

**NANCY** So seeing where animals are going, so you can avoid them if they're coming after you or so you can catch them  
**KANWISHER:** if you're going after them, right? One of the arguably uniquely human abilities is precision throwing, right? No other animal can do that. That's a very human thing. Although, visual motion is shared with lots of ability to see motion is shared with lots of animals.

What else did you notice? What else seemed funny or harder to discern with stop motion? Yeah?

**AUDIENCE:** We care about small details like [INAUDIBLE] to understand what the person is seeing.

**NANCY** Yeah. Yeah, so I was making notes to self. I haven't done that demo before. But in future, it would be really good  
**KANWISHER:** to have the audio quality terrible. Because if the audio quality is terrible, you would lean more on lip reading. And we might have noticed more. But it's really hard to do that probably even at relatively fast flicker rates because that motion information is important. Absolutely. What else?

How about beyond just lip reading? What else did you notice about the faces, mine or Jim's? Could you-- yeah?

**AUDIENCE:** They were static. So it was kind of hard to tell like emotion because a lot of the ways we express emotion is very nuanced.

**NANCY** Exactly. Exactly. Facial expressions are incredibly subtle. Like little microexpressions flicker across the face in a  
**KANWISHER:** tenth of a second and go away, and you guys detect them. Like we're very, very sensitive to those things.

Sometimes if you see somebody in a hallway and, for a moment, there's an expression that flickers across their face and then they give you a normal smile, but you can tell from that expression that actually they didn't want to see you, for whatever reason, right? We catch those things. We're really, really good at catching those little fleeting expressions. And those probably have to do with not just sampling with fine temporal frequency but probably seeing the direction of motion of each little part of the face. OK?

OK, so this is just common sense reasoning about what we might have motion for. OK? And so you guys got all the things that I had in mind. OK, so now the next question, just kind of thought question, speculation question, given these many different things that make motion important to us, biologically, ecologically, in our daily lives, maybe that's important enough that we might allocate special brain machinery to processing motion. What do you think? Important enough? Could you get by if you lived in a strobe world all the time? Could you survive just fine?

Hard to say, right? Might be hard. I mean, we probably don't need to go hunting down predators. But you walk across Vassar Street. And there's some pretty dangerous predators coming down Vassar Street in the way of cars, right? You need to know where they're going and whether you can cross in front of them. So it's actually pretty hard to live life without being able to see motion. And I'll tell you about a woman who has that experience later in the lecture.

OK, next question, just think about this. I'm not going to test you on it or anything. It's not the topic of this course. But it's a perspective you should take. Imagine that this were a CS course and I gave you a segment of video. And your task was to write some code that takes that video input and says whether objects are moving in that movie or says which objects are moving or how much they're moving or what direction they're moving. What kind of code would you have to write to take that video input to try to figure that out? OK, so just think about that.

We're not going to be writing code in this class. But a lot of what we're going to be doing is thinking about, how do you take this kind of perceptual input and come out with that kind of perceptual inference? And what kinds of computations would have to go on in between whether those computations are going on in code that you guys write or in a piece of brain that's doing that computation? And thinking about how you might write the code gives you really important insights about what the brain might be doing. OK?

All right, so that's the point of all of that. The Marr reading talks about all of this. And the key point we're trying to get here is that you can't understand perception without thinking about what each perceptual inference is necessary for ecologically in daily lives and about the computational challenges involved in making that inference. OK? So we'll get back to all that next week and beyond.

But meanwhile, here's the agenda for today. So here's the agenda. We just did the demo. We're now going to skip and do some neuroanatomy, absolutely bare basics. Because on Wednesday, we have this amazing opportunity to have one of the most famous neuroscientists in the world do a dissection of a real human brain right here right in front of you. It's going to be awesome. And I don't want to waste that opportunity or embarrass ourselves by having people not know the bare basics.

So we're going to do the bare basics. It's all stuff you should know from 900 and 901. And I'm going to whip through it fast, so we can get to more interesting stuff and get back to visual motion. OK? That's the agenda.

