PROFESSOR JOHN GABRIELI: Last time we discussed how people can approach psychological issues in terms of experiments, and at least correlations in some cases or causal studies through experiments. And we discovered that if you think about money, what happens? On average, you become more self-reliant or less willing to help, right?

We discovered that if you just change the way that men and women approach each other at a dating event, you change their internal feelings and their external behaviors simply by who's approaching whom. So we learned all kinds of things that you might or might not have known unless you did the experiments. And for all these things that are our mental life-- our thoughts, our feelings, they are all supported by our brains.

And so for me personally as a neuroscientist, I've always thought that the brain is one of the three amazing things out there in the natural world. With the origins of the universe, the origin of life. And the brain that allow us to think and feel, to see, that remember, really everything that we do comes from that. OK.

So here's this device. And I want to share with you just this phrase that people sometimes use, which is that your mind is what your brain does. That your mind is what your brain does And so the readings from Oliver Sacks for today kind of remind you of that.

So there are two women who have seizures of various kinds. And what happens in them? So one is Mrs. OC, 88-year-old woman. And what starts to happen to her? She starts to hear songs. And so powerfully, not just when you have a little song in your head, that it's hard for her to hear conversations. For her, a conversation like we're having now, it's as if the music stayed on really loud.

Turns out she's having temporal lobe seizures. The temporal lobes are the parts of the brain that are terribly important for hearing. So music is something that we hear. And then she has a right temporal lobe infarction. She's had an injury in the right temporal lobe. Music, for most of us, is more dependent on right hemisphere processes than the left. So that makes it unusual.

And how does she feel about the whole process? So what's generating the songs, though? What's generating the songs that she hears? Yeah, her memory. Her brain, right? Because in epilepsy, what's happening? Neurons are firing. When neurons fire in organized patterns, those are memories, desires, physical actions, thoughts. When they're firing for no good reason like an epilepsy because of some brain difficulty, they just start firing. But the neurons that happen to be firing will drive certain mental processes that they normally support.

In this case, the neurons that are firing away are ones that are involved in memory or songs and perception for songs. And when they fire, it's as if you heard the song itself. Because when you hear my voice or when you hear a song, you're never hearing the song. You're always hearing what your neurons are interpreting the sound that comes to your ear. Your mind is what your brain does in that sense, and in a very central way.

If you had an injury in that part of the brain, you can be cortically deaf and never hear a sound, even though all the information came through your ear. So without your brain interpreting the environment, you wouldn't know what it is. But if your brain starts to fire on its own, that's just as good a signal as if you heard a song itself. Because that is the stuff of hearing songs.

So she enjoyed it, actually. She declined taking anti-convulsive medications. Because she felt it was a portal to her past, right? The songs that she heard were ones that reminded her of her life and were kind of pleasant to hear. It was like being on a nonstop highlight film of for life, or a highlight MP3.

So now an opposite response to a similar phenomenon comes from a Mrs. OM in her 80s. She hears songs, but she also hears a lot of ringing and hissing. It's not limited to the song itself. She doesn't mention any of this for how long? Four years. She's hearing ringing, hissing, songs. She knows because her mind is fine that they're coming from nowhere but inside her head. But she doesn't tell anybody. That's a huge burden, right?

And why doesn't she tell them? Yeah, yeah. And especially if you're in your 80s, and you're going around saying, I'm hearing things, people go, OK. Were putting you in the old age home, right? You're out of it. So she doesn't want to give up her freedom. And she gets a short playlist, just three songs, and hears them over and over and over again.

You may have had the experience that some songs you hear for a while. You like them more, and then you get tired of them. If you had only three all the time, every day, and a bad version that was hissing and ringing, you would get pretty tired of the songs too. That stops by anti-convulsive medications and medications that stops the seizures, stop the songs.

And so it's sort of a beautiful story, when two opposite emotional responses for how your mind is what your brain does. Now from this, the fact that songs are played back as if you had pulled out songs from your computer or shelf somewhere, you might think that the brain retains these records perfectly throughout life and epilepsy would just sort them. But we'll come back to that later on, and say that in very much, we don't think memory is that way.

But we do remember songs that are important for us. And if our brain just starts firing in the same place where we store those songs, we hear them just as real as your cortex hears it when it hears the actual song itself. Because that's the place where you hear it.

So this is the kind of evidence that at least in some sense, your mind is what your brain does. And so here's this amazing brain. It's about two to three pounds. But every thought and feeling you'll ever have, or every physical movement, every desire, every thing that you're proud of or ashamed of that crosses your mind will be supported by this structure.

So I'm going to talk a little bit about the neurons, just a little bit about the neurons that compose the brain, and a little bit about a quick tour through the gross organization of the brain. We'll come back to many of these structures as they're relevant to different things like memory or emotion or personality later in the course. Talk a little bit about the enterprise of trying to say which parts of our brain support which parts of our mind. Missteps about that, famous cases about that, that have turned out to have roughly the right message.

And we'll focus on hemispheric specialization, the thing in humans where our left hemisphere and our right hemisphere are organized to accomplish different things, to support different mental functions. And the surprise from split brain or commissurotomy patients, that these different mental lives that support our different parts of the brain, that they can live in isolation. They don't even know they're there one to the other. So let me rephrase this.

