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Topic
Literature & Language

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Linguistics

Language and the Mind

Course Guidebook

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At Colgate University, Professor Kelly teaches on topics related to language, brain, and development. He has been a visiting scholar at the University of Washington and the Max Planck Institute for Psycholinguistics in the Netherlands. The Princeton Review has recognized him as one of America's top 300 professors.

Professor Kelly is the president of the International Society for Gesture Studies. His expertise focuses on how the body shapes language and thought in children and adults. Professor Kelly has published more than 50 papers in scientific journals, and his research has been funded by the National Science Foundation. He coedited the book *Why Gesture? How the Hands Function in Speaking, Thinking and Communicating*. His work has been featured in various media outlets, including *The New York Times*, *The Atlantic*, and *Scientific American*.■

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LANGUAGE AND THE MIND

Language is the ultimate human invention. It is the tool that makes all other tools possible as well as the most powerful communication system in the world. But what gives the human mind the unique ability to use language? Where did it come from? How did it get here, both in our species as a whole and within each one of us as individuals? These are some of the big questions explored in this course, which synthesizes research across a wide range of disciplines using a handy framework.

A common assumption is that human brains must have evolved in specialized ways to acquire language. However, current theories suggest that this may be exactly backward: Rather than the brain originally adapting itself to language, it may be that language adapted itself to fit the human brain.

This course explores that possibility and considers the implications for the human mind. It begins by asking what language is and what it is not. Language is a complex system of things. Although it shares many features with communication systems of other species, language has some special properties elevating it into a league of its own.

This course uses an organizing model known as the 3-D framework. For a topic that is so deep and wide, the framework is necessary to elucidate how genes, brains, bodies, and environment interact to give rise to minds that have language. The framework considers mechanisms for language across multiple timeframes and from different angles of analysis.

Traditional linguistic approaches have focused mainly on speech as the primary medium and monolingualism as the main model of study. Although this classic approach has revealed much information, our current understanding has benefitted tremendously from taking a broader view. This course celebrates language in all its forms:

- The written word. Writing gave birth to modern civilization. Because it was invented so recently—slightly more than 5,000 years ago—humans are not born with an innate neural module for reading and writing. Rather, genes designed for other purposes interact with the written word over development, and this constructs a specialized reading-writing network in the brain.
- Sign language. Sign language is every bit a language as its spoken counterpart. In addition to exploring similarities and differences to speech, the course dispels some myths about sign language.
- Embodied language. Many theorize that bodily actions—such as hand gestures, eye gaze, and facial expressions—were the foundation for language evolution. What aspects of spoken language are still grounded in the body, and what parts have transcended it? The answer may lead to breakthroughs in robotics, artificial intelligence, and neurorehabilitation.
- Multilingualism. Around the world, using more than one language is not the exception—it's the rule. How do multilingual minds handle multiple languages, and what are the costs and benefits of having them?

Building on the basic biology that learning language sculpts the brain, the course finishes by asking how language shapes other aspects of the mind. It considers how having a particular language influences a mind specifically as well as how having any language can expand and limit a person's world generally. In the end, the course reveals what makes language possible and how it has turned the human mind into the most extraordinary creation on the planet.

1.

LANGUAGE IN MIND

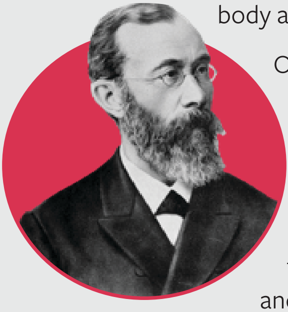
Any product of human civilization was influenced by language. It is possible that without language, the human mind might never have imagined anything in the first place. This lecture first looks at preexisting models of the mind. It then presents a model of the mind that will be used in the rest of the course, and it closes with a look at how language fits within that model.

Earlier Models of the Mind

One of the classical models of the mind is dualism, which can be traced back to the ancient Greeks. Dualists saw the mind as two distinct entities: a physical part, which includes the body and brain, and a nonphysical part. For Plato, that was the nonmaterial world of ideas. Later, in traditional religious dualism, the nonphysical part was seen as the spiritual soul.

The most famous dualist of all, René Descartes, took dualism out of the religious realm and placed it more in the secular world. This type of dualism was called mind-body dualism. The body was a machine, and the mind was the home of thought, reason, and consciousness. The two entities were completely separate, except for where they met in the brain through a structure called the pineal gland.

Around the time Descartes was arguing for his mind-body dualism, a rival model of the mind called materialism was gaining popularity. Materialism is most associated with Baruch Spinoza, Thomas Hobbes, and John Locke, and it blurs the distinction between the mind and body. For these philosophers, mind and body are one and the same.



Once the floodgates of materialism were open, it was just a matter of time before the mind became an object of inquiry for scientists. The first scientist to test aspects of the mind in a truly scientific fashion was the German physiologist Wilhelm Wundt. In 1879, Wundt founded the first official laboratory for psychological research at the University of Leipzig, and the field of scientific psychology was born.

Wundt's approach to studying the mind became known as structuralism. Structuralism viewed the conscious mind as composed of smaller building blocks of basic sensations and perceptions. Although structuralism didn't last long as a field of scientific psychology, it introduced a conceptual approach for understanding complexity at high levels—such as conscious thought—by reducing it to much smaller units of analysis, including basic sensations and perceptions.

The combination of these two things led to a model of the mind called biological reductionism. This model views all aspects of the mind as grounded in the body, and it dispenses with the idea of the mind altogether. There is no mind—only a body. There are only neurons firing or genes expressing. This view gained popularity in the 20th century with the incredible advances made in biology, chemistry, and physics.

In the 21st century, radical reductionism is still embraced by some scientists, but it has hit some major roadblocks in its attempt to understand the complexities of the human mind. For example, reductionists cannot agree on what the lowest level is: Should it be neurons, genes, molecules, quarks, or even mathematical equations?

This Course's Model of the Mind

The basic principles behind emergent properties offer a new way to think about the mind. An emergent phenomenon might result from a synergistic interaction between the brain, the body, and the environment. The mind is not reducible to any one of these parts alone; it exists only through the combination of them.

This definition draws from the other models' strengths while avoiding their weaknesses:

1. Drawing from dualism, we can preserve the mind as a special entity without having to commit to a separation from the body.
2. Drawing from materialism, we can scientifically study the mind as we study any other thing without committing ourselves to a blank slate. Perhaps aspects of the mind emerge from combining innate attributes of the brain and the body with experience from the environment.
3. Drawing from reductionism, we can appreciate the biological and physical building blocks of the mind without viewing them as the only important items. The other levels higher up may be just as significant.

Where Language Fits

Just like the mind, language may be an emergent property that is the result of a synergistic interaction between brains, bodies, and the environment. One implication of viewing language as something that lives partly outside our heads is that we see more clearly how language can affect us. If language is similar to other tools we use, it is easier to appreciate how it has transformed us and our environment.

Without the explanatory power of language, it is not possible to keep building more and more sophisticated machines. Language is necessary to advance from simple tools like levers and hammers to advanced tools like computers and satellites.

In fact, without language, the human mind cannot even conceive of creating other tools in the first place. From this perspective, language actually transforms the mind to allow it to do things it could not do without language.

The 3-D Framework

A conceptual model known as the 3-D framework is useful for organizing and analyzing the issues discussed in this course. Each of the framework's three dimensions are necessary to understand something as complex as language and the mind. The three dimensions are causation, levels of analysis, and timeframe.

Causation concerns two things: What causes a thing, and what does the thing cause? This distinction is inspired by Aristotle's efficient cause and final cause. In more modern times, the Nobel Prize–winning biologist Nikolaas Tinbergen referred to these two types of causes as mechanisms and functions.

With writing, a mechanism would be the antecedent conditions that produce the behavior of writing. An example would be a desire to express oneself. In contrast, the function is the consequence of writing: making one's feelings public. For every behavior, there are things that produce it (mechanisms) and things it produces (functions).

In the 3-D framework, there are three levels of analysis: biological, psychological, and social. The biological level focuses on small things like neurons firing and genes expressing as well as larger-scale biological activity, such as brain regions communicating and turning thoughts into actions. The psychological level concerns subjective experiences, like feeling, thinking, and perceiving. The social level concerns how an organism interacts with things that are outside the body, which includes humans and objects.

In the example of writing, the biological level concerns brain regions that are dedicated to one's native language. The psychological level concerns the desire to express oneself. The social level concerns the societal conditions that compel one to write.

The final dimension of the 3-D framework is the timeframe—that is, the scale on which one wants to understand the cause and effect of something. It may help to think of this as a timeline from short to long.

Here are different increments to keep in mind:

1. Very brief increments—that is, one millisecond to the next.
2. Longer increments: one day, week, or year to the next.
3. Still longer increments: one generation to the next.
4. Even longer increments: one millennium or evolutionary eon to the next.

This course examines moment to moment, developmental, historical, and evolutionary timeframes. Approaching a subject from these different timeframes fundamentally changes how we think about them.

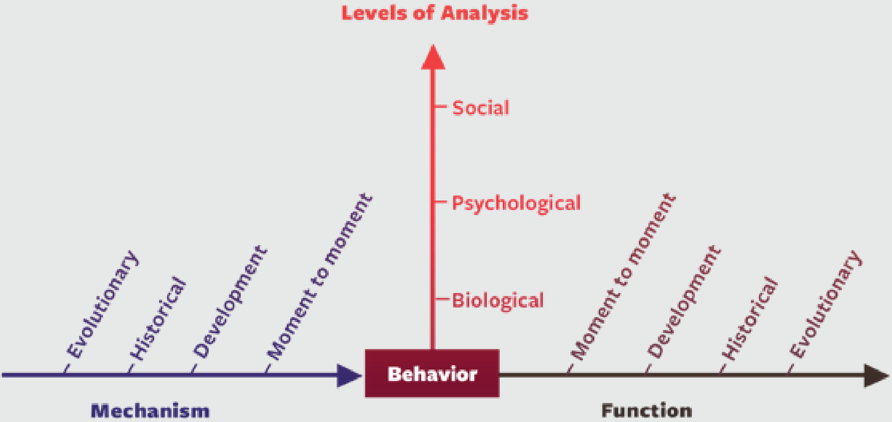
Returning to the example of writing, the smallest timeframe—the moment to moment—involves the immediate antecedents to putting pen to paper: neurons firing to link ideas into words or a flash of inspiration. The developmental timeframe concerns slower mechanisms, such as how a lifetime of using language has wired the brain to think in words.

The historic timeframe considers the larger context in which a behavior occurs. This context involves large concepts like cultural institutions, national identity, and technological innovations.

Finally, the evolutionary timeframe involves chunks of time millions of years long, a scale that differentiates one species from the next. This timescale makes it possible to discuss the unique genetic baggage that different species carry around with them. Particularly relevant is the fact that humans have a set of genes and some basic learning abilities that endow us with the capacity to write.

Bringing It Together

The three dimensions of the framework interact with one another. For example, a mechanism can have three levels, and each level can span four timeframes. As an example of this in action, consider this apparent contradiction: If reading and writing are innate, how can we not be born with a specialized brain mechanism dedicated to them?



The 3-D framework offers a way out. The only way to solve this puzzle is to consider mechanisms for reading and writing on different timeframes and multiple levels of analysis. To begin, on an evolutionary timescale and a biological level, humans are genetically equipped with brain regions that are designed to do very general things (like seeing objects, hearing sounds, controlling motor movements, and making associations). Humans are also evolutionarily endowed with a brain that is highly plastic. Neuroplasticity means that the brain can change itself in response to the environment.

On a developmental timescale and a social level, human children are massively exposed to spoken and written language throughout their formative years. Before children begin to read and write, most have heard, used, or seen many millions of words.

Here is where the two timeframes and two levels meet: The massive social exposure of words over development combines with the brain's innate potential to change itself. In turn, this transforms brain regions that were evolutionarily designed for more general things like vision, hearing, motor movements, and making associations. It transforms these regions into a specialized reading and writing device.

In this way, reading and writing are emergent properties of the mind. Part of this is innate and controlled by genes, but another part is the result of prolonged experience with the environment. It's not possible to explain reading and writing by focusing only on one timeframe or only a single level of analysis. The key is to understand how these dimensions interact.

> ## Suggested Reading
>
> Sapolsky, *Behave*.
>
> ## Question to Consider
>
> Using the 3-D framework, can you dissect and analyze an aspect of the mind that is particularly interesting to you? Here are a few sample topics: perceiving human faces, mathematical thinking, musical ability, psychological disorders, and bilingualism.

2.
LANGUAGE AS A SYSTEM

A very basic but important question is this: What is language? To begin tackling that question, this lecture defines five components of language. Those components are syntax, semantics, morphology, phonetics, and pragmatics. (These are sometimes referred to as levels.)

Syntax

Syntax primarily concerns the rules for how a language orders words in a sentence. An example of the default structure in English is this sentence: “The child opened the door.” This follows a form called SVO syntax, with SVO standing for subject, verb, and object. The *child* is the subject, *opened* is the verb, and the *door* is the object.

Other languages order sentences differently. Forty-four percent use a subject-object-verb pattern, including Japanese, Turkish, and Hindi. Additional setups exist as well. The takeaway point is that there are multiple ways for syntax to function across languages.

SVO Languages

More than 40 percent of all languages conform to the SVO pattern. English, Spanish, German, and Mandarin are well-known examples.

Semantics

In linguistics, semantics is the study of word meanings. More technically, it is the study of symbols and their referents. One of the most striking facets of semantics is that the meaning of each word is traditionally defined by other words. This makes semantics an endless cycle of symbols referring back to themselves.

Additionally, linguistic symbols differ across all languages. Some of this variation is in sheer number: One Korean dictionary lists more than 1 million words, whereas Oxford’s classical Latin dictionary lists roughly 40,000.

The semantic component of language is notable for being a system within a system. There are different word types that have quite different properties. For example, consider open- and closed-class words.

Open-class words form a category of words that can be changed, added, or removed from a language. In English, these are nouns, verbs, adverbs, and adjectives. For instance, the word *trousers* has largely faded into obscurity, but words like *email* have come into existence. In contrast, closed-class words are words that form a more fixed category that is not easily altered. In almost all languages, these are prepositions, articles, and pronouns.

Morphology

The next component is morphology. This linguistic component is made up of morphemes, which are the smallest meaningful grammatical units of language. Take this sentence as an example: "I'm getting really hot." The word *hot* is a single open-classed morpheme, but every other word in the sentence has two morphemes. *I'm* is a contraction of *I* and *am*. The word *getting* uses the verb stem *get* plus -*ing*, which is how English indicates an activity happening in the present. And the term *really* is formed with *real* plus -*ly*, which is how English turns an adjective into an adverb. Note that -*ing* and -*ly* are closed-class morphemes.

Languages vary in how many morphemes they pack into a word. English is relatively light on morphemes. Most words are one or two, but certain words have many more. For example, the word *antidisestablishmentarianism* was created in 19th-century Britain to protest attempts to remove the Church of England as the official state religion. It has six morphemes.

Phonetics

The smallest part of language is the phonological or phonetic component. Spoken words and morphemes are all made up of phonemes, which are the most basic meaningful sound units of a language. In a sign language, they would be the smallest manual units. English has a total of 44 phonemes.

Within a language, there are rules about which phonemes can and cannot follow one another. For instance, while Polish allows many consonants to cluster without a vowel, English permits far fewer. English allows three at most at the front of a word, as in *splash*, and four at most at the end of a word, as in *twelfths*.

As with morphemes, there is a large range of phonemes used in different languages. On the low end, the Amazonian language of Pirahã is thought to have only 11 phonemes, and on the other end, there are African click languages that have up to 141 phonemes.

Pragmatics

The final component of language, pragmatics, refers to how people use language, and it reveals language as a powerful tool for accomplishing social goals. In the study of pragmatics, these goals are often referred to as intentions, and understanding intentions can be a tricky business.

For example, take this sentence again: "I'm getting really hot." There are many potential meanings of this utterance. One meaning is a literal statement about a person's rising temperature. Another meaning could be that the person is becoming angry. Yet another option is that it could be an indirect request to turn on the air conditioning.

There is often nothing inherent in the literal meaning of the words that reveals a speaker's intentions. To solve this problem, a listener needs to make a pragmatic inference about the intentions of the speaker.

Because pragmatics involves social goals, it interfaces with culture in ways that other parts of language do not. In fact, pragmatics is the one component of language that can get people in the most trouble when communicating with people from other cultures. For instance, many Americans love sarcasm, but it can come across as confusing or rude in some other cultures.

Conclusion

Language is nonlinear and multidirectional. In addition to piecing the smallest units into larger ones, language works in the other direction too: The largest units work backward to simultaneously guide the processing of the smaller ones.

For example, pragmatic goals and intentions are often the starting point, not just the ending point, for all other parts of language. Recall that in the example, "I'm getting really hot," the meaning of the utterance is largely dependent on the context.

Another example comes from when the syntax of a sentence sets the listener or reader up to expect a certain meaning. Consider this utterance: "Time flies like an arrow, but fruit flies like a banana." The syntactic trick here is that *flies* in the first part of the sentence is a verb, but in the second part, it is a noun. These are called garden path sentences because they lead the listener or reader down one syntactic path, only to play a trick with a different path later.

Suggested Reading

Sedivy, *Language in Mind*.

Warren, "Perceptual Restoration of Missing Speech Sounds."

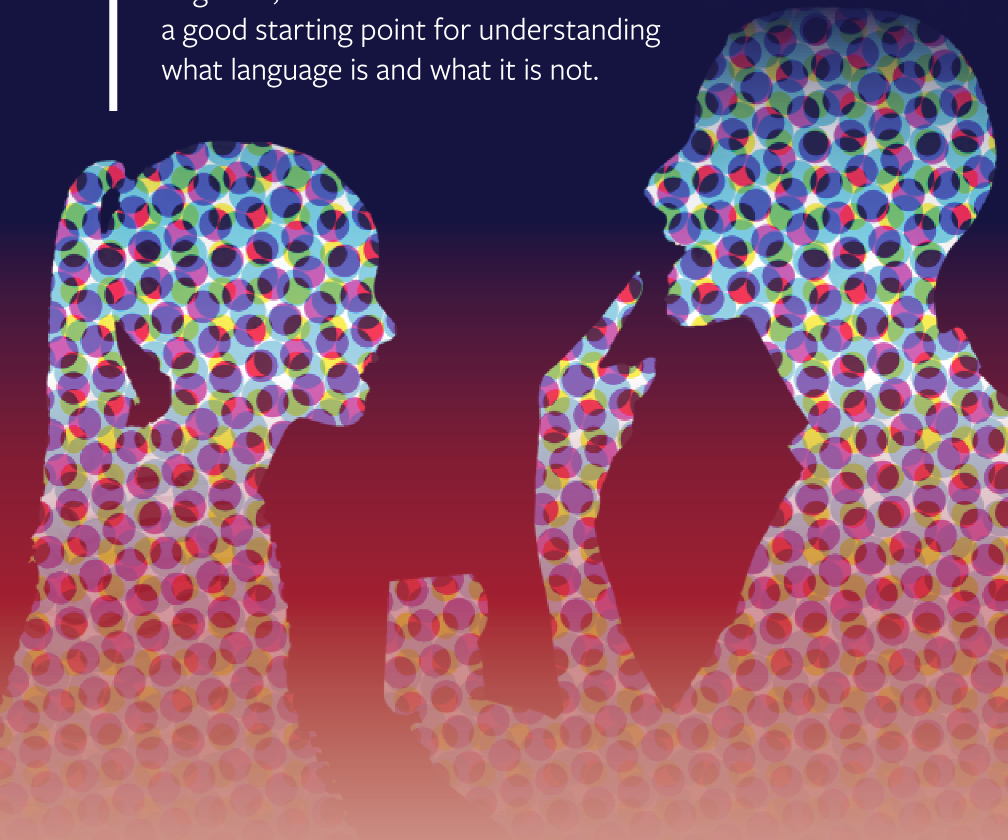
Questions to Consider

Can you think of other ways that different components (levels) of language interact to allow language to function properly? Over development or when learning a second language as an adult, how might some components of language facilitate other components?

3.

ELEVEN LINGUISTIC UNIVERSALS

This lecture presents a list of 11 linguistic universals that are true of all human languages. Nine of these universals are drawn from what the American linguist Charles Hockett called basic design features of language. The lecture also adds two additional features that reflect recent advances in developmental psychology and cognitive neuroscience. Together, these 11 characteristics form a good starting point for understanding what language is and what it is not.



Feature 1: Duality of Patterning

The first feature, duality of patterning, refers to language having a double structure. Smaller units like phonemes possess no inherent meaning, but these combine to create meaning at higher levels, like morphemes, words, and sentences.

Feature 2: Arbitrary Symbols

Arbitrary symbols are the feature that has received the most attention from linguists, philosophers, and scientists. In spoken language, the relationship between a word (or a symbol) and its meaning (or its referent) is largely arbitrary and based on the quirky conventions of particular languages.

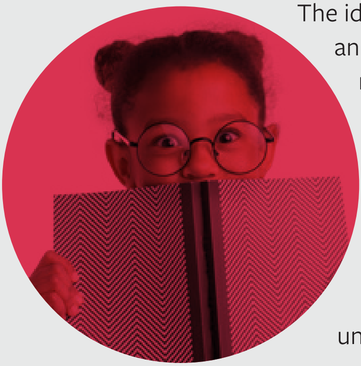
However, many words possess a feature that cognitive linguists call iconicity. For example, onomatopoeias are classic examples of iconicity. The words *buzz* and *bang* sound like what they mean, to some extent.

Feature 3: Language Is Rule Governed

All languages are rule governed. The rules are hierarchical in nature, which means that rules of larger units of language are built up from smaller and smaller units. This refers back to the idea of duality of patterning. For example, the syntax of a language works only if the rules of semantics are in place. Semantics rely on rules of morphology, and these morphemes require that the rules governing phonemes be followed.

Feature 4: Generativity

In the late 1950s, the linguist Noam Chomsky developed a theory that children learn language because they are born with an innate set of rules that allows them to create novel linguistic utterances. Chomsky called this the generativity of language, and Hockett later called it productivity.



The idea is that people can generate or produce an infinite number of new things that they have never heard simply by using words in a rule-governed way.

For instance, at the morphological level, children are so creative that they often make up words that don't exist in their native language, like pluralizing the word *fish* as *fishes*. This ability seems to be uniquely human.

Feature 5: Displacement

Displacement refers to the fact that language can be used to communicate about things not in the here and now. For instance, children talk about topics that are displaced when they ask questions such as "How many days until my birthday?"

This sort of communication is quite rare in the animal kingdom. However, there are some well-known exceptions of animals communicating outside of the here and now. For example, bees communicate about the precise location of far-off food sources.

Feature 6: Cultural Transmission

Cultural transmission means that human language is not directly and completely passed down through our genes. Nobody is born with a brain designed to speak Portuguese, Bantu, or Hawaiian. To speak these languages, we need to learn them first.

This should not be taken for granted, because most other species are different: They are born with an innate and fixed set of communication signals, so there is no learning required. This is not true of all animals—for example, songbirds are a notable exception—but it is true for most animals.

Feature 7: Reflexiveness

Perhaps the most interesting and unusual topic that humans talk about is talk itself. This feature is called reflexiveness: Human language can be used to describe or refer to itself. This occurs in many ways. A simple example is "I didn't hear you." There are also more complicated examples. For instance, the legal profession is built on the interpretation of words.

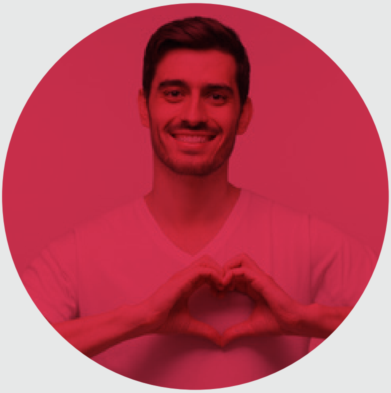
Communicating about communication is what cognitive psychologists call metacognition, and it goes hand in hand with another unique aspect of the human mind: Humans can think about thinking. This is one of the crown jewels of human cognition.

Versatility of Human Communication

The features of displacement, cultural transmission, and reflexiveness illustrate the remarkable range of human communication. Absolutely nothing is off-limits for humans.

Feature 8: Specialization

Language is specialized for one purpose: to deliberately communicate. This may seem self-evident, but consider that other behaviors can communicate without being specifically designed for it. For instance, imagine a person cursing after stubbing his toe. Was he trying to communicate something, or was that just a reflex? Flirting, too, can be unintentional.



Those examples are murky, but language is crystal clear. When a person says a word or produces a sign, he or she has one purpose in mind: to communicate.

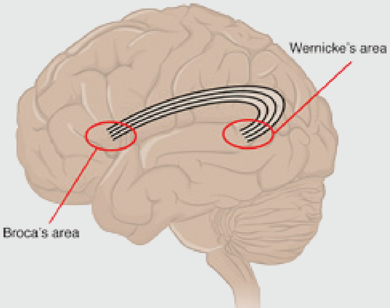
Feature 9: Prevarication

The ninth design feature is prevarication, which means that human language allows us to lie. The fact that humans lie seems bizarre given the semantic property of language. Humans put great effort into creating precise words for things, so why would we not accurately describe those things with the right words? The answer comes from the pragmatic component of language: Pragmatics tells us that words are driven by intentions, and lying with language can help actualize goals.

Feature 10: The Standard Brain Network

The final two items are add-ons to Hockett's original list of design features. Rather than being features of language per se, these are universal patterns of how language is organized in the brain and how it unfolds during development. There is remarkable similarity in the neural machinery for all language users on the planet. The brain is divided into two hemispheres, the left and the right, and four lobes: the frontal, temporal, occipital, and parietal lobes.

For most people, the left hemisphere contains brain regions that are specialized for language. For example, there is a region in the posterior part of the left hemisphere frontal lobe called Broca's area that is traditionally associated with language production. Farther back in the superior temporal lobe is Wernicke's area, which is traditionally associated with language comprehension.



This neural organization is uniform across brains. Although a small percentage of people have their Broca's and Wernicke's areas in the right hemisphere—and some even have it distributed across the left and right hemispheres—there has never been a case in which the two areas are entirely absent in someone who uses language.

Feature 11: The Shared Developmental Trajectory

The final universal has to do with language acquisition. Across all languages, there is a shared developmental trajectory, especially within the first year of life.