All right, so some absolute bare basics of the brain, the human brain contains about 100 billion,  $10^{11}$  neurons. And that's a very big number. That's such a big number it's approximately Jeff Bezos' worth. Well, it was until Mackenzie got into the picture. So we'll see. No, you don't need to remember this number. Just know it's a really big number.

Basics of a neuron, here's a neuron. A neuron is a cell like any other cell in the body. It's got a cell body and a nucleus, just like any other cell in your body. But the thing that's distinctive about a neuron is it has a big long process called an axon. It's got a bunch of dendrites, the little processes, the little thingies near the cell body.

And out at the tip of the axon, that's your classic neuron. Many neurons have a myelin sheath, a layer of rolled up fat around the axon made up of other cells. That makes the axon conduct neural signals faster. OK, you should know all that. I'm not trying to insult your intelligence. I'm just trying to make sure everybody's with the program here.

OK, so you have thousands of synapses on each neuron. And that means you have-- to put it technically-- a shitload of synapses in your brain. OK? Another important point, the brain runs on a mere 20 watts. And if you're not impressed with that, reflect on the fact that IBM's Watson runs on 20,000 watts. So one of the cool things about the human brain is not just all the awesome stuff that we can do that still no computer can do, that I talked about last time, but also how incredibly energetically efficiently we do it with our human brains.

So most of this course is going to talk about the cortex. That's all the stuff on the outside of the brain. That's that sheet wrapping around the outside of the brain, that folded outer surface. It's approximately the size and area of a large pizza. But there are lots of other important bits too. And I'm going to just do whirlwind tour of those other bits now.

OK, so you can think of the brain as composed of four major kinds of components. Deep down in the bottom of the brain, you have the brain stem, where the spinal cord comes in here. And the rest of the brain is up there. And the brain stem is right down here. And the cerebellum, this little cauliflower like thing that sits out right back there.

And in the middle of the brain, you have the limbic system with a whole bunch of subcortical regions. And we'll talk about a few of those in a moment. And you have white matter, all the cables and connections that go from one part of the brain to another part. This is an actual dissected human brain. And all those kind of weird fibrous things are bundles of axons connecting remote parts of the brain to each other. You can see them in gross dissection. OK? And of course, you have the cortex.

OK, so these are just four major things to think about. And before we spend the rest of the course on that, we're going to do just a teeny little bit on the other major bits. OK, and I'm going fast. So just stop me if any of this isn't clear.

All right, so the reason we're doing this in part is that, with a dissection of a brain, some of the main things you see are those subcortical structures, right? And so even though the course is going to focus on the cortex, each little different bit of the cortex to the naked eye looks like any other bit of the cortex. It's the subcortical stuff that looks different, right? So that's why we're doing this.

OK, bare basics on the brain stem, you can think of it as a bunch of relays in here, different centers that connect information coming up from the spinal cord and send it through into the cerebellum. So it's, in many ways, the most primitive part of the brain. That means it's shared with animals that branched off from us very far back in mammalian evolution. But it's also essential to life. OK?

So you can get by with most of your cortex gone. Like you may not have a lot of fun. You may not really know what's going on. But you will stay alive. But you can't get by without your brain stem, right? It controls all kinds of basic crucial bodily functions, like breathing, consciousness, temperature regulation, et cetera. So it's not interesting cognitively. But it's crucial for life.

Cerebellum, this beautiful thing here, it's basically involved in motor coordination. But from there on out, there's a huge debate about its possible role in cognition. And so there's lots of brain-imaging studies where people find that the cerebellum is engaged in all kinds of things from aspects of perception up through aspects of language understanding. You can find activations in brain-imaging studies. Nonetheless, the best guess is that you actually don't need a cerebellum for any of this.

So if anybody's interested, I'm going to actually try to remember to put it up as an optional reading on the site. There's a recent article in *The Atlantic* or *The New Yorker* about a kid who had no cerebellum. And he learned to walk late and slow. Nobody knew what his problem was. But he learned to do pretty much everything. Like he's pretty much fine. His motor coordination isn't great, but he's fine. Yeah?