As you sit there, the thought is you might have independent parts of your mind supported by independent part of your brain. And at any one moment, your consciousness might be in one part, and then it might move to another. And just like there's all these people in this room, your brain might be all these things having their own independent thinking lives.

They have to interact a lot. But how much might there be independent modules in your brain that are doing their own thing. And now you're thinking about music, and those turn on, and that's where your consciousness is. Now you're thinking about history. Now you're thinking about dinner tonight. And different parts of your brain turn on and that's when your consciousness is moving from one part of your brain to the other. But the other parts keep going. So we'll see how plausible is that.

So it took a long time for people to decide that the brain actually is the stuff of the mind. Smart philosophers like Plato said, well, it's part of the body that's closest to the heavens. That's where the gods might reside, so that's a good place to have your mind and that's where your brain is. A sort of GPS approach to locating where the mind might be.

Aristotle said, wait a minute. It's the warm and active heart-- the heart was very impressive in post-mortem examination of people who have passed away-- that houses the mind. And that it cools, and there's an inner brain. So the brain was kind of a radiator that would sort of cool stuff off to keep the heart in optimal. And even now, we talk about people having a big heart, right? A cold heart, a warm heart. We still talk about human personality or character in terms of heart.

Galen said that the brain was surrounded-- there's ventricles in the middle of the brain that have fluid, cerebral spinal fluid. And he hypothesized that the brain was the packing material that protects that fluid. Hang on to that fluid, that's all your stuff. We're going to cram a lot of stuff around it, right? Like the bubble pack that comes in the boxes. And of course now we know it's the opposite way around. The mind is in the physical, the dense part of the brain, not that.

And then ideas from Descartes, the pineal body is one of the very few structures that's in the midline of the brain, that doesn't have a thing on the left and a thing on the right. And so he thought maybe that's where things get unified in the whole brain. It all comes together as the place that runs the whole brain. And that's a wrong idea. But people were trying to figure out what was going on.

In modern neuroscience, there's many levels of analysis of the brain. So if you go to any neuroscience program, like Department of Brain and Cognitive Science, you will actually see scientists who study things like molecules and synapses, molecular neurobiology, how neurons work, how neurons form networks, little organizations of things that solve problems at a higher level, maps, systems in the brain as a whole.

In this course, we mostly have to operate at this level. That's the place where it's easy for us to relate in some ways parts of the mind as we understand it, of human nature as we understand it, and physical parts of the brain. It's very hard for us to get that to molecules at the moment. But lots of neuroscience is working to connect these things at different levels.

And I can't resist talking for one second, too, about the fact that we know our brains were not designed from scratch. You are not humans 3.0 or 98.0, right? Everything in us in some way evolved from other species that were similar to us, and far enough back, dissimilar to us. So there's lots of speculation about how it is that we balance parts of the brain that are ancient in their evolutionary roots, that are more recent in their evolutionary basis, and what that means about us. Another sense in which we're comprised of multiple society of brain systems in between our ears.

So we know the cells in the brain are glia support cells and neurons, that a neuron-- and I know you all know all this. Oh, let me say a word about notes. So we sent PDFs of the lecture notes from the first two lectures and the third one just recently. Starting tomorrow, we'll send you the PDF of each lecture, the latest by the night before the lecture. So you will be able to print it out or look at it on the computer.

But neurons have a soma or cell body. Those make up the grey matter when we look at the brain. They have an axon that can be covered with myelin that makes the white matter. The dendrite is the extensions of the neurons that have the input to the neuron. We know that neurons communicate by neurotransmitters across synapses, junctions between different parts of neurons. When you have a collection of cell bodies, people call it a nucleus. When you have a collection of axons, they call it a tract.

It's just vocabulary and stuff. And you know this from other courses, just reminding you about them. And then you get these unbelievably startling kinds of numbers, which are always huge estimates. But they show you how amazing your brain is, and how hard it is for us to deeply understand how the brain works. I mean, we understand incredibly more than we did 10 years ago, 20 years ago, 30 years ago. We're incredibly far from understanding how your brain accomplishes the amazing things it accomplishes.

So it has about 100 billion neurons. It has about 100 trillion synapses, connections among neurons and dendrites. If you were to lay out the very thin myelinated axons in your brain, just the big axons that get myelin, it's estimated that you'd have 62,000 miles of axons. That's pretty good, right? Now you really want to wear helmets when you go skateboarding or anything, right? And about 100,000 miles of dendrites in each of you.

So this is why the brain is amazing and hard. It's fantastic in its complexity. An average neuron may have up to 15,000 connections, 1,000 synapses, and up to 1,000 neurons. There's different ways of thinking about the computational power of a neuron. But they estimate that these might have, each one the computational power of something like a medium-sized computer. So it's not the best computer, but you've got 100 billion of them.

Now, that's the easy part. Take 100 billion neurons and your computer's in your head. The hard part is to get them all working together efficiently. And you're not sitting around going, "Computer 33, get up to speed here. Something's wrong here." You don't even think about them. You just go about your business.

The time for information to go from neuron to neuron is pretty slow compared to fast computers, pretty fast for biology, 10 milliseconds. And everybody thinks the secret of the brain, whatever it will turn out to be in many ways, is that you can run a fantastic number of computations simultaneously and collaboratively. But we don't have a deep understanding of how that all plays out.