The first shared aspect of language development is that all newborns possess an innate ability to perceive phoneme contrasts in all languages. We know this based on classic work done by Janet Werker from the University of British Columbia in the 1970s.

Over the first six months of life, babies focus their attention on the phonemes that are the most relevant to their native language. Following this perceptual focusing, babies begin to practice producing these phonemes in the form of babbling. These babbles are not restricted to speech sounds. Deaf babies who are exposed to sign language as their primary language babble with their hands.

The next stage is that children start to understand their first words at six to seven months of age. Shortly after this, babies start to point at things in their environment. Researchers believe that this is an attempt to communicate one's attention toward and intentions about objects in the world. Finally, by roughly their first birthdays, most babies start to say their first recognizable words.

Suggested Reading

Hockett, "The Origin of Speech."

Questions to Consider

To what extent are the design features of language unique to language? How might they actually reflect more general aspects of the human brain?

4.
COMMUNICATION IN THE ANIMAL KINGDOM

To understand how language is uniquely sculpted to the human mind, it is necessary to use the 3-D framework to explore the biological, psychological, and social prerequisites that make humans the perfect fit for language. This lecture explores the psychological and social commonalities and differences in communication and cognition between humans and nonhumans.

Honeybees

The first place to look for commonalities and differences is in the natural communication systems of nonhuman species in the wild. Modern research in the areas of ethology (the study of animal behavior) and comparative psychology has greatly benefited from methodological advances in audio, video, and computer technologies, and we now know more about nonhuman communication than ever before.

One notable species is the honeybee. These bees have a very impressive communication system for letting other bees know about the location of food sources, such as flower nectar. When a worker bee finds a food source, it rushes back to the hive and performs an elaborate dance on the surface of the honeycomb. This dance communicates information about the direction, distance, and quality of a food source.

The dance of bees and the language of humans differ in some significant ways. To start, unlike human language, a bee dance is an innately specified system that is not learned by observing others. Additionally, the elements of dance may not be truly symbolic in the same way as human language. Finally, bees dance only about food and water. This suggests that the function of their dance is fixed and narrow.

Vervet Monkeys

One of the classic studies on primate vocal communication was done with vervet monkeys by three researchers in 1980. Vervet monkeys are small, gray-haired monkeys that live in groups in woodland and mountain areas of East Africa. They have three primary predators: leopards, eagles, and pythons. These predators are so dangerous that vervet monkeys have developed vocal alarms that let the rest of the group know of their presence.

The calls are specific to the three types of predator. The researchers found that leopard alarms cause monkeys to run for cover in trees, eagle calls caused them to run for cover in rocks or low bushes, and snake alarms caused them to search the ground around them.

Follow-up studies showed that this skill was not entirely innate. Baby vervets learned how to make the appropriate calls by observing adult monkeys produce the calls.

Chimpanzees

Chimpanzees in the wild communicate with vocalizations and hand gestures. The pioneering primatologist Jane Goodall was one of the first scientists to document that chimps produce various types of bodily gestures when interacting with other chimps.

In one of the largest-scale studies done in the wild, Catherine Hobaiter and Richard Byrne recorded more than 4,500 gestures produced by the Sonso community of chimpanzees from the Budongo Forest in Uganda. These gestures were produced by dozens of chimpanzees, both adults and children, and there were more than 60 distinct meanings recorded.

The takeaway point is that it appears that other animals can use arbitrary symbols to deliberately communicate meanings with other members of their species. However, it is worth pointing out an aspect of this sort of nonhuman communication that is different from language. There is very little evidence that these animals naturally string together more than one or two calls or gestures in rule-governed ways to produce novel sentences.

Teaching Language to Dogs

This lecture now turns to the question of whether it is possible to teach language to nonhumans. There have been countless natural experiments tried with humans' best friend: dogs.

It is clear that dogs can learn basic words, including *sit* and *stay*. Additionally, there are many cases of dogs that have vocabulary of dozens and even hundreds of words. The most famous and impressive example is Chaser, a border collie trained by the psychology professor John Pilley. Chaser was said to know more than 1,000 words for commands, toys, and objects, which is comparable to a typical human three-year-old.

One key difference between a word-learning dog and a typical child is the inferences they make when learning new words. When a child learns a word, they implicitly categorize those words based on certain features, particularly the shape of an object.

Matters are less clear with dogs. Emile van der Zee performed controlled experiments on a different border collie named Gable and found a different type of categorization: the size of an object. Even that was not stable from one learning trial to the next. Compared to dogs, humans seem to have very specific and consistent cognitive heuristics that guide their early word learning, suggesting that they start with some quite distinct cognitive machinery.

Dolphins and Language

Dolphins naturally communicate by whistling, which some believe has symbolic properties. For example, dolphins seem to have distinct whistles for particular referents. Building on this, there have been attempts to teach dolphins an even more elaborate language-like communication system.

The most extensive investigation was done by Louis Herman, who conducted systematic tests of bottlenose dolphins at the University of Hawaii for more than three decades. Herman's two most famous dolphins were Phoenix and Ake. Phoenix was exposed to an artificial tonal language that was transmitted by computer through speakers broadcasting underwater.

Phoenix was able to learn an impressive number of tonal words, and she could also understand basic syntactic distinctions. For example, she could differentiate between "take the ball to the hoop" and "take the hoop to the ball."

Phoenix's comrade, Ake, was just as impressive. Unlike Phoenix, Ake was trained to respond to videos of hand gesture commands with underwater button presses. (Dolphins press buttons with their noses.) Perhaps Ake's most striking linguistic feat was to correctly respond to questions about remembering objects that were not physically present.

In one experiment, when asked if a hoop was or was not located in a different tank that Ake could not see, she was able to answer correctly more than 90 percent of the time. This is one of the few examples of displacement in nonhuman communication.

Additional Work on Primates

Dolphins are impressive, but the most promising bet for teaching language to animals comes from work on primates. Much of the modern work on teaching language to primates can be traced back to a paper written in 1909 by the American psychologist Lightner Witmer. He inspired a century of research on primate language with his paper titled "A Monkey with a Mind."

The paper focused on Peter, who was a three-year-old captive chimpanzee. (Despite the paper's title, he was an ape, not a monkey.) Peter had been impressing audiences in the Vaudeville circuit for his remarkable humanlike behaviors.

Witmer was so intrigued by Peter that he asked his trainer if he could do scientific tests on Peter's cognitive abilities. Peter passed many of the complex tests Witmer threw at him, but Peter's language skills were not quite as impressive.

Peter could understand basic commands, but Witmer wondered whether Peter could have learned more had he been exposed to language at a younger age. This simple question set the stage for language-training studies on primates for the next 100 years.

Many of the early attempts to test this hypothesis took an extreme approach: Researchers adopted baby chimps and tried to raise them as human children. However, in the late 1960s, researchers took a new approach to immersing primates in language. Influenced by research showing that sign language shared all the basic universals of spoken language, researchers moved away from vocal training to training of hand gestures, or signs.

One of the most famous cases is Washoe. Washoe was studied by a husband-and-wife psychologist pair, Allen and Beatrix Gardner. Adopted as a two-year-old, Washoe was taught American Sign Language (ASL) as her exclusive form of communication. Washoe eventually learned more than 350 novel ASL signs. She could understand and produce sign strings, and in some cases, she could communicate about things not present in the here and now.

Challenges to the Work

There are other well-known examples of language learning in primates, such as Kanzi the bonobo and Koko the gorilla. However, there are also major challenges to this line of work.

First, many scientists have argued that there is a high degree of so-called rich interpretation of the data. Language-training studies require an immense amount of time, energy, and resources, and this makes it hard for the researchers to see things objectively.

A related critique concerns the nature of what is actually learned by the animals in these studies. Essentially, the question is this: Are primates, dogs, and dolphins really learning to communicate like humans, or are they just learning to produce complex behaviors in response to various cues?

Suggested Reading

Gardner and Gardner, "Teaching Sign Language to a Chimpanzee."

Seyfarth, Cheney, and Marler, "Monkey Responses to Three Different Alarm Calls."

Questions to Consider

Do you think that scientists have not been creative enough in testing whether nonhuman species are capable of language? Have they been too anthrocentric in imposing a human communication system onto a nonhuman mind? Can you think of a better approach?

5. GENES, BRAINS, AND EVOLUTION

Being exposed to language is not enough to ensure its development. This lecture explores the genetic and biological landscape that allows language to thrive in humans but not other species.

Basic Background Information

The latest estimates show that our bodies contain approximately 35 trillion human cells. (Aside from human cells, there are other cells present, which are largely bacteria.) Almost all human cells contain a long, coiled molecule of DNA that is organized according to 23 pairs of chromosomes. Each of these chromosomes contains hundreds or thousands of individual protein-making molecules called genes. In total, we have roughly 20,000 genes. These genes provide the basic instructions of what each cell is supposed to do.

Overlap

Within the human species, there is remarkable overlap of genetic material: We share about 99.5 percent of DNA with one another.

The concept evolutionary conservation means that basic genetic mechanisms are reused by a large number of species. Often, these are biological processes that serve basic survival functions, ranging from the small—like ion channels that modulate cell activity—to the large, such as important organs. This shared equipment is worth highlighting because it suggests that the features unique to particular species need not require completely new genes.

This logic runs counter to commonly held intuitions about language. Because language is so complex and so novel, it seems logical that there must be a special set of genes dedicated to it.

However, recall that language is not a single thing: It is a system of things. Evolution may have selected for the system, but parts of the system were borrowed from genetic material shared with other species. This is the basic idea of evolutionary conservation: Evolution often tinkers with old things to make new ones.

As it pertains to language, this view was best summed up by the cognitive scientist Elizabeth Bates. Bates did not see language as a new machine built out of new parts. Based on the principle of evolutionary conservation, Bates viewed language as a new machine built out of old parts.

There are two main genetic arguments to support Bates's view of language. The first is that there are no single genes for any complex behavior. Just like there will never be a gene for empathy, schizophrenia, or belief in God, there will never be a gene for language.

Second, there is growing evidence from molecular biology that genes involved in language are not unique to humans. As with other cases of evolutionary conservation, the genes used for language are shared among many species.

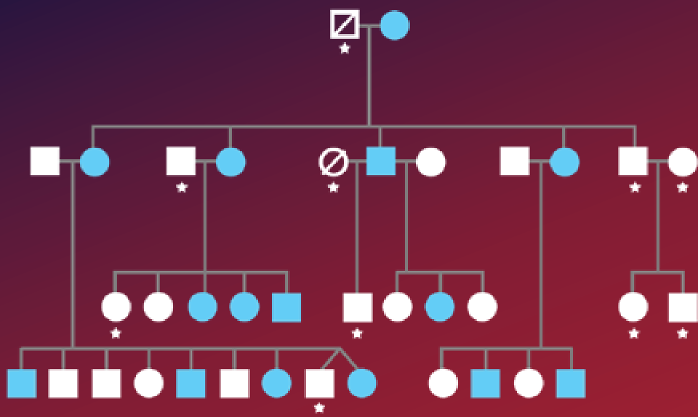
FOXP2

One particular gene has received the most attention in the molecular study of language: FOXP2. The story of FOXP2 starts with a British family in the 1980s, medically dubbed the KE family. Members of this family were observed to have an unusually high preponderance of a particular language disorder called developmental verbal dyspraxia.

One of the defining symptoms of this disorder is a difficulty combining phonemes while saying words. The disorder in the general population is quite rare, but across three generations of the KE family, about 50 percent of members had some form of it. This led to the hypothesis that there may be a genetic mechanism underlying the problem.

In 1998, neuroscientist Faraneh Vargha-Khadem, geneticist Simon Fisher, and their colleagues published a paper locating the problem on a stretch of genes on chromosome 7. Later, in 2001, using more powerful gene imaging techniques, the exact location of the mutation was identified on the FOXP2 gene. Later still, it was discovered that the problem was caused by a modification to just a single letter of the FOXP2 DNA sequence, which was traced back to a mutation passed down by the grandmother of the KE family.

Pedigree of the KE family



The FOXP2 gene produces a protein called the FOXP2 protein. The human version of this protein differs by only two (out of 175) amino acids from the chimp version and by only three from the mouse version. This protein acts on various other cells during prenatal development to affect not just the brain but also other organs, such as the heart and lungs.

Although the FOXP2 gene is implicated in many aspects of an organism's development, its effects on the brain are what directly connect it to language. In humans, the brain regions that are affected downstream by the FOXP2 mutation are areas involved in motor control of the mouth and tongue, which are clearly necessary for speaking.

Using state-of-the-art gene-editing techniques, scientists now have the capability to extract segments of human genes and insert them into the genome of other animals. For example, Wolfgang Enard has done research that snips the human mutation of FOXP2 and places it into the appropriate segment of the genome of living mice. The result is significant disruption to motor brain regions involved in controlling high-pitched vocalizations, which is how baby mice communicate with their mothers.

Enard also describes the opposite technique: inserting a fully functioning human FOXP2 gene into a mouse genome and testing what happens. Remarkably, this resulted in a proliferation of neuronal connectivity in motor regions of the mouse brain. Research is ongoing. If these changes correlate with enhanced vocal motor performance in the genetically altered mice, it would suggest that the human variant of the FOXP2 gene may have indeed been an evolutionary springboard from more simple communication to the complexities of language.

Beyond FOXP2

Beyond FOXP2, there is hope that we will discover new gene variants that connect to different aspects of language. Language is a complex system. The FOXP2 gene links mostly to phonological and some syntactic aspects of language, but other aspects of language are unrelated. Perhaps we will find genes that map onto these other parts of the system.

There are cases of other genetic disorders where some aspects of language are disrupted, but others are spared. For example, Williams syndrome is a genetic disorder caused by the deletion of 26 to 28 genes on the seventh chromosome. This causes a unique psychological and social profile.

Carolyn Mervis of the University of Louisville did some of the pioneering work on Williams syndrome, and she describes a disorder where there are severe cognitive deficits in math and spatial abilities but a relative sparing of some language abilities. In particular, phonological and semantic abilities are close to average in these individuals. However, their syntactic abilities are lower than their phonological and semantic skills, and their pragmatic abilities are extremely compromised.

These pragmatic deficits are reminiscent of problems also seen in individuals with autism spectrum disorder (or ASD). The National Institutes of Health describes children with ASD as “often socially withdrawn” and as having trouble with verbal communication.

However, some people with ASD have incredibly rich vocabularies and very sophisticated syntactic skills. This suggests an interesting dissociation between semantic and syntactic abilities from pragmatic skills.

To sum up, here are a pair of takeaways from this section of the lecture:

- Because language is a complex system, we must recognize that different aspects of language are affected by different genes and gene networks.
- It is likely that much of the machinery of language is built on genes that are shared with other species.

Homologies in Brain Structure

A homology is a structure or a process that is shared among species due to a common evolutionary ancestor. They can be at the gene level, as with FOXP2, and also at a higher level of organization, such as cell types or organs.

Humans and many other animals share homologies related to language. For example, the chimp brain and human brain are anatomically very similar. We both share the basic hemisphere and lobe structures. Even Broca's and Wernicke's areas have homologous structures in the left hemisphere of chimps. Just as with humans, these regions are involved in the production and comprehension of vocalizations.

Even though there are many homologies between humans and our closest primate cousins, there are some major differences. For example, a human brain is much bigger than a chimpanzee brain, even when adjusted for relative body weight. Recent research by a leader of the Human Genome Project, David Haussler, suggests that these differences may be driven by a unique family of genes called NOTCH2NL. These genes emerged after humans split from the ape lineage several million years ago.

This genetic difference may also be responsible for the number and complexity of neural connections in the human brain. One recent estimate is that there are 100 trillion connections.

Neural Connections

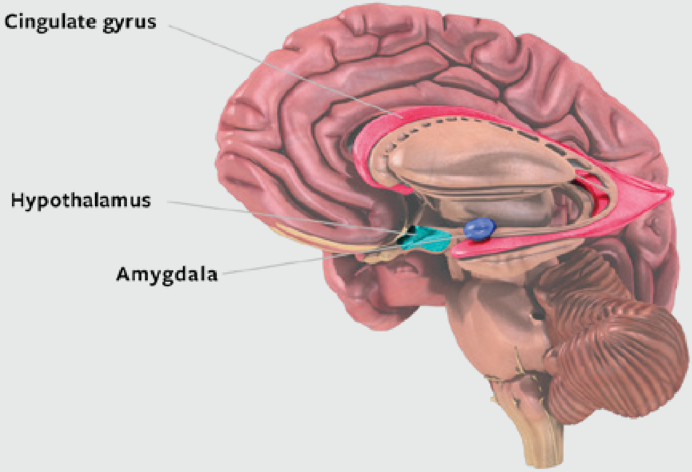
More than sheer number, the way neurons are connected is crucial. One of the novel aspects of the human brain is how many connections it has between new and old brain structures.

In all mammals, the newest part of the brain, called the neocortex, lies on the surface of the brain. Older parts, like the subcortex, lie deeper beneath the surface. Both structures are very old: It is estimated that the neocortex was added on top of the subcortex when our distant mammal ancestors diverged from reptiles during the time of the dinosaurs.

The neocortex is where most high-level cognition occurs. That is where Broca's and Wernicke's areas are located in humans. It is also where the executive functions are housed, mostly in the frontal lobe. These executive functions in the frontal lobe are involved in monitoring and regulating thoughts and actions.

In contrast, the much older subcortex is where many basic survival and emotional centers are located. One of the functions of having more neural connections between the frontal lobe and the subcortex is to have an increased ability to modulate and regulate basic impulses and drives. In general, this executive processing function of the frontal cortex is one of the most important attributes of all mammal brains and human brains in particular.

This is relevant to language when it comes to the differences in what species communicate about. Most animal communication is about basic topics such as food, territory, protection, and sex. These are all primal instincts that have direct links to survival, either immediately or in the long run. The primary neural mechanisms underlying these drives are located in a subcortical brain network called the limbic system, which contains structures such as the hypothalamus, amygdala, and cingulate. Having weak connections from the frontal lobe to the limbic system allows these lower and older brain regions to drive and dominate communication.



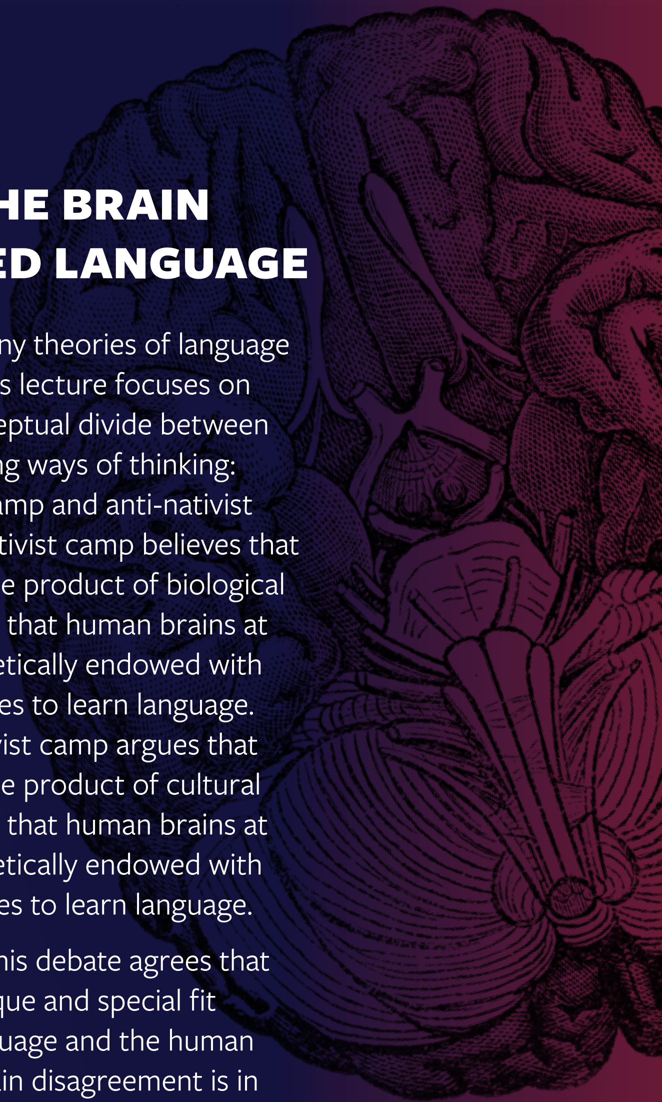
Matters are different in humans. Because we develop much stronger connections between the frontal cortex and the limbic system, humans have much more control over what they communicate about. Humans still have plenty of the basic limbic system urges, but our frontal lobes have liberated us from constantly focusing on them. In addition to freeing us up to talk about a wider range of things, the frontal lobe has helped us learn how to be more reflective about our behavior and the behavior of others.

Suggested Reading

Fisher and Vernes, "Genetics and the Language Sciences."

Questions to Consider

Elizabeth Bates makes this claim: "Language is a new machine built out of old parts." What other aspects of the human mind might also be constructed this way? In contrast, what aspects of the mind might be new machines built out of new parts?



6.
HOW THE BRAIN CREATED LANGUAGE

There are many theories of language evolution. This lecture focuses on a broad conceptual divide between two competing ways of thinking: the nativist camp and anti-nativist camp. The nativist camp believes that language is the product of biological evolution and that human brains at birth are genetically endowed with specific abilities to learn language. The anti-nativist camp argues that language is the product of cultural evolution and that human brains at birth are genetically endowed with general abilities to learn language.

Everyone in this debate agrees that there is a unique and special fit between language and the human brain. The main disagreement is in what initially drove this relationship: Did the brain adapt to language, or did language adapt to the brain?

The Nativist Proponents

Proponents of the nativist camp include linguists like Noam Chomsky and psychologists like Steven Pinker. They believe that the human brain gradually evolved something called a mental organ that was specifically designed for language.

The idea is that at some point in our evolutionary past, there was a genetic mutation that changed our ancestor's brains, transforming their regular communication into something more like language. Because this type of communication was so adaptive and so key to the survival of the individuals who used it, it rapidly spread language genes throughout the population from one generation to the next.

The Anti-Nativist Proponents

In contrast, the anti-nativist view approaches the relationship of language and brain in a totally different way. Morten Christiansen and Nick Chater's theory of language evolution turns the language/brain relationship on its head. Instead of viewing language as shaping the brain, they see it the other way around: The brain has shaped language.

Christiansen and Chater point out that a fundamental tenet of natural selection by evolution is that organisms need stable environments to adapt to. Because it can take millions of years for an organism to radically change itself, it requires that the new environment does not also change. The theory suggests that language is not part of our genetic endowment at birth but rather a cultural invention of our unique brains.

Reconciling the Views

Nativists and anti-nativists agree that the human brain is genetically endowed with some impressive cognitive and social skills. These skills apply to more than just language; for example, they might have helped our ancestors in domains such as hunting and building. In psychology, skills that serve multiple functions are called domain-general.

One likely scenario is that humans possessed some powerful domain-general skills in our evolutionary past that they co-opted to create language. Perhaps some individuals in a community started to apply their general skills of problem solving, pattern recognition, and perspective taking to how they communicated with others in their community. Over time, from one generation to the next, it is not hard to imagine how these communication skills could have gradually transformed to become more and more like what we now call language.

This is the genius of Christiansen and Chater's theory: There is no need to posit any special genes for language. Language could have arisen out of old genes that were simply repurposed for language.

However, one large question is this: If language didn't arise out of a specific genetic change to the brain, what general brain changes gave birth to language? Scientists are a long way from answering this question. Scientists do not even agree when language first evolved: Estimates are anywhere from 100,000 years ago to 4 million years ago.

Without knowing the timeline, it is very hard to know what changed in the brain to enable language. There are many theories, but most of them share one common denominator: the prefrontal cortex. Archaeological records suggest that over the past 2 million years, the human brain has tripled in size, and much of that growth was concentrated on the frontal lobes. Connectivity plays a role as well.

Putting this all together, one reasonable hypothesis is that the frontal lobes of our prelanguage ancestors evolved to become better problem solvers, pattern recognizers, and perspective takers. These general skills supercharged our communication system, giving it the spark that would eventually turn it into language.

Yet another question emerges, though: How did domain-general skills of the brain help our ancestors turn general communication into what we now call language? To put it in Christiansen and Chater's terms, how did the brain shape language? Four lines of evidence provide clues into how this may have happened.

Evidence Line 1: Written Records

First, we can use written records to understand how languages have changed over time. One way languages change over time is that they become more learnable. When a language propagates over several generations, many aspects of the language that are hard to learn become less prominent, and many aspects that are simple to learn become more prominent. Along these lines, languages change to exploit the strengths of human cognition. For instance, the fact that humans are good at taking different perspectives allows our pragmatics to become less blunt and more refined. The takeaway point is that languages don't change randomly. They are constrained by the people using and learning them.

Evidence Line 2: Modern-Day Language Creation

A second set of clues comes from modern-day language creation. Take, for example, the Al-Sayyid Bedouin community, which comprises about 3,500 people living in an isolated village in the Negev desert. Largely because of their isolation, they have had an unusually high rate of congenital deafness since the mid-1930s. This makes for a fascinating question: How do these deaf individuals communicate?

Al-Sayyid Bedouin community

That question was answered by a team of international researchers: Mark Aronoff and Carol Padden in the US and Irit Meir and Wendy Sandler in Israel. The answer is that they have invented their own language called Al-Sayyid Bedouin Sign Language. This is a fully functioning language that has evolved over time. This language's establishment and evolution suggest that some general skills may be innate, and learners may use those to mold the language as they acquire it. In this way, the brain is shaping the language.

Evidence Line 3: Computational Linguistics

A third line of work comes from an interdisciplinary field called computational linguistics. This field brings together computer scientists, philosophers, psycholinguistics, anthropologists, and neuroscientists who use computers to simulate language development, evolution, and change.

One of the leaders of this field, Simon Kirby of the University of Edinburgh, did a series of studies in which he created a computer program that taught virtual learners novel symbols and meanings over many trials through a process of iterated learning.

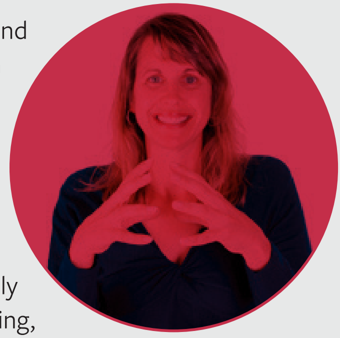
Eventually, there emerged a systematic organization that looked a lot like language. From these results, Kirby concluded that the virtual learners imposed organization on what they were learning at every iterative step to make it increasingly easier to learn for the next generation.