**AUDIENCE:** How would you define the consciousness in this context?

**NANCY**  
**KANWISHER:** Oh, that's a good question. And it's a big question. And it's a question that nobody knows how to answer, not just me. So Christof Koch, who does more work on the neural basis of consciousness than just about anybody, has been going around saying, for about 15 years, we must not get stuck on a premature definition of consciousness because we don't know what that thing is that we're trying to understand.

So I'll hide behind Christof's parry of that question and say we'll talk about it later in the course. But there are many different ways of defining it from the difference between being awake versus asleep, which is some of the functions that go on here, the difference between being knocked out and completely unconscious under general anesthesia, which is different from being asleep. Those kind of states of consciousness are regulated, in part, in here, yeah. OK, so you can get by without a cerebellum. But it's not recommended.

Moving right along, all those subcortical bits, we're just going to talk about three of the most important ones, the thalamus, this big guy right smack in the middle of the brain, very large structure, the hippocampus, and the amygdala. OK, let's talk about the thalamus. Think about the thalamus as a Grand Central Station of the brain, OK, with all of these connections going to all those parts of cortex coming in and out of the thalamus like that. OK?

So one of the key things about the thalamus is that most of the incoming sensory information goes by way of the thalamus en route to the cortex. OK? So if you start with your ear, there's sensory endings in your ear that we'll talk about later in the term. And they send neurons into this, the thalamus here, this yellow thing, through a bunch of different stages. They make a stop in the thalamus. And then they come up here to this green patch, which is auditory cortex. OK?

Similarly, somatosensory endings, touch sensors in your skin that enable you to feel when you're being touched come in through the skin. And they make a stop in the thalamus. And then they go up to somatosensory cortex up there. OK?

Similarly, visual signals that come in from your eyes make a stop in the thalamus and then go up to visual cortex. OK, what's the name of the structure in the thalamus that those axons make a synapse in? Coming up from the eyes, you make a synapse here. And you go up to visual cortex.

**AUDIENCE:** LGN.

**NANCY**  
**KANWISHER:** LGN, perfect. What does it stand for?

**AUDIENCE:** Lateral geniculate nucleus.

**NANCY**  
**KANWISHER:** Perfect. OK, you should know that. This is review from 900, 901. OK, yes? Sorry. OK, which sensory modality does not go through the thalamus en route to cortex between the sensory nerve endings and the cortex? Sorry?

**AUDIENCE:** Olfactory.

**NANCY** Yes. Yes. You guys are on the ball. Yes, olfactory system is the one sensory modality that doesn't make a stop in  
**KANWISHER:** the cortex. You can sort of see that here. From the nose, it goes straight up into olfactory cortex right there.

All right, so that's the standard view of the thalamus is this kind of like relay station where all the external sensory information comes in there, makes a stop, and then goes up to cortex. OK? That's my thalamus act. Boom. Like that, right? OK.

But, increasingly, there's evidence that the thalamus is much more than a relay station. And why would you bother with a relay anyway? Kind of doesn't mean anything. Kind of means like we don't know what's going on here because you wouldn't just make a synapse for no reason, right?

OK, and so the first thing to note, is there are lots of connections that go back down the other way? There are 10 times as many connections that go from primary visual cortex right here in me, right here in this guy in red, there are 10 times as many that go backwards down to the thalamus as go forwards. That's mind blowing, right?

Information comes from the eyes up into the brain. What the hell are those things doing going backwards, OK? Well, they're doing all kinds of interesting things. So that's the first indication that the thalamus isn't just relaying stuff in a stupid, passive way.

And the second whole line of work, which many people are working on, but I think some of the most awesome work on this topic is done by our own Mike Halassa in this department. And he does these incredible studies that you can do in mice with these spectacular methods that we can't use in humans, where he can really take apart the circuit and magnificent detail. And he's showing that the thalamus is involved in all kinds of high-level cognitive computations in mice. It's really stunning work. When the mice have to switch from doing one task to another, the thalamus plays a key role in gating the flow of information from one cortical region to another, OK?

