

# Chapter 1

## Human Language as a Scientific Phenomenon

### *Section 1: The Specialness of Language*

#### **What Is Special About Language**

Language is our most important and universal communication medium. As humans, we rely on our capacity to communicate with one another and to “speak our mind.” However, we almost never stop to consider that these abilities are made possible by three facts: we can move our bodies in highly skilled ways; these skilled movements create physical changes in the environment that our senses can apprehend; our brains allow the development and use of a complex system of structuring information for expression to other individuals. As scientists, it is fascinating to turn a scientific eye and scientific tools to studying each of these aspects of language. One reason for this fascination is precisely because our language feats are accomplished with ease and no real awareness on our part of their intricate and structured nature. Throughout this book, we will investigate both the nature of language and our human linguistic abilities.

All healthy humans, and only humans, are born capable of using language, and people acquire these abilities simply through exposure without any overt instruction. You may have to take lessons to learn to play the clarinet, but no children need “do this–don’t do that” lessons to learn their first language. Children gain this ability simply through their normal course of development and interaction with other speakers of a language, just as infants learn visual depth perception or toddlers learn to walk.

Language’s capacity for transmitting information is unrivaled. We’ve all heard the expression “a picture is worth a thousand words.” But while humans can transmit information to one another through facial expression or visual constructions or touch or even smell, none of these can transmit

the enormous amount of detail and specificity that is possible with the use of language. Language can also be tremendously evocative – a poem or story or conversation with a boyfriend or parent can move one to tears, hysterical laughter, an intense insight, or a visceral opinion. Not only does language succeed remarkably in transmitting information from one individual to another at a particular time, it permits the continuity of culture over time through oral, written, and now digital recording of knowledge.

For the scientist newly come to the study of language (perhaps like yourself), an objective quantitative and experimental approach to investigating language can prove challenging for exactly the same reasons that make language an interesting object of study: namely, most people – other than your rare linguist or psychologist – simply don't think much about speaking language. Certainly all of us – even language scientists – learn and use language effortlessly. So as *scientists* of language, we will need to become objectively aware of aspects of language that we normally pay no attention to. To dissect its properties as scientists will require us to suspend the preconceptions or biases we may have about how people speak and also require us to be willing to learn about tools scientists use to investigate human behavior – physical measures of the world and human behavior, techniques for experimentation, and critical analysis of data.

## The Speech Chain

Let's consider an extremely simple exchange of information through language. Suppose you are at a party (and are over the legal drinking age) and further suppose that the party has run out of beer. It might occur to you that more beer is needed. Seeing as how friends, however close, do not in fact have ESP, in order to express this desire for more beer, you will need to formulate a message and speak it. In addition to knowing the **proposition** or idea that you wish to express, you will now need to select and combine words to express this thought – in English these words might be *we*, *need*, *more*, and *beer*. However, the particular language you speak, in addition to determining the sounds used to form each word (and even how many words are needed) also determines how these words are to be combined. A linguist would call sensible combinations – *we need more beer* – **grammatical** and term nonsensible combinations – *more need beer we* – **ungrammatical**. (This is a specialized use of the term grammatical having nothing to do with the schoolroom rules.) Now, mind you, a thirsty partygoer is nowhere near finished yet. Having selected the words and put them into a sensible combination, our partygoer must convey them to someone, preferably someone having money, at the party. To do this, the partygoer will have to move his or her mouth or **vocal tract** in intricate fashion using the vocal folds, tongue, jaw, nasal port, and lips. Each word

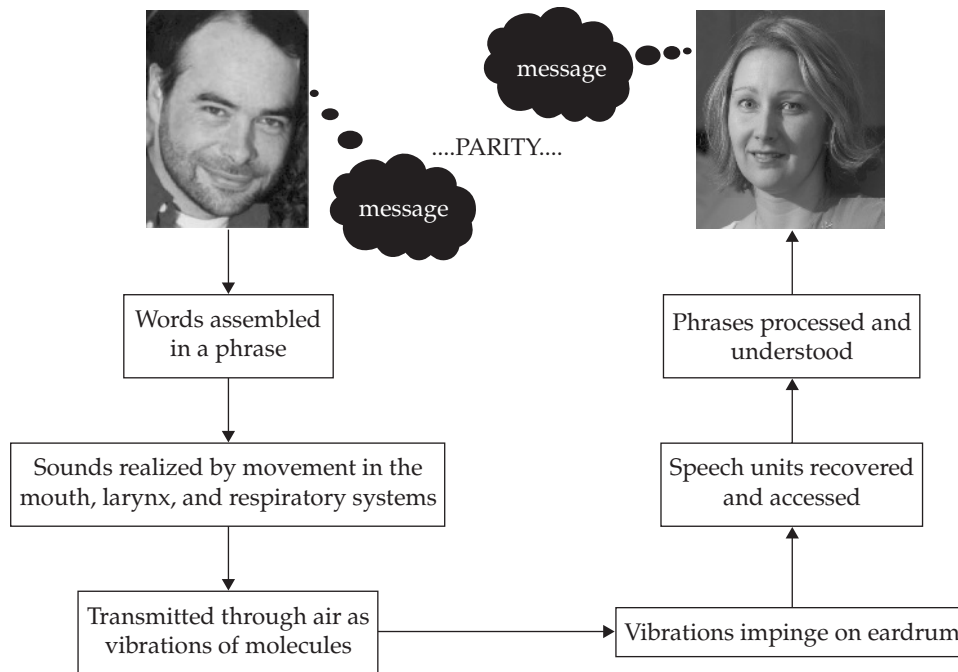


Figure 1.1 The speech chain

is associated with a set of complexly organized movements that cause sound waves to propagate or travel through the air. If the partygoer has been paying attention to where his or her friends are at the party, these sound waves will come into contact with the eardrum of a nearby listener. The listener's brain will respond to the nerve signals created in the inner ear by activating the words in their mind that are consistent with the physical acoustic signal that they just encountered. From these words, the listener will be able to reconstruct the intended message. When the listener recovers the message, and the speaker's intended message matches the one received by the listener, we say that **parity** has been achieved. This is a primary goal in communication.