Although a far cry from real language evolution, this is a useful existence proof. It shows that linguistic complexity can arise from very humble beginnings. It also suggests that languages are dynamic and change even if learners do not.

Evidence Line 4: Laboratory Studies

The fourth line of research involves using this iterative learning paradigm with real live people. Kirby and colleagues have done a number of these studies in the laboratory. Kirby has replicated the computer simulation results with humans, and he has shown that change can happen over far fewer trials.

In a study with Erica Cartmill, an expert on hand gestures, human subjects were asked to learn and teach the meanings of hand gestures that were paired with dynamic scenes on a video, like a ball rolling or bouncing down an incline.



Among early generations of learners, the gestures that people produced were extremely idiosyncratic. After only 10 iterations of learning, the form and order of gestures all became much more uniform, both within and across subjects. It seems that just like virtual learners, real learners impose structure to make the learning task easier and more systematic over time.

Taken together, these four lines of work suggest that brains do not necessarily need to change to make a tight fit with language; the very act of learning itself may exert a powerful pressure that turns unstructured communication into structured language.

The Nativist Defense

Most experts now accept the anti-nativist and cultural-learning mechanism for language evolution. However, accepting this does not necessarily mean rejecting the nativist, biological-adaptation account entirely. Both mechanisms may be right on different timeframes.

Even if communication originally adapted itself to the brain, it did eventually evolve into what we now call language. And once it became language, what was to stop it from exerting its powerful influence little by little back on the brain? Brains do change over evolution; they just change more slowly than language.

There is good reason to believe that brains do adapt to language. For example, if our ancestor’s brains became used to using a tool with such incredible power, why wouldn’t their brains eventually change to become even more receptive to language?

When the brain has grown so accustomed to using language to get things done, it becomes a default way to pursue goals. When we so regularly and effectively achieve those goals with language, this feeds back on the brain: The more useful language is, the more the brain adapts to become receptive to it.

Suggested Reading

Christiansen and Chater, *Creating Language*.

Dennett, *From Bacteria to Bach and Back*.

Sandler, Meir, Padden, and Aronoff, "The Emergence of Grammar."

Questions to Consider

Can you think of examples of cultural memes that live outside our heads but are part of our minds? For example, the philosopher Daniel Dennett argues that religious stories are one such meme. Do you agree with him?

7. GESTURE AND THE ORIGINS OF HUMAN LANGUAGE

This lecture looks at how different timeframes converge across different levels of analysis to tell a story of what our earliest attempts at language might have looked like. The lecture does so by highlighting an everyday behavior that often flies under the radar: hand gestures.

Additionally, this lecture presents the claim that the human body—particularly the hands—was the foundation on which humans initially built language. To support this claim, this lecture puts together four different pieces of a puzzle.

The first piece comes from neuroscience: Spoken language and manual gestures are bound in the brain. The second piece stems from gesture's present-day prevalence: It is everywhere. The third considers how humans use gestures uniquely compared to other species. The fourth concerns the many positive functions of gesture for present-day communication.

Neuroscience

Most scholars now believe that language is not a premade and specialized module in the brain at birth; instead, they see it as emerging from more general cognitive and social skills combined with physical interactions with others over development.

Gestures might have functioned as an early precursor to language. One basic function of a gesture is to represent things not in the here and now. For example, our ancestors could point to places out of sight (over a hill or in a cave) or mime building a fire by flinting rocks that weren't actually present.

However, direct archaeological support for this claim is difficult to find. Unlike the origin of actual physical tools, there are no fossils for language and gesture. Because of this, one approach is to study the brain structures of present-day humans to reveal clues about the past.

Human language is built on brain regions that contribute to controlling the hands. For example, structures in the left hemisphere involved in language are also involved in grasping objects.

The overlap between language and action in the brain is not just general; it is highly specific. We know from the pioneering work of neurosurgeon Wilder Penfield that the human brain is organized in a topographical way, like a city with distinct but interconnected neighborhoods. Additionally, Friedemann Pulvermüller of the Free University in Berlin showed that language was also mapped onto motor areas of the brain.

Work like this has led to a theory of brain functioning called simulation theory, which states that one way we understand language (and concepts more generally) is by neurally simulating how we would actually interact with real objects in the world. Language uses the body just as much as the body uses language.

Prevalence

If gesture is still linked to speech in our current language use, this would suggest an even tighter relationship in our past. Research shows that people of all ages, languages, and cultures gesture when they speak. In fact, children gesture before they speak.

Gesture accompanies the nearly 7,000 distinct spoken languages documented in the world. It is not new to the scene: Gesture has been depicted in religious art for millennia in all parts of the world.

David McNeill, a researcher at the University of Chicago, has the most established theory for why we gesture. McNeill argues that the reason we gesture when we speak is that gesture and speech are part and parcel of language. They are actually two different—but tightly coupled—incarnations of our thoughts.

Because speech is highly arbitrary and conventional, words are not inherently related to their meanings. On the other hand, gesture is imagistic and idiosyncratic, which means that the form of a gesture directly relates to its meaning. McNeill's theory states that gesture and speech are simply two sides of the same thought, and only by considering them together is it possible to understand someone's complete message.

Blind Gestures

Blind people use gestures, including when they are talking to other blind people.

Uniquely Human Usage

If gestures are so prevalent and such a fundamental part of language in humans, we should use them differently than animals that do not have language. The leading expert on comparing gestures in humans and nonhumans is Michael Tomasello.

Tomasello theorizes that human language is unique not because it is special in and of itself. Instead, it is special because it is built on special social skills that have evolved distinctively in humans.

People are driven to share attention and cooperate with one another. People are also remarkable mind readers. For Tomasello, both of these basic social functions manifest themselves first in children's hand gestures. Even though animals, such as chimps, can be trained to point at things, their gestures all attempt to satisfy immediate desires, such as obtaining a reward. Human gestures have two additional functions.

One is simply to share attention with other people. To appreciate this, consider how much pointing happens when a person reads a picture book to a young child. The child is not requesting anything: If she points to a picture of the moon, she does not actually want the moon. She simply wants to share attention to it.

A second unique function is to offer help. Imagine a person in a café seeing another customer drop a $10 bill as she walks by. Most people would reflexively make eye contact with the person and point to the money on the ground, even though they would profit from taking the money for themselves. This cooperative use of gesture is distinctive to humans.

In both of these examples, note the complex mind-reading that is required. In the first case, the adult and the child each have to know that pointing to the picture of the moon is not a request for the moon, and crucially, they have to know that the other knows it too. In the café example, the other customer has to know that the pointer is not requesting the $10 bill for themselves.

According to Tomasello, these differences in how humans and nonhumans use and interpret gestures are at the heart of what makes us different from all other species. Humans use gesture as a way to read minds and coordinate actions with others. This mind-reading and social cooperation are what language is all about, and the fact that gesture is such a handy tool for doing it speaks volumes about its importance.

Sign Language

The neural link between language and the hands is perhaps most apparent in the case of sign language. Like spoken languages, sign languages operate according to a set of grammatical rules that vary by language but are consistent within the language. This gives sign the same power as spoken languages to create an infinite number of meanings by stringing together signs in novel ways.

The External Functions of Gesture

People do gesture for others, but that's only half the story. Scientific research shows that we also gesture for ourselves. These can be thought of as the external function—we gesture for the benefit of others—and the internal function—we gesture for our own benefit. A single gesture often has both functions.

First, consider what gesture does for other people. Outside of sign language, the clearest example of a gesture designed for other people is an emblem. Emblems are conventionalized hand shapes that often stand alone in their meaning. The OK sign is an emblem.

According to Adam Kendon, one of the pioneers of modern gesture research, emblems have the advantage of not needing speech, which works well in situations requiring discretion or stealth. Another advantage is that they are effective from a distance in noisy environments.

A second function is that gestures help make a message clearer. Additionally, because gesture adds meaning to speech, it can be used to help people learn new things. Co-speech gestures also help a person make a better impression. For example, in the context of the classroom, research shows that students like teachers who gesture during a lecture more than ones who do not. Students also say that they learn more from teachers who gesture.

Gestures can also function to build rapport between people. As many successful salespeople and politicians already know, subtly mimicking another person's gestures can increase persuasiveness.

The Internal Functions of Gesture

Embodied theories of language not only explain why we gesture; they actually predict it. Gesturing makes speaking much easier. Moving your hands can move your mind. An extreme example of this is what Susan Goldin-Meadow calls gesture-speech mismatches. A mismatch is when someone says one thing with their words but another with their hands. Goldin-Meadow shows that only the combination of both things reveals the complete thought.

For example, adults know that changing the appearance of a tall glass of water by transferring it to a short, wide dish does not change the essence of that thing. The amount of water has not changed, only the appearance. However, a seven-year-old would likely be fooled by the change of appearance.

Just before seven-year-olds figure this out, their gestures often lead the way. Goldin-Meadow's research shows that children who are just at the transition of not being fooled by appearances produce gestures that complement their speech: If they speak about the different heights of the containers, they simultaneously gesture about the different widths.

In this way, the information in the gesture compensates for the content of the speech and reveals a more sophisticated understanding: The containers may be different heights, but that is offset by their different widths. This basic phenomenon applies to any problem where there is a significant transition in knowledge, and it occurs in children as well as adults.

Gesture reflects peoples' changing knowledge, but it goes beyond that: It also changes their knowledge. For example, allowing someone to gesture on a hard math problem can give new insights into how to solve that problem. On the other hand, prohibiting someone from gesturing disrupts their ability to think.

Suggested Reading

Church, Breckinridge, Alibali, and Kelly, eds., *Why Gesture?*

Kelly, McDevitt, and Esch, "Brief Training with Co-Speech Gesture Lends a Hand to Word Learning in a Foreign Language."

Tomasello, *Origins of Human Communication*.

Questions to Consider

If you think about the five different components of language, which ones lend themselves more—and which ones less—to co-speech hand gestures? What aspects of language may have started in the body and then were liberated from it over evolution?

8. DEVELOPMENT: A MIND UNDER CONSTRUCTION

This lecture discusses three big mechanisms for development: innate knowledge, powerful learning tools, and unconscious tuition from others. These mechanisms interact over development to create a dedicated face-processing region in the brain.

Chuck Close and the FFA

The artist Chuck Close paints giant, abstract portraits that are made up of hundreds of little boxes on a grid that—up close—look like a jumble of pixelated colors. However, when viewers stand back at a distance, the pixels come together to create the distinct image of a face. The part of the brain that flips this switch from confusion to clarity has been called the fusiform face area, or FFA for short.

This lecture's guiding question involves the FFA: Is the FFA designed to process faces specifically, or could it have served a more general function, like processing any type of meaningful visual information?

Development

To introduce the scientific study of human development, it is necessary to have a philosophical foundation for the big issues. The biggest issue concerns the age-old question of nature and nurture. Historically, these have been treated as black or white options: Either people are born with what they need to know about the world, or they need to learn it from experience.

These extremes have carried a legacy into modern-day linguistics, neuroscience, and psychology, but they have given way to a more balanced view. It is now commonly accepted that the human mind is the result of both nature and nurture.

The most exciting questions now in developmental psychology and neuroscience are concerned with determining exactly what is built into humans at birth, and how and when those things interact with the environment throughout development.

A helpful guide in addressing these questions is the book *The Scientist in the Crib*, written by Alison Gopnik, Andrew Meltzoff, and Patricia Kuhl of the University of Washington. The book takes an approach similar to this course's 3-D framework, and it outlines three major mechanisms that drive development.

Those mechanisms are innate knowledge, powerful learning tools, and unconscious tuition from others. The first and the third best correspond to the classic nature-nurture dichotomy, and the middle one serves as a bridge between those two.

Innate Knowledge

When developmental psychologists speak of innate knowledge, they are talking about the baggage that humans have accumulated over the course of evolution that they bring to personal development. There is vigorous debate about the nature of this knowledge.

On one hand, there is the domain-general view. Domain-general knowledge refers to built-in abilities that are very broad and can be applied to many different domains. The other type of innate knowledge is domain-specific knowledge, which is something that is innately specified for a very particular function.

This idea brings up the guiding question about the FFA: Is it designed to process faces specifically, or does it serve a more general function? Most researchers now believe that the FFA serves a more general function at birth. Evidence for this comes from clues on multiple levels of analysis and different timeframes. Here are two clues for now:

First, although research does show that babies have a clear preference for faces over other objects at a very early age, findings suggest that a more general mechanism, such as symmetry detection, might drive our early preference for faces. Additionally, babies also look at animal faces for longer than objects, which points away from a specific preference for human faces.

The second piece of evidence comes from neuroimaging studies on infants. Rebecca Saxe and her team at MIT investigated brain activation of babies as young as four months old when viewing images of faces versus natural scenes. Although there were large-scale brain areas that differentiated faces and scenes, it was not localized in the FFA, like it is in adults.

Powerful Learning Tools

It seems that the brain must undergo some significant changes in order for the FFA to become specialized for processing faces. This idea leads to the topic of powerful learning tools. Even with innate knowledge—specific or general—we also need some inborn cognitive and social skills to help us build on that knowledge.

By far the most influential pioneer of innate learning mechanisms was the Swiss developmental psychologist Jean Piaget. The ability to make associations and experience emotions are necessary innate tools. According to Piaget, children also possessed much more sophisticated tools beyond those.

For example, Piaget argued that children are innately driven by curiosity, and they are predisposed to a type of systematic thought and action that would be familiar to any laboratory scientist. Just like scientists, babies are innately capable of making predictions about the world, manipulating things in it, and observing and recording the outcomes. This is why Gopnik, Meltzoff, and Kuhl referred to babies as "scientists in the crib."

Much of babies' scientific exploration is done through direct experience—that is, learning by doing. Piaget also stressed another powerful learning mechanism: learning by watching. Imitation is one of the most powerful tools that humans have for learning about the world.

Plasticity

The grandmother of all mechanisms that unites all learning and development is the neural process of plasticity—that is, the property of the brain that enables changes to its neural connectivity. The idea is fairly simple: If a particular neural connection produces useful behavior, that connection is strengthened. If it is very useful, it might even sprout new connections to strengthen it further. However, if a connection no longer serves a useful function, it is weakened or even eliminated.

Our brains are much more plastic early in life versus later in life. Plasticity functions to help us specialize during development. Humans come into the world with an empty survival kit packed into our DNA. We have to learn to survive. This is in contrast to many other species that enter the world ready to go.

We use plasticity to learn what is important for our survival. Because humans inhabit such a complex physical and social world, it is not possible to genetically build in everything we will need to survive.

The fact that adults have such a clear neural architecture for processing faces—and infants do not—suggests that plasticity has sculpted our brains during development to make it this way. This reorganization comes with some real benefits: Because faces convey such important social information, having a fully dedicated brain region to quickly and accurately process them would serve a real survival function.

This clarifies the tradeoff between being more plastic early in life and less plastic later in life: Being open to change early on helps the brain learn and commit to what's important, and locking in later allows it to process that information much more efficiently.

Prosopagnosia

The FFA does not work properly in Chuck Close. The artist has a severe form of a disorder called prosopagnosia, which in his case is a hereditary condition that makes it extremely difficult to recognize faces. According to Close, the reason he paints faces in his signature style is because it is the only way he can make sense of them.

This raises a big question: What causes the brain to lose its plasticity and become more rigid and specialized? One possibility is that it is just an innate mechanism. This is true to some extent, but scientists believe that a more powerful force is responsible. This is Gopnik, Meltzoff, and Kuhl's third and final mechanism of development: unconscious tuition from others.

Unconscious Tuition from Others

Unconscious tuition from others has to do with a sort of guidance, but not in the traditional sense. Explicit guidance can powerfully shape the mind; for instance, that is why we have schools. Unlike its formal counterpart, unconscious tuition is done spontaneously, naturally, and inadvertently by parents and other adults, older siblings, and peers.

Children are prolific learners, and they start their informal education from the day they are born. Other humans bombard them with social aspects of culture, including language. Human babies are awash in words from the moment they are born.

For the first three years of life, most children hear on average more than 10,000 words a day. Some who are raised in highly verbal environments hear more than 30,000 words a day. Most of these words are not even directed at the child. They are just a natural part of the environment.

The mechanism of unconscious tuition can be applied to the example of face processing. Informal face training for humans starts on the first day. It begins when parents hold newborn babies about a foot from their own face. It continues nonstop from there.

Our brains change to more efficiently process faces with every new exposure. Capitalizing on the brain's plasticity, we dedicate a chunk of cortex specifically for faces. Real estate is expensive in the brain, so this is a big commitment.

Conclusion

Even though the FFA becomes specialized for faces, does that necessarily mean that it is innately designed for faces specifically? This was the question asked in the late 1990s by Isabel Gauthier, a cognitive neuroscientist. In a study, Gauthier used fMRI to investigate FFA activation in adults who were and were not bird experts. She reasoned that bird experts have comparable experience identifying birds as they do humans.

If the FFA is innately designed specifically for human faces, this bird expertise should not matter, and human faces should produce more FFA activation than faces of birds. If, however, the FFA is driven by visual expertise more generally, bird experts should have similar FFA activation to human faces AND bird faces.

Whereas non–bird experts showed the signature FFA activation only for human faces, bird experts showed comparable activation for both bird AND human faces. This activation was related to their behavior: The more active the FFA was for birds, the better the experts remembered their faces in a later memory test. This effect has been replicated many times, and it has even been generalized to other areas of expertise, such as images of cars and chess positions.

Findings such as these have caused most of the scientific community to stop using the term *fusiform face area*. Many now instead use the term *fusiform expertise area*. The idea is that humans are born with a part of the brain that has the domain-general ability to dedicate itself to efficiently processing highly salient and important visual information, be it faces, birds, cars, or whatever else is important. If someone is exposed to enough of this visual input, it triggers the fusiform expertise area to undergo plasticity and become specialized.

Suggested Reading

Gauthier, Tarr, Anderson, Skudlarski, and Gore, "Activation of the Middle Fusiform 'Face Area' Increases with Expertise in Recognizing Novel Objects."

Gopnik, Meltzoff, and Kuhl, *The Scientist in the Crib*.

Questions to Consider

Gopnik, Meltzoff, and Kuhl refer to babies as "scientists in the crib." Can you think of other examples beyond language where developing humans might be actively testing hypotheses about their world? For example, how might you view the so-called terrible twos or even teenage rebellion from this perspective?

9.
SPECIALIZING IN SPEECH SOUNDS

There are almost 7,000 languages on the planet, and they are composed of hundreds of different phonemes. Faced with such a diversity of speech sounds, it's not unreasonable to think that babies come into the world with very limited auditory abilities, and then, through massive exposure and experience, they start to hear the sounds of their particular language. However, that is not how evolution has solved the problem.

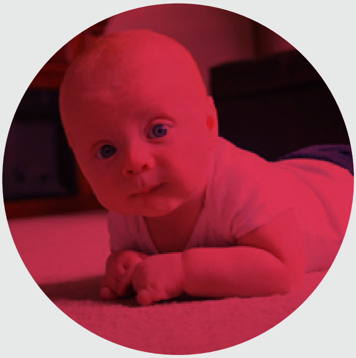
Phonetic Abilities

Rather than coming in with blank slates, babies are evolutionarily designed to enter the world with some very impressive phonetic abilities. We have learned this from a groundbreaking line of work by several researchers on infant speech development.

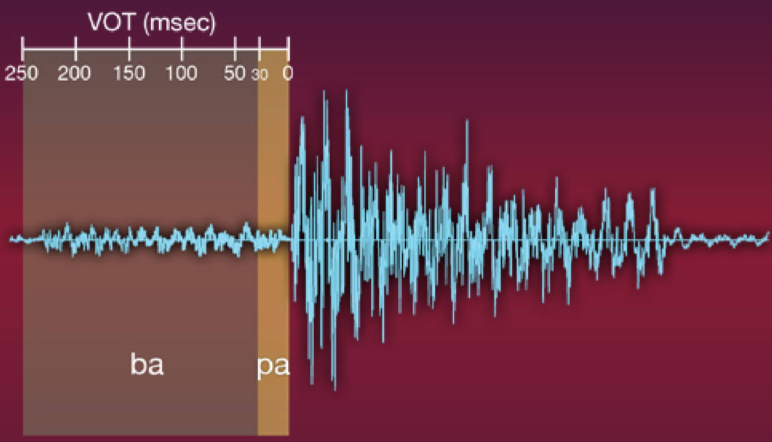
The pioneering paper was published in 1971 by the speech scientists Peter Eimas and Paul Jusczyk at Brown University. Eimas and Jusczyk were interested in whether babies could process phonemes categorically, like adults do.

For example, Japanese adults know that the short /u/ phoneme in *shujin* belongs to the category of short vowels, but the long /uu/ phoneme in *shuujin* belongs to the category of long vowels. This categorical distinction between vowel length doesn't exist in English: Elongating vowels in English may sometimes add a nuanced connotation to words, but it does not qualitatively and invariably change their meanings as it does in Japanese.

A challenge for the researchers was that it is impossible to directly ask young babies how they hear different phonemes categorically or continuously. Solving this problem was the creative insight of Jusczyk and Eimas.



They took advantage of something that babies are born to do: suck. All babies have an innate reflex to suck more when they are interested and less when they are not. The idea was to present babies a phoneme from one category over and over until they got bored and began sucking less, and then measure what happened when the babies heard a new phoneme from a different category. Remarkably, Jusczyk and Eimas found that even babies as young as one month old could categorically distinguish the sound /ba/ from /pa/.

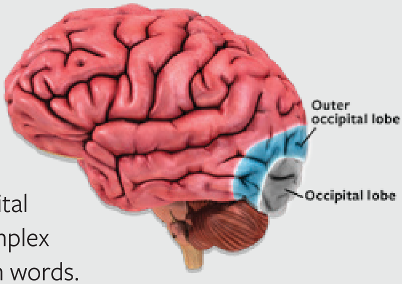


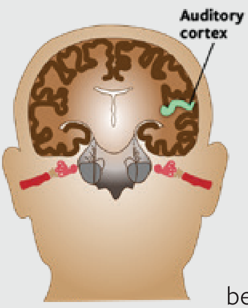
In another study, Janet Werker and Richard Tees conditioned six-month-old English-speaking infants to turn their heads when they heard a difference between two slightly contrasting phonemes. Babies could do this in English, and they could do it in Hindi as well. These babies had never been exposed to a single Hindi contrast in their entire lives, so this ability was not learned from linguistic experience. Instead, it must be innate. This finding has been replicated with dozens of languages and with younger babies, so this is a very powerful and robust form of innate knowledge.

Neural Mechanisms

Neural mechanisms underlie this phoneme specialization process. An important concept here is that of topographical organization. Different lobes of the brain have different functions; along the same lines, there are smaller regions within those lobes that have more specific functions.

For example, at the outer edges of the occipital lobe, the fusiform expertise area is specialized for processing complex visual objects like faces. This is in contrast to different parts of the visual system in the occipital lobe that are specialized for other complex objects, like furniture, plants, and even words.





The same thing is true for auditory processing. The primary auditory cortex (also called A1) is located in the superior temporal lobe along a stretch of cortex called Heschl's gyrus. After a sound reaches the ears, A1 is the first part of the neocortex that processes these sounds. The cells in A1 that process these sounds are highly organized.

Phonemes are processed in a network extending beyond A1. Scientists believe that there are dedicated and specialized cell networks for individual features of the phonemes in one's native language. The function of having specialized cells for aspects of native speech sounds is to help humans process their language quickly and accurately.

An important feature here is neural plasticity—that is, the brain's incredible ability to change itself. This is the quintessential domain-general mechanism because it applies to everything. The brain starts with some innate structure, but through experience, plasticity allows those structures to become more specialized and efficient.

Synaptogenesis and Synaptic Pruning

Two complementary aspects of plasticity are synaptogenesis and synaptic pruning. Synaptogenesis refers to the process of the brain creating an increasing number of dendrites to make new synaptic connections. Synaptic pruning refers to the process of the brain cutting back on these synaptic connections.

Research by the neuroscientist Peter Huttenlocher at the University of Chicago has shown that over the first few months of a human baby's life, A1 undergoes a rapid period of neurogenesis, but after about six months, it undergoes neural pruning.

It is now believed that babies are born with neural connections that allow them to immediately start paying attention to whatever sounds they may hear in their particular language environment. Over the first six months of life, babies start to expand the neural connections that are involved in processing native speech sounds. After that, the brain starts to prune the connections that are not involved in processing native speech sounds while strengthening the ones that are.

The end result after one year of life is a reorganized auditory system that has roughly the same number of synaptic connections in A1. However, the nature of those connections has been radically transformed. At first, the connections allowed the baby to process all speech sounds fairly well, but after one year, the neural reorganization allows the infant to process native speech sounds extremely well.

The Cost

There is a cost to this plasticity. It means that the cells that used to process phonemes in other languages are gone. These connections have been pruned away because they served no useful purpose for the developing baby.

All this has some significant consequences for how our brains hear speech sounds. Pat Kuhl is one of the leading experts on neural aspects of phoneme development, and she describes a fascinating function of all this neural reorganization: the perceptual magnet effect.

When the brain commits to certain phonemes in one's native language, it creates prototypal categories of each of those phonemes. These prototypes are useful because every speaker of a given native language produces slight variations in their phonemes. This is true even for people speaking the same dialect of English.

If the variations are too great, the magnet can't quite reach the word, and the result will be confusion. However, as long as the phonetic variations are not too great, the perceptual magnet constantly bends what it hears to assimilate variations into the prototypes. In other words, most of the time, the perceptual magnet unconsciously translates those differences into the sounds that make the most sense to a person's brain.

Brains and Distortion

Being exposed to one's native language changes a person's brain to warp what it actually hears in the world. That means that we don't have objective access to auditory information in the environment. Everything is distorted.

From the perspective of this course's 3-D framework, an important question is what possible function this could serve. One possibility is that it helps our survival. Donald Hoffman, a cognitive scientist, argues that evolution has designed humans to massively distort our perceptions.

He argues that the function of perception (and cognition more generally) is not to accurately process the world around us. Rather, the function is to help us better interact with that world. Hoffman posits that millions of years of evolution have built brains that distort reality and allow us to live in an illusion that helps us function better.

Returning to the concept of the perceptual magnet, it makes sense that our brains would gloss over variations of phonemes if it ultimately allows us to understand a wider range of speakers in a faster and more accurate way. The goal is not to hear every variation of what a speaker says; the goal is to accurately identify what a speaker means with a spoken message. That is the problem that evolution has tried to solve, so it makes sense that we would adapt our brains to do it better.