All right, moving along, the hippocampus, I you guys all learned about this. The number one gripe in this department as we learn about H.M. in every course. So that's going to happen here. But it's going to last about 20 seconds. So here goes.

That's a normal slice of the brain like this. Here's the hippocampus on either side. It's like a whole curled up deal right there and right there. And here is H.M.'s brain, the famous H.M., who had surgery to remove his hippocampus on both sides, and completely lost his episodic memory for anything that happened after his surgery. OK? You all remember that, right? If anybody hasn't heard of H.M., send me an email. And I'll give you some background reading.

OK, so very loosely, the hippocampus involved both in this kind of long-term episodic memory that H.M. lost. And it also plays a key role in navigation, which we'll talk about in great detail in a few weeks. And I just want to say that some cases are even more extreme than H.M.

So there's a case of Lonni Sue Johnson. And I am trying to get you guys a video. And I didn't get it in time. But I'll show it to you later in the term if you're interested. Lonni Sue Johnson had a viral infection that went up into her brain.

She was an extremely accomplished person. She did illustrations on the cover of *The New Yorker*. She was a pilot. She had her own farm in which she raised lots of stuff, a very smart, interesting, multitalented woman, who had this terrible tragedy of getting viral encephalitis at I don't know what age, but middle age. And she now does not remember a single event in her life.

She's smart. She's funny. Her personality is totally intact. She can answer questions. She can paint. She can do all kinds of things. But she does not remember a single event in her life. That's pretty astonishing. Reflect on what it means to have the sense of self if you don't remember anything in your life. Yeah?

**AUDIENCE:** Can she remember her name?

**NANCY** That's a good question. I'm not sure she. Might know her-- yes, she does know her name. Actually, it is evident in  
**KANWISHER:** this video. But the video, well, so she doesn't remember. At one point in this video, she's asked, were you ever married? And she's lovely and sweet and gentle and kind of low key. And she's like, you know, just don't remember. I might have been. I might have been. She was married for 10 years.

So that's the hippocampus. Important. You don't want to lose that one. Yeah?

**AUDIENCE:** About H.M., if the hippocampus is used in long-term memory, why is it that it being removed caused him to not form memories?

**NANCY** Well, so long-term memory means-- it's a vague term. It means the formation and retrieval of memories that are  
**KANWISHER:** going to last a long time. So in H.M.'s case, he can access a lot of the memories from before his injury. In Lonni Sue's case, she can't do even that. OK?

All right, the amygdala, OK, amygdala is a Greek word that means almond. Because the amygdala is the size and shape of an almond. And so just for fun, we're passing around some almonds, my favorite kind. Have some almonds and pass them around.

All right, OK, so the amygdala is involved in experiencing and recognizing emotions, especially fear. The simple statement that you should remember about what the amygdala does is just remember the four F's. You guys all know about the four F's, fighting, fleeing, feeding, and mating.

OK, patient SM lost her amygdala on both sides. OK? She cannot experience fear. She doesn't recognize fear on facial expressions of other people. And she doesn't experience fear herself. OK? And so that's the striking piece of evidence on what the amygdala does. Her face recognition is normal, recognizing identities. Her IQ is normal. She's overly trusting of other people. OK? OK, so that's all you need to know about the amygdala for now.

OK, let's talk about white matter, just brief review. Here's a kind of tunnel through a piece of cortex. OK, so my brain cortex is wrapping around like that. If we took a piece like this, just took a segment out like that, this is the outside of the brain up there. Cortex runs like this.

And gray matter is the stuff on the outer surface that's full of cell bodies, OK? White matter are the axons, the processes that come out of those cell bodies and travel elsewhere in the brain. OK? Everybody clear on that? OK, so we got gray matter up here and white matter down there, mostly myelinated axons that have that layer of fat to make them conduct fast. And so you'll see bundles of white matter in the dissection.