How can such a complex behavior be so intuitive? The human brain has an inborn or innate capacity for language development and use. This means that it has neural structures whose functionality is, or becomes, specialized for language. Just as humans have evolved to have upright gait, stereoscopic vision, and fine manual manipulation abilities, they have evolved to use language. In addition to the specialization of the human brain, these evolutionary adaptations have also included anatomical and functional characteristics of the vocal tract and auditory system.

It's important to realize that while we have been drawing a picture of *spoken* language, the brain and body can demonstrate the same important

properties with language in another modality, namely *signed* language. Language does not necessitate the use of the vocal tract, sound, and the auditory system; it merely requires that humans act in the environment so as to create a structured, information-carrying signal that other humans can perceive well and with parity. Just like spoken languages, signed language also requires movement of the body in a highly skilled way; these skilled movements create physical changes in the environment that our senses can apprehend (reflection of light off the body sensed by the retina), and our brains allow the development and use of a complex system of structuring information in signed languages. In fact, there is a strong correspondence between the parts of brain that process spoken language through vision (i.e., during reading) and the parts of the brain that process signed language (necessarily via vision).

## Language Knowledge

What kinds of scientists study this phenomenon of language? The answer is, fortunately, many different kinds of scientists: linguists, psychologists, physiologists, physicists, physicians, engineers, computer scientists, speech-language pathologists, and educators, for example. In this text, we will use bits of information from a variety of scientific arenas to consider the questions of what knowledge is acquired when a child learns language, how this learning is accomplished, and how speaking and understanding take place.

Linguists describe and/or model what people (often subconsciously) *know* that allows them to speak their language. One piece of knowledge that this includes is the set of sounds used in their language and precisely how to articulate and coordinate them. It's clear that people become highly skilled at making a particular set of sounds or vocal tract actions because when we are confronted with a sound or sound-sequence that's not in our own language – such as the sound at the end of *Bach* or at the end of *Favre* – we often substitute other sounds or combinations – you've heard these pronounced, no doubt, as [bak] or [farv]. (We will be using square brackets in this book to indicate sound pronunciation, known as **transcription**.)

Another type of knowledge that humans have about their language is the connection between a certain sound pattern and its specific word meaning. Like the particular sounds in one's language, the meaning of myriad sound sequences – words – must be learned: the sounds “eegl” means a predatory bird in English and the same sequence of sounds means a hedgehog in German. Humans must learn the mapping between sound and meaning that exists in the particular language(s) they are learning, because a child comes into the world prepared to learn *any* human language. Lastly, a person must know how words may be combined with one

another in ordered structures and what those combinatorial structures mean. So in English, objects follow verbs, but in Navajo, Japanese, Basque, and Hopi, they precede them. In addition to needing to learn all of this – and apparently doing it with amazing grace and speed by the early years of life – a language learner will also need to learn the appropriate patterns of interaction among participants in a conversation or discourse. We use the term **linguistic competence** to refer to all the myriad patterns that a language user knows that allow for the production and comprehension of language. A person's linguistic competence is the idealized body of knowledge of the structures, sequences, and organizations that may or may not occur in his or her language and their relation to meaning. When linguists want to refer to this body of specialized knowledge, they use the term **grammar**. The term grammar does not mean to a linguist what it means to a grade school English teacher. For a linguist, "grammar" is used to mean a theoretical or formal description of linguistic competence or certain aspects of competence.

## Languages Change

One preconception we might have about language is that it exists in some pristine form in the minds of a particularly prestigious speaker or group of speakers. In fact, different forms of a language occur in a variety of socio-economic and geographic groups. And every instantiation of language in the mind of any individual is equally valid and worthy of scientific study. Language also changes with each generation of speakers. You don't speak in the same way as your parents and grandparents; nor will your children use the same form of language that you use. Some of these changes found in a particular generation are ephemeral or short-lived. Will the once derogative term "geek" leave the language in the next generation, or perhaps become a positive term for a technologically sophisticated person? Some changes to a language will persist and become incorporated into the more widely spoken language. Believe it or not, the term "email" was once actually limited to academics and technophiles. The fact that language is always changing means that your linguistic competence will be different than that of your parents and children.

You can no doubt think of examples of geographic differences in vocabulary – "pop" versus "soda," "fountain" versus "bubbler." Can you think of pronunciation variants around the United States? In the West, where the authors of this book live, the words *cot* and *caught* are generally pronounced the same; however, in the Northeast, they have different vowels. Likewise *pull* and *pool* and *which* and *witch* are often homophonous in the West, but certainly not elsewhere. Generation-related variation in pronunciation can be harder to pin down, but we find that most undergraduates

pronounce “The End” with the “the” rhyming with “duh” not with “dee.” However, most older folks prefer the other pronunciation for the article when it occurs before a word starting with a vowel. A language change currently in progress relates to the grammaticality (used in the *linguistic* sense, *not* the prescriptivist middle-school sense) of using the word “fun” as an adjective, in addition to its standard use as a noun. Anyone is perfectly likely to use *fun* as a noun (“I had a lot of fun at the party”); in addition, many of those people, though not all, will also be comfortable saying “It was a really fun party,” with an adverb modifying *fun*. However, the older generation of speakers would not say, “It was the funnest party I’ve been to this year,” while younger folks will find this adjectival use (note the –est adjectival suffix) perfectly acceptable. Another youthful example of a standard noun being called into use as an adjective as language changes is “dope,” meaning (we gather, since we are too old to find ourselves using this) “cool” or “hip.” A case of an adjective being used as a noun is the currently popular phrase “my bad.” As you can see, language is constantly in flux across groups of people and even to some degree in individuals over their lifetime. As psycholinguists we examine the competence of any particular individual speaker, at some point in time. We investigate the knowledge that that speaker has that allows him or her to speak and understand.

