joseph. 1978. Initial and final consonant sequences. In *Universals of Human Language: Volume 2, Phonology*, edited by Joseph Greenberg, 243–279. Stanford University Press.

Halle, Morris. 1978. Knowledge unlearned and untaught: What speakers know about the sounds of their language. In *Linguistic Theory and Psychological Reality*. The MIT Press.

Hayes, Bruce, and Colin Wilson. 2008. A maximum entropy model of phonotactics and phonotactic learning. *Linguistic Inquiry* 39:379–440.

Heinz, Jeffrey, and William Idsardi. 2017. Computational phonology today. *Phonology* 34:211–219.

Maddieson, Ian. 1984. *Patterns of Sounds*. Cambridge, UK: Cambridge University Press.

McCarthy, John J. 2008. The gradual path to cluster simplification. *Phonology* 25:271–319.

Oxford, Will. 2014. Patterns of contrast in phonological change: Evidence from Algonquian vowel systems. *Language* To appear.

Pater, Joe. 2009. Weighted constraints in generative linguistics. *Cognitive Science* 33:999–1035.

Prince, Alan, and Paul Smolensky. 1993. Optimality Theory: Constraint interaction in generative grammar. Tech. Rep. 2, Rutgers University Center for Cognitive Science.

Prince, Alan, and Paul Smolensky. 2004. *Optimality Theory: Constraint Interaction in Generative Grammar*. Blackwell Publishing.

Sapir, Edward. 1925. Sound patterns in language. *Language* 1:37–51.

Sapir, Edward, and Harry Hojier. 1967. The phonology and morphology of the Navaho language. *University of California Publications* 50.

Wilson, Colin. 2006. Learning phonology with substantive bias: An experimental and computational study of velar palatalization. *Cognitive Science* 30:945–982.