And so here's an actual photograph of the slice through a brain. So all that white stuff up there is white matter. OK, and so you might say, well, that's just a big bunch of wires. Who cares about that?

That's a good question. But actually, the wires are pretty damn interesting and pretty fundamental. And so I'll just give you a few reasons. And you don't need to memorize every one of these. I'm trying to give you a gist of why we might care about this. And then there will be a whole other lecture on networks and connectivity later in the course.

Well, first of all, white matter is 45% of the human brain, OK? So it takes up a lot of space, all those wires connecting one bit to another bit. And I would say we cannot possibly understand the cortex and how it works or any little piece of it without knowing the connectivity of each piece to each other bit of the cortex, right? Imagine trying to understand a computer or a circuit without being able to see the connections between the bits. Like it would drive you crazy. That's the situation we're in now in human cognitive neuroscience. It, frankly, drives me insane. But that's where we are.

Next thing, the long-range connectivity of each little bit of cortex, some little bit right there in my brain, is connected to some bunch of other remote regions in my brain. And that particular set of connections is distinctive for that patch of cortex. So you can think of it as a connectivity fingerprint of a patch of cortex. OK, so one of the ways that the different bits differ from each other is by way of their connectivity fingerprints.

And I'm going to skip the rest of these because we're going to get back to them later. And I'm going to run out of time. And I'm going to assign the TAs to sound the gong at 12:15. OK? Good.

All right, now we're up to the cortex. This is really, laughably, shallow. But whatever, that's what we're doing here. So here's this cortex. And as I mentioned, it's a whole big sheet. And the different bits look really similar if you just look at them or slice them up.

So how are we going to figure out how this thing is organized? Well, OK, now we're up here talking about cortex. All right, let's start with the easy parts, which you've already seen.

You've already seen this up here. These colored bits, visual cortex, auditory cortex, somatosensory cortex, gustatory taste cortex, those bits are like the easy parts of cortex. Those are called primary sensory regions. There's also motor cortex right in front of sensory cortex.

So those are the primary regions. They're primary in the sense of this is the first place that sensory information lands up at the cortex coming up from the senses, right? OK, and all of that input is wired through what structure?

**AUDIENCE:** Thalamus.

**NANCY** Yes. Thank you. So how are these regions organized? Well, they have maps. Every one of these regions has a  
**KANWISHER:** map. And each of them has a map of a different thing.

So let's start with visual cortex, and we're going to talk about the map that lives in visual cortex. But the prior condition for understanding that map is to understand the concept of receptive field, which you should know. So I'm going to whip through it quickly.

OK, so here is how you map the receptive field as a property of an individual cell in a brain. OK? So the classic way in animal neuroscience is you place an electrode in the brain next to a neuron in monkey visual cortex. OK? So here's this monkey. He's got an electrode right in his brain right next to a neuron in visual cortex. And every time that neuron fires, you get a spike. You hear a spike.

OK, now you train the monkey to stare at a fixation spot without moving its eyes. OK, I can do this with humans without training you. I can just tell you, look at the tip of my nose. OK, so keep your eyes on the tip of my nose. I can see if you're looking elsewhere. So look at the tip of my nose. OK?

OK, so you train a monkey to do that. That takes a few months. And then they can do that. And then while recording from neurons in his brain, you put stimuli over here, put a flash over there or a flash over here or a flash over here or a flash over here. OK, you can stop looking at my nose. It's not all that fabulous a nose, I realize.

OK, so a receptive field is the place in the visual world that makes a given neuron fire. OK? So if there's a neuron in your brain that responds to a flash here but not a flash here or here or here or here, the receptive field of that neuron is right there. Everybody got that idea?

OK, so in visual cortex, neurons have restricted receptive fields. They don't respond to anything anywhere in the visual field. They respond to a particular place in space. OK, if that's confusing at all, ask a question. Because it will come up again and again.

All right, so that's what the rest of this slide says, what I just said. Blah, blah, blah. It doesn't matter. That's a receptive field. Different visual neurons have different receptive fields for different parts of space.