## So What is Language Anyway?

We have stated that all and only humans use language. Animals do use communication systems, some rather sophisticated. These systems, however, do not exhibit all the hallmark properties shown by language. We will want to consider what are the characteristics common to all communication systems and what characteristics might be exhibited by language alone. These characteristics were generally enumerated by a linguist named Charles Hockett in the 1960s and have been presented over the past half century in various versions. Here are the properties we think are important for you to know.

All communication systems, by definition, must have a means of transmitting a message. Humans generally use a vocal-auditory **mode** for their language, but a manual-visual mode is also possible, as can be found in signed languages. No human language, however, incorporates whistles, foot stamps, or claps (though other nonlanguage types of human communication may use these). Some animals use a hormonal-olfactory chemical mode of transmission to communicate group recognition, alarm, sex, territory, or aggression information. For example, moths convey sexual information via pheromones, while cockroaches convey aggression, and hyenas convey territory marking. Also, the signals of all communication

systems, again by definition, must be **meaningful**; they are not random or nonsensical. The signaling in a communication system also serves a useful function for the animal in its environment, that is, it is **ecological**. It may aid in finding food or finding a mate or protecting offspring, for example.

Two other properties of communication systems have to do specifically with the relation between individual communicators. Some animal communication systems, including human language, must be learned through **interaction** with other individuals sharing that communication system. All babies can and will learn whatever language (or languages) they are sufficiently exposed to in childhood through interaction, regardless of the language spoken by the biological parents who contributed their DNA. In humans all aspects of the language system require exposure to other individuals to develop successfully, even though the ability to learn language is an innate genetic endowment. In some other species, such as in some birds, certain aspects of the communication system are learned while other parts are genetically coded. In yet other species, such as some insects, all communication is encoded directly in the genetics, so deviations, modifications, or innovations to the system by the creature simply are not possible. Humans, and a number of sophisticated animal communicators, also exhibit **reciprocity** in their communications, meaning that any particular individual can both create a communicative signal and understand such a signal. I can speak an utterance to communicate a message and also I can understand such an utterance if someone else speaks it to me. Some animal communicators may only send one type of signal, for example, indicating their sex, and another individual may only be able to receive that signal. A female organism in such a system can perceive the “I am male” signal but can’t send it, and vice versa. Such a communication system does not exhibit the feature of reciprocity.

Some communication systems, including human language, have the property of **arbitrariness**. This means that the form of the signal (e.g., a word form) is not required to be related to (e.g., sound like) the thing it represents. In fact, it rarely does (which is to say that onomatopoeia is the

The mosquito species that carries yellow fever communicates mating availability by an acoustic matching of the sound created by its wingbeats. While the male wingbeat sound is normally higher in pitch than the females, when near one another these mosquitoes signal mating availability by converging to an even higher tone that is an overtone or harmonic of these two frequencies. Thus the **mode** could be said to be wingbeat-auditory (though their auditory system is rather different than a mammal’s); the signal is **meaningful** and **ecological** in that it conveys information about an important activity for the animal in its environment – the opportunity for reproduction.

exception, not the rule, and even onomatopoeic words vary arbitrarily from language to language). Many animal communication systems use iconic signals and therefore do not exhibit the property of arbitrariness. Honey bees use movements that indicate the direction to a food source by effectively “pointing” to it; distance to the food is also related directly to the speed of the bee’s dance; and this appears to be an innate, unlearned, behavior of honey bees. We humans, however, must learn the words of our particular language; there is nothing that requires that some particular sequence of sounds have some particular meaning, as we saw with the *eagle/hedgehog* example earlier. Further, the allowed patterns found in a particular language for how words may be combined is also arbitrary and language-specific. There is nothing in the environment that requires that an adjective precede or follow the noun it modifies; different languages make an arbitrary choice.

Scientists studying language have arrived at further features that, linguists would argue, distinguish human language from all other forms of natural communication. The first unique feature of language is that messages are generated from recombinable parts – this is the property of **compositionality**. The recombinable parts that compose messages are called the language’s **discrete units** and crucially the patterns of recombination are meaningful; they encode meaning differences. Messages in human language are communicated by phrases composed of words. Compositionality also applies at the level of words. Words are composed of combinations of sounds or vocal tract actions that individually do not have any meaning of their own. There are a limited set of speech units in any particular language that can be recombined to form meaningful words. Messages communicated by nonhuman animals generally do not show compositionality. Nonhuman animals use signals that cannot be broken down into parts that the animal can recombine to make new or alternate messages. The signal communicating the message is, if modulated at all, modulated in a continuous way – say for example, in loudness or strength or rate. It is true that scientists have argued about the existence of compositionality in animal communication from time to time, but overall naturally occurring animal communication systems appear to lack compositionality.

Another particular property of human language is that it incorporates the possibility of communicating about objects, events, and emotion that are not in our immediate environment – a dream you had last year, a graduation ceremony you hope to participate in next year, or the surface of Neptune. Linguists have called this language property **displacement** because messages can concern items displaced in space and time. Messages are not necessarily driven by stimuli present in the animal’s – human’s – environs. Human language even allows us to talk about things that patently don’t exist, like a dessert you’ve never had but imagine tasting



or the wedding you called off. It is reasonable to attribute this ability to the complexity of human cognition, but even acknowledging that, human language still provides the means for communicating about the past, the future, and counterfactual situations.