So here's a cartoon of this amazing axon, the cell body, and the dendrites to get inputs to it. The axon is the output signal of a typical neuron. Neurons can have these beautiful arborizations, tree-like properties of dendrites. Neurons have all kinds of different shapes in different parts of the brain, presumably reflecting their different missions, what they have to accomplish.

An incredibly complicated cellular factory inside all of them is producing different things. This is a big overview. This is not for you to learn a specific fact. And this, here's an actual neuron that's injected in the fantastic tree of connections it makes within the neurons to accomplish its mission. Here's a cartoon of a synapse, places where neurotransmitters signal from one axon to one dendrite, for example.

Here's an actual picture. Here's the package of vesicles that house the neurotransmitters in them, making a connection or a synapse onto a dendrite. And you just have a fantastic number of these. And as you're sitting in you right now an unbelievable amount of stuff is going on-- releasing them, cleaning them away so they don't hang around too long, building new ones to get ready to go. It's just an unbelievable story per neuron, never mind the whole of them.

So now we take a step back to the brain as a whole. Here's the front of the brain, top of the brain, back of the brain. I'm going to say a word about the cerebellum, which we'll talk very little about in this course. The cellular organization of the cerebellum is so consistent that people estimate that half of all the cortical neurons in the brain are in the cerebellum. And if you see this cerebellar size is small, not that large, it's because it's packed so tightly.

And it's so consistent in its organization that people thought, that's the first part of the brain we'll crack. Because the organization is so clear that we'll be able to figure out what it's computing and how it does it. And it's turned out to be about as mysterious a structure as any.

I can't tell you the number of debates about what people-- we know it's involved in motor control, but in many other things, as well. The wiring diagram, knowing it, what's connected to who, turns out to be only a tiny step in understanding how what part of the brain does what it does. So here's this mysterious cerebellum.

And then here's a basal ganglia that we know is involved in movement. Parkinson's Disease affects it. Huntington's Disease affects it. It's also involved in learning habits of all kinds. It's also involved in the reward systems of the brain. What have we found delightful and important? What did we want to do because the reward system is turned on? We'll come back to that later on.

And then the limbic system, the part of the brain that's involved in emotion and memory-- amygdala and hippocampus. We'll come back to that. If you don't have this structure intact, you can't form new memories ever again. We'll talk about patients like that.

And then we'll come to the smarts of the brain, the cerebral cortex, four lobes-- frontal, parietal, occipital, and temporal. You have four on the left and four on the right. These lobes are comprised of gyri. That's the part of the brain that sticks out. And then there's this sort of indentation where it dives deep into a sulcus. Comes back up, it's the next gyrus, dives deep into the next sulcus.

A huge sulcus is called a fissure. Here's a Sylvian fissure that separates the temporal and frontal cortices. And one of the reasons that people have speculated about why do we have a thing like that? Why do we have these waves of a gyrus going up and then plunging into the depths, then coming back up like this again and plunging from sulcus to sulcus?

And nobody really knows. But there's kind of a speculation that's fun and plausible. One thing we know is that bigger cortices are good, not so much one person to another, but across species. Your smarts are in your cortices-- language, higher-level thought, and so on. So on the whole, a species that has bigger cortices has a lot of opportunities for thought and social development and so on.

So you could imagine having babies with heads this big. They'd be really smart, maybe. But what would be the problem? What would be the big problem? Think about it not from your perspective, perhaps, if most of you are sort of teenagers or young 20s or something like that, most of you. So you don't remember your birth experience directly. But who remembers your birth experience pretty well? Your parents? OK. All right. It's your mother, especially.

Giving birth is a pretty painful, specific, challenging process. So if a head this big came out, it would be incommensurate with the birth canal that the mother can afford. It's already pretty challenging with your head as big as it is when it comes out. That's the challenge of birth. It's not getting the arms and legs out. Its the head that's too big.

So now we have a problem that the mother's birth canal is only so big. We want as much brain and smartness in our species and in ourselves as possible. So how are we going to get a lot of neocortex in there? We're going to fold it. A lot of neocortex in there, but a smaller volume to get out through the birth canal. And that's thought to be why the brain has this elaborate plunging from sulcus to sulcus, and this sort of convolved physical structure.

And if we think about the brain, we can think about things that go into our brains, about the outer world. So when you see, vision enters through this area, or when you hear, it enters here. When you touch or when you move your body, these are the motor cortical neurons. So it's either sort of major inputs or major output. That's in blue. That's the areas that are devoted to specific perception or modalities or sensories.

And then we have areas in yellow here. They are the areas that are sort of closely tied to one modality. But already, they're interpreting what's going on. And then you have areas in pink here that are sort of not tied to any modality and are devoted to what we might call abstract thought.

And you can see the prefrontal cortex, the part of the cortex that's in front of the motor cortex. There's a huge swath like that. We'll come back to that. We think it's terribly important for thinking, problem solving, and many aspects of the highest human mentation.

Now we're a huge believer in the end that form follows function in the brain. And if we understood the correct relationship between form and function, we'd be very far. And a neuroanatomist named [? Broadbent ?] made the following heroic effort. What he did is he sectioned brains into lots of thin slices. And he followed them through a microscope.