Now here comes the important idea. In visual cortex, two neurons that are next to each other in visual cortex have nearby receptive fields. OK? So that's the concept of retinotopy or the map in visual cortex. So you basically have a map of the visual world in your visual cortex because there's this systematic layout just like you have in your retina.

In your retina, visual information comes in. And because of optics, different parts of your retina respond to different parts of the image. But that information is propagated back through the LGN up to primary visual cortex where you still have a map of the visual space up in primary visual cortex. OK?

So that map is called retinotopic in visual cortex because it's oriented like the retina. And so here's a particularly kind of gruesome but very literal depiction of this property of retinotopy in a monkey brain. This is an experiment done very long ago by Roger Tootell.

And what he did was he used a method called deoxyglucose. And so what deoxyglucose is a molecule that's a whole lot like glucose. But it's got one little change in the molecule, which means it gets stuck on the metabolic chain. And so it gets taken up by cells that want to take up glucose. And then it gets stuck in there and can't be broken down.

So it builds up in cells that are metabolically active. OK? So you can put a little radioactive tracer on deoxyglucose, inject it into a person or an animal. And what happens is it builds up with this radioactive tag on all the cells that were active. Make sense?

OK, so Tootell did an experiment where he had the monkey fixate on a spot. And he presented this stimulus here. So the monkey's fixating right there. And this stimulus is flashing on and off.

He injects the radioactive deoxyglucose into the monkey while the monkey's looking at this. And then, I'm sorry to say, he killed the monkey, rolled out visual cortex into a sheet. And there it is. And you can see the bullseye pattern that the monkey was looking at across the surface of visual cortex.

Does everybody get that? OK, so that shows you very literally what a retinotopic map is in the brain. It's just like the map of the visual world in the retina. But there it is up in the back of the brain. And humans have this too. OK?

And so this can be shown in humans with functional MRI. We'll talk later more about the methods of functional MRI. But here's a very high-resolution functional MRI experiment done by some people over MGH Charlestown.

By the way, when I have names on slides, it's just because, in science, we don't get paid that much. And so our credit for our cool data is kind of all we have. And so I can't stand to talk about other people's cool experiments without giving them credit. I do not expect you to learn the names. It's just my little personal tic that I need to have their name there to give them credit, even though you don't know who they are. OK.

OK, so what this guy John Polimeni did was show human subjects this stimulus here. They were fixating right there. And the stimulus is flickering with the dots kind of dancing around. And then he looked on the back in visual cortex on the surface of the brain, and he sees an M there.

It's the same stimulus. It's just flipped upside down, which is not deep or interesting. The cortex has to be oriented one way or another. The brain doesn't care whether you turn it around, right? And your map of visual space is upside down in the back of the head. And you see that M. Does everybody get how that also shows retinotopic properties in the brain in human visual cortex? OK.

All right, so the key idea of retinotopy is that adjacent parts of the visual field are mapped to adjacent parts of the cortex. All right, OK, a little bit of terminology just because people are fast and loose with these things. I've already referred to V1 and primary visual cortex. It's also sometimes called striate cortex. It's all the same thing.

It's the part of the visual cortex where the information first comes up from the LGN right back here. So in me, it's right there. Most of it is in the space between the two hemispheres. But a little bit sticks out on the side. So in this person, that yellowy orange stuff, that's primary visual cortex, which is the same as V1 and striate cortex. OK? That's just terminology.

All right, just as we have maps for visual space, we have maps for touch space. And so you've probably seen this diagram here of the map of touch space going across somatosensory cortex like this. So this is a picture of a slice like that, showing you which parts of the body are mapped out to which parts of space. And you can see that particularly important parts of the body get bigger bits of cortex. Yeah?

OK, just as we have visual maps and touch maps, we have auditory maps in auditory cortex, which is right on the top of the temporal lobe right in here. And what's mapped out in auditory cortex is auditory frequency, high versus low versus high frequencies of sound. And so you see that here's a piece of auditory cortex in one subject, showing you regions that respond to high frequencies, low frequencies, high frequencies. Here it is another subject, high, low, high, another subject, high, low, high.