Human language also has the potential to express an infinity of messages – it is an **open-ended** system. There are infinitely many sentences possible in a language, and new words can always be made up and added to a language when there is a use for them; indeed, this happens all the time. This may seem an obvious property of human language, but it has an important implication that you may not have thought of. The fact that all human languages are **open-ended** means that humans cannot learn their language by memorizing a set of possible messages. Other animals appear to learn (or innately be genetically provided with) a fixed set of messages that they use to communicate. Unlike these other animals, you will always be able to say something new that you have never said before and even that you have never heard said before. Try it for fun right now: think up a sentence that you believe you have never, ever said and never, ever heard before. It's not even a very hard challenge for us humans. For other animals, such a communication is not possible.

What makes possible this productive capacity of human language? Linguists sometimes use the term **generative** to describe language's combined properties of **compositionality** and **open-endedness**. Language is **generative** because it is based on a systematic relation of meaning and sound created by body actions. Meaning is of course internal; for meaning to become accessible between a speaker and listener – between a language producer and perceiver – it must be transmitted in the environment. By this, we simply mean that humans do not have ESP! Remember the speech chain we looked at above? This transmission is done by combining units of production (which we will discuss at length in later chapters) that can be recovered and decoded by the listener.

Linguists are interested in understanding the cognitive units used as the building blocks of human language and the system of relations among units of different sorts. An important system in language is its **syntax**. Syntax is the system of how words may be arranged in an utterance to convey meaningful relations among them. Consider, for example, the sentences:

Toby gave the book to Dani.  
Dani gave the book to Toby.

The syntax of English determines that in the first sentence it was Toby who did the giving and that what he gave was a book and the person to whom he gave it was Dani. The second sentence specifies a different set of relations between Dani and Toby. Syntax refers to the structuring of units of meaning (for now, words) in sequence via structural (hierarchical)

**Table 1.1** Properties of Communication Systems

Meaningfulness	<i>All communication systems</i>	↓
Ecological validity		
Reciprocity	<i>Some communication systems</i>	↓
Learned through interaction		
Arbitrariness		↓
Compositionality	<i>Viewed as properties particular to human language</i>	
Displacement		↓
Open-endedness		
Duality of patterning		

organization or relations between words. (We will discuss the notion of hierarchical organization in later chapters.)

Words are meaningful units and are part of an expandable set. But words also are composed of cognitive units. Linguists call the system that governs the organization of units composing words **phonology**. Phonology structures a relatively small set of units that is *not* expandable. In English, for example, the sounds composing “top” can be rearranged to form “opt” or “pot” (though not “pto” or “otp”), but a speaker of English could not wake up one morning and decide that a brand new sound, let’s write it <!>, could be used to form words in English. In any particular language, words, new or old, must draw from a stable, small set of nonmeaningful units called **phonological units**. *So in human language the meaningful messages (both sentences and words) are infinite in variety by virtue of the fact that words are produced from a system of combining a finite set of meaningless units.* Linguists, since Hockett in the 1960s, have described this hallmark property of language as **duality of patterning**.

### **What Scientists of Language – Including Linguists – Don’t Do (at Least for a Living)**

Scientists who study language are not interested in prescriptive grammar, that is, rules that some authority decrees ought to be followed in speaking and/or writing a language – things like “don’t end a sentence with a preposition” and “don’t split an infinitive” and “don’t say *ain’t*.” (Notice how often the folks who apparently hold these positions of authority come up with rules starting with “don’t.”) Many of these rules in fact come from historical idiosyncrasies of a language. Prescriptivist views of language are often motivated sociologically, as nonstandard dialects of a language are often held in poor regard. Because of this, using these dialects can

inhibit upward socioeconomic mobility of these speakers, and learning and implementing prescriptive grammatical rules might help to increase this mobility. This does not mean that pejorative judgments about nonstandard dialects are linguistically or scientifically valid. The idea that one dialect is *intrinsically better* than another is simply false. For a scientist of language, every person's own system of speaking his or her language is a legitimate and valuable object of scientific study. Scholarly linguists are not interested in prescriptive rules that suggest that a particular way of speaking is good or bad or right or wrong. (W)

Throughout this book, you will see a (W) symbol at various locations. This indicates that there is accompanying material to be found on the book's website, [www.discoveringspeech.wiley.com](http://www.discoveringspeech.wiley.com)

## Summary

### Chapter 1, Section 1

- 1 Wherever humans exist, language exists.
- 2 All languages continually undergo change.
- 3 The relation between sounds and meanings are arbitrary in language.
- 4 All languages use a finite set of discrete sounds that are combined to form words; these words form a potentially infinite set.
- 5 Words themselves can be combined in systematic and meaningful ways to produce sentences.
- 6 All languages are equally complex, expressive, and valuable for study as examples of specialization of the human cognitive system.

## Section 2: The Study of Language as a Cognitive Science

Section 1 of this chapter introduced the notion that speakers of a language have specific pieces of **linguistic knowledge** about how their language works, and about how language in general works, which we called **linguistic competence**. The study of language as a cognitive science is, to a large degree, the scientific study of linguistic competence: what is the nature of the knowledge that allows us to produce and understand language, and how does this knowledge develop in young children? Section 2 begins to explore how linguistic competence can be studied scientifically. But first, we want to consider additional examples of the kind of linguistic knowledge a speaker of a language has, and we introduce additional concepts for thinking about linguistic knowledge.

## The Nature of Linguistic Knowledge

As we said earlier, the kind of knowledge at issue here is not the rules of grammar that you may have been drilled in when in elementary school. Rather, we are talking about the kind of knowledge that you – or any language user – has by virtue of having learned a language natively, which means as a young child. As an example, consider the following exercise devised by the linguist Morris Halle, to demonstrate the knowledge that English speakers have about English words. In all likelihood, none of the words in (1) are familiar to you; in fact, some may seem downright bizarre. Now, suppose you were asked to select the words that *could* be a word of English; which would you choose?