This distortion is not without drawbacks. One consequence of having a strong perceptual magnet for a person's native language is that it becomes very hard to relearn how to hear sounds in a foreign language.

Suggested Reading

Hoffman, *The Case against Reality*.

Kuhl, "Early Language Acquisition."

Werker and Tees, "Cross-Language Speech Perception."

Question to Consider

Synaptogenesis in the primary auditory cortex (A1) peaks at around six months of age, and then the process of synaptic pruning begins. Consider this fact: The prefrontal cortex undergoes synaptogenesis throughout adolescence and early adulthood, and only then does it begin to slowly prune. What is the function of these two different neural timetables?

10.
NAVIGATING A WORLD OF WORDS

There has been a great deal of research empirically investigating how young children map meanings onto words in real-life language development. As this lecture shows, human babies possess some innate and learned heuristics that give them a head start.

Patterns and Word Boundaries

From ages 6 to 12 months, babies start to narrow their perceptual focus on native language phonemes. This age range is also when they begin to understand words in their native language.

In 1996, Jenny Saffran published a paper that changed the way we think about how infants learn language. She found that eight-month-old babies are able to extract statistical regularities in continuous speech to identify words and word boundaries—that is, when one word ends and another begins.

Babies are such good pattern recognizers that they can learn what is a word—and what is not a word—from extremely limited auditory input. This is a very robust finding that has been replicated many times. Additionally, it has been extended in interesting ways, including these three:

1. The ability appears to be innate. A Finnish team of researchers has measured electrical activity of newborn baby brains and found that they also use statistical regularities of syllable combinations to identify words and word boundaries.
2. Research by Saffran's advisors, Richard Aslin and Elissa Newport, has shown the ability to detect patterns in speech probabilities is not unique to humans. Monkeys can do it too. This suggests that the skill is built on mechanisms shared with other species.
3. This pattern-recognition ability shows up in other modalities, such as vision, suggesting that it is a domain-general skill and not one specifically designed for language.

The takeaway point is a familiar one: Humans are born with some innate domain-general knowledge and powerful learning tools that allow them to get an early jump on learning language.

Identifying Meaning

Once a baby has identified a word, the baby needs to learn what the word means. Babies receive help from two places: Adults provide useful hints to clear up ambiguities, and babies have some powerful biases and heuristics that help constrain potential meanings.

Ellen Markman was one of the first developmental psychologists to systematically study the cognitive constraints on children's early word learning. She identified three in particular that greatly help children: the whole object assumption, the mutual exclusivity bias, and the taxonomic assumption.

The whole object assumption refers to the tendency of a language learner to think that a word refers to a whole object and not its parts. This bias can cause children to make occasional mistakes, but overall, it is very helpful.

The mutual exclusivity bias is one of the most robust heuristics that people use in understanding language. Essentially, this bias keeps people from assigning new words to objects they already know. (Note that in practice, items often have multiple labels, however.)

Markman's third constraint is the taxonomic assumption. Once children move past mutual exclusivity and have accepted that objects often have multiple labels, they start to appreciate that words often refer to categories of things. For example, if a person were to point to a dog, she could label it as a *dog* or more generally as a *pet* or *animal*.

Category Labels

Researchers have explored how early babies treat new words as category labels. Babies are surprisingly savvy at very young ages. In one remarkable study, Alissa Ferry, Susan Hespos, and Sandra Waxman tested categorization at the raw age of three months.

They presented these infants with pictures of different species of fish. With each picture, they also played an audio track that said: "Look at the toma. Do you see the toma?" They did this eight times with eight different pictures of fish, but they used the same audio track for each one. Next was the test phase: The babies were shown two pictures. One was a new exemplar of the fish category, and one was a picture of a totally new category: a dinosaur.

The key measurement was to record which objects the babies looked at more. Remarkably, these preverbal infants differentiated the two pictures, looking longer at the image within the same category, the fish, than the one in the new category, the dinosaur.

A relevant question here is: Does this really have to do with babies using speech to form categories, or does it just indicate that the babies had gotten into the habit of looking at fish, not dinosaurs? The researchers addressed this valid question by repeating the exact same study with a different set of three-month-olds, but there was one change: They replaced the auditory naming of the objects with an auditory tone during the exposure phase. There was a sound that accompanied each picture, but no speech.

After eight exposures of fish and tones, the babies were shown the two objects: a new fish and a dinosaur. The babies did not differentiate the two pictures. It was as if they had not been forming a category at all without a repeated verbal label.

It's possible that the babies didn't really understand what the words meant, and they just learned that when they hear language and see similar things, they should start grouping those things in their minds.

However, these findings are still impressive. They mean that very young children might be using language to help orient their minds to categorize things in the world, and this could help them constrain their early guesses about what words actually mean.

Humans are not the only ones who use language to categorize the world. There is evidence that dogs can learn words in a categorical way.

Suggested Reading

Markman, "Constraints Children Place on Word Meanings."

Saffran, Aslin, and Newport, "Statistical Learning by 8-Month-Old Infants."

Questions to Consider

The film *Arrival* is about a linguist trying to decipher the language of an alien species that has landed on earth. Watch that film and consider Quine's conundrum. Given that aliens may differ from humans in every way—biologically, psychologically, and socially—would it ever be possible to truly understand an extraterrestrial mind? For that matter, will humans ever truly understand other terrestrial minds? If this intrigues you, check out the philosopher Thomas Nagel's provocative essay called "What's It Like to Be a Bat?" When you finish, try to answer his question.

11.

LEARNING TO PLAY THE GAME OF LANGUAGE

The pragmatics of language is very important. Without understanding the richness of social intentions, motivations, and context, there is no hope for people to have successful communication. This lecture discusses what young children know and learn about their social world and how they use that information to navigate the endless ambiguities of language. It also looks at some interesting studies related to language and the brain.

Joint Attention

In the 1970s, the psychologist Jerome Bruner performed some classic research. Using cutting-edge technology of his time, Bruner analyzed videotapes of nine-month-olds spontaneously interacting with caregivers in their homes. He was looking for social behaviors that could be signs that babies were learning about the goals, motivations, and intentions of adults.

Bruner made many interesting observations, but the one that best links up with language learning is a behavior he dubbed joint attention. This referred to how babies seemed especially interested in sharing visual focus on objects with adults. Bruner argued that when babies and adults are looking at the same thing, they mutually know that they're both looking at that thing.

Given that joint attention emerges just before children start speaking, it likely serves as a mechanism for early word learning. Here is how it might work: When an infant and adult mutually know that they are looking at the same object, the infant infers that any word that the adult says must refer to the thing that they are both looking at. It is as if the child and adult have a tacit agreement that labeling objects always happens in the social context of joint attention.

Evidence of Joint Attention

Because infants hear thousands of words every day, having a social mechanism that links some of those words to particular objects in the environment greatly simplifies the learning task. However, this raises a question: What is the evidence that infants use joint attention to actually learn words?

In one of the first systematic attempts to explore this question, Dare Baldwin, a developmental psychologist, did a series of studies on children in the throes of early word learning. In one study, Baldwin was interested in whether 18-month-olds would learn a name for a toy if there was no joint attention with an adult.

The children were placed in a room with a few novel toys in it. Crucially, these were toys that they had never seen, so there is no way children could have known the names for them. When they started playing with the toy that interested them, an experimenter labeled it by saying, "Dawnoo. There's a dawnoo."

This labeling occurred in two different conditions. In one condition, the experimenter was right next to the child looking directly at the toy. In the other condition, the experimenter was next to the child but was sitting on the other side of an opaque screen. The child couldn't see where the experimenter was looking. In both cases, the child heard the exact same speech—the only difference was that in one case, the child and adult shared joint attention, and in the other, they did not. The main finding was that when there was joint attention, children frequently mapped the word *dawnoo* onto the toy they were playing with. When there wasn't joint attention, children did not reliably learn the new word.

Lending a Hand

Eye gaze is not the only useful nonverbal tool in the word learning process. Hand gestures also play a huge role. Infants and adults communicate with hand gestures well before they start communicating with words. Pointing gestures, in particular, are especially prominent.

Babies point to get things they want and to comment on things and inform people about them. For example, Ulf Liszkowski and his colleagues have done a series of experiments with one-year-olds showing that they produce gestures to serve both of these functions—to comment and to inform.

It is notable that much of this early nonverbal communication happens before infants even begin to speak. This implies highly sophisticated perspective-taking skills for preverbal infants. For example, pointing to interesting objects suggests that infants believe that other people will also find the same things interesting.

The flip side is also likely: Paying attention to where adults point helps an infant understand what is interesting to other people. All of this early exchange of information helps a baby understand what sorts of things might be interesting to others, and this could be very useful for understanding what words refer to.

Taking Perspective

Perspective taking is the key to the savvy pragmatic use of language. Children have some decent perspective-taking abilities even within their first year of life, but as they head into their second year, they go to the next level.

This period marks the start of a gradual transition from having a somewhat egocentric view of the world toward one that carefully considers the different perspectives of others. There is even a name for this skill: theory of mind, or ToM for short.

This gradual development of perspective-taking skills is highly correlated with language development. As perspective taking becomes more sophisticated, so does language. This has led some to hypothesize that perspective taking is a key mechanism for language development. That certainly seems to be the case for things like joint attention and early word learning, and it is possible that improvements in theory of mind help with later stages of language development as well.

Derailment

One way to approach this link between perspective taking and language acquisition is to consider cases in which perspective taking goes off the tracks in development. An example is autism spectrum disorder (ASD). Children with ASD exhibit significant language impairments, and they also have difficulty taking the perspective of others.

Additionally, they gesture differently. Developing children will typically point to things to request them. These are called imperative gestures. They also gesture to comment and to inform. In contrast, the gestures of infants and toddlers with ASD are almost always imperative.

Eye gaze is also different. Most children with ASD fail to engage in joint attention, and they often don't make eye contact with people in the same way. In one eye-tracking study, Warren Jones and Ami Klin showed that for the first two months of life, children at risk for autism found eyes equally interesting as typically developing children—they looked just as long at them. However, from ages two to six months of age, the group at risk of ASD looked less and less toward eyes compared to the control group.

All children are born with an innate preference for looking at human eyes. Most children quickly realize that the eyes offer social clues about people's interests and intentions. This realization, in turn, causes even more attention to the eyes. From there, the cycle repeats itself, and attending to the eyes eventually becomes a habit by the time children start learning language.

Things are different for children with ASD. Although they start life just as interested in human eyes, for some reason, they never learn that eyes are a gold mine of social information. They never develop the habit of attending to the eyes during language learning.

The Empathy Switch

The condition of psychopathy also presents intriguing links between perspective taking and language. The popular stereotype of a psychopath is a cunning person with no empathy, but research suggests that psychopaths may be more empathic than previously thought.

In a 2013 study, Christian Keysers and colleagues teamed up with Dutch forensic psychiatric clinics to measure empathic brain responses of prisoners diagnosed with psychopathy. Under very close guard, the team had inmates come into the lab to receive fMRI scans of their brains while they viewed pictures of people in pain.

In non-psychopath control subjects, these images strongly activate many of the same parts of the brain that are active when people are actually in physical pain. This is interpreted as a type of neural empathy: People understand the pain of others by simulating it in their brains.

Psychopaths are different. When the inmates were in the scanner, they showed much less empathic activation in these pain regions, suggesting that they had difficulty taking the perspective of the people in the pictures.

When the inmates were explicitly asked to take the perspective of the people in pain, their results looked much more like the control group's. However, there were some big differences in the frontal lobes, suggesting that psychopaths were engaged in a much more strategic and controlled form of thinking.

This finding adds nuance to the traditional view of psychopathy: It's not that psychopaths are incapable of taking the perspective of others. Rather, they are simply very strategic about when they do it. Empathy is a default mode for most people, but it appears to be optional for psychopaths.

The study suggests that one reason why psychopaths can be such smooth talkers is that they have an empathy switch: When it serves their purposes, they can turn it on and see things from another person's perspective. After all, the best con artists are masters at telling people what they want to hear.

Matters change abruptly after the charm has achieved its goal. Once they have hooked and drawn someone in, having empathy may get in the way of doing bad things to a victim, so it would be highly adaptive for psychopaths to turn it off. This is the worst of both worlds: using empathy to gain trust and then shutting it down to do harm.

Suggested Reading

Baldwin, "Infants' Contribution to the Achievement of Joint Reference."

Jones and Klin, "Attention to Eyes Is Present but in Decline in 2–6-Month-Old Infants Later Diagnosed with Autism."

Question to Consider

Brain-to-brain communication has always been a popular science fiction trope, but with the development of new technologies, entrepreneurs are working hard to make this a reality. Considering what you know about pragmatic communication, what might be gained and lost by such direct communication that bypasses language?

12. MASTERING THE STRUCTURE OF LANGUAGE

This lecture discusses how the mind is wired from birth to see structure in language. It is also wired to use this structure to organize and communicate information. As with other aspects of language development, this innate mechanism interacts with linguistic experience over childhood to allow the design of language to emerge.

Pattern Recognition and Hypothesis Testing

The syntax and grammar at the core of a language rely on the ability to produce, recognize, and predict patterns. Pattern processing is one of the most widespread and useful mechanisms that humans innately possess.

Infants constantly collect data and test hypotheses about their world. The general process underlying this cycle is a type of probabilistic learning called Bayesian learning. The basic idea is that we make predictions about the world based on a combination of two things: current evidence and prior knowledge. The power of Bayesian learning is that once we test a prediction or change our prior knowledge, it updates the probabilities of future predictions. This cycle is on a never-ending loop.

Bayesian learning allows for a very fluid and dynamic process of educated guessing. Predictions can constantly be updated based on new evidence. Additionally, learning an important new piece of information can change a person's prior knowledge, and this can radically change how he or she interprets patterns of evidence. Bayesian learning also allows for the creation of powerful, flexible rules about the world.

Less Is More

Bayesian learning is a nice example of a constraint on language acquisition that brings something extra to the learning process. However, some language-learning aids involve subtracting rather than adding. One example illustrating this is a hypothesis by Elissa Newport, aptly named the less-is-more hypothesis.

Newport's idea arose in response to a longstanding observation in language learning: Children learn language better than adults—a lot better. We know this from decades of research on second language learning (or L2 learning, for short), where children consistently outperform adults in terms of L2 pronunciation, morphology, and complex syntax. If you recall, Pat Kuhl had one explanation for this paradoxical finding: Children's brains are much more plastic than adults' brains, and this plasticity helps them keep their options open.

Newport provides a different explanation: In addition to having brains that are more plastic, children possess a much more limited cognitive capacity than adults. Because adults are capable of encoding and retaining much more information than children, they learn linguistic structure in a more holistic way. In contrast, because young children have a much more limited memory system, they learn linguistic structure in a more compositional way.

For instance, an adult may learn a whole word made up of three morphemes without realizing that it is composed of those three morphemes. For every new word that adults learn, they map the whole word onto an independent meaning. It is only after some time that they realize that individual morphemes are contained in the word, which causes them to try to analyze the parts after they have encoded the whole. This is a convoluted and cumbersome process familiar to anyone who has ever tried to learn a foreign language as an adult.

In contrast, because young children can't encode and remember as much as adults, they initially only remember parts of words.

Over time, this sort of piecemeal learning will actually be more useful for the child to appreciate the morphological complexity of the language. In this way, processing less information allows children to learn more.

The Role of Limitations

Given that maturational limitations on memory are very useful in helping young children learn language, it's worth asking what role these constraints played in the large-scale evolution of language.

The constraints did not evolve specifically to help children learn the structure of language. We know this for two reasons. First, these cognitive limitations are very domain-general; they affect every aspect of a child's mind, including perception, action, attention, emotion, and language.

Second, these maturational limitations didn't evolve for any purpose at all. These constraints are just a natural byproduct of human brains taking a very long time to develop. That is the unavoidable biology of altricial species. We have an extended period of cognitive and physical immaturity. There is a term in biology for phenotypic characteristics that are byproducts of some other aspect of an organism. They are termed *spandrels*, which was coined by the Harvard paleontologist Stephen Jay Gould.

The alternative is to flip matters around, as Morten Christiansen and Nick Chater suggest doing. Instead of asking if maturational constraints on learning evolved in response to the structure of language, we might ask if the structure of language evolved in response to maturational constraints on learning.

Christiansen and Chater's argument is that because the basic biology of the human brain changes much more slowly than cultural artifacts like language, the brain is a more likely anchor for evolution than language. After all, humans were an altricial species with an extended period of immaturity for millions of years before language even entered the scene. This suggests that when language did arrive, it had a stable neural environment to adjust to.

A constant feature of that environment is that brains are in a form of extended immaturity while they learn language. Therefore, whatever structure language initially took in its evolution should have exquisitely adapted to that particular cognitive environment. Language evolved to be learnable in the context of the type of brain that was learning it.

Language out of Thin Air

It is no longer controversial to claim that there are innate mechanisms for language development. However, there is still debate over the nature of these innate mechanisms: Are they specific to language or more domain-general? Most scientists now believe that domain-general theories are the more parsimonious and persuasive explanation. However, this issue is far from resolved, and there are some empirical findings that remain active battlegrounds.

One relevant area involves sign language. Before the 1970s, the medical community in the United States was not convinced that sign language was a real language. One implication of this view was that the medical community actively discouraged the teaching of sign language to deaf children. In its place, they advocated for lip reading.

Unfortunately, this often had damaging consequences for both children and parents because lip reading is extremely hard and not very reliable. Despite the practice of not teaching sign to deaf children, many of these children created a language of their own. It was called home sign, and it was systematically documented by Susan Goldin-Meadow as part of her doctoral dissertation.

Home sign looks a lot like a conventional sign language. It has structure and consistency. Additionally, it bears uncanny resemblance among children who develop it. Individual signs differ across children, but the structure is very similar. This is true not only in the United States. Goldin-Meadow also observed a similar structuring in deaf children from Taiwan.

One of the most striking shared structures of home sign is its syntax. Home signers in America and Taiwan both use an ergative syntax. Ergativity concerns how subjects and verbs are ordered in a sentence. Spoken English or Mandarin are not ergative languages. This is remarkable, and it raises the question of where the common structure derived from.

One possibility was that it came from the co-speech gestures of the parents. Goldin-Meadow considered that, and she found that the gestures of American and Taiwanese parents are very different from each other. It was also likely that the similarity was not coming from some shared aspect of the environment, because America and Taiwan are very different culturally.

The question remains: What gives rise to this commonality? The domain-specific theorists argue that there is some special module built into the human brain that allows language to unfold in a structured and consistent way, despite not receiving conventional input. This is compelling. The fact that something so language-like can emerge without any formal instruction makes a domain-specific mechanism sound attractive.

The domain-general theorists see home sign as evidence that the brain is wired in a way that is conducive to learning language and also many other things. For example, there may be basic cognitive constraints that guide how meaning is mapped onto imagery and action. There may be strong social instincts to share and communicate perspectives with others. There may be probabilistic learning mechanisms that detect and impose regularity onto the world. These may combine to create language without being specifically designed for language.

In this case, it is difficult to know what the right answer is. Perhaps both views are correct. It is possible that language initially emerged from a domain-general mechanism in our evolutionary past, but once language arrived on the scene, it put selective pressure on brains to accommodate it.

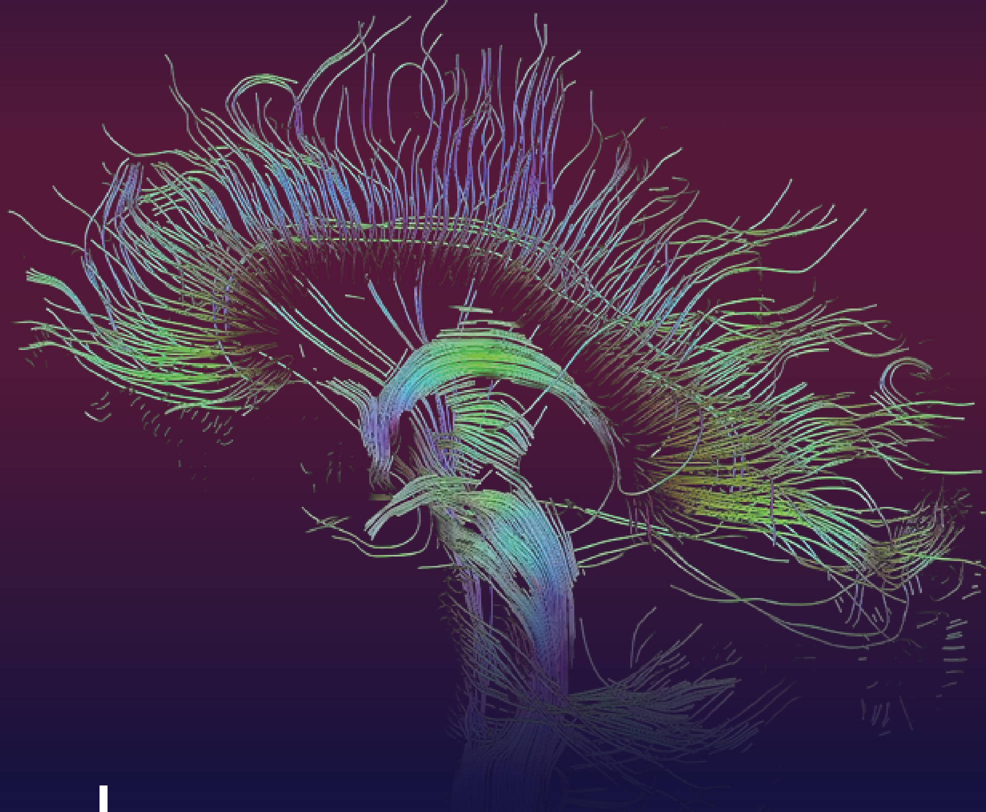
Suggested Reading

Goldin-Meadow and Mylander, “Spontaneous Sign Systems Created by Deaf Children in Two Cultures.”

Newport, “Maturational Constraints on Language Learning.”

Questions to Consider

Can you think of examples of how learning new vocabulary helps with learning syntax? What about examples of how learning syntax helps with learning new vocabulary? How can pragmatics help with both?



13.
THE BRAIN AS A WINDOW INTO THE MIND

A rare disorder called Capgras delusion causes people to believe that a close loved one has been replaced with a perfectly disguised imposter. This lecture discusses the neural mechanisms of Capgras delusion as a way to capture three basic principles of the human brain. Following that, the lecture looks at how advances in neuroscience methods are allowing scientists to ask new questions about how the brain works.

The Biological Basis of Behavior

The first principle this lecture discusses is neural specialization. During prenatal development, genes help to direct traffic, guiding which cells should migrate to which parts of the brain. Most of these cells are designed to go to very specific places and to serve highly specialized functions. Once they arrive, many require further input from the environment to activate their particular roles. Connecting to the Capgras delusion example: When a Capgras patient views her father as an imposter, a very specific part of the brain—the fusiform face area—responds to the face of her father.

This principle of specialization works in tandem with the second principle: The brain is an elaborate network. Some basic functions of the brain are localized in just one area, like visual cells for processing color, edges, and motion. However, complex processes, like vision, must integrate these subprocesses, so an interconnected neural network is required. In a person with Capgras delusion, the FFA is undamaged, but the connections are broken. The exact mechanism involved in Capgras delusion is still being worked out, but it involves links between the FFA and other key brain areas.

The third principle is that the brain is plastic and built for change. This is especially true early in life, but the brain is capable of change throughout a person's lifetime. It had better be, or else you'd be in big trouble! Every time you learn something new—no matter how old you are—your brain changes. At the biological level, neural change is what learning is.

This plasticity is integral to the first two principles. Even though genetics sets the basic blueprint for the brain, experience with the outside world is necessary to activate and fill in the details for many functions. For example, this is true in the FFA, where experience with particular faces is necessary for specializing cells to process those faces.

Plasticity is also the key to recovery from broken connections in the brain. There are no drugs to fix brain damage. The main treatment is to undergo intense mental rehab. If a patient suffers from Capgras delusion, one treatment may be to repeatedly associate pictures of a loved one with positive emotions. Over time, this may allow weakened connections to get stronger, and in highly plastic young brains, it could even help create new connections to replace the old ones.

Learning about the Brain

The 1990s were an exciting time for neuroscience. There were many areas of growth, but one of the most significant legacies was the spread of neuroimaging techniques available to scientists. In general, these techniques involve two basic types of tools: There are spatial tools for helping researchers pinpoint where things happen in the brain, and there are temporal tools for recording when they happen. This spatial and temporal information provides two pieces of the puzzle in helping researchers know what is happening in the brain.

Spatial Neuroimaging Techniques

Spatial neuroimaging techniques answer the question of where brain activity occurs. The modern tools are called structural imaging techniques, but for a long time, researchers had to mostly rely on postmortem analyses of brain damage to map how different parts of the brain relate to different aspects of behavior.

Structural imaging techniques take static snapshots of brain structures, and many of these snapshots can be compared to determine what areas are reliably associated with behavioral impairments. These techniques allow scientists to compile entire inventories of brain images to more precisely describe brain-behavior relationships.

Another strength of these techniques is that they can look at brain structures immediately after damage, before there is any time for the brain's plasticity to compensate for that damage. After all, traditional brain damage studies had to wait until the patient died to look at brain structure, which could happen decades following the actual damage.

However, there is one giant limitation of these structural imaging techniques. Because they are static snapshots of the structure of brains at rest, they cannot directly measure brain activity while it is actively engaged in some sort of behavior.

This is where fMRI, or functional magnetic resonance imaging, enters the picture. In the early 1990s, Dr. Seiji Ogawa and his team added an important component to traditional MRI techniques. Standard MRIs measure magnetic properties of the brain to make a map of brain structure, but fMRIs are also able to measure real-time changes in brain function by recording the magnetic properties of blood flow within those structures.

This technique led to an exponential increase in research on brain function and has given rise to several new fields, like cognitive neuroscience, clinical neuroscience, and neuroeconomics. These fields have made it possible to answer questions that were previously out of reach using data from structural imaging. For example, disorders such as Capgras delusion would likely be missed with structural imaging techniques alone. The structures may appear intact, but the breakdown is in how the structures function and connect with one another. Blood flow can show which parts of the network are working properly and which parts are compromised.

The Power of the Brain

In 2013, one of the three most powerful computers in the world—a supercomputer in Japan that could handle 10 quadrillion operations per second—required a full 40 minutes to simulate an approximation of what the brain does in just one second.