And every time the brain tissue changed, the neurons looked different, he would change the number of the area. So he started in something like Area One. And the neurons look pretty similar. And he's moving, moving, moving. And then all of a sudden they start to look different, the neurons. And then that becomes something like Area Three. Moving, moving, Area Four. Moving, moving, Area Six.

So every time the neurons looked different to his eye, it gets a new number. The idea being when the neurons look different, they have a different job to do. And that part of the brain does something different. And there's lots of debates about the best way to do this, or different interpretations. But something like this holds true in a striking way. The cellular organization of the brain reflects in some way what that part of the brain is accomplishing, what part of your mind it supports.

And then we have simplified color pictures of this. And we'll come back to neuroimaging next time. But it's turned out to have a second life in neuroimaging. Because when scientists across the world want to compare their neuroimaging results, they'll talk about, well, I got activation in Area 46, or I got it in Area 21.

It's become a nomenclature for the organization of the human brain that allows you to integrate all kinds of imaging data about the human species. And here's a view from the inside of the brain. And here's a structure chord, the corpus callosum, that we'll come back to in the next few minutes.

So how much are functions localized or distributed? How much is-- you have a specific thing your mind does, and it's in one place in the brain versus it's spread over a range. And this idea of how much things are distributed or localized for mental functions in the brain has been a source of huge debate. And I'll show you a misstep, and then I'll show you some things where we think we have it more correctly.

The misstep is a phrenology. And the most famous name in this is from Gall. Spurzheim is another one. And in the 19th century-- that's the 1800s-- the phrenology took hold a lot. And there's a sort of a Freudian story. If you want to call it that, of Gall, which is that apparently when he was a student, he viewed himself as a very effortful and fastidious student who took all the notes you're supposed to take, and worked very hard for exams and did everything you were supposed to do.

But shock of shocks, some students did better than he did. And he looked around the classroom. He said, who are these students doing better than I am? Because I'm trying as hard as I can. And some students are doing better. And he said, hey, one thing I notice about these students is they all seem to have big foreheads. OK?

[CHUCKLES]

Now, I don't know how accurate he was scientifically. But apparently, this was a emotionally transformative moment for Gall. And you'll see in what way this ended up guiding his science. So Gall and Spurzheim were actually good neuroanatomists. They describe lots of things about the brain that were correct that were kind of unknown at the time.

For example, the pyramidal tracts, the tracts that move from your motor cortex-- say on your left to control your right hand, or on your right to control your left hand-- they describe those very well. But here's where they got kind of funny. They said, OK, we can describe the physical organization of the brain. But now let's say which part of the brain is which part of the mind. And in a way that we now consider a bit willy-nilly, they began to assign different mental processes to different parts of the brain.

And the way they did it was they said, I'm going to look at somebody. And let's pretend somebody you know is very combative. What they began to figure was this. Well, maybe the part of the brain that's involved in being combative-- the more combative you are, the more you have of it.

So if I feel your skull above the part of the brain that I think goes with being combative, if you have a big rise there, if I feel your head-- and most of our heads are a little bumpy-- the person who's really combative is going to have a lot of bump there. And the person who's very meek will have none. OK, does that make sense?

They have these little categories as they just thought about people. And they developed this idea that they could find where cautiousness was, or precociousness, or secretiveness. You'd give it a big bump there. Let me show you this picture. Here's a device you would step into that would have springs go down, and then it would go up, and they would say, where do you have the high bumps? And where do you have the little bumps?

Now all of this is wrong. Because it's a naive way and not a scientific way to do it.

Weirdly enough, look at what they put below the eye-- language. Now that's a weird place to put it. And what they saw was a soldier who had a wound that went his eye and into his brain. And they said, OK, he had trouble producing language. And they said, well, that's where language is. Language is not below your eye.

But they didn't realize that the wound went up into what's something called Broca's area. We'll talk about that in a couple minutes. And so they weren't that wrong. They just didn't think through where the end of the injury was. All the other ones, we completely dismiss these days. But we have to worry about naive ways in which we link the life of the mind to the stuff of the brain.

And they did a control experiment. "The famous physiologist, Magendie, preserved with veneration the brain of Laplace," who's a big name in the history of chemistry. "Spurzheim had the natural wish to see the brain." Spurzheim was the phrenologist. "To test the science of phrenologist, Magendie showed him instead the brain of an imbecile. Spurzheim, who had already worked up his enthusiasm, admired the brain of the imbecile as he would have admired that of Laplace."

So this was a control assess. I give you a brain of somebody who's not a genius in chemistry, and you go, oh my gosh. This chemistry part of the brain is unbelievable. And this is the old idea we talked about, that if you have an idea you believe in as a scientist, you will always find positive evidence for it everywhere you look.

Back to the brain, and let's talk about this part, the lower part of the orbital frontal cortex. It sits right above your eyes. Your eyes would be something like here. And we know something about what that part of the brain does from the famous case of Phineas Gage.

He was involved in railroad construction in Vermont. And that involved exploding rocks to level the area so they could put in train tracks. They would drill a hole, put in some fuse, put in the powder. And they would use a tamping iron to push down the sand and powder so there would be a big explosion to flatten the rock.

And at age 25 in 1848, he has a mind who was described as well-balanced, energetic, and persistent. He was the ideal employee, resourceful, hardworking. He was made a foreman, a leader. He was the most efficient and capable in the group. And on September 13, 1848, something big happened.