- (1) ptak, mgla, thole, vlas, hlad, flitch, plast, dnom, sram, rtut

In all likelihood, you chose the items *thole*, *flitch*, and *plast*. Moreover, virtually all English speakers when asked that question would come up with the same answer. Speakers of a language apparently make the same judgments about words they've never heard or seen before! The only way they could do this is if all the speakers of a language rely on some common pieces of knowledge about how their language is structured. In this case, you were making a judgment based on the consonant sequences that can occur at the beginning of real English words. For example, English words cannot begin with a "d" sound followed by an "n" sound, although that "dn" consonant sequence is perfectly fine *within* a word, as in the word *sadness*. (Note that we are talking about *sound* sequences, not *letter* sequences or spelling – this exercise would work equally well if you only heard the words pronounced without seeing them.)

Having chosen *thole*, *flitch*, and *plast*, consider the following questions: if those words were singular nouns, how would you make them plural nouns? If they were verbs, how would you put them in the past tense? In thinking about the answer, don't worry about how you would *spell* the resulting word, but focus on how you would *say* them – in fact, try saying them out loud right now.

You probably answered the first question with "thole-z," "plast-s," and "flitch-ez," and the second question with "thole-d," "plast-ed," and "flitch-t." As before, you undoubtedly had no trouble doing this, and you probably did it quickly and without much effort. Now notice what you did: although in each case you formed a plural out of a singular, the *sounds* you used to do so were different. Why were they different? And why would all native speakers of English come up with the same answer? Remember, these are words you've never heard before!

The answer to both questions is that you were relying on your linguistic knowledge of forming the plural and past tense in English. In fact,

modifying the sounds you use to produce the plural marker is something you do all the time in English. You may not have noticed it before now, but when you form the plural of English words, the sounds you use for the plural depend on the sounds in the word, in particular, the sound right before the plural marker: the plural of *cat* is pronounced “cat-s,” but the plural of *dog* is pronounced “dog-z,” and the plural of *maze* is pronounced “maze-ez.” This is knowledge that you have by virtue of being an English speaker, and it’s knowledge you brought to bear on the task of pluralizing words you’ve never seen before – and virtually all English speakers would behave as you did.

The knowledge you relied on in this exercise is the kind of linguistic knowledge we explore in this book. There are three critical features of this kind of knowledge: first, it is **implicit**. By this we mean that it is not (necessarily) knowledge that you are consciously aware of, or could explain to someone. Until reading this chapter, you probably weren’t aware of the different sounds you used in forming the plural or past tense. And we haven’t yet discussed in any detail the factors that actually determine what plural or past tense sound you produce in particular circumstances. Yet, despite having no **explicit** understanding of these factors, you and all English speakers consistently produce the same patterns of behavior with respect to these linguistic activities. In this sense, the knowledge you are using is implicit.

A second, and related, characteristic of linguistic knowledge is that it is **automatic**. We can produce words and form sentences from sequences of words without giving it much thought. Likewise, we can’t help interpreting the language that we hear spoken around us. In short, we don’t have to make a conscious effort to put our linguistic knowledge to use; it happens automatically. Contrast this with other skills such as solving a long division problem. It takes more than simply seeing the problem written on the page to solve it – the answer doesn’t just pop out at us. Rather, we have to consciously apply the *explicit* rules we learned for solving such problems. This is different than how we speak and understand in our native language.

This brings us to our third important feature of linguistic knowledge: it is **untaught**. We use this term to refer to the fact that linguistic knowledge is not explicitly taught to children (as long division is), yet children end up acquiring the knowledge nevertheless, in some cases very early in their life. In some sense, this feature arises from linguistic knowledge being implicit; one can’t explicitly teach implicit knowledge. However, just because it isn’t explicitly taught, we are not suggesting that linguistic knowledge isn’t *learned*. Clearly there are many things speakers have to learn about their language. As we saw from our exercise, speakers learn what sequences of sounds are permissible at the beginnings of words in their language. However, although *mgla*, *dnom*, and others, are not potential English words, they are possible words in other languages, such as

Russian, and speakers of those languages would respond differently when asked to choose possible words from (1). More broadly, speakers learn what speech sounds their language uses, what the words are, what they mean, how their language orders subjects and verbs within a sentence, and so on. The crucial point is that much of that knowledge is acquired by children without instruction; merely being immersed in an environment where a language is spoken is sufficient for a child to learn it.

These three characteristics of linguistic knowledge make it an interesting challenge to study. We can't simply ask people to introspect, or introspect ourselves, on the underpinnings of linguistic knowledge – its implicit, automatic, and untaught nature makes it inaccessible to this kind of study. What we can do is study the effects of linguistic knowledge, both by studying the patterns present in the utterances language users produce, and by studying the behavior of language users in controlled experiments. In addition, recent technological advances make it possible to measure activity-dependent changes in the brain during language processing, adding yet another tool. Below, we introduce a framework from **cognitive science** for approaching the scientific study of language. We touch on the kind of discovery that is possible by behavioral observation and experimentation, as well as some of the challenges in inferring knowledge from behavior.

## **Studying Linguistic Knowledge Scientifically: The Framework of Cognitive Science**

Cognitive science encompasses an interdisciplinary approach to the study of intelligence, in the broadest terms, whether in humans, other species, or collections of organisms or entities. Linguistics and cognitive psychology are both part of the cognitive sciences, as these disciplines are interested in understanding specific kinds of human intelligence. Another important discipline is computer science, because most cognitive scientists view intelligence behavior within individuals as involving **computations**. One influence of computer science on cognitive science is in terms of the kinds of formal distinctions it makes. For instance, in computer science, a distinction is often made between **data** and **procedures**. Procedures are the operations a computer program performs, like addition, multiplication, and so on. Data are the entities that the procedures manipulate: numbers, words, images, and so on. A computer program is roughly a specification of data and procedures, as well as a specification of which procedures operate on which data entities, and when, to perform some function(s). Cognitive scientists often make a similar distinction in studying the human mind – the distinction between **mental representations** and **mental processes**. We said earlier that the study of language as a cognitive science is the study

of linguistic competence, or linguistic knowledge, so we can be a little more specific now, and divide this into the study of the mental representations underlying linguistic knowledge and the mental process underlying linguistic knowledge (we'll sometimes use the terms **representations** and **processes** in what follows). Essentially, the processes operate on the representations.