Building on the fMRI technology, researchers can use software to map connective tissue among brain areas to map out the connections in the brain. Diffusion tensor imaging (or DTI) is one such technique that can create maps of white matter tracts to better understand the information superhighways of the brain.

Temporal Tools

As useful as it is to understand where things happen in the brain, it is also important to understand when they happen. In terms of temporal resolution, techniques such as fMRI are slow. Current fMRI sensors can only see brain changes that happen on the order of seconds, which is a snail's pace in terms of the speed of neural processes.

To measure neural processing at this level of temporal resolution, neuroscientists must rely on techniques that are built for speed. One of the most well-established techniques is called event related potentials, or ERPs. ERPs are portions of the brain's EEG signal, which is measured by an electroencephalogram.

This EEG signal is produced by postsynaptic discharges of large groups of neurons in the brain that pass through the skull and are measured by electrodes on the scalp. An ERP is a time-locked portion of this EEG signal. Time locking means that an experimenter records only the brain's repeated response to particular types of stimuli, like faces or words. In this way, the resulting electrical average reflects the neural activity that is unique to different stimuli.

For example, a researcher studying a Capgras patient may be interested in the timing of how the patient processes the face of the supposed imposter. There is a typical time course and topography of a brainwave that is produced by a face, so if the ERP in response to the imposter's face is different from the face of a non-imposter, it is possible to make inferences about what different type of neural process is involved when seeing the imposter.

Specifically, if the two brainwaves differ within 200 milliseconds of seeing the face, it would suggest an early event that involves low-level perceptual processing, such as how the brain initially categorizes the face. If the difference occurs much later, after roughly 500 milliseconds, it would suggest a late event that involves higher-level cognitive processing, such as how the brain attaches emotional meaning to the face.

The Best of Both Worlds

In the past few decades, there have been technological innovations that allow neuroscientists to measure the timing and location of neural events. One of the most powerful—and expensive—techniques is called magnetoencephalography (or MEG). MEG uses a powerful magnet that is supercooled down to −452 degrees Fahrenheit. These cooled magnets are able to detect very small magnetic fields that are produced by electrical generators in the brain called dipoles.

By measuring dipole activity, MEGs can measure the location of the electrical activity in small clumps of thousands of neurons as well as the millisecond-to-millisecond time course of that neural activity. Using this combined spatial and temporal resolution, an MEG could determine if a Capgras patient first processed two faces similarly in visual areas toward the back of the brain but then later differentiated them in frontal regions of the brain. This sort of pattern would lend support to the hypothesis that the patient's problems in Capgras are more evaluative than perceptual in nature.

One of the most exciting developments in neuroscience techniques is called neurostimulation. Unlike neuroimaging methods—which are designed to record brain activity—neurostimulation does what it sounds like it does: It stimulates brain activity. The idea is that neuroimaging can show researchers when and where brain areas are involved in some sort of process or behavior, and then neurostimulation can actively test whether that area is an actual causal mechanism of that process or behavior.

For example, transcranial magnetic stimulation (or TMS) uses handheld electrified coils to shoot pulses of magnetic fields through the skull into the surface of the brain. These magnetic pulses can either depolarize or hyperpolarize large patches of neurons in particular brain regions. Generally speaking, if the region is depolarized, it disrupts that brain region's ability to do its job, but if it's hyperpolarized, it can enhance that region's ability to carry out its function. The disruptions are sometimes referred to as virtual brain lesions, and the enhancements are occasionally referred to as neural augmentation.

If a researcher wanted to determine if Capgras delusion is caused by breakdowns in the right frontal lobe during processing, the researcher could test it in people who don't have the disorder. The strategy would be to use TMS to disrupt (or create a virtual lesion) in this brain region—at just the right time—milliseconds after showing pictures of familiar faces to people who don't have the delusion.

If the right frontal lobe is a key mechanism for Capgras, this stimulation may cause problems in people's ability to cognitively evaluate the faces. This would lend support for the theory that Capgras delusion is not a perceptual problem as much as it is a problem of attaching meaning to faces.

Neurostimulation has gone to the next level with a radical technique: neurostimulation implants. Deep brain stimulation (DBS) was pioneered in the mid-1980s as a powerful new treatment for Parkinson's disease. It involves implanting electrodes in the subthalamic nucleus, which is a structure deep in the brain that produces the neurotransmitter dopamine. The idea is if this part of the brain is stimulated, there will be more dopamine produced in the patient, and this increased dopamine can help to reduce some major symptoms of Parkinson's disease.

Since this initial work with Parkinson's, there have been attempts to place neural implants in other brain regions to treat problems like obsessive-compulsive disorder, chronic pain, and even depression. Some researchers are now using implants to record from a variety of brain sites to determine how and where different brain regions contribute to different brain functions.

Suggested Reading

Ramachandran, *A Brief Tour of Human Consciousness*.

Question to Consider

Most genes must be activated by environmental triggers from the immediate cellular environment all the way out to the external social environment. As a general rule, the more complex a behavior or trait is, the more it relies on the environment. What does this mean for claims about what is innate in the human mind?

14. HOW THE BRAIN COMPREHENDS LANGUAGE

One day in 1939, an Englishman called Henry G. was admitted to the Bristol General Hospital in a state of unconsciousness after falling from a bus. Once Henry G. awoke, he gave the impression of having gone completely deaf from hitting his head. However, after closer investigation, it became clear that Henry G. had a much more peculiar deficit: He had lost the ability to understand human speech.

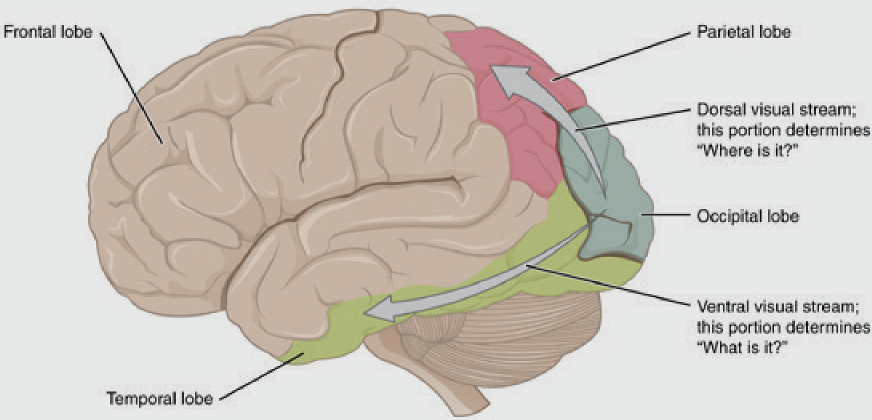
Henry G. had a rare condition called auditory verbal agnosia, or pure word deafness. This lecture discusses how disorders like this one shed light on the neural mechanisms for language comprehension. It highlights the big three neural principles: specialization of function, the network property of the brain, and the power of plasticity.

Dual Streams: Vision

To better understand the journey that speech takes to create linguistic meaning in our heads, vision is a helpful gateway. Vision is one of the most studied processes of the brain, and neuroscientists believe that some fundamental aspects of vision are shared by many other systems, including language.

When photons reach the eye, they are chemically transduced into electrical signals that are sent through subcortical relay stations to the back of the brain in the occipital lobe. The primary visual cortex, or V1, is located in the occipital lobe. That is the start of two journeys.

From V1, visual information is split in two parallel streams, one going downward and one going upward. The one going down is called the ventral stream, and its function is to process the visual details of whatever thing a person is viewing. At the same time this is happening, the dorsal stream is processing a complementary piece of visual information: the location of the object. This pathway runs upward from V1 through brain areas specialized for processing motion and finishes up in the parietal lobe, where neurons analyze the relative location of the object to one's own body.



These systems work in parallel to process visual information. Damage to one part of the system impairs one aspect of vision but not the other. Damage to the front end of the ventral stream disrupts the ability to correctly identify what an object is, but it spares the ability for the dorsal system to determine where it is. The opposite is also true. Neuroscientists believe that the primary function of having these two parallel visual streams is that vision can specialize its processing while also ensuring that it is very fast.

Dual Streams: Language

This neural strategy of dividing and conquering is so effective that it is now believed that it is also used in language processing. Although originally hypothesized by Carl Wernicke himself in the late 1800s, this dual-stream hypothesis for language has gained new life a century later with the advent of functional neuroimaging methods. Most notably, a version of this model was reinvigorated in 2007 by the cognitive neuroscientists Gregory Hickok and David Poeppel.

When speech sound waves travel toward us, they are funneled from the external ear, called the pinna, inward to the eardrum. The pinna funnels and amplifies speech sound waves before they hit the eardrum. The vibrations there are mechanically transduced into action potentials in the cochlea and are then sent via subcortical relay stations to A1 in the temporal lobe. A1 is topographically organized for sound input, just like V1 is for visual input.

From A1, all processes move to the surrounding superior temporal cortex, which has been traditionally called Wernicke's area. It has multiple functions. One of the earliest stages of processing after A1 is to recognize acoustic features of words. It was once assumed that this processing occurred only in the left hemisphere, but it is bilateral. For example, neuroimaging scans show that patients with lesions to only the left superior temporal lobe can still recognize words as words.

However, bilateral damage to this part of the brain is devastating for word recognition. In fact, this is most likely what caused Henry G.'s pure word deafness. He could not hear words as words. For him, it was all gibberish, and modern neuroimaging scans now show the culprit to be bilateral damage to this brain region.

Researchers have used fMRI on non-brain-damaged participants to show that this region may be specialized for the sounds of language. Many studies have now found that the bilateral superior temporal lobe is more active for speech stimuli than complex non-speech sounds, suggesting that it is indeed one of the first processing points that treats speech as a special type of acoustic signal.

This is also the first stage of processing that distinguishes phonological features within spoken words themselves. Hickok and Poeppel argue that the left hemisphere analyzes the fine-grained details of phonological forms, whereas the right hemisphere does a more holistic analysis.

100,000 Miles

Here is an interesting fact, via the psycholinguist Julie Sedivy: It is estimated that the average 20-year-old has approximately 100,000 miles of these white matter tracts.

The Ventral Stream

From the superior temporal lobe, the two streams split. One travels ventrally and the other dorsally. These two pathways ride along two well-established white matter tracts.

Regarding the ventral speech stream, the transitional area connecting the posterior superior temporal lobe and the middle temporal gyrus is where words are recognized as having meaning. Damage to this area produces receptive aphasia, which was traditionally called Wernicke's aphasia. Unlike patients with pure word deafness, these patients can produce and hear speech as speech, but the speech lacks appropriate meaning.

With the advent of spatial neuroimaging methods, we now have hundreds of studies implicating this region as a mechanism for attaching meaning to words. Temporal neuroimaging methods have shown that this semantic processing occurs milliseconds after phonological processing at earlier stages. As a general rule, as information travels farther toward the anterior part of the temporal lobe, the neural mechanisms become increasingly specialized for processing more complex semantic information.

Another notable feature of moving toward the anterior portion of the ventral stream is that it becomes increasingly more left-lateralized. As it becomes more specialized for complex semantics, the left hemisphere takes on more and more of the processing burden. The right hemisphere is still involved in processing meaning, but it does a much more coarse-grained analysis.

Activation Zones

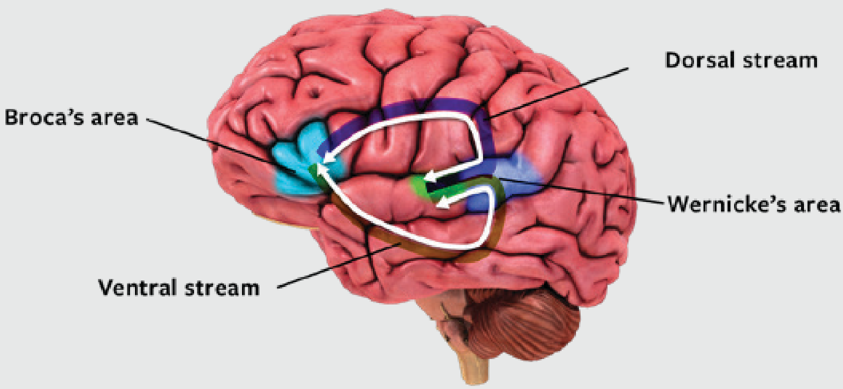
In one of the largest meta-analyses on the brain's semantic system for language, Jeffrey Binder and his team reviewed more than 500 PET and fMRI studies and found that there were a few main areas of activation. One area was located in the cortical areas surrounding the left auditory cortex, including the left temporal lobe and parts of the inferior parietal region. Connections to these areas are thought to activate visual imagery. For instance, one mechanism for remembering the meaning of the word *key* is to reactivate the visual perception of images of keys.

However, it's important to note that semantic memory and visual perception do not overlap fully. There are cases of brain damage to these visual areas where object recognition is completely lost, but patients can still correctly understand the meaning of words associated with those objects.

Another important zone is located in the motor and premotor cortex in the frontal lobe. As shown in the work of Friedemann Pulvermüller, when someone hears the word *kick*, the foot region of the primary motor cortex becomes active, but when they hear *throw*, the hand region gets involved. Again, the overlap is not complete: There are cases of brain damage where the motor system is compromised, but linguistic knowledge about what objects do is preserved.

In addition to neocortex activation, limbic regions also get in on the act of attaching meaning to words. The part of the subcortex responsible for encoding and retrieving memories, the hippocampus, is constantly active when searching for word meanings. And because many words have episodic and emotional associations, parts of the cingulate cortex become active at attaching those associated meanings.

In 2016, Jack Gallant and his team conducted a methodologically innovative study measuring the brain's semantic processing not of isolated words but of whole narratives. Gallant's team found that words activated practically every square inch of the brain's surface. The activation maps were highly organized.



After the meaning of words is assembled from all corners of the brain, the information is channeled toward the final stop on the ventral pathway: the left inferior frontal gyrus (or IFG). The left IFG is involved in the integration of multiple pieces of information. In this case, the information that must be integrated is the meaning of words and their syntactic context. This final step is necessary for comprehending language in its full creative complexity.

Studies have produced direct evidence that the left IFG is constantly monitoring and updating the syntactic context of language, which is not only useful for correctly understanding complex meanings but also for predicting meaning that is coming down the stream.

The Dorsal Stream

While information moves up and down the dorsal stream, a second set of processes is ongoing in the dorsal stream. It is helpful to think of words as objects: The function of the dorsal language stream is to act on those objects. This is not as much of a stretch as it seems. For example, one way for the visual system to know an object is to interact with it. In a similar way, one way for the auditory system to know a word is to produce it. For the dorsal stream, knowing is doing.

The significance of this mechanism is clearest when considering how infants learn to produce language in the first place. When a baby babbles, it is coordinating its motor system to match what its auditory system is hearing. Humans are born with an ability to hear all phonemes, but the motor system is much less advanced. It requires months of practice to learn how to produce the phonemes it hears. This extensive experience lays the tracks for the dorsal route in the first few years of life.

The first stage of the dorsal route goes from Wernicke's area to the left Sylvian parietal temporal region (or SPT). SPT gets its name from straddling the Sylvian fissure, which divides the temporal and parietal lobes. As a general rule, the dorsal stream is much more left-lateralized than the ventral stream, and this is because motor commands for producing speech are located mostly in the left hemisphere.

The SPT takes the phonological signal from earlier stages and rehearses it. Another function of SPT is to learn new vocabulary items. Interestingly, rehearsing happens mostly for more complex words. For words composed of relatively simple or highly familiar phonemes, this stage seems to be skipped, and it is handled downstream toward the endpoint of the dorsal route.

The main path for this downstream connection is a tract of white matter fibers called the arcuate fasciculus. The final stop of these fibers is the left prefrontal cortex and the IFG. These regions are heavily involved in overt speech production. In fact, damage to the left IFG is what produces Broca's aphasia.

Broca's area—and the left IFG more generally—also serves a syntactic function. It has long been observed that Broca's aphasics have deficits in comprehending complex sentences. This syntactic function of the left IFG has been corroborated in many functional imaging experiments. Additionally, developmental studies have shown that children's syntactic abilities are positively correlated with the strength of connection between the left IFG and more posterior parts of the ventral stream.

These developmental data suggest that the IFG is strongly shaped by practice and experience, much like the FFA with face processing. In fact, just like the FFA, the left IFG may be more domain-general than originally thought. There is growing evidence that it processes syntactic patterns in language and is sensitive to complex patterns outside of language, such as music.

A domain-general view might explain why the dorsal and ventral routes converge in the left IFG. Peter Hagoort of the Max Planck Institute for Psycholinguistics argues that the left IFG is a "unification site" that combines information across semantics, syntax, and pragmatics too.

In other words, its function is to gather all the relevant pieces of information in a communicative utterance and then piece it together into a coherent package.

Just like the ventral stream, the unified meanings generated by the left IFG feed backward along the dorsal stream. This helps earlier dorsal stages to quickly connect motor representations to the acoustic signal coming from A1.

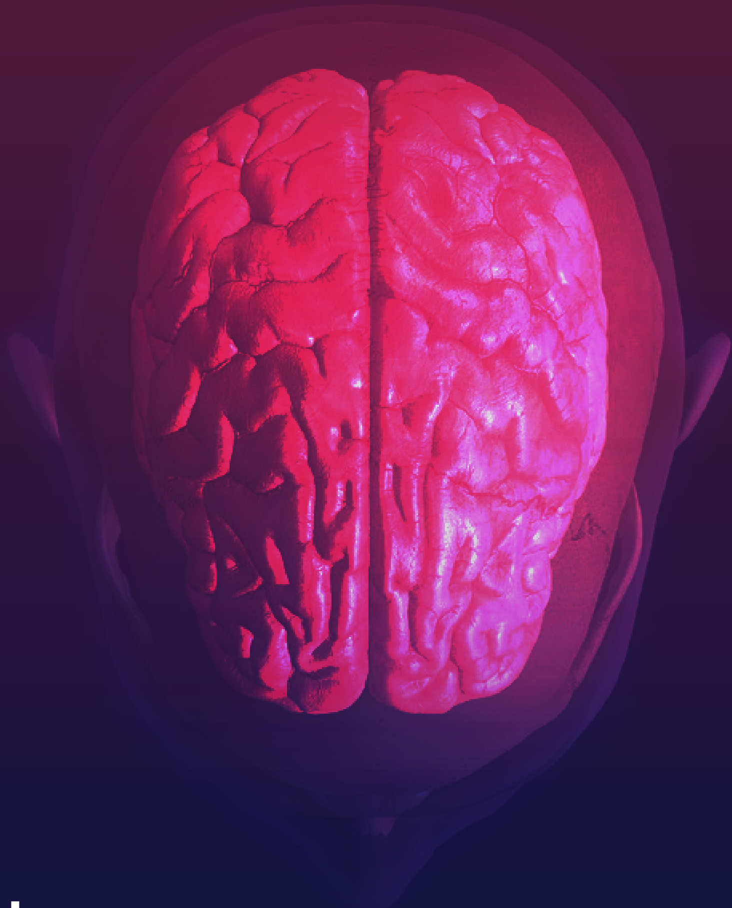
Suggested Reading

Hickok and Poeppel, "The Cortical Organization of Speech Processing."

Huth, de Heer, Griffiths, Theunissen, and Gallant, "Natural Speech Reveals the Semantic Maps That Tile Human Cerebral Cortex."

Questions to Consider

Greg Hickok and David Poeppel's dual stream model explains how the brain balances speed and accuracy in processing language. Using the 3-D framework, how might this moment-to-moment mechanism relate to language change over the historical timeframe? For example, how might these two complementary pressures—speed and accuracy—gradually change phonetics, morphology, or syntax as language is passed down over multiple generations of users?



15.
HOW THE BRAIN PRODUCES LANGUAGE

This lecture explores the mechanisms involved in language production. The process of speaking involves a complex network of specialized brain regions honed by genetics and experience.

What's a Thought?

The spark that prompts someone to speak in the first place is a bit of a mystery because it is internally generated: It's the thing in your head you want to communicate.

Most of us would call these things thoughts. However, modern-day cognitive scientists are increasingly skeptical about the conventional notion of thoughts. One problem is that no one has ever seen one directly. A thought is just a convenient construct that we use to explain things we subjectively experience.

Another problem is that a thought is typically viewed as a stable and discrete thing. However, from a neural point of view, thoughts are dynamically shifting and multidimensional. A final reason that traditional notions of thought are on shaky ground is that we don't know when a thought occurs. It is unclear if a thought occurs only when we're consciously aware of it, or if it exists in some form before subjective awareness.

Still, despite not knowing what thoughts are—or when or how they occur—many neuroscientists believe that the brain generates something in advance of our conscious awareness. For instance, readiness potential is an electrical brain response first observed in an EEG experiment done in 1983 by Benjamin Libet. The experiment measured electrical activity on the scalp as people voluntarily reached for objects.

The main finding was that a distinct brainwave—the readiness potential—preceded awareness of voluntary reaching by several hundred milliseconds. Itzhak Fried and his colleagues have since replicated this interesting finding in epilepsy patients with electrodes implanted in their frontal lobes.

There is a range of interpretations of these findings, but the results clearly show that some sort of unconscious neural activity precedes action. If this is the case for relatively simple things like reaching, it suggests that for more complex actions—like using language—there may be a large and clandestine neural network operating behind the scenes.

Two Stages of Speech Production

Spoonerisms, a type of speech error, are named after Reverend William Archibald Spooner, don of Oxford College around the turn of the 20th century. Spooner was famous for his linguistic slip-ups. For instead, instead of using the phrase "a loving shepherd," Spooner is said to have given us: "The lord is a shoving leopard."

Mistakes like this reveal that speaking unfolds according to a premediated plan: What else could explain why parts of words that should appear later in an utterance mistakenly show up earlier? Spoonerisms are cousins to a different preplanning error involving swaps of entire words within an utterance. For example, imagine someone saying: "Can you get some kids for the snacks?"

Psycholinguists argue that these two types of speech errors represent two different stages of speech planning. Exchanging entire words within syntactic categories provides a glimpse into the initial abstract stage of conceptual planning. The technical word for these preplanned abstract concepts is *lemma*, which in ancient Greek means "premise." Once the lemma has been planned, the next stage begins. The second step involves putting those abstract ideas into the proper phonological forms, and Spoonerisms happen during this step.

But still, even if run-of-the-mill priming explains these findings, they clearly show that linguistic planning stages involve more than just the neutral nuts and bolts of language. This opens the door to a wide range of information being part of the production process.

Neural Models of Speech Production

For more clarity on the different stages of language production, it is helpful to shift to the neural level of analysis, beginning with what brain damage can tell us. Wernicke's aphasia is traditionally viewed as a problem with language comprehension, but that has proven to be overly simplistic.

One of the telltale signs of Wernicke's aphasia is called a paraphasia. There are many forms of this. There are phonemic paraphasias, which involve missaying parts of words. Semantic paraphasias, meanwhile, involve perfectly articulated words showing up in semantically incorrect places.

A patient with Wernicke's aphasia can have both types of paraphasia, but they often have only one. In these cases, it has been hypothesized that phonemic paraphasias are caused by damage in the dorsal stream involved in phonological processes, and semantic paraphasias are caused by damage to the ventral stream involved in meaning.

It's difficult to reliably map these areas with functional neuroimaging because of all the plasticity that takes place after brain damage. However, there are some more direct techniques that have nicely shown this functional specialization.

Earlier, Dr. Wilder Penfield developed a procedure to map the brains of epilepsy patients before extracting tumors. He opened up the skull and electrically stimulated certain parts of the cortex to determine localized functions. That technique continues to be the most direct way that neuroscientists can map the specific functions of the human brain. In 2010, David Corina and his team used the same technique to map language functions of more than 100 epilepsy patients having tumors removed from their left hemisphere.

While lying fully conscious on the operating table—with their brains exposed—patients were asked to name objects presented in pictures. While naming the objects, the surgeon electrically stimulated the left hemisphere to determine a safe place to operate.

There were many interesting findings, but the most relevant is that on average, stimulation to the dorsal language stream produced more production errors such as phonemic paraphasias. Stimulation to the ventral stream produced more semantic paraphasias. This finding fits very well with the two-stage model of semantic and phonological speech planning.

Broca’s Area

The brain’s left hemisphere is home to the most well-known mechanism for speech production: Broca’s area, which is where speech sounds are turned into speech actions. Fitting with this course’s 3-D model, the ability to speak comes from a combination of genetics and experience.

Genes dictate that the posterior part of the frontal lobe will ultimately specialize for planning and producing speech movements. Auditory experience with one’s native language over development allows those cells to eventually mimic what they hear.

In patients with Broca’s aphasia, the ability to link speech actions to speech sounds is compromised, and it creates a telltale kind of dysfluency. If Wernicke’s aphasia is a breakdown in knowing the right thing to say, Broca’s aphasia is a malfunction in physically saying it.

Broca’s aphasics are painfully aware of their condition, whereas Wernicke’s aphasics seem much more oblivious. When Wernicke’s aphasics use a paraphasia, they act as if it makes total sense. Broca’s aphasics are much more sensitive to their listeners. Often, they will resort to writing things down for people to make themselves understood.

Congenital Deafness

Congenital deafness makes it so hard to speak because there is no auditory target for Broca’s area to hit.

Retraining the Brain

The most impressive demonstration of neural plasticity in the human brain comes from an operation called complete hemispherectomy. This is a radical, last-resort operation to treat patients (mostly children) who have life-threatening seizures caused by abnormalities on one side of the brain. The procedure involves opening up the skull and surgically removing the entire affected hemisphere from the patient’s head.

These procedures were pioneered in the early to mid-1900s, but they were revamped and refined in the 1980s by surgeons at Johns Hopkins Hospital. (One of the people responsible was America's most famous brain surgeon: the 2016 presidential candidate Dr. Ben Carson.) Today, doctors can isolate smaller regions within a hemisphere, but in some cases, a full extraction is still necessary.

When the entire left hemisphere is removed, the immediate consequences are dramatic. Assuming the patient had left-lateralized language (which most people do), the removal of that hemisphere completely shuts down speech—at least temporarily. There is much individual variation, but many patients can start recovering language functions within weeks.

This sort of recovery is possible because the right hemisphere undergoes extensive plasticity and ultimately adopts the functions of Broca's area. That process is amazing, and a large factor in making it happen is the fact that the right hemisphere already does a large amount of work during language production.

While Broca's area is working on articulating words, there is a corresponding region in the right hemisphere working on a higher level. This homologous brain region simultaneously provides a rhythmic structure that connects spoken words across an utterance. Linguists call this acoustic link prosody.