There was a miscommunication. An iron that was three feet, seven inches in length-- I'll show you a picture in a moment, because even if you've heard this story, until you see a picture of it, you can't grasp how big this was compared to a human being. There was a miscommunication, the explosion went off early. He was directly over it. The rod flew up, went through his head, all the way through his head. And it had the power to land 30 yards away after exploding up into the air.

And by March of the next year, he was back at work. Not too long a vacation, a recovery period for that big a thing going through your head. But his personality had fundamentally changed. So here's his cast of his actual head and his skull. Here's where it shot up through here and out this hole. Here's the actual rod compared to that. So if you haven't seen this, you can underestimate the amazingness of this thing.

And at the time he was famous not for the reason we now think of him. He was just a Ripley's believe it or not story of that a human survived at all. So Antonio Damasio has attempted to reconstruct by computer where this rod shot up through here and out into 30 yards away. They're that big compared to him.

And the amazing thing, and described by a physician who worked with him at the time, is "the equilibrium to his intellectual faculties and animal propensities seems to have destroyed. He is fitful, irreverent, indulging at times in the grossest profanity. Little deference for his fellows, impatient of restraint, conflicting with his desires. At times pertinaciously obstinate, capricious and vacillating, devising many plans of future operations, which are no sooner arranged than they are abandoned in turn for others appearing more feasible."

Exactly the opposite of who he was before. He was a responsible, efficient leader. And now he's a totally irresponsible person doing all kinds of things that make no sense. "A child in his intellectual capacity, he has the animal passions of a strong man." So he completely changed who he was. In this regard, his mind was so radically changed that his friends and acquaintances said that "he was no longer Gage."

So here's a physical insult to the brain that changes the character of a person, that changes what we would think of as the moral judgments. Of when is it right to tell the truth, having plans and being a responsible, trustworthy person, completely changed by this injury. One interpretation is this part of the brain is essential for making moral judgments and being of good character.

What would be another interpretation of why he might have changed, just common sense besides that this part of the brain does that? We want to not be for phrenologists, OK? So the first thought is, this part of the brain supports what we think of as moral reasoning and character. Well, what else could you imagine might have happened? Yeah.

AUDIENCE: He had a giant spike driven though his skull and is upset about it?

PROFESSOR JOHN GABRIELI: Yeah. I'll make up something like that. But a more psychological and different interpretation, let me try this one. He was getting ready for the future. I'll be a foreman today, and then next week, I'll be executive vice president, and then I'll be associate executive president.

And a rod goes through his head, and he goes, wait a minute. Life is short. It could end at any moment. Why not just do what I want to do all the time? Because the next rod could come who knows when. And I had all these plans, and I was promising people things next week that I delivered on. But that's a sucker's life, because your life can end like that. So forget all the stuff about-- just enjoy the moment.

That's a possible thing, OK? You see movies like that, where people are told, you have so long to live, and they change. What would you want to convince yourself that it wasn't something like that, which is not an unreasonable interpretation? What you would want to see, at a minimum, is that if you have brain injuries other places in the brain, you don't see that. And if you have other people with brain injuries in the same part of the brain, you see that consistently.

At a minimum, you want to say it's not just a big brain injury. But it's consistently a brain injury in this part of the brain that leads to this kind of behavior. And for at least this example, that's true. Other patients with similar injuries behaved similarly. People with very big injuries elsewhere in the brain don't behave similarly. So there's a lot of reason in the end for us to believe that this part of the brain is essential for something that we consider almost metaphysical. Character has this incredibly physical dependence.

And relatively recently, just a few years ago, they discovered a picture of Phineas Gage himself. Here's the rod. Here's the injury to his eye, his eye is damaged. So one more example, and then we'll switch this refrain. Paul Broca. And Broca's area in the brain, here's Paul Broca. Here's a brain of a patient named Mr. Tan.

And let me say a word about the story. So in France, a number of people observing patients with injuries had talked about that the left side of the brain is important for speech. Until then there had not been much ideas that the left and right were fundamentally different. So there's always sort of a background before the discovery.

And there's a talk in 1861 which describes a man who lost his speech but understood everything said to him. He couldn't produce speech. He could understand speech. His intelligence is still unimpaired. His speech is gone. And then Broca heard that talk, and he went back, and five days later a patient named LeBorgne, who had lost his speech-- he could only say two things, "tan," and he could swear like crazy.

And our current thought about that is swearing that's emotional and intuitive, not the one where you think, OK, I'm going to swear now to scare somebody. But the one-- you stub your toe in the middle of the night, and you really let out a curse-- we think that's guided like an animal cry by the basal ganglia. Those heartfelt, really emotional cursing is not really language. It's actually the same cry an animal makes on injury. And it uses some of the same neurocircuitry.

But for higher level cortical stuff, the only word he could say was "tan." He died in 1871. They looked at his brain, and they found this change in the left frontal cortex. And we now call that Broca's aphasia, the inability to speak despite the presence of-- your mouth can move, and you can understand language pretty well. We'll come back to that.

So we talk about Broca's area, and then Wernicke-- the Broca's area's important for production. And here's the kind of damage. And we'll come back to Broca's aphasia later in the course. So this was a big hint that there's something different between the right and the left hemispheres. Now in what percentage of people is language, especially speech production, predominantly in the left?