This distinction emphasizes the fact that what we know as speakers of a language is not only facts about the language (e.g., its sounds, its words, the words' meanings, etc.), but also how to cognitively manipulate those entities in the act of speaking and understanding: how to generate a sentence from a set of words, how to apply grammatical operations to a word (e.g., making it plural, putting it in the past tense, etc.). The distinction also provides a framework for thinking about how to investigate the nature of linguistic knowledge, because we see that there are, broadly speaking, two different kinds of knowledge that we need to study: the *what* and the *how*.

How can one study linguistic knowledge? If we want to find out what mental representations and processes are involved in language use, what are we really looking for? If we could watch the brain in action as it processes language, would we expect to be able to "see" the representations of sounds, of words, of meanings? What would these representations look like? The computer analogy is again useful. Suppose we want to understand the way a piece of software works, say, a program that checks for spelling errors in a document. Somewhere in the computer there must be some representation of the words that the computer "knows" how to spell. Surely we don't expect to be able to see the words by opening up the computer and looking inside, or even opening up the microprocessors – the computer's "brain" – and looking inside. The words as we know them don't exist visually in the computer, yet there is a coded representation of them – in the case of digital computers, coded as voltages in semiconductor memories or flux states on magnetic disks.

In the human brain as well, words must be represented somewhere. And, as in the computer analogy, we should not expect to be able to "see" the words inside the brain in any obvious sense. Rather, we should expect that the words are represented in some special code in the neural circuitry of the brain, just as words are represented in a special code in the electronic circuitry of the computer. However, while we understand how computers

In the interests of full disclosure, we make one further comment on the words listed in (1). The words we identified as possible English words – *thole*, *plast*, and *flitch* – in fact *are* part of English! A thole is a pin used to hold an oar in place on a boat, and a flitch is a side of cured meat, or a section of a log. While not a word on its own, "plast" is an ending in many English words (e.g., cytoplasm), and carries the meaning of cell or organized particle.

represent words (because humans designed them), we know relatively little about how the *neural* hardware codes anything as complex as language. Does this mean that we cannot learn anything about linguistic knowledge in the brains of language users? Fortunately, it does not; there are methods of discovering the representations and process of language in the brain that don't require understanding how neural circuits code words or other units of language. Let's again turn to an example with computers to understand how we can learn about knowledge without a physical characterization of how knowledge is coded in a medium (brain or computer). (Though the physical details of knowledge and learning are also of great interest to scientists.)

Returning to our spelling-checker program, we could ask whether the program looks up a word alphabetically to see if a word is correctly spelled; in other words, does it go through all the As and Bs before getting to the Cs and checking whether "carr" is a correctly spelled word? If we don't know the details of how the computer codes letters and words, how could we test this? We might construct an experiment whereby we give the program words that start with different letters at various positions in the alphabet and measure how long (using a super accurate timer) it takes to render a decision about the spelling of the word. If the time taken is correlated with the position in an alphabetized list, then we have some evidence that is at least consistent with an alphabetical organization of the words. Furthermore, such a correlation would tend to argue against alternative plausible organizations of words, for example by length, or by frequency of use.

It's a good place to note here that although we discussed the problem just mentioned as a question of representation (how the words were organized), we could also think about it as a question of processes (how the words were searched). Suppose we found evidence for alphabetization in the experiment above, does that mean that there is a physical alphabetical list in the computer's memory – one that spatially organizes "car" before "card," and so on? Maybe, maybe not; we wouldn't know from just this experiment. It could be that the physical representation of words in the computer's memory is more random, but the *procedure* that searches through the memory processes alphabetically. What we would know is that **functionally**, the words are stored alphabetically. This means that when the word representations are accessed by the spell-checking process, alphabetic position plays a role in how quickly the process is completed. For many questions in cognitive science, including questions of linguistic knowledge, understanding the **functional** characteristics of representations and processes is a fundamental goal of the research. A functional description of a cognitive system defines what the important components are, and how they are organized and interact. This kind of analysis can be extremely revealing about the nature of cognitive mechanisms and



representations, without providing details about how the brain (or other computing device) physically supports them.

Let's step back briefly and consider some of the concepts that were implicit in the preceding discussion. We made the important distinction between understanding how a system worked at a functional level, and how the hardware of the system – the computer or the brain – actually encoded representations and carried out the processes. Within a functional level of analysis, we made an additional distinction between the broader goal of a procedure – for example, analyzing whether a word a user typed is misspelled or not – and how the procedure actually carries out the goal – for example, organizes the words it knows alphabetically, or by word length, or by frequency of use in the language. The importance of these distinctions in cognitive science was emphasized by David Marr, a neuroscientist who studied visual processing. Marr labeled the three levels we just discussed with the following terms:

- **Computational level** – This is the level of analysis pertaining to a broad description of a system. Addition and multiplication are terms that describe aspects of what calculators and computers (and humans) do, at a computational level. “Checking a word’s spelling” is also describing a function of a system at a computational level. Notice that these are broad, rather abstract conceptual descriptions that don’t describe detailed steps in a process.
- **Algorithmic level** – This level describes specific ways in which a system carries out functions, describing the organization of representations – for example, whether a list of words is organized alphabetically, by word length, or by word frequency in our example above – and the specific steps in processing the representations, much like a flowchart does. The distinction between computational and algorithmic levels is important, as a given computation could, in principle, be carried out by many different algorithms. As we saw, one can devise experiments to test the degree to which the behavior of a system is compatible with various algorithms, and rule out some on the basis of the experiments’ outcomes. Together, the computational and algorithmic levels provide an account of the functional properties of a system.
- **Implementational level** – This level describes how a computational medium (e.g., a digital computer, the human brain) implements an algorithm. In a computer, it refers to how digital circuitry encodes binary representations (the 0s and 1s that are the fundamental representational units in computers), and how the various components of the computer – the memory, processor, keyboard, and so on – are connected. In the brain, it refers to neural coding and neural circuitry, as well as the connections between the sense organs and the brain. Note that any algorithm could, in principle, be supported by many different implementations.