The takeaway point is that when the right hemisphere takes over the functions of Broca's area, it's definitely not a blank slate. Because the right and left hemispheres normally communicate constantly over a bundle of fibers called the corpus callosum, each hemisphere is well acquainted with what the other is doing. This means that even though the right hemisphere is designed for rhythmic aspects of speaking, in extreme cases, it can repurpose part of itself to be more like the left hemisphere.

This sort of plasticity is most prevalent in children, but the brain maintains some plasticity throughout life. This opens the door to a number of therapies for people who suffer brain damage as adults. The standard treatment for Broca's aphasia is repetitive picture naming, which mostly targets the damaged left hemisphere. Speech therapists have also tried some more innovative approaches involving the right hemisphere.

One novel approach capitalizes on hand gestures. Broca's aphasics instinctively produce hand gesture as a form of compensation. By drawing heavily on the right hemisphere, the spatial and temporal properties of gesture can help aphasics find words and say them with a more natural prosody.

A second creative therapy capitalizes on the right hemisphere's penchant for melodies. Back in 1904, Dr. Charles Mills published an account in the *Journal of the American Medical Association* about an aphasic patient who learned to sing his words instead of speaking them. Others have made similar observations, and they have ultimately led to an official musical treatment called melodic intonation therapy, which was developed in the early 1970s.

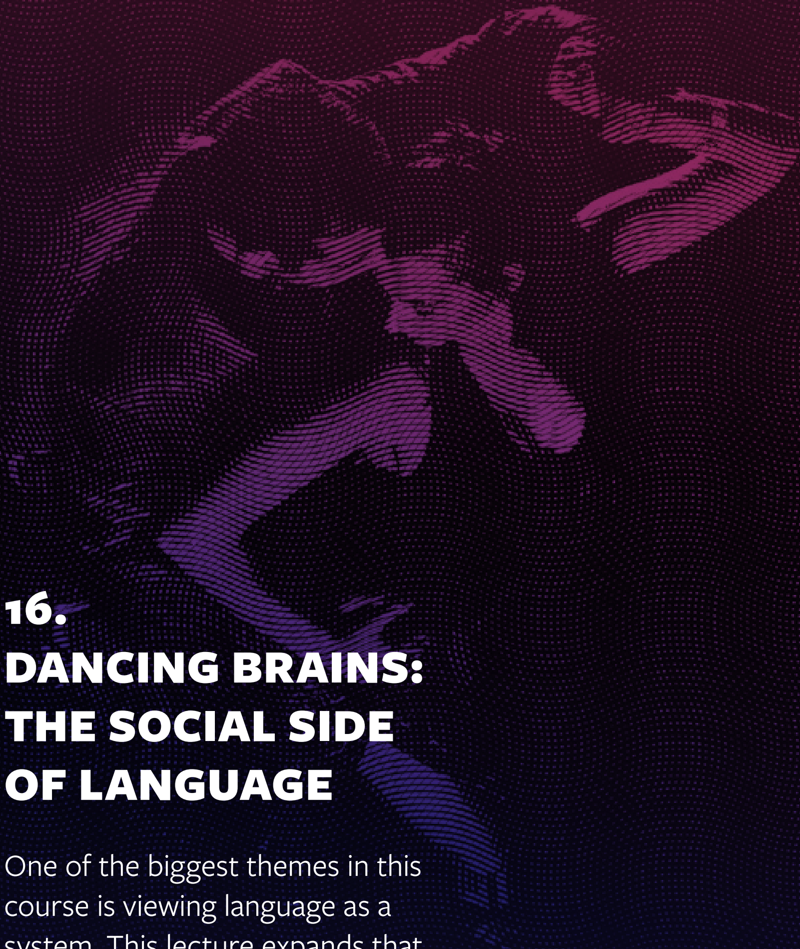
Suggested Reading

Petersen, Fox, Posner, Mintun, and Raichle, "Positron Emission Tomographic Studies of the Processing of Singe Words."

Schlaug, Marchina, and Norton, "Evidence for Plasticity in White Matter Tracts of Chronic Aphasic Patients Undergoing Intense Intonation-Based Speech Therapy."

Questions to Consider

The readiness potential reveals the time course of thoughts that precede actions. However, can't producing actions also produce new thoughts that did not previously exist? Can you think of any examples of this?



16.
DANCING BRAINS: THE SOCIAL SIDE OF LANGUAGE

One of the biggest themes in this course is viewing language as a system. This lecture expands that system beyond individual brains. It looks at language from the vantage point of brains—highly social brains—interacting with one another.

Changing the Question

Traditionally, many psychologists and neuroscientists have studied social interactions by focusing mainly on the individual as the appropriate unit of analysis. The question has been: What is inside an individual's head that allows for social communication with others?

Toward the latter part of the 20th century, scientists interested in highly complex social activities, like language, began expanding this narrow focus. Instead of zooming in on the individual, many now focus on the social activity per se.

Brains in the Mirror

Neural mechanisms allow these joint activities. Simulation theory is the idea that the brain processes something by reactivating the parts involved in directly experiencing it. For example, there is not much difference in neural activity when a person bites an apple, imagines biting an apple, or imagines someone else biting an apple. This sort of shared simulation has been shown in many fMRI studies by Marc Jeannerod and Jean Decety, and it suggests a possible neural mechanism for how people subjectively understand the perspectives and actions of others.

Simulation theory can explain what happens in individual heads and how two heads become linked as one. A well-known mechanism for making these neural links comes in the form of mirror neurons. Originally discovered in the prefrontal cortex of monkeys by Giacomo Rizzolatti, the mirror neuron system in humans is activated both when a person produces an action, like reaching for an object, and also when a person observes someone else produce that same action.

Over the years, our understanding of the function of this mirror system in humans has greatly expanded. It is responsible for our understanding the intentions of actions and feeling the pain of others. It is also now being implicated in autism spectrum disorder, psychopathy, altruism, and even addiction.

One of the most misunderstood aspects is where they come from: Are they innate or a product of learning? Here, the 3-D framework can be useful, using the motor mirror system as an example. When very young infants view the reaching behaviors of others, the mirror system won't be triggered. That is because infants must first have enough experience over development to master reaching for themselves.

Only when reaching becomes part of their repertoire can babies activate the mirror properties of the neurons. Only a fraction of motor neurons have mirror properties, so it seems that just a subset of them have innate mirroring potential. In this way, the answer of where mirror neurons come from requires us to consider mechanisms on multiple levels and different timeframes: The system is the product of genes conserved over evolution, and plasticity and experience during development.

Brains Resonating Together

Since the turn of the millennium, the field of social neuroscience has progressed well beyond mirror neurons. Methodologies have advanced, allowing for more dynamic questions about how people synchronize with one another in real social interactions. For example, rather than just measuring one person's brain in response to a social stimulus, it is now possible to simultaneously measure the brain activity of multiple people engaged in a joint activity.

One of the first studies to pull this off was done in 2011 by Ulman Lindenberger and his team at the Max Planck Institute for Human Development in Berlin. They measured the EEG activity of pairs of guitarists playing short melodies together. The main finding was that the two guitarists synchronized their brains not only while they were playing together but also just before they began to play. The most synchronized frequency range was a range associated with voluntary control of motor actions. This means that the brains of the guitarists were on the same page even before they started playing.

This doesn't show that neural synchrony is the cause of playing in sync with one another. Perhaps things like mutual eye gaze, head nods, and foot tapping to a beat are what synchronized their brains before playing and while they played. At the very least, though, this innovative study shows that brain synchrony is a valid neural marker of jointly coordinated social interactions.

If neural synchrony is not the cause of social coordination, what is? One answer comes from an ambitious project that measured brain synchrony in a high school classroom over the course of a whole semester. David Poeppel and his team at the Max Planck Institute for Empirical Aesthetics in Munich had 12 students and their teacher all wear portable EEG headgear over the span of 11 sessions of a biology class.

There were a number of interesting findings, but the most relevant concerns the alpha frequency of brainwaves, around 8 to 12 Hz. (Alpha readings reflect how deeply someone is paying attention.)

This simultaneous alpha frequency of all 12 students was most synchronized when they reported being more cognitively and socially engaged in class. This suggests that a common focus of attention may be what unites brains to become synchronized with one another.

The Predicting Brain

Again, neural synchrony is not the driver of joint engagement, but even if it is not the immediate mechanism, it may ultimately serve a downstream function of facilitating social coordination. Just like a bell continues to resonate long after it has been struck, neural synchronization may have enduring social vibrations.

Traditional models of communication are static: There is a sender, and there is a receiver, and they serially transmit information in an orderly fashion. However, real face-to-face communication is nothing like this; it's almost always much more dynamic and messier. As the Scotland-based psychologists Martin Pickering and Simon Garrod put it, communicators are "moving targets," and coordinating between them is much more like a dance than a transmission.

In their model, Pickering and Garrod view this tangled overlap between speaking and listening not as a flaw but as an actual design feature that allows communication to work so well. Consider all the overlap in a real, everyday conversation: imitating head nods and hand gestures, mirroring facial expressions, and so on. These behaviors align people's brains, and this resonates over time to help predict what will happen next in the interaction.

Birds Communicating

Birds are one of the only other species born not knowing how to communicate with their kind. Like humans, they must learn it.

People don't always make the right prediction, but that's OK, because we can easily adjust on the fly. These spontaneous corrections are what linguists call conversational repairs, and people do them constantly.

A Social World in Our Heads

When we use language, we draw upon a large reservoir of what is mutually known among speakers. The Stanford linguist Herb Clark calls this mutual knowledge common ground. He argues that without it, successful communication is impossible.

In the most extreme example, communicators must have common ground in what language they speak, but there are many other nuanced layers, including cultural factors, levels of expertise, knowledge of terminology, and so on.

In one experiment, Thomas Holtgraves manipulated whether indirect requests were spoken by people who were higher in the social hierarchy, like a company boss, or more equal, like a coworker. The common ground in this case is that it is much more socially permissible for bosses to ask people to do things for them.

That is what Holtgraves found. Participants processed the utterances as indirect requests more often and much faster when the speaker was of a higher status. Additionally, people seemed to bypass the literal content of the message more quickly in this higher-status condition too. This last part is particularly interesting because it suggests social information seemed to be built into the original message.

Social Surrogates?

Human laughter is highly social in nature. In the 1990s, Robert Provine did a series of studies on this subject. Provine found that humans are 30 times more likely to laugh in a social context than when alone. People laugh not necessarily in response to something funny; laughter most often springs from just sharing certain experiences with other people. Lastly, Provine found that laughter is highly contagious.

One function of shared laughter is to socially bond with other people. There seems to be something special about sharing a good laugh that brings people together. However, any sort of social mirroring can function in a similar way.

For instance, Franny Spengler and her colleagues had pairs of people play pantomime games where they either mimicked or did not mimic each other's actions. Dyads that mirrored one another produced higher levels of a hormone called oxytocin, which is involved in social bonding. This suggests that there may be something biologically special about synchronizing behaviors with others. Being in sync may bring out our social best.

Suggested Reading

Dikker, Wan, Davidesco, Kaggen, Oostrik, McClintock, Rowland, et al., "Brain-to-Brain Synchrony Tracks Real-World Dynamic Group Interactions in the Classroom."

Pickering and Garrod, "An Integrated Theory of Language Production and Comprehension."

Questions to Consider

Charles Darwin claimed that laughter is not unique to humans, and recent research has shown that dogs, chimps, and even rats emit distinct sounds in response to certain types of pleasure. Do you think that laughter plays the same social function for these animals, or is there something unique about the pragmatics of human laughter? What might someone like Michael Tomasello say about this?

17.
HOW WRITING TRANSFORMED THE MIND

The written word is a technology that has changed brains, elevated minds, and transformed civilizations. Even though our brains are not specifically designed for this technology at birth, prolonged and explicit exposure to it can repurpose parts of the brain intended for other things. In the end, these cobbled-together parts combine to create a neural network that eventually becomes dedicated to reading and writing in our mature brains.

Reading Rewires the Brain

There are two main parts of the story of reading and writing in the brain, and both of them take place in familiar brain regions. The first part of the story involves the homologue to the fusiform face area (FFA). The FFA is located in the fusiform gyrus, which spans the ventral part of the occipital and temporal lobes. It is a bilateral structure, which means it traverses both the left and right hemispheres. In the case of face processing, the FFA is right-lateralized, which means that the right hemisphere does most of the work.

Its corresponding homologue is over in the left hemisphere. Stanislas Dehaene has dubbed that region the visual word form area. It is specialized for processing written words. This makes sense given what we know about the left hemisphere generally: It is specialized for sequential and componential processing.

The Birthplaces of Writing

Most scholars trace the invention of writing independently back to at least two different civilizations: Mesopotamia and Egypt.

Both hemispheres are still involved in processing faces and words, but the two sides approach them differently. The right hemisphere does more of the work when it comes to faces, and the left hemisphere does more of the work when it comes to written words.

The second part of the reading network involves the ventral and dorsal route for language processing. When children are learning to read English, for example, they spend a lot of time trying to sound out letters in words. We know from brain damage and neuroimaging studies that this overt sounding out during reading activates phonological mechanisms running up and down the dorsal stream. Even after children stop overtly reading aloud, they continue to covertly simulate this production in the same region.

Bradley Schlaggar and Bruce McCandliss explain that through massive repetition and neural plasticity, this sounding-out process gradually helps the ventral and dorsal streams of speech processing connect with the visual word form area. This neural network becomes established at different times for different people, but nobody comes into the world with such a network. It is not innate, and it requires experience with written objects to shape it.

Dyslexia

Even though this neural network for reading is not innate and must be built over time, that does not mean there are no genetic components. Dyslexia is one big reason why we know that reading is partly genetic. Dyslexia is common and is conservatively thought to affect at least 3 percent of the world's population. It's a very specific disorder that appears unrelated to overall intelligence.

The National Institute of Neurological Disorders and Stroke defines dyslexia as "difficulty with phonological processing, spelling, and/or rapid visual-verbal responding." Note these two pieces: sounding out words and visually mapping letters to sounds. Those involve the reading network.

The heritability of dyslexia is estimated to be around 60 percent. This means that in the entire population of readers, 60 percent of the variance in the behavioral manifestation of dyslexia can be explained by variation in genes across individuals.

There are genes for motor control and visual processing abilities as well as genes for linking up those two systems. When confronted with the technology of the written word, the brain does its best to wire up the reading system, but in the case of dyslexia, there is some genetic malfunction with parts of that network. This does not mean there are genes for dyslexia. It does mean there are genes that get co-opted for the system.

Synesthesia

When looking at a written word printed all in black, a small percentage of people do not perceive that word as written in black. Instead, they see it as a rainbow of colors, with each letter having its own distinct hue. This phenomenon is known as grapheme-color synesthesia, and it is part of a larger phenomenon in which the brain has unusual cross talk during certain sensory experiences. This cross talk comes in many forms: Some people with synesthesia hear colors, others smell sounds, some feel numbers, and a few even taste words.

Synesthesia is rare in the general population. Conservative estimates are that only about 1 in 2,000 people have some version of it. Interestingly, there seems to be a much higher incidence among artists and other creative people.

Letters evoking colors is one of the most common types of synesthesia. Often, these color combinations are experienced emotionally or seen by the synesthete to be beautiful or ugly.

One well-established theory by V. S. Ramachandran and E. M. Hubbard is that there are crossed wires in the fusiform gyrus connecting the visual word form area to the nearby V4 area. V4 is in the secondary visual cortex and is specialized for color processing. There are clusters of cells dedicated to processing every color a person experiences. The theory posits that in infant brains, there are exuberant connections between this area and the neighboring visual word form area, and over typical development, plasticity prunes them away. However, this does not happen in synesthetes, and the cross-wired connections remain.

Other theories downplay structural plasticity and focus more on functional plasticity. Even in neurotypical brains, there are connections between the visual word form area and V4 as well as many other areas. In fact, there are many silent connections between adjacent areas of the brain. These are called latent synapses.

In neurotypical brains, high-level inhibitory mechanisms dampen communication along these latent synapses. Some scientists think things are different in synesthetes. The psychologists Peter Grossenbacher and Christopher Lovelace argue that a synesthete's inhibitory mechanisms are weakened, and this is why there is cross talk between adjacent areas. Some compelling evidence to support this is that hallucinogenic drugs, such as LSD, decrease inhibitory mechanisms in the brain, which can induce massive synesthetic experience. The logic is that because these drug effects come on so fast, it would be impossible that new neural connections are created on the spot.

One problem with both of these theories is that they can't truly explain synesthesia involving links between nonadjacent brain areas. For example, some people experience certain words with particular smells, and because the brain areas responsible for both of those senses are so far apart, it is hard to see how they became linked up in the first place. There is some promising evidence that some of these links are genetics-based, but researchers have not yet been able to map specific genetic mechanisms onto specific types of synesthesia.

Regardless, the takeaway point is this: Both synesthesia and dyslexia nicely illustrate the network property of the brain. While dyslexia shows how the wiring between typically connected regions can be too weak, synesthesia shows how the wiring between atypically connected regions can be too strong. Just like typical reading development, both show how genes and experience combine with plasticity to ultimately create neural structures dedicated to the written word.

Suggested Reading

Borges, "The Library of Babel."

Dehaene and Cohen, "The Unique Role of the Visual Word Form Area in Reading."

Ward, "Synesthesia."

Questions to Consider

Research by Linda Henkel has shown that compared to simply observing something, taking photographs of that thing makes people forget it more easily. Why might that be? Do you think the same thing happens when you put your thoughts into writing? Why or why not?

18.
SIGN LANGUAGE: LANGUAGE IN OUR HANDS

The World Federation of the Deaf estimates that worldwide, more than 70 million people use sign, which comes in many distinct forms, as their native language. This lecture explores that often-overlooked form of language. Exploring a version of language that operates in a different modality than speech can give a wider and deeper appreciation of what language is.

Sign as Language

The lecture begins by breaking down sign language according to our five linguistic components: pragmatics, syntax, semantics, morphology, and phonology.

Starting with pragmatics, it is clear that the deep need to share information with other humans has always been a driving force in the use of sign. For example, there was a flourishing community of signers on the island of Martha's Vineyard from the early 1700s to the mid-1950s. Historical records suggest that Martha's Vineyard Sign Language came from an earlier sign language in England called Old Kent Sign Language. The language flourished on Martha's Vineyard because of the unusually high number of deaf people who lived there and its acceptance among the hearing community. The fact that it was used both by hearing and deaf people alike for so long is a testament to the powerful social drive to connect through language.

The semantic component of sign language involves the meaning of words. In the Saussurean tradition, words not only serve as symbols for things but as arbitrary symbols. For instance, the American Sign Language (ASL) word for *sunlight* is a small, one-handed, circular movement off to the side of the head. Then, the signer opens the hand toward his or her face. This seems fairly iconic, but there are still some arbitrary elements. For instance, why not have the hand directly overhead? Why not make a fist instead of a circle? Even with signs that are highly iconic, there are always arbitrary elements.

When it comes to morphology and syntax, a myth about sign is that it basically borrows its grammar from spoken languages. There is no question that spoken languages influence sign languages, but sign has many unique grammatical features too.

For example, Auslan is the imported sign language used by the Australian deaf community. It was brought to Australia by British and Irish deaf signers in the 19th century, and it differs from English in many ways. The past tense is one way: English adds the morpheme -*ed* to regular verbs to indicate an event happened in the past.

Auslan has no such marker, but instead it begins the sentence with a temporal statement and then describes an event. Take this example: "Week past, I wash my car."

Another myth about sign language is that it is all about the hands. This is not the case. For example, in 2012, New York City mayor Michael Bloomberg gave several press conferences about the administration's response to Hurricane Sandy. At the podium, the mayor was joined by an ASL interpreter named Lydia Callis, who used animated and assorted facial expressions. These expressions were not just optional visual flourishes, like they are for spoken language. Instead, they were actual parts of the morphology, syntax, and semantics of ASL. In fact, the whole body is used in sign language.

The final component is phonology, which, in speech, is determined by the physical configurations of the motor articulators, such as the lungs, throat, tongue, and lips. Phonology in sign is determined by the physical constraints of the hands, face, and body. The hands are the primary articulator.

In the realm of sign phonology, a key figure is the pioneering linguist William Stokoe. In 1960, Stokoe published *Sign Language Structure*. The book was notable for three large reasons. First, it put an official name to the unique version of sign language used in America. It has been known as American Sign Language ever since.

Second, Stokoe created a notation system for recording sign utterances in writing. Up to that point, no sign system had ever been reliably recorded on paper. Third, Stokoe's book was the first to empirically demonstrate that ASL was an actual language, just as rich in structure as any spoken language. One of Stokoe's main areas of focus was the phonology of sign.

The phonology of spoken language concerns several parameters, such as shape of mouth, location of tongue, timing of vocal cord vibration, and so on. Stokoe showed that ASL was composed of similar parameters, but all in the manual modality. The big three are the shape, location, and motion of the hands. This means that for every sign, these three things systematically combine to produce distinct meanings. Since Stokoe's publication, there have been a few other phonetic parameters added, like palm orientation and signals with the face.

Development and the Brain

The final pieces of evidence that have sealed sign as a real language came from the fields of developmental psychology and cognitive neuroscience. Developmentally, the native acquisition of speech and sign is remarkably similar. Verbal babbling and babbling with the hands both occur at around six months of age, and this is followed by non-sign pointing at about nine months of age. These typically lead to one-word speech and sign at about one year. By 18 to 24 months, signing and speaking children are stringing together two signs or words to form simple sentences. These simple sentences follow reliable word order rules.

Additionally, clinicians know from patients with brain damage that signers can have aphasia. Just like hearing aphasics, signers with Broca's aphasia understand meaning, but they have difficulty producing basic phonological forms. Although the signing of Wernicke's aphasics appears fluent, individuals with this form of aphasia have great trouble understanding and producing meaning. MRI scanners reveal that each type of aphasia has a neural profile of damage that looks a lot like its spoken counterpart.

Findings like this have helped debunk one of sign's biggest myths: Deaf signers and hearing speakers have totally different brains. In terms of neural mechanisms, language is language, largely regardless of modality.

Tying back to one of this course's themes, over evolution, the brain didn't adapt to language; language adapted to the brain. That is what Morten Christiansen and Nick Chater theorize produced the tight fit between the brain and language in the first place.

Running with this, we might conclude the following: Because hearing and deaf individuals are born with comparable domain-general neural architecture, both groups have created a language system that works according to those shared mechanisms. Although the superficial form clearly differs, signed and spoken languages are both products of the same language-ready brains.

Sign Culture

One final myth is the belief, held by many hearing people, that all deaf signers would rather use spoken language. The truth is that it is not so simple. For the first time ever, technological innovations like cochlear implants offer deaf children a chance to boost their hearing abilities, and this can make a huge difference in successfully learning to use spoken language. While most people in the deaf community are enthusiastic about such technologies, there is real concern that learning spoken language will come at the cost of implanted children not learning sign language.

Culture and language are inextricably tied. For deaf people, sharing a form of language that is perfectly suited to the people who use it produces an incredible sense of community. This can build a real love for the language.

As much as any culture—and perhaps much more—the sign community is proud of their language, and they view it as inherently beautiful. Many hearing people are surprised to learn that, just like spoken language, sign language can be an art form. Deaf culture has its own revered poets, talented singers, and enchanting storytellers, all of whom exquisitely sign. Many expressions are unique to the language and culture, capturing things in a way that could never be expressed in speech.

Suggested Reading

Johnston and Schembri, *Australian Sign Language* (*Auslan*).

Xu, Gannon, Emmorey, Smith, and Braun, “Symbolic Gestures and Spoken Language are Processed by a Common Neural System.”

Questions to Consider

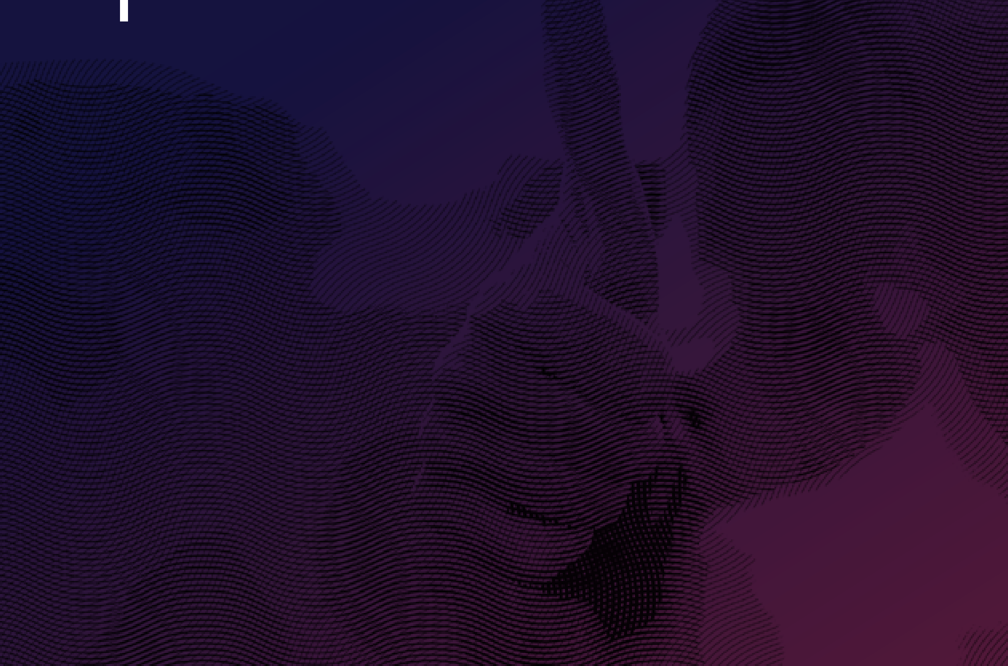
What are some advantages and disadvantages of sign languages compared to spoken languages? Can you see the benefits of a hybrid form of communication that takes advantage of both modalities?

19.

EMBODIED LANGUAGE: MIND IN BODY—BODY IN MIND

The hands are closely tied to language. This lecture considers the rest of the body. The lecture focuses on answering this question: What can communication in its most embodied form tell us about language and the mind?

The mind emerges from how the brain interacts with the environment through the body. In this way, the body isn’t merely a vessel for the mind. It’s actually part of the mind. This is the idea of embodiment, which has roots in a number of different fields, including philosophy, psychology, and neuroscience.



Philosophy and Embodiment

Starting with philosophy, the body has always been viewed as a central feature of the mind in many Eastern traditions, like Buddhism. For example, Zen Buddhism has long rejected the notion of the body as just a shell for the mind. In this form of Buddhism, body and mind mutually comprise the self.