And our best answer for that comes from a thing called the Wada Test. So this is a test given to patients who are undergoing neurosurgery for something like epilepsy, sometimes for tumors. And they want to know for you personally with great certainty, which hemisphere is the eloquent or speaking hemisphere?

Because they want to remove more tissue if they're away from your language areas, and less tissue if they're near your language areas. Maybe they won't even do a certain surgery if they're too much in the middle of your language areas. Because in many cases, it's so frustrating for people to lose their ability to speak their thoughts, that they'd rather have the seizures, for epilepsy, than be unable to speak.

So physicians and neurosurgeons are very worried about that. So what they give you is, they give you a test where they put in a drug called sodium amytal. And they inject it into your femoral or carotid artery. It feeds up. And the way that the vasculatures between the two hemispheres-- it mostly shuts down the operation of one atmosphere. If you're injected in this femoral artery, it'll mostly shut down your left. In this one, it will mostly shut down your right.

And while the patient has one hemisphere turned off, and they know this because for example, let's say they shut down this hemisphere with the injection. You're waving your arm. It falls down because your motor system can no longer control your arm. You're blind in this field. We'll talk about that. Many of the mental processes done by this half of the brain are shut down.

And then they'll test you like crazy to see if you can talk. They'll say, what are the days of the week? What's your name? Name these pictures. OK? Until the drug wears off. And then you come back two days later or a day later, and they'll inject the other side. And they'll know with near certainty in you which is the side of your brain that does the speaking.

And best estimates are that something like 90% to 99% of people speak from their left. Even left-handers mostly speak from the left hemisphere. Because these are patients with epilepsy, we're not quite sure how they generalize to everybody. We wouldn't do this with typical people. Because these kinds of tests are invasive and a bit risky.

But our best estimates are that if you're right-handed, it's almost certain you speak from your left hemisphere. And if you're left-handed, about 80% of left-handed people also speak from the left hemisphere. So it doesn't go by handedness, which makes handedness a bit more of a mystery.

So now switch from grey matter discussions to white matter. In the middle of your brain is something called the corpus callosum. Here it's viewed from the middle, if we cut the brain this way. 200 million myelinated fibers that connect the similar areas from the left and the right.

This is what hooks up the left and right hemisphere from spot to spot. Here it is connecting-- and this is from the side view-- so it's a huge white matter area. Corpus callosum. And people noticed it because it was so striking. But they couldn't figure out what it does.

And it kind of started to figure a little bit in philosophical debates. Would a divided brain-- if you cut the brain down the middle-- would it read to separate stores of mood, predisposition, knowledge, and memory? That is, if your two halves of your brain were divided from one other, would you be sort of two people?

Now, we're not going to do that to you. But the fascinating thing is, are you two people to start with, who talk to one another sometimes across your corpus callosum? And William McDougall said, well, the unity of consciousness does not depend on the unity of the nervous system. And he volunteered for commissurotomy to cut the corpus callosum.

Erickson noted in 1940 that epileptic seizures would become generalized convulsions often in animal models-- if the seizure began here, it would spread to the corresponding part of the opposite side of the brain, and become a much worse seizure. So they got the idea that if they cut the corpus callosum in patients with severe epilepsy who did not respond to medications that maybe that would make the seizures less severe.

Does that make sense? Because you wouldn't transmit the seizure from the left to the right or the right to left. But people were sort of almost making jokes about the corpus callosum. Because they couldn't figure out what it does. They said, "The corpus callosum is hardly connected with the psychological functions at all. It is for transmitting seizure activity from one hemisphere to the other." That's kind of a neurology joke.

Or Karl Lashley at Harvard, "to keep hemispheres from collapsing into one another." You do have to have structure to keep things from collapsing. So now I need to tell you a word for the next couple minutes for this to make sense, about how your visual system is organized.

So here's the world out there. And if you're looking straight ahead, everything to the left people call the left visual field, everything to the right people call the right visual field. And we'll look at this more next week a little bit. But weirdly, your eyes are not set up in that way. You could think this eye looks at this half, and this eye looks at that half.

The way it's set up, each eye looks at both fields. Each eye looks at both fields. And then the neurons that leave the eye get organized here in the optic chiasm. So by the time they move out towards the brain, everything in the opposite half of the world is reflected.

So everything that's in the right visual field starts in your brain in the left hemisphere. Everything that's in the left visual field starts in your brain in the right hemisphere. Does that make sense? So the first part of your smart neocortex that knows what's out there as you're looking at a face, a word, a scene, anything-- the right occipital cortex notices what's on the left, and the left occipital cortex notices on the right.

Things are so seamlessly integrated in the brain that you don't ever have that feeling. You almost never have like, we're getting bad signals on the left here. If you didn't have a course like this, you wouldn't know that exists. And you could wonder, why on Earth is it like that? Is it just to torture students and confuse them about fields, eyes, and brains?

And people debate about some evolutionary history behind this. But it's a great big mystery-- why we don't organize things much more simply and just go all the way this way. Quite the opposite. We have in the left posterior areas, that's where we see the right half of the world. And then things get integrated. Is that OK?