In a nutshell, the computational level provides a description of *what* the system does, the algorithmic level addresses the question of *how* the system carries out its functions, while the implementational level describes *what tools or equipment* the system uses.

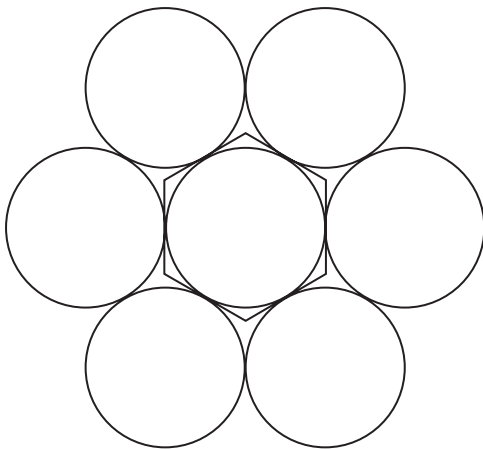
Notice we can learn about one level without knowing a lot about lower levels. For instance, in our spell-checker example, we didn't have to know about how letters and words were coded in computer circuitry to devise an experiment that could reveal how the known words were organized and searched. Likewise, we don't have to know about neural codes to learn about the representations and processes underlying language use. Indeed, what scientists can learn from studying the computational and algorithmic aspects of linguistic knowledge may ultimately inform our understanding of their implementation in the brain. This is because theories at the functional levels provide a framework for interpreting phenomena at the implementational level. Without such a framework, the organization and function of neural circuits would be virtually impossible to interpret. It would be like trying to understand what voltage fluctuations in computer memory meant, when you have no information about what the computer is doing, what problem it's solving, and so on. It would be like trying to figure out how an automobile engine worked without knowing anything about the "goal" of the engine (e.g., to convert the energy in liquid fuel into kinetic energy to move the car).

We have been discussing the implementation level mostly in connection with the brain, but it's important to note that, for language, other parts of the body are involved in this level of analysis. In particular, the vocal tract and the ear are crucial components of the implementation of language in the spoken modality, just as the hands, and the eye are for the implementation of language in the signed modality. It's also important to realize that, just as a functional understanding of a cognitive system provides a framework for analyzing the implementational level, understanding the implementational level, in turn, constrains the kinds of algorithms one might propose. For example, as we will see in later chapters, properties of the human vocal tract and the fact that in speaking we produce sounds in a coordinated manner affect the way adjacent sounds influence each other – for example, a "k" sound is physically produced differently depending on the sounds occurring before and after it. This is an effect of the implementation of human speech, but the result in the acoustic signal requires listeners to work with this variability if they are to recover the intended message. Therefore, we might expect that part of the algorithms and computations of speech perception are specialized to deal with these consequences of facts about implementational level: facts about how speech is implemented in speakers influences the kinds of computational processes we expect to find in perceivers.

## The Complex Relationship Between Behaviors and Underlying Mental Representations

The study of behavior can reveal a great deal about the functional organization of human knowledge, or knowledge in any species. However, scientists must also be aware of factors outside of the brain that could lead to systematic patterns in behavior. In some cases, what appear to be interesting or “clever” properties of an organism’s knowledge turn out to be otherwise. One example is the honeycomb that bees construct to store honey and rear offspring. Mathematically, the hexagonal lattice structure is the optimal construction for storing liquid using the least amount of wall space – an excellent efficiency since producing the wax that makes the honeycomb walls consumes a great deal of honey. The intricate structure would seem to suggest that the honeybees have some sort of blueprint or representation of the honeycomb pattern in their brains, honed by evolution. How else could they construct the honeycombs so well?

While there is some debate on the precise mechanism of the honeycomb formation, on a number of accounts the hexagonal cells are an **emergent** property of a collection of bees building the comb at once, rather than the result of a master plan inside a bee’s brain. One intriguing theory is that the hexagons are formed as the warmed up wax flows like a liquid around the bees building the honeycomb. A bee is roughly cylindrical, so many bees working in close quarters produces an array of closely packed cylinders, which would look like an array of circles in two dimensions (see Figure 1.2). Because of the geometry of closely packed circles, any given bee is making contact with six other bees around it. As the bees in this configuration produce wax for the comb, they produce a great deal of heat,



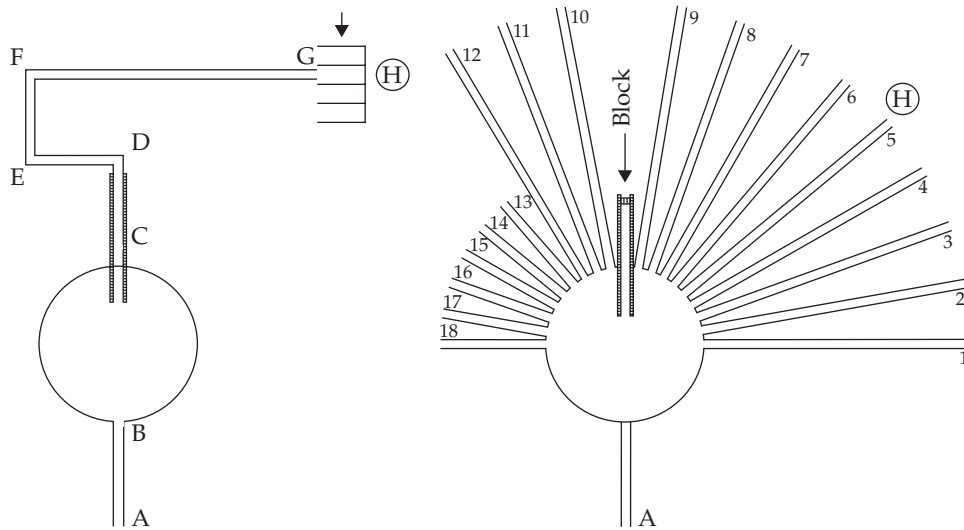
**Figure 1.2** Circles represent honeybees. The hexagon depicts the resulting form of the flowing wax, which is subject to forces from the central and surrounding bees