Until recently, the body has not received as much attention in Western philosophy. Most now credit the French phenomenologist Maurice Merleau-Ponty as the first Western philosopher to give serious attention to the body in human subjective experience. For Merleau-Ponty, the body serves as a constructive mesh between the brain and the environment, and this blurs the distinction between the inner mind and outer world.

Psychology and Embodiment

Merleau-Ponty's ideas have had a large impact on scientific theories as well. This is most directly evident in the mid-20th-century psychological work of the husband-wife team of James J. Gibson and Eleanor Gibson. Like Merleau-Ponty, the Gibsons saw the body as creating a mesh between the brain and the environment.

They explored this interconnection through very naturalistic scientific studies in which people interacted with objects in everyday contexts. In these studies, they observed that people don't seem to perceive their environment directly; instead, they experience it according to certain affordances. An affordance is an aspect of the environment that lends itself to a particular way of physically engaging with it.

The Gibsons were not the only prominent psychologists to emphasize the body. Another was the developmental psychologist Jean Piaget. Piaget developed a theory called constructivism that emphasized how children actively constructed their knowledge over development. Piaget theorized that children act like small scientists who physically tinker with the world.

They use their bodies as tools to test hypotheses about things around them, like the physics of objects and the consequences of actions. Piaget's work has been criticized on methodological grounds, but his central claim about how the body constructs knowledge has endured.

Neuroscience and Embodiment

In neuroscience, certain theories place a central importance of the body in neural processing. For example, many see simulation theory as a neural pillar of embodiment. In a similar way, Giacomo Rizzolatti's work on mirror neurons is seen as support for embodiment in perspective taking.

Before the 1990s, there were two competing views of the brain: One saw the brain as a general-purpose device like a computer, which computed and solved problems in a highly abstract and binary way. The other view of the brain saw it as a complex machine with many specialized parts for solving very particular problems.

These so-called modules were functionally isolated from one another, which highlighted a sharp distinction between the body and higher-level thought. Both of these views waned in popularity during the rise of embodiment, but now they are making a comeback and adding important nuance to modern theories of embodiment.

Critiques of Embodiment

Despite the current popularity of embodiment, many scientists are pushing back on the idea, especially in its more extreme forms. One radical view of embodiment is that because humans have evolved minds in the ubiquitous context of bodies over millions and millions of years, all thought and all feeling is constrained by the body in some way. There are three big problems with this extreme view.

The first critique is that embodiment is not an all-encompassing mechanism for the mind. Research in cognitive neuroscience has shown that not every concept, memory, or feeling is embodied. Some are represented in the brain in purely abstract ways.

The second critique highlights the functional limits of embodiment. For understanding concrete things—like an apple or a comb—it is obvious how neural embodiment is useful. Less obvious is how embodiment is useful for understanding abstract concepts like good and evil.

The final critique of embodiment is best illustrated through an example from the documentary *AlphaGo*. It's about the ancient Chinese board game Go, and it features a match between the 18-time world champion Korean player Lee Sedol and a computer program called AlphaGo.

The program was created by Google's DeepMind division in London, and it learned how to play the game through deep learning. AlphaGo was fed massive amounts of data from previous Go games while also training itself by playing actual Go experts. After training, it was 100 percent in control of its own moves during each game with Sedol.

AlphaGo beat Sedol four games to one, and it displayed creative moves. If a computer can manage to accomplish this without a body, it seems to raise doubt about how much humans must use their bodies to think.

Grounded Cognition

Overall, the evidence suggests that some aspects of thought lend themselves best to an embodied form and other aspects are better suited for more abstract representations and processes. For example, the neuroscientists Bradford Mahon and Alfonso Caramazza present a hybrid view that they call grounding by interaction.

The idea is that all thinking has an abstract component, but when possible, the way it becomes instantiated is through embodied perceptions and actions. In this way, abstract thought is grounded in how the body interacts with the environment. When viewed from this perspective, the mind has the best of both worlds: It can quickly and flexibly process abstract concepts without any limits while also materializing and exploring that abstract information through concrete bodily experience.

Embodied Language

Given that the mind is both embodied and disembodied, it's worth asking how this plays out in face-to-face communication. In other words, how do the arbitrary and abstract elements of language interact with the iconic and concrete expressions of the body?

The key here is to recognize that language originally evolved within face-to-face contexts. In addition to the hands, the early forms of human language most certainly used other aspects of the body, including eye gaze, body posture, facial expression, lip movements, and tone of voice. In language's natural face-to-face habitat, the body is an extremely important tool for communication. The main benefit of face-to-face interactions is that the body can help us understand what communicators mean. Brains are built for this sort of multimodal processing.

For example, in the primate brain, the modalities of vision and audition synergistically interact to help differentiate important things like threats versus non-threats or mates versus non-mates. Language was built on top of these multimodal mechanisms, so it's no surprise that humans depend on the body so much when we communicate.

Emotional Expressions

The psychologist Paul Ekman headed an ambitious research program investigating how facial expressions may universally display emotions across cultures. Although there is still debate, most scientists now generally accept that certain basic facial expressions—like happiness, anger, and fear—are universally used and differentiated across cultures, and they serve as reliable social signals for most people on the planet.

However, emotional expression does not stop at the face. The cognitive neuroscientist Beatrice de Gelder is an expert on how emotion conveyed through the face and the body combine. Her work has found that the brain perceives emotional messages quickest when the face and body postures are emotionally congruent. When the face and body express the same thing but conflict with the emotional tone and content of speech, people go with what they see, not with what they hear.

The Body and Pragmatics

Pragmatics is all about assessing the social intentions of a communicator. The body is perfectly suited for that job. For example, take threat detection. Our fight-or-flight response is triggered by threatening stimuli, including aggressive postures and eye contact, angry facial expressions, and hostile tone of voice.

According to the neuroscientist Joseph LeDoux, these threats are processed by two simultaneous pathways in the brain. He calls the first one the low road of threat processing. This low road is based on an evolutionarily ancient direct connection between sensory receptors, like the eyes and ears, and the amygdala, which is one of the oldest structures in the animal brain. The function of this pathway is to quickly alert the organism of immediate danger, and this happens within milliseconds.

At the same time, the high road of processing involves a much slower route, on the order of seconds. The high road involves the primary sensory cortices and the hippocampus. The high road creates a deeper and more thorough assessment of the threat in context.

Suggested Reading

Mahon and Caramazza, “A Critical Look at the Embodied Cognition Hypothesis and a New Proposal for Grounding Conceptual Content.”

McGurk and MacDonald, “Hearing Lips and Seeing Voices.”

Question to Consider

Consider statements like “Follow your heart’s desire.” It seems natural to associate the body with emotion. Traditionally, feelings in the body have been contrasted to what is supposed to happen in the head, like perceiving, thinking, and reasoning. How does embodiment blur this distinction?

20.
THE MULTILINGUAL MIND

This lecture discusses the complexity of language in its multilingual form. It is helpful to understand this lecture's terminology: The term *multilingual* refers to living with more than one language and regularly using them in daily life fluently. The term *fluent* refers to speaking or signing in a flowing manner. Finally, the term *monolingual* refers to being fluent in only one language.

Multilingual Variability

One widespread myth is that a bilingual brain is simply two monolingual brains rolled into one. This is incorrect. Although there are many similarities, bilingual and monolingual brains are different in some important ways. For instance, multilingual neural mechanisms are much more complex and variable than monolingual ones.

This variability is caused by a number of factors, including how many languages a person speaks, the similarity among those languages, whether they are learned at home or in the classroom, and the amount of use each one receives. The biggest factor, however, may be age of acquisition.

Age of exposure strongly predicts phonetic ability in a language. For example, Elissa Newport and colleagues have argued that many linguistic components are very fragile. Mastering them requires exposure to a language within the first 12 years of life. In addition to accent, there are sensitive components like complex syntax and inflectional morphology (such as markers for past tense and plurals).

However, Newport observes that other linguistic aspects—like vocabulary, simple syntax, and basic pragmatics—are relatively easy to learn even late in adulthood. Still, there is much variability in what late learners can handle.

Multilingual Brains

In 1997, Karl Kim, Joy Hirsch, and their team at the Sloan-Kettering Cancer Center in New York published a landmark study investigating how age of second language acquisition affects the language network in bilingual brains. The study used fMRI to compare differences in the Broca's and Wernicke's areas of people who learned second languages as infants or as adults.

Participants were put in a scanner and asked to internally generate silent sentences to activate neural networks of one language and then the other language. The main finding was that while Wernicke's area showed no differences across languages for both early and late learners, Broca's area did show a difference: For late learners, the two languages activated two separate subregions of Broca's area, but for early learners, both languages activated an overlapping area.

This pattern in Broca's area makes sense given the dorsal stream of language processing. This part of the language network is where phonological forms of words are activated and executed. Patricia Kuhl's theory of native language neural commitment is helpful here. Because the brain commits to phonemes of a language (or languages) early in life, it can use prime real estate in Broca's area for the job. However, if a second language is learned after this neural commitment, it must rely on a different part of Broca's area that is not as optimally suited for phonological production.

Since Kim and Hirsch's landmark experiment, subsequent neuroimaging studies have mostly confirmed these differences using a variety of languages and ages. Additionally, a recent meta-analysis shows that the later in life someone learns a second language, the more space is required in Broca's area.

Multilinguals versus Monolinguals

One of the biggest differences between monolinguals and multilinguals is that multilinguals must build mechanisms for keeping track of their separate languages. The prefrontal cortex is constantly at work when we use language. It has to keep track of what was just said, and it must monitor what to say next.

On top of that, it also has to suppress information that is distracting to the task at hand. This suppression is hard enough for monolinguals. Multilinguals must work extra hard because when they are speaking one language, their other language (or languages) must not get in the way.

Evidence for language coactivation and suppression in multilinguals comes from many different lines of research. This lecture now turns to four of them.

Widespread Multilingualism

The linguist François Grosjean estimates that more than half of the world's population regularly uses more than one language.

Bilingual Aphasia

The first line of research involves bilingual aphasia. One distinctive, but not uncommon, problem in bilingual aphasics is pathological mixing of languages within an utterance. It's called pathological mixing to set it apart from voluntary mixing.

Voluntary mixing is perfectly natural, with one example being Franglais, a mix between French and English. Pathological mixing is where an aphasic can't control swapping languages.

In 2000, Franco Fabbro and his team of neurolinguists published a landmark case study of a patient who demonstrated pathological switching of his two languages: Italian and Friulan. (Friulan is a language spoken in northeastern Italy.)

The patient frequently alternated entire sentences between Italian and Friulan, even when speaking to people who didn't understand one of the languages. In this particular case, the patient was aware that he was making these switches, and it caused him great distress.

After his symptoms got worse, and he started having difficulty walking and driving, he went to his doctor, who suggested an MRI to look for structural abnormalities in his brain. The results showed that he had a large tumor growing in the left inferior frontal gyrus. The damage was not quite in Broca's area, which explained why he could still speak fluently in both languages.

The damage was to an area slightly anterior to Broca's area. It was located in the prefrontal cortex's executive control network, which is important for neural inhibition. In this patient's case, damage to the left PFC made it impossible to stop alternating between languages, and it also produced more general deficits in social inhibition.

Since this study, there have been other cases of structural damage to the left PFC and pathological code switching. As with Fabbro's case study, these patients also demonstrated more general deficits in social inhibition. This has led many researchers to conclude that this is not a problem specific to language, but rather a more domain-general problem of executive control.

Neurotypical Bilingual Brains

A second line of evidence for the co-activation of multiple languages comes from research on neurotypical bilingual brains. In one simple but creative approach, the psycholinguist Albert Costa exploited the fact that some bilinguals have many shared vocabulary items across their two languages. These overlaps are called cognates.

For example, take Spanish-Catalan bilinguals, who have an unusually high number of cognates. In Catalan, the word for *cat* is *gat*, and in Spanish, it's *gato*. Costa had fluent Spanish-Catalan bilinguals look at pictures of things that either had cognates in the two languages or didn't have them. The task was to name the objects in either Catalan or Spanish as quickly as possible.

The prediction was that if the mental lexicons of Catalan and Spanish were both active when trying to name a picture, bilinguals should be slower to name objects that had no cognates. That's exactly what Costa found. He interpreted this finding to mean that when bilinguals are searching for lexical items for a particular meaning, both languages are simultaneously active.

The Other Side of Cognates

The third line of evidence for multilanguage co-activation considers the other side of cognates. For all bilinguals, there are some words that randomly sound similar across their languages but have completely different meanings.

For example, the Russian word for *stamp* is *markka*. A similar-sounding but different-meaning word in English is *marker*. What happens when a Russian-English bilingual hears the beginning of the words *markka* and *marker*? Do they activate both meanings in their heads momentarily?

That was precisely the question asked by the psycholinguists Viorica Marian and Michael Spivey in a 2003 eye-tracking study. The experiment studied Russian-English bilinguals as they listened to a Russian speaker referring to different objects in Russian. Also involved was a computer screen that had an image of a stamp on the left side and a dry-erase marker on the right side. When subjects heard the Russian word for *markka*, their task was to press the side of the screen where the object was located—in this case, the left side.

This sounds like it should be a straightforward task, but the eye-gaze patterns suggested something more nuanced. When the stamp was paired with a marker, bilinguals looked at the marker about a third of the time. This means that there was competition between the phonological forms of the two words, *markka* and *marker*. In contrast, when the stamp was paired with a competing image that had a totally different-sounding English translation, like a candle, the bilinguals were three times less likely to look at that competitor.

The experiment was done entirely in Russian, so there is no reason for English to be active in the first place. Despite this, it wasn't possible for the bilingual subjects to totally tune out the irrelevant language, even when it was disruptive.

Language Attrition

It is not true that once a person has mastered a language, it is mastered for life. Without activity, all languages decay. This applies to a person's first language, too. Linguists call this language attrition.

Neuroimaging Studies

The final line of evidence comes from neuroimaging studies exploring how languages are activated and deactivated in neurotypical brains. The neural mechanism for this process has been dubbed the bilingual language control network by the neurolinguists David Green and Jubin Abutalebi.

In addition to the left prefrontal cortex, the network involves other areas outside the traditional language network, like the inferior parietal lobe, cerebellum, and thalamus. A particularly important area is the anterior cingulate cortex (ACC). The ACC is a subcortical brain structure involved in error detection and conflict monitoring.

Neuroimaging studies have shown that the ACC is heavily used in bilinguals when monitoring which language is most appropriate for a given communicative context. Interestingly, this region is most active for low-proficiency multilinguals, presumably because they are the ones who are most likely to make errors.

The ACC and left PFC combine to perform two critical functions for multilinguals: They determine when to engage and when to disengage different languages. Both functions are important, but it turns out that disengaging requires much more brainpower. In a neuroimaging study in 2018, Karen Emmorey and colleagues investigated this control network. They found that turning off a second language requires much more effort than turning it on.

Suggested Reading

Costa and Sebastián-Gallés, "How Does the Bilingual Experience Sculpt the Brain?"

Grosjean, *Life with Two Languages*.

Question to Consider

Decreased plasticity makes language learning harder for older people. Based on what you learned about neural inhibition in the prefrontal cortex, can you think of another mechanism for why late learners may struggle to master an additional language?

21.
DOES LANGUAGE SHAPE THOUGHT?

Answering the big question of how language makes us human requires the full power of the 3-D framework. It is necessary to consider mechanisms and functions that operate on different timeframes and across multiple levels of analysis.

Beginning with this lecture, this course uses the 3-D framework to explore two ways that language can shape who we are. One way considers how having any language molds various aspects of the mind, like emotion, personality, and thought. A second way considers how having a particular language—like English, Hebrew, or Navaho—influences minds specifically.

The second, specific effect of language is much more controversial than the first. That specific effect is the focus of this lecture.

The Whorfian Hypothesis

Eskimo-Aleut languages have many words that describe snowy things. This diverse vocabulary was first formally discussed by the anthropologist Franz Boas in his 1911 work, the *Handbook of American Indian Languages*.

For example, Inuit has a few different word stems for the term *snow* in addition to many morphemes that add nuance to the central meaning. Some variants describe snow blowing, slushy snow, hard snow, and so on. Even though many languages, like English, generate most of their grammatical complexity through syntax, other languages, like Inuit, put more complexity into their morphology. This observation was made controversial by a later claim from the budding linguist Benjamin Lee Whorf.

In 1940, Whorf published a short paper called "Science and Linguistics" in which he took Boas's observation a few steps further. He argued that possessing so many unique words for *snow* caused Eskimos to experience their world differently than people whose language has only a few terms for *snow*. Eventually, these ideas congealed into what is now referred to as the Whorfian hypothesis or the Sapir-Whorf hypothesis. The latter name reflects the contribution of Whorf's teacher, the linguist Edward Sapir.

Two Versions

The hypothesis sprouted two versions, one strong and one weak. The strong version is called linguistic determinism, which is the idea that language enables or dictates thought. This view can lead to some extreme interpretations, including: If a person's language doesn't have an expression for something, the person can't experience it. Taken to its logical extreme, this view leads to some absurd conclusions, with one being that babies don't think at all until they learn language.

Unfortunately, this extreme version distracts from the much more plausible version of the hypothesis, which is called linguistic relativity. This toned-down version claims that differences across languages simply influence differences in thinking. This is still hotly debated, but the debate is more about the nature and extent of this influence, and less about it being logically nonsensical.

A Snowy Argument

The Eskimo snow example is the controversial topic that began the debate. One of the most well-known critiques was from the British-American linguist Geoffrey Pullum. Pullum made his argument first in an essay. In 1991, he turned it into a book: *The Great Eskimo Vocabulary Hoax*.

One of Pullum's main arguments was that, in terms of semantics, there is nothing special about how Eskimos refer to snow. They may have dedicated words to describe various snowy things, but other languages can do the same thing. For example, unlike Inuit, English does not have a single word for "snow drifting along the ground," but English can still easily express that concept.

Here is a reasonable counterargument: Might there be something special about having a single, dedicated word for a concept versus having many optional ways to express it? When snow is blowing sideways, there is no choice in Inuit to simply use a generic word for snow. Using the precise one is obligatory.

In English, we have the freedom to say what we want about the snow. In the context of how habit and plasticity are related, this distinction between vocabulary that is optional versus nonoptional might make a big neural difference.

Imagine a person taking the same route home from work every day for a year. Now compare that to the person randomly trying different routes on different days for that period. The habit of taking the same route nudges the brain to notice things about that particular route that one might miss with a random set of routes. This can be thought of as a type of neural commitment that guides the brain to experience and notice certain things.

Honorifics

The Japanese language features many components that deal with social relations. It has extensive vocabulary and morphology that highlight people's places in the social world. In some cases, the exact same verb is marked by different suffixes according to one's social status in a situation. The job of these suffixes is to make clear the social hierarchy between the person talking and the person listening. These are called honorifics.

Honorifics are present in English too, but they are different in two big ways. First, they don't affect verbs, and they're not marked by morphemes. They're usually standalone nouns or adjectives, like *doctor*, *professor*, or *madame*. The second reason is that the use of English honorifics is highly variable, especially in America. For example, some people insist on being referred to with a certain honorific much more than others.

This relates to linguistic relativity because in addition to these linguistic differences, Japan and America have some big cultural differences. Respecting one's place in the social order is an explicit value in Japan, whereas in America, it's much more fluid. In fact, many Americans reject social hierarchies and actively try to disrupt them.

Value Systems and Language

A relevant Whorfian question is this: Is it possible that these different value systems are influenced by the different honorific patterns of the two languages? At least on the surface, it makes sense how using honorifics may strengthen certain cultural habits of mind.

However, a complication is this: How can we be sure that it's the honorific structure of the language that is influencing the cultural value and not the other way around? Isn't it equally possible that a culture that values a structured social order would create a linguistic system that reflects that order? This is the gist of the argument that John McWhorter presents in his 2014 book *The Language Hoax*. McWhorter's critique is that language merely reflects culture, and it is culture that does all the heavy lifting in influencing thought across different groups.

To explore this critique, a well-known example from the realm of language and spatial cognition is helpful. The cognitive scientist Lera Boroditsky is fond of doing the following demo in lecture halls around America: She asks the audience to close their eyes and point due north. Audiences typically have trouble with this seemingly simple task.

Contrast this ignorance with the behavior of an Aboriginal community in northern Australia. The community lives in Pormpuraaw, on the western edge of Cape York, and their primary language is called Kuuk Thaayorre. The language is different from English in how it describes spatial relations. Rather than relying on relative spatial terms like *left* and *right*, it uses absolute spatial terms like *north*, *south*, *east*, and *west*.

Speakers of Kuuk Thaayorre also happen to be very good with cardinal directions. If asked to close their eyes and point due north, they have little problem. The linguistic anthropologist Stephen Levinson has a video of a girl in Pormpuraaw who correctly identifies directions even after being blindfolded and spun around five times. The girl is among many in the community who can do this.

To systematically test these spatial abilities, Levinson and colleagues have conducted several field studies in Pormpuraaw (and in other places where people use absolute directions in speech). As a comparison group, they also tested Dutch speakers in the Netherlands, who use relative spatial terms, as is the case in English. Their findings imply that because Kuuk Thaayorre speakers habitually use absolute terms for space, they encode that information in a compass-like way.

McWhorter might argue that the landscape of Pormpuraaw is ideally suited for cardinal directionality, and their language simply reflects this fact. In contrast, Westerners like the Dutch live in a landscape where absolute directions may not be the best way to describe and categorize space. After all, with so much of Western life operating indoors, large-scale landmarks are less prominent and can't always be counted on. This may naturally lock in relative spatial terms, like *left* and *right*, as the most useful form of language in these cultures. Perhaps it is the physical environment that affects thought and not the language. This possibility signals trouble for linguistic relativity.

Color

This lecture concludes with a look at color, and specifically this Whorfian question: Do people see blue because they have a word for blue? Not all languages have words for every color. Even some standard color words in English are relatively new to the language. For example, the term *blue* made its appearance relatively recently, only after the arrival of certain other color words.

Debi Roberson and her team at the University of Essex studied color words of a community of cattle herders in Namibia. They found that the herders' language, Herero, does not have as many color terms as does English. Whereas English has 11 basic color words, Herero has only 5. For example, the single Herero word *zuzu* subsumes a range of darker colors that English speakers would identify separately.

Additionally, the Herero speakers do not sort colors the same way as English speakers do. It appears that the two groups have categorical differences in how they perceive and organize colors. However, keep in mind that this does not mean that the differences in color vocabulary cause the differences in categorization.

Suggested Reading

Haun, Rapold, Janzen, and Levinson, "Plasticity of Human Spatial Cognition."

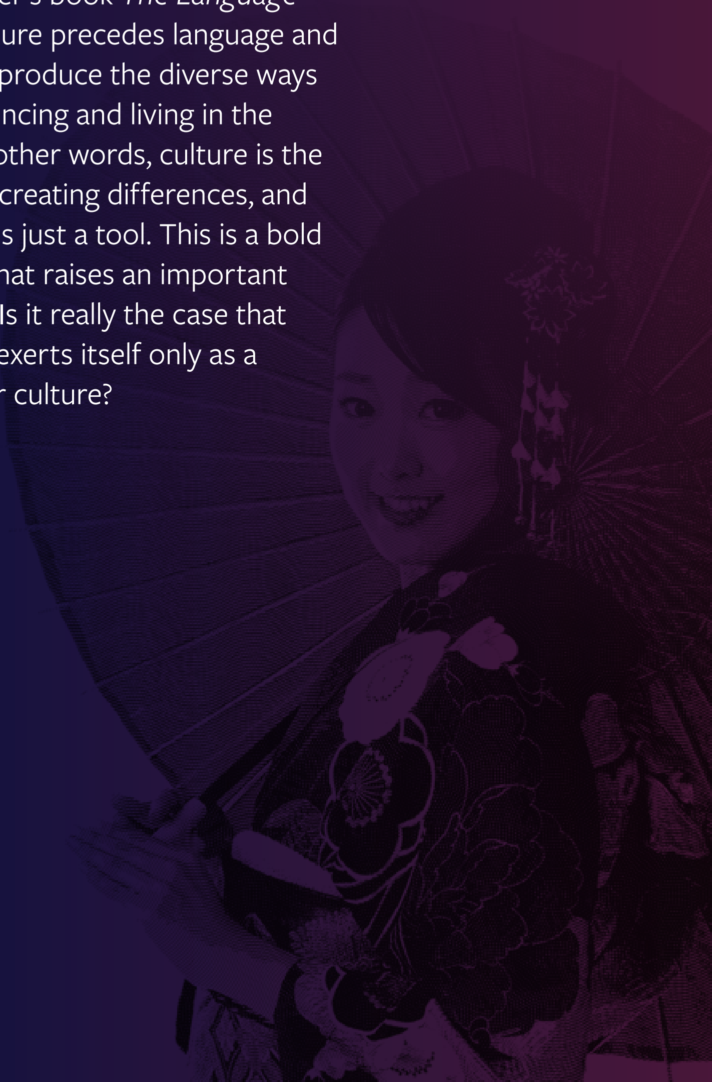
McWhorter, *The Language Hoax*.

Questions to Consider

What sort of experiment do you think would help test the causal claims made by linguistic relativity? Can you think of a way to control for variables like physical environment and cultural differences—and then test the direct effects of different languages on thought?

22.
DOES CULTURE SHAPE LANGUAGE?

According to the linguist John McWhorter's book *The Language Hoax*, culture precedes language and uses it to produce the diverse ways of experiencing and living in the world. In other words, culture is the agent for creating differences, and language is just a tool. This is a bold position that raises an important question: Is it really the case that language exerts itself only as a vehicle for culture?



The Color Blue

English speakers can capture about 15 percent of the visible color spectrum within the word *blue*. This range includes very light hues, like powder blue, to very dark ones, like royal blue.

However, in Russian, matters are different. There are two categories of blue that roughly mean “light” and “dark.” They are *guloboy* and *siniy*. The distinction between *guloboy* and *siniy* is categorical and obligatory. They are actually separate colors, like purple and red in English. There doesn’t seem to be an obvious cultural reason for this linguistic difference.

This presents an opportunity to see if linguistic relativity can operate outside the influence of culture. In one well-known experiment, a team led by Jonathen Winawer measured Russian speakers’ speed at differentiating colors within and across these categorical boundaries.

They presented Russian speakers with a triad of color squares on a computer screen. The top color matched one of the bottom two colors—the target—but not the other color—the competitor. The task was to ignore the competitor and find the target color as quickly as possible.