Keep in mind also that our left hemisphere moves our right hand, and our right hemisphere moves our left hand. So at least that's the same story-- opposite hemisphere seeing the opposite field, controlling the opposite hand. So imagine these kinds of patients who had the surgery that divided the corpus callosum or treatment of epilepsy. Let me tell you a couple things.

Clinically, it was pretty rarely done. There weren't that many of them. It's pretty rarely done nowadays, first. Second, the first thing that people noticed was, it didn't have much an effect on the patients. It's a fascinating story. Nobody noticed anything for decades. Because they didn't have the right questions to ask. So these patients are not like astounding patients, I can't believe when I see them. They seem pretty much like the same as they were.

I'll show you a video in a couple minutes of two of them. They're not looking unusual in most ways. But when people figured out what to ask of them, they saw remarkable things. They saw two minds in one head. And here's how they saw that. If they showed them a picture, let's say of a spoon and a picture of a cup simultaneously in the two fields, they would be up briefly and go.

But it's easy for you to say, I saw a spoon and I saw a cup. They would say, what did you see? And the person would say, a cup. And that would be it. What did you see? A cup. Because the information in the right visual field goes into the left hemisphere. That's the speaking hemisphere. So left hemisphere says, I saw a cup.

The right hemisphere saw this perfectly well. It's typically not the speaking hemisphere. So that information is locked in the right hemisphere, and it doesn't have access to the speaking part of the brain in the left hemisphere. So each hemisphere had its own experience, and only the left hemisphere could speak.

You would integrate this information instantly via the corpus callosum. But each hemisphere only knew what it saw. And so here's another example, which is not only that each hemisphere only knows what it knows. But it's completely ignorant that the other one knows anything.

It's as if the two of you were sitting next to each other and don't know each other, are not passing notes or tweeting or whatever. It's as if like, do you know exactly what the person next to you is thinking? No, not necessarily. So that's exactly what it is like, like you're in one person in their brain, in their skull.

So they would show them a square in the left visual field and a triangle in the right visual field. You would say, I saw a square, I saw a triangle. What do you want? Here's what happens. If they're asked to say, say what did you see? And then behind a board, draw what you saw. The board is there so it's not confusing them.

So here's what they say. What did you see? I saw a triangle. Because it's in the right field, it goes into their visual area in the left hemisphere. That's the speaking hemisphere. But if they're drawing with their left hand, what do they draw? The square. Because the right hemisphere saw a square, so the left hand is drawing, it draws the square.

So simultaneously they will say, a triangle, and the hand behind the board will draw a square. And the patient is not bothered in the least. Because each hemisphere only knows what it knows. The reason they have the board there is if they didn't have the board there, then the left hemisphere would see you drawing a square. And you go like, why am I drawing a square? I saw a triangle. And the person would be weirded out. Does that make sense?

But here's the thing. The amazing thing is both of them have a lot of smarts by themselves. And they're completely unaware of what the other hemisphere knows. Again, the idea is in you, the hemispheres are talking all the time. But at lots of moments, different parts of your brain might be knowing different things. And we have a lot of belief for that. But this is the most striking demonstration.

So here's a patient who was asked to say what he saw and pick it up. He had one instruction. Read what you see, and pick it up with your left hand. So he sees the word ring. In the speaking hemisphere, he says ring. His left hemisphere sees the word key, has enough language to read that. And it picks up the key behind the board. And it never says, I saw two things or anything like that in most cases.

So let me stop here. And can we do the first video? So you're going to see an example of a patient named Vicky who's going to be tested by Mike Gazzaniga. You're going to see two videos with Mike Gazzaniga when he was younger and when he was older. He did a lot of the work with these split brain patients. Plus, Alan Alda from MASH will visit Mike Gazzaniga in the second one.

So one of the really interesting things is these split brain patients have given us a chance to ask, you and I, what are some different ways in which the right hemisphere and left hemisphere are your own minds? And what are the things they seem to care about, and that are useful?

So here's one example from Jerre Levy. It's a very clever experiment. She would show in the left or right visual field something like this. And then say, in free view, which of these two things is more similar? And on purpose it's ambiguous. On purpose you could say, well, this is more similar because it has a similar shape or appearance. This is more similar because I use a spoon and a fork to eat a piece of cake.

And if this was seen by the left hemisphere, people would pick by function. If this was seen by the right hemisphere, the patients would pick by appearance. So the ideas is that the left-- and this is the power of having two hemispheres in parallel figuring out what's going on-- one is figuring out what's the information I need about shape and things like that in the world? And what's the information I need about function?

And because you have two semi-independent brains in you, you're constantly figuring out form and function and then using whatever you need to use to solve the problem in front of you. Does that make sense? So here's another nice one. Here's scissors projected into left visual field. The right hemisphere, that would pick the spoon and the fork. Because the crossing shape is resembling that.

In the right visual field, left hemisphere, people would pick the needle and thread. Because that functionally goes with scissors. So your mind is seeing the same thing, but in one case it's tuned, in the left hemisphere, to functions, and the right hemisphere to appearance.

So these are just notes for you going over what I said. So they talked about, would you have two different consciousnesses in you? It's hard really to tell. They did one experiment with Vicky, where they would present a nude picture in the left visual field unexpectedly-- and this was a long time ago, it was a shocking thing. And the patient would blush and giggle.