and the wax becomes malleable and liquid, and flows around the cylindrical bees. The forces on the wax from the central bee and the bees surrounding it shape the wax into a hexagonal form. Thus it is the physics of the bees' formation and the wax that results in an array of hexagonal cells. In fact, this mechanism is related to the very physical phenomenon that makes hexagons an efficient shape for storing liquid in separate compartments. So, according to this theory, it is physical phenomena that makes the ideal hexagonal configuration, not a clever design represented in honeybee cognition.

On the other hand, sometimes apparently sophisticated intelligent behavior is indeed more directly linked to the mental representations and processes of the organism exhibiting the behavior. For example, rats can learn to navigate through mazes when rewarded with food at the end of the maze. At first, they may make many wrong turns and take a long time to get to the end. But after a number of tries at learning the same maze, they end up taking only a path that takes them to the food. The rats internalize some sort of representation of their trajectory through space that allows them to "solve" the maze. What is the nature of that representation?

Many psychologists at the beginning of the twentieth century believed that rats were simply remembering motor sequences – the movements of their limbs as they traversed the maze and made turns at choice points. Sequences that led to a reward were reinforced, and those that did not were inhibited. On this view, just as the honeybee has no representation of the hexagonal cells it will build, the rat has no real representation of the space it traverses, only the steps (literally) it needs to take to get to the food at the end. But through a variety of experiments, scientists discovered that rats build up rather sophisticated spatial representations of the location of the food with respect to the start of the maze, and that these representations are more like maps than representations of motor sequences.

In one such experiment, rats were initially trained on a simple maze that included an alley to a circular table and a continuation on the opposite side of the table (Figure 1.3.i). That path continued on a series of turns, with food at the end. The trajectory along the path was often in a direction away from or tangential to the food. After rats learned to traverse the path quickly, the maze was modified so that the exit path from the circular table was blocked, and over a dozen additional paths were added at intervals around the table (Figure 1.3.ii). Rats initially tried to proceed through the original maze arm, but found it blocked. They returned to the circular table, and after exploring the entrances to the newly added paths, almost unanimously chose the path that pointed directly to the location of the food (which they could not see). They could not have used memory of motor sequences to traverse the new path, as the sequences were completely different from the ones in the original maze. However, if the rats had built a representation of the location of the food relative to their



**Figure 1.3** (Left) Rats learned to navigate from start (A) to food (G). (Right) Rats would traverse path (5), in direction of the unseen food, when their usual passage was blocked.

*Note.* Images copyright © 1992/1946 by the American Psychological Association. Reproduced with permission. The official citation that should be used in referencing this material is Tolman, E.C., Ritchie, B.F., Kalish, D. (1946). Studies in spatial learning. I. Orientation and the short-cut. *Journal of Experimental Psychology*, 36, 13–24. The use of APA information does not imply endorsement by APA.

starting location, they could then choose a path that would lead directly to that location. Numerous experiments involving different techniques followed this one and converged on the idea that rats have some sort of mental map that they use in navigating through space.

In summary, in some cases an organism’s intelligent behavior is linked to mechanisms in the brain. In others, explanations for apparently sophisticated or intelligent behavior lie outside the brain. Understanding the physical world in which organisms exhibit a behavior can be extremely important in forming theories about the cognitive underpinnings of that behavior.

Are we like bees or like rats?

We’ve just seen how an organism’s behaviors that on the surface seem to draw on complex knowledge could result from constraints outside of its brain. Could such constraints be involved in our behavior in our earlier example involving plural and past tense formation? Maybe we’re always trying to produce an “s” sound, but perhaps something about the physical mechanisms of speech require that the “s” is produced as a “z” when it

follows the “l” in *thole*, but not when it follows the “t” in *plast*. This would be important for our understanding of linguistic knowledge, because in that case we would then be more like bees, whose intricate hexagons do not exist in their minds, rather than the rats with their mental representations of space.

We can rule out the alternative explanation just offered if we can show that there are words in English (or any language, for that matter) in which “s” sounds can follow “l” sounds. In fact, there are many English words where this happens, as in *pulse* – we don’t say “pulz”! So, for better or for worse, we seem to be more like rats than bees when it comes to this piece of linguistic knowledge. But just because we ruled out one alternative hypothesis doesn’t mean that there aren’t others we should consider. As scientists, we want to analyze all plausible alternatives. So far, the best explanation for the systematic patterns we observed in our previous examples is that speakers rely on implicit, automatic, and untaught linguistic knowledge when producing words.

### *Summary*

#### **Chapter 1, Section 2**

- 1 Linguistic knowledge is implicit, automatic, and untaught.
- 2 Linguistic knowledge is supported by mental representations and mental processes.
- 3 A cognitive system can be analyzed at the computational level, the algorithmic level, and the implementational level. Analysis at the first two levels constitute a functional analysis of the system.
- 4 A functional understanding of a cognitive system can be very informative, and needn’t require a detailed understanding of the implementational level, though it may be informed by such an understanding.
- 5 Intelligent behavior is not always due to models of the behavior in the mind of the organism. Sometimes external factors blindly constrain behavior in seemingly intelligent ways.