The main finding was that Russian speakers were 124 milliseconds faster at matching the top color to the bottom target when the competitor was from a different color category. This advantage was not present for English speakers who did the same task. For English speakers, there is only one general category of blue, not two. Additionally, for Russian speakers, obligatorily distinguishing colors in speech actually helps to visually distinguish them in perception.

It seems unlikely that these findings are the product of cultural mechanisms. English and Russian speakers both use the same full spectrum of colors in everyday life, and the distinction between light and dark blue does not have any special significance in Russian culture. Additionally, language areas in the brain are active during color processing, which suggests a likely linguistic mechanism.

Two Mechanisms

Other studies help to tell a more complete story about the relationship between language and the mind. In 2011, Veronica Kwok and Li Hai Tan led a study that investigated how exposing Mandarin speakers to new words for colors might induce plasticity in visual areas of the brain. In the experiment, participants were presented two shades of green, and then they were taught two made-up labels for these two shades: *áng* for light green and *sòng* for a slightly darker green. The same thing was done for two shades of blue, with different made-up words.

After just three days, there was an enlarged cluster of gray matter in a region of the visual cortex specialized for color. The findings show that the brain's inherent plasticity allows for structural modifications even after short bouts of practice.

Another experiment, published in 2017, was led by Anna Franklin and Alice Skelton. The subjects of this study were four months old. The study sought to answer this question: Before being fully immersed in language and culture, do preverbal infants have an innate bias in how they process color?

There were two interesting findings. The first was that infants made color distinctions that aligned remarkably well with categories that commonly occur in the world's different color lexicons. This is notable because color categorization in this experiment occurred long before children acquire words for color.

The second interesting finding was that infants' color distinctions nicely corresponded to two neural subsystems in the brain's processing of color. The primary visual cortex (V1) is organized in a highly structured fashion, with different dimensions of color requiring specialized computational mechanisms. These mechanisms appear to act like biological fault lines, and infants seem to use them to make categorical distinctions between hues.

The research on infants by Skelton and her colleagues gives us insight into the evolutionary mechanisms of color vision. These foundations are ancient—much older than language. This suggests that the brain's architectural and computational constraints for vision were the impetus to the world's color vocabularies in the first place. In other words, because our eyes naturally differentiate certain colors, our language systems evolved to name them.

In combination with these basic evolutionary fault lines for color differentiation, experience with language over development often accentuates these breaks. Sometimes it can alter them. This was the case with the variation of color terms across Russian and English speakers.

Evolution gives humans a genetic head-start in color processing. This combines with the brain's inherent plasticity, which allows social mechanisms over development to either deepen those pathways or forge new ones based on unique experience. This hybrid way of thinking about linguistic relativity is gaining more and more support from cognitive scientists.

A Control Knob

In 2017, Terry Regier proposed a helpful way of reconciling how universal foundations for cognition—like innate color biases—can coexist with the Sapir-Whorf hypothesis. Regier's solution was to cast linguistic relativity as a type of Bayesian probabilistic inference. The idea is that when we are sure of something, we don't need the help of language, but as uncertainty grows, so does our reliance on linguistic categorization.

Regier has a catchy name for this mental process: He calls it the cognitive control knob. When basic perceptual information is sufficient, people don't need to turn the knob. As perceptual certainty goes down, people turn up language to give an extra boost.

Regier's idea is a classic domain-general approach to understanding the mind. At its core, the mechanism is basically a Bayesian probability analysis: When a person is uncertain about something, how does he or she weigh different information or cues to constrain decisions? That is an extremely general process. It applies not just to language cues but to all possible constraints on decision making.

Cultural Relativity

We can think of culture as a constraint, too. This is how the researcher and professor Daniel Casasanto views it. Casasanto likes to relate linguistic relativity to what he calls cultural relativity.

By cultural relativity, he means something similar to Whorf's linguistic relativity. He explains the idea in this manner: "Certain aspects of people's thinking vary relative to the cultural practices they engage in." In one of his favorite examples, he talks about metaphors for space being used to conceptualize the passage of time and how different cultural practices lead to different metaphors.

First, he sets this up by pointing out that people across *all* cultures use spatial metaphors to talk about time. For example, in English, the past is behind us, and the future is in front of us.

Casasanto makes an interesting observation: The sagittal axis—which refers to the front and behind—is nearly universal for spatial metaphors for time. However, no known language ever verbally refers to time on the lateral axis, which refers to left and right. In English, one would expect to hear "Monday comes before Tuesday," but not to hear "Monday is to the left of Tuesday."

A seminal experiment demonstrated this. In 1991, the cognitive scientist Barbara Tversky had more than 1,000 English-speaking and Arabic-speaking children and adults place stickers labeled with the terms *breakfast* and *dinner* relative to a sticker labeled with the term *lunch* on the middle of a table.

The English-speaking subjects were much more likely to place the breakfast sticker to the left of the lunch sticker and the dinner sticker to the right of it. The Arabic speakers did the opposite. Arabic is read and written from right to left, not left to right like English. It appears that the cultural convention of reading and writing has caused the two groups to conceive of the arrow of time differently.

A problem remains: Correlation does not equal causation. To pin down causality, Casasanto and his colleague Roberto Bottini devised an experiment with Dutch speakers. Like English, the Dutch read and write from left to right. In the experiment, subjects were asked to read phrases that had a common spatial metaphor for time, like "a year earlier." The task was to press a red button if the phrase was about the future and a blue button if it was about the past.

The red button was situated to the right side of the screen, and the blue button was on the left. (There were also trials that counterbalanced the colors to rule out color as a cause.) Importantly, the experimenters never mentioned the location of the buttons, only the colors. This was to ensure that subjects didn't figure out that the location of the buttons was even relevant to the experiment.

The main finding was that subjects were faster to press the buttons when they spatially matched the flow of time. For example, when they read "a year earlier," they would press the button when it was on the left faster than when it was on the right. This was flipped with phrases about the future, like "a year later."

Some subjects were asked to read sentences that were mirror reversed, which meant they had to go from right to left, not left to right.
This is initially hard to do, but it becomes easy with practice. Even after just five minutes of this practice, the spatial effects were completely reversed. Now people were fastest when pressing the left button for the future and the right button for the past.

This is a nice example of the usefulness of the experimental approach. Because the same subjects showed two different patterns, we can rule out that language or other cultural factors were at play. Those things were held constant, and the only thing that differed across conditions was reading direction.

Cultural Values

Another relevant study was performed in 2001 by Takahiko Masuda and Richard Nisbett. They explored a well-known cultural difference between Japanese and American people: Japanese culture focuses more on how individuals collectively fit into a social context, whereas American culture focuses more on individual autonomy.

The experiment asked participants from both countries to watch a short video of an aquarium scene. In the foreground, there was a large central fish flanked by some small fish swimming past some seaweed. There were also some other peripheral details, like shells, crabs, and bubbles in the background.

After watching the video twice, both groups were asked to verbally recall everything they saw in the video from memory. The main finding was that Japanese speakers excelled at holistically remembering the scene, recalling details about stationary objects and smaller creatures in the background much better than Americans. However, there were no differences in how both groups remembered the large focal fish or other moving objects that were more prominent.

These findings were taken as evidence that basic cognitive processes, like attention and memory, are influenced by cultural values regarding the holistic analysis of a situation. Japanese culture values how an individual's behavior fits into a larger context, so that's what the Japanese subjects noticed and remembered from viewing the scene.

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Regier and Xu, "The Sapir-Whorf Hypothesis and Inference under Uncertainty."

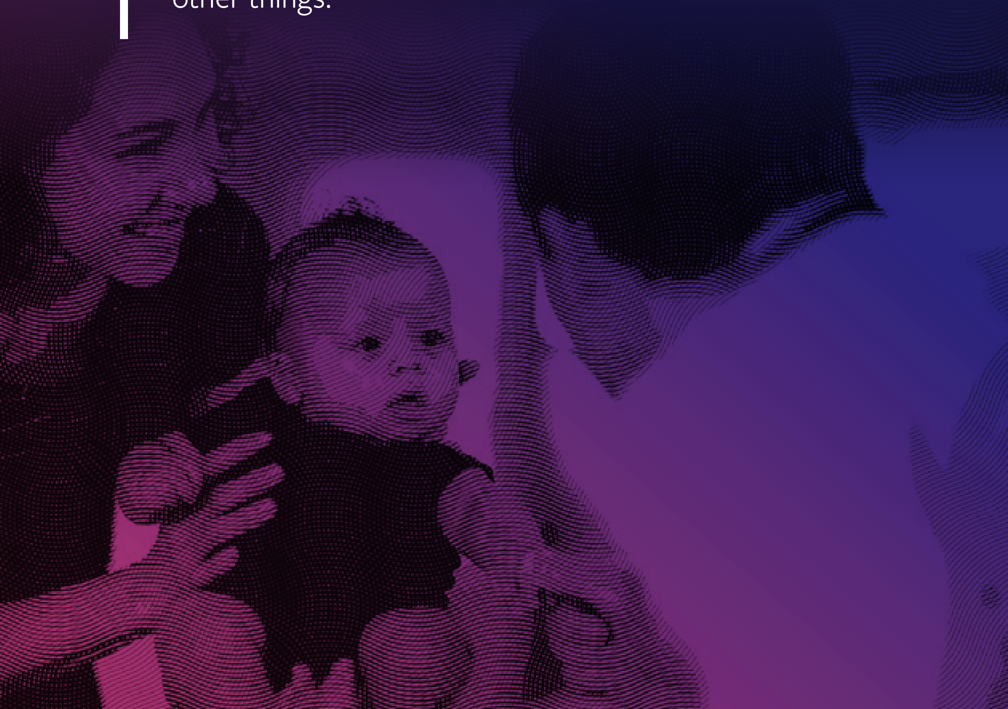
Questions to Consider

Running with Regier's cognitive control knob analogy, can you think of examples in your life when language or culture—or both—played more or less of a role in how you experienced something? Did these instances involve different degrees of uncertainty?

23.
THE BENEFITS OF BILINGUALISM

This lecture focuses on answering a specific question: What occurs as a result of multilingualism? To answer this, the lecture first makes a distinction between the intended function of speaking more than one language and its many unintended consequences.

The functional purpose of multilingualism is clear: to increase the number of people one can effectively converse with. However, as the eminent biologist Nikolaas Tinbergen points out, the fact that a behavior is designed for one thing doesn't preclude it from doing other things.



The Prefrontal Cortex

Speaking multiple languages requires a powerful prefrontal cortex (or PFC), presumably to control and monitor which language is being used at what time. This role of the PFC is a classic domain-general skill; it's not specific just to language. Given that, might this constant linguistic flexing of the PFC affect other aspects of cognition too?

This was the question that made Ellen Bialystok of York University in Canada famous. In her 2001 book *Bilingualism in Development*, Bialystok introduced the general public to the idea that being bilingual enhanced cognitive control in children and adults. Cognitive control is a metacognitive ability of the PFC that involves deploying attention to what is relevant while ignoring what is not.

Bialystok cleverly used a well-known measure of cognitive control called a Stroop task. Stroop tasks require one to focus on one dimension of a stimulus while actively ignoring another dimension.

For example, imagine seeing the word *blue* written on a computer screen. Also imagine that sometimes it is written in a blue font, but other times it is written in a red font. Finally, imagine that the task is to identify the color of the font—red or blue—while ignoring the actual meaning of the word.

On average, people are much slower at doing this when the word and font differ. Bialystok found that compared to monolinguals, bilingual children and adults showed much smaller timing differences, suggesting that they could more easily focus on the relevant piece of information without getting distracted by the irrelevant piece.

One explanation for these findings is that because bilinguals can have up to a lifetime of experience activating and suppressing languages—and switching back and forth between them—they are constantly flexing their cognitive control muscle. This allows them to become very good at using cognitive control for all sorts of metacognitive activities—not just ones related to language.

Bialystok and her colleagues have also found that multilingualism may offer protective effects for normal age-related memory loss. For example, in one study, Bialystok reported that memory loss is delayed by four years in multilinguals compared to monolinguals.

Personality and Multilingualism

The pioneering sociolinguist Susan Ervin-Tripp was one of the first researchers to empirically study how people change when they speak different languages. Ervin-Tripp had French-English bilinguals perform a well-known psychological assessment called the thematic apperception test, or TAT. The TAT involves pictures of ambiguous scenes, like a man pulling away from a woman's embrace while the woman looks directly at the man. These evocative pictures are designed to produce diverse stories about what is happening in the scene, what people in the scene are thinking and feeling, and what is going to happen next.

One group of bilinguals was shown a set of pictures and asked to tell a story about them in English. Then they were shown the same set again (in a different order) and asked to tell stories about them in French. In a second group, the bilinguals did the same thing, but they started in French and then switched to English.

The main findings were that when the bilinguals were speaking French, they had more descriptions that mentioned verbal arguments, but when they were speaking English, they had more themes that included physical violence. Interestingly, when talking in English, people were also more likely to describe the women in the scenes as being supportive as wives, helping their husbands achieve their goals.

More recently, Michéle Koven of the University of Illinois has done some interesting ethnographic analyses of French-Portuguese bilinguals speaking their two languages. According to Koven, when a bilingual speaks in one language, that language reactivates all the past experiences that are unique to speaking that language. The past experience becomes temporarily part of the present identity.

Decision Making

Another interesting area of study is how bilinguals make decisions when processing emotionally charged information in each of their languages. We know from psychologists like Nobel Prize–winner Daniel Kahneman that emotion can bias people to make irrational decisions.

How does language fit into these decisions? This was the question asked by Boaz Keysar and his students at the University of Chicago. In 2012, they published a paper: "The Foreign-Language Effect: Thinking in a Foreign Tongue Reduces Decision Biases."

The researchers performed several experiments that involved different forms of risk-taking and different bilingual languages. They led Keysar and his team to conclude that a foreign language provides greater cognitive and emotional distance than a native tongue. This distance allows people to do a more objective analysis of information during decision making.

This distancing mechanism has fascinating philosophical implications. Consider this classic ethical question: If you could throw a switch to divert a trolley car from one track where it will kill five people to a side track where it will kill only one person, would you pull that lever?

Albert Costa and his colleagues asked a variation of this question in a 2014 experiment involving various types of bilinguals, including English/Spanish in the US, Korean/English in Korea, English/French in France, and English/Hebrew in Israel. Replicating previous research, subjects in all languages were much less likely to choose the utilitarian option of pulling the lever, which from a purely rational and objective point of view saves the most lives.

Interestingly, people were particularly reluctant when doing the task in their native languages: Only 20 percent said they would pull the lever. They were much bolder when doing the task in a second language. On average, they were more than 50 percent more likely to flip the switch.

These findings further suggest that using a foreign language helps to cognitively distance people from emotionally charged issues. Additionally, psychotherapists have long noted that their bilingual patients often work through hard emotional problems better in their non-native language than their native one.

Social Skills

If learning multiple languages gives people access to two different worlds, could exposure to more than one language enhance certain social abilities in multilinguals? For example, consider perspective taking. Monolingual children often grow up with uniform linguistic common ground: If everyone they know speaks the same language, it can feed the belief that they all share something major in common.

Growing up with multiple languages is different. Having linguistic variety may cause children to work harder to keep track of what is mutually known and relevant at any given time. The cognitive science team of Dan Sperber and Deidre Wilson theorize that this mechanism of relevance is the key to success in all social communication. When you are exposed to one language, one major type of common ground is relevant, but when you are exposed to multiple ones, relevance is much more fluid.

Zoe Liberman, Katherine Kinzler, and their colleagues have explored these issues with children and infants. For example, in one 2015 experiment, four- to six-year-olds growing up with just one language were compared to children exposed to multiple languages in a game that required social perspective taking.

The game involved an adult speaking about some objects that the adult and child could mutually see and some other objects that only the child could see. If children were considering the perspective of the adult speaker, they should tune out information that only they could see. That is where common ground was absent. They should perk up when communication shifted to objects that they could both see—that is, when common ground was present.

The main finding was that monolinguals looked at the two objects equally, whereas children exposed to a second language looked primarily at the object that both could see, suggesting a greater sensitivity to the adult's perspective. The research team has since gone on to replicate this basic finding in 14- to 17-month-olds, so this boost to perspective taking starts early.

Suggested Reading

Bialystok, "Bilingualism."

Keysar, Hayakawa, and An, "The Foreign-Language Effect."

Question to Consider

Even within a single language, different social contexts require different ways of communicating. Consider how you talk differently around your family, friends, coworkers, and strangers. How might going back and forth among these pragmatic contexts shift aspects of the mind even within a single language?

24.
HOW LANGUAGE MAKES US HUMAN

The mind is an emergent property produced by a synergy of the brain, body, and environment. Language is a powerful tool in this emergence. This lecture explores the extent of that power, particularly how language is linked to mathematics, logic, storytelling, categorization, and metaphor.

The Mathematical Mind

Some people think about mathematics and language as totally separate things. However, mathematics is deeply grounded in language. In the mid-1990s, cognitive neuroscientist Stanislas Dehaene published a book called *The Number Sense*. He explained that humans have two main mechanisms for mathematic ability.

The first mechanism, called the approximate system, is an innate domain-general skill that comes as standard equipment for human infants and is even shared across many other species. The system can make basic numeric distinctions in an approximate fashion without doing formal counting.

This is different from the second mechanism, called the exact system, which is unique to humans starting at about age three. The exact system uses symbolic processing to understand numbers. For example, only a human can differentiate 59 dots from 60. Only a human is capable of counting that high.

This second mechanism taps into the symbolic property of language. Math and language are thoroughly connected in the brain. Using functional neuroimaging, Dehaene and others have shown that when a person solves basic math equations, many parts of the brain's language network are activated. Disrupting that network with neurostimulation disrupts the ability to do that math.

This disruption is most extreme in cases of aphasia. Often, aphasics lose the ability to do even basic arithmetic, but their ability to do approximate estimations remains.

Logic

A second major product of language—with a close relation to mathematical thought—is the capacity for logic. Logic is a cornerstone of Enlightenment thinking, and just like math, it is firmly grounded in the symbolic properties of language.

However, logic may not always be a good thing. The poster child for logic in 1921 was a young Ludwig Wittgenstein. Early in his life, Wittgenstein embraced a view that came to be known as logical positivism, which held that if logical analysis cannot be used to solve a philosophical problem, it is not worth solving.

Later in life, Wittgenstein started to see the dangers of logic. Here is a quotation from 1953 in Wittgenstein's posthumously published *Philosophical Investigations*: "Philosophy is a battle against the bewitchment of our intelligence by means of language."

This is classic Wittgenstein, full of nuance and double meaning. Here is one read on the quotation: When it comes to human thought, language is both a disease and the cure. On one hand, philosophers can use everyday language to identify and investigate important philosophical problems.

On the other hand, we can be misled by logical propositions of language, such as "If *x*, then *y*." Wittgenstein came to believe that these propositions can create pseudo-problems and provide answers to questions that have no basis in reality. That is what philosophy must fight against.

Storytelling

A third major use of language is to construct narratives. Telling stories is a signature feature of being human. Humans tell tales both grand and small. Consider the powerful narratives driving human civilization. Big-picture historians, like Yuval Noah Harari, argue that it was the narrative and imaginative power of language that built human societies over the past 70,000 years.

For example, in his ambitious book *Sapiens: A Brief History of Humankind*, Harari argues that humans have used language to create highly useful fictions that give artificial meaning and structure to our world. Take one of our most useful and long-lasting fictions: money, which is just an idea based on linguistic agreement among people.

People also create narratives on much smaller scales. For example, people create the stories of their lives. Narrative identities are extremely important, and fostering them can help people have a meaningful existence. Sometimes this means telling a story of one's life that is not entirely based on reality.

For some people, telling positive stories is much harder than telling negative ones, and this can cause much psychological pain. On a larger scale, fictions at the global level have done incredible damage over the course of history. Humans are natural storytellers, and we must accept that, big or small, these tales can take us to some good places. They can take us to some scary ones as well.

Categorization

A fourth potent function of language is its ability to carve up the world into categories. In a notable psychology study related to this, an MIT research team led by Leonard Lee went to real bars in Boston and had subjects do taste tests of two beers: Samuel Adams and what they called MIT Brew, which was just Samuel Adams plus several drops of balsamic vinegar.

When knowing nothing about the secret ingredient, subjects chose the MIT Brew 60 percent of the time. However, when they were told the secret ingredient right before they took a sip, that number plummeted to about 20 percent. Even though people drank the exact same thing in both conditions, naming vinegar as an ingredient left a bad taste in people's mouths.

The ability to categorize is certainly not unique to humans, but language greatly enhances categorization because it explicitly marks a category. That is what words do: They signal what they are and what they are not. The word *dog* conjures up thoughts of features like fur, tails, and barking, and it inhibits thoughts of features like feathers, wings, and chirping.

Another powerful function of words is to create new categories where none existed. For example, the *Dictionary of Obscure Sorrows* is a website and YouTube channel created by the artist John Koenig. His dictionary is made up of new words that capture unusual but oddly familiar categories of experiences that—at least in English—have no name. One example from his work is the word *sonder*, which means "the realization that each random passerby is living a life as vivid and complex as your own."

Even though categorical thinking is extremely useful, it is a double-edged sword. Linguistic categories can exacerbate differences. They can promote harmful stereotypes, and they can deceive us into thinking the world is simpler than it really is. As with the other products of language, we must be clear-eyed in taking the good with the bad.

Metaphor

This lecture's final major function of language is metaphor. Upon close examination, it may be surprising how often we use metaphors in daily life. In 1980, George Lakoff and Mark Johnson published a splashy book titled *Metaphors We Live By*.

The book described the ubiquity of conceptual metaphors in everyday language. By showing their prevalence, Lakoff and Johnson made the case that metaphors are much more than just artistic flourishes. They are actually a fundamental part of human thought.

Metaphor makes the abstract concrete, and this breathes life into language. For example, consider Wittgenstein's statement: "Philosophy is a battle against the bewitchment of our intelligence by means of language." This captures the imagination much better than saying, "Philosophers must recognize that language can confuse us, and they need to work hard to ensure that never happens."

Another function of metaphor is to extract specific elements of something. If categories are good at drawing boundaries between different things, metaphors excel at highlighting similarities. By using the familiar word *battle*, Wittgenstein accentuates that philosophy is a process that can be violent, protracted, heroic, winnable, and painful, just to name a few elements. These connections help us to structure thought in targeted ways.

Additionally, metaphor is a fount of creativity. It bubbles up in every possible place: music, law, art, poetry, film, literature, science, politics, and so on. Mapping one thing onto something similar yet different is a vehicle for seeing the world in a different way.

However, therein lies its biggest downside. Metaphor is never a perfect vehicle. Something is always added, and something is always lost. This is a big problem for anyone using metaphor to try to capture the truth about the world. Perhaps metaphor is simply the quintessential manifestation of minds that have language—minds that understand one thing by mapping it onto another.

Suggested Reading

Clark, *Being There*.

Dehaene, Spelke, Pinel, Stanescu, and Tsivkin, "Sources of Mathematical Thinking."

Lakoff and Mark Johnson, *Metaphors We Live By*.

Question to Consider

Consider this metaphor: Language is a double-edged sword. Building on the five examples from the final lecture, can you think of any other examples of how language helps and hurts humans?

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Lecture 21

Haun, Daniel B. M., Christian J. Rapold, Gabriele Janzen, and Stephen C. Levinson. “Plasticity of Human Spatial Cognition: Spatial Language and Cognition Covary across Cultures.” *Cognition* 119, no. 1 (2011): 70–80. This study compares the spatial abilities of Dutch and Namibian children whose languages differ in how they capture space.

McWhorter, John H. *The Language Hoax: Why the World Looks the Same in Any Language*. Oxford University Press, 2014. McWhorter’s book offers a critique of linguistic relativity by arguing that Whorfian effects are confounded with culture, and culture is the most powerful force in most experiments on linguistic relativity.

Lecture 22

Kwok, Veronica, Zhendong Niu, Paul Kay, Ke Zhou, Lei Mo, Zhen Jin, Kwok-Fai So, and Li Hai Tan. “Learning New Color Names Produces Rapid Increase in Gray Matter in the Intact Adult Human Cortex.” *Proceedings of the National Academy of Sciences* 108, no. 16 (2011): 6686–6688. Kwok and colleagues conducted an MRI study to show that even after brief training of new words for color, the brain makes structural changes in visual areas that process color.

Regier, Terry, and Yang Xu. “The Sapir-Whorf hypothesis and inference under uncertainty.” *Wiley Interdisciplinary Reviews: Cognitive Science* 8, no. 6 (2017): e1440. Regier and Xu introduce the idea of the cognitive control knob to explain how people use language when uncertainty is high. This helps to reconcile many of the apparently contradictory studies investigating the Whorfian hypothesis.

Lecture 23

Bialystok, Ellen. “Bilingualism: The Good, the Bad, and the Indifferent.” *Bilingualism: Language and Cognition* 12, no. 1 (2009): 3–11. This is a short summary of the work by Ellen Bialystok on the cognitive consequences of being bilingual.

Keysar, Boaz, Sayuri L. Hayakawa, and Sun Gyu An. “The Foreign-Language Effect: Thinking in a Foreign Tongue Reduces Decision Biases.” *Psychological Science* 23, no. 6 (2012): 661–668. Keysar and company present data from multiple experiments showing that compared to one’s native language, speaking a non-native language (learned later in life) causes people to be more rational when making decisions.

Lecture 24

Clark, Andy. *Being There: Putting Brain, Body, and World Together Again*. MIT Press, 1996. Clark presents a philosophical and scientific argument for why the mind should be considered an emergent property of the brain interfacing with the environment through the body.

Dehaene, Stanislas, Elizabeth Spelke, Philippe Pinel, Ruxandra Stanescu, and Sanna Tsivkin. “Sources of Mathematical Thinking: Behavioral and Brain-Imaging Evidence.” *Science* 284, no. 5416 (1999): 970–974. Using multiple neuroimaging techniques, this paper shows that mathematical reasoning activates traditional language areas of the brain in addition to regions involved in visuospatial processing. In this way, the symbolic processes involved in language are an important mechanism for mathematical thinking.

Lakoff, George, and Mark Johnson. *Metaphors We Live By*. University of Chicago Press, 2008. In this classic book, Lakoff and Johnson describe the ubiquity of metaphors in language. They argue that rather than being a mere linguistic flourish, metaphorical thinking may be at the core of human cognition.

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