When asked to explain why you were blushing and giggling, all she could say is, oh doctor, you have some machine. She knows something funny happened and inappropriate. She can't tell you just in the language in the hemisphere that saw it.

And so she gives this other kind of description.

Another kind of a favorite one is the dresses one. There was one patient who went back to work in his father's grocery store. And this could be frustrating, early on after his treatment. He would stock things onto a shelf with one hand and remove it with the other. You could imagine that would be a slow work day.

These kinds of weird behaviors pretty much clear up within weeks. After that, you have to test to see the difference. Another one, they presented the instructions -- walk across the room to the left visual field, right hemisphere. Person gets up, walks across the room.

That person's asked, why did you walk across the room? Person doesn't know why. Because their speaking hemisphere didn't see it. And they'll just say something like, I was thirsty. So interestingly, they fill in motivations. They don't say, I don't know why, or I have a split brain. What do you expect? I mean they're being tested for that, right?

But they seem like they want to fill in some other explanation. And I'll show you another example for that. And social psychologists have said-- because they like this-- they said, this is an example that people are desperate rationalizers for ourselves. We'll come back to this in social psychology. You could think about whether it's true for yourself or not.

That when things are contradictory, we don't say, oh, things are contradictory. We say, well, here's why, as we explain our own behavior, that we have to rationalize our own behavior. So here's the example. Here's the picture. So here's a split brain patient. And he's shown pairs of pictures in visual fields.

And he's supposed to pick two of them in free vision, then relate to what he sees. Here's the picture that he sees. Boom, this goes up and goes away. Now both hands go and pick something related to what the person just saw. OK So this is shown briefly. It disappears. This hand-- let me do this right-- the chicken went to this part of the brain that controls this hand. So the claw goes to the rooster.

This hemisphere saw a snowy scene, controls this hand and it goes for the shovel. So now they're going to make the patient confront the weirdness of what he just did. His hand went out. Each hemisphere points to what it saw. And again, his answer could be, I'm in an experiment. You're constantly tricking me. I know that. Basically they know that, they're in an experiment.

But his answer is, I saw a claw-- that's the speaking hemisphere. I picked the chicken. OK, that's fine, left hemisphere is speaking. And then you have to clean out the chicken shed with a shovel. OK You understand? He's creating a story to make his behavior seem coherent. Rather than just saying, I'm an experimental subject and that's why you're testing me.

Here's the last thing I want to show you for two minutes. And then I'm going to show you a film that touches on this. Psychologists are interested in understanding also in what way we see the forests and the trees. You see the bumper stickers, think globally, act locally. Let's talk about global and local, or parts and wholes.

So the whole here is H. And the locals are S. Does that makes sense? It's a way to operationalize an experiment looking at the forest versus the trees of S's. Here the whole is the C, and the local elements are O's. And there's a painter who did beautiful pictures. You'll see another example. But he made whole faces out of vegetable parts. OK, do you see that?

Every part here of this face, if you look at it piece by piece, is a different vegetable or fruit. So it's a sort of play on this thing, and you'll see the movie that way. He made the whole face of the parts of this. But here's what split brain patients do. And I'll show you something else in a moment.

They're asked shortly after surgery to copy this. It's right in front of them all the time. It's right in front of them all the time. Just copy what's right in front of you. If they do it with their left hand, right hemisphere, you see that you get the forest but not the trees. Here's the trees, and then they don't look that good, honestly.

But still, there's some Y-ish thing there. Copy this. It's right in front of you. If it's the left hand, you get the forest but not the parts. If it's the right hand, you get the parts but not the forest. Does that make sense? It's as if each hemisphere is one hemisphere-- the left hemisphere is seeing the parts, and the right hemisphere is seeing the whole.

So that's awesome. Because you don't have to be global or local. Your mind is simultaneously figuring out the local parts and the global parts. And then you can use whatever is the useful information. Your mind, because you have multiple brains in you, is sort of figuring out what it needs to do.

Last thing I'll show you, and then we'll do one more video. Here are patients who have injuries after stroke. It's the same idea, though. So here's what they have to copy. It's right in front of them. Just copy it exactly. That's all they have to do. If the patient has damage on the right, he loses his sense of wholeness.

You see there's lots of Z's, that's the parts perceived by the intact left hemisphere. But the right hemisphere is not giving very much information about the whole. Here's another patient with left hemisphere damage. That person fails to appreciate the parts, but gets the whole. Here's the same thing down here. A patient with right hemisphere damage appreciates the parts in the intact left hemisphere, but doesn't appreciate the whole in the injured right hemisphere.

Conversely, here's the injured left hemisphere. That patient copies the whole. The right hemisphere gets it, left hemisphere is missing the parts. The amazing thing? It's right in front of them. They're copying it. But if your brain is injured, it no longer appreciates that the whole exists or that a part exists. It's as if it wasn't there.

So that's how much our mind is what our brain does in this regard. And so if we do the last video you'll see that again.

Any questions on what you saw? So I would say neurons are unbelievably-- we can't even begin to figure out your brain at the neuron level. We're so far from that. The big message from this last part besides hemispheric specialization is that your brain-- and we'll show you this over and over again in this course-- is a society of semi-independent brains doing their own thing, sharing information as needed.

And the more we study the brain, the more we understand how many parts of you there are that are semi-independent and autonomous. Thanks.