OK, so the point of all of this is that primary somatosensory cortex has maps. Everybody clear on this? The different sensory modalities map different dimensions.

OK, so what about the rest of cortex? Like you can see, most of the cortex is not primary sensory cortex. Is the rest of cortex just mush? Or are there separate bits like primary sensory areas?

And if so, do those other bits have maps? And if so, what are those maps of? OK? We just took you from 100 years ago to the cutting edge of the field is asking this question in lots of different ways right now. OK?

OK, let's back up and ask, what counts as a cortical area anyway? I just posited that these primary sensory regions count as distinct things. They're like the things, right? They're separate things in the brain. OK? And if for no other reason, then they get direct input from the thalamus, right?

OK, but let's back up and ask, what exactly is a cortical area? And we're going to consider this question by considering the three key criteria for what counts as a cortical area. OK, the first one is that that region of cortex is distinct from its neighbors in function. Neurons there fire in response to something different from the neurons in the neighboring region. OK, that's very vague right now. But we'll illustrate that.

The next one is-- I mentioned this before-- each distinct region of cortex has a different set of connections to other parts of the brain. It has a distinct connectivity fingerprint. OK? And the third thing is, for at least some regions of the cortex, they're physically different. If you slice them up and stain them and look at them really carefully, they might look a little different than other bits of the cortex. OK?

So those are three of the key criteria that have been used to say, this bit of cortex, it's a thing, right? It's distinct, right? OK, so let's look at the classic example beyond those primary regions. Those are the most classic regions. Those are the primary regions we've already talked about. Those are the ones nobody would fight you on that.

This one is next in line. Nobody would fight you if you say, visual area MT, that's an area. Well, they might. But most people wouldn't. OK, and then from there on out, it's all fighting all the time.

OK, so let's talk about visual area MT. It's a little patch of the cortex in a monkey brain. This is a side view of a monkey brain. And in this human brain, it's that little patch right there.

OK, so this region meets all the criteria to be a distinct visual area. So how do we know this? Well, we know this from lots and lots of different methods. So I'm going to whip through a few of those to give you a gist of how we can find evidence that that region is distinct in functional connectivity and the physical stuff, sometimes called cytoarchitecture. OK?

All right, function, how would we know that region has a different function? Well, one way, the classic way is to record from individual neurons in monkey brains. So if you stick a neuron into monkey visual cortex while the monkey is looking at the stimulus that I'll show you in a second, you'll hear the responses of an individual neuron. Each click will be the response of an individual neuron to the stimulus.

So let's play this thing, except it's not making any sound. Chris, can you help me? Oh, right. Duh. That part, OK, see when the bar of light moves this way, it makes a lot of firing and not when it moves the other way? Let's watch it for a second. Watch the bar move again.

See? It responds less when it's moving in a different direction. Everybody got that? What is this area right there called? Yeah, this area right here in the middle.

**AUDIENCE:** [INAUDIBLE]

**NANCY**  
**KANWISHER:** Exactly. That's the receptive field. That's the part of visual space that makes this neuron fire. OK, this neuron also has a property called direction. It's sensitive to motion, as you see. But it's also specific to specific directions of motion. Everybody see that?

OK, so that's a direction-selective neuron in monkey area MT. And here's a way of showing, with data, what you guys just saw. This is a map of different directions in polar coordinates. And this shows you how much-- this is a single cell being described here.

This is the direction selectivity of that cell, showing you that when the stimulus moves in this direction, you get a lot of firing. When it moves in this direction, you get less firing. And can everybody see how this plot shows you the direction selectivity of that cell? Make sense? Right. OK, so that shows you what you just saw in the movie.

So this is one way to establish the function of visual area MT is stick electrodes in there and record directly from them when a monkey looks at different kinds of stimuli. And you see direction selectivity when you do that. OK, further, if you actually do this systematically, moving across next door bits of monkey area MT, what you find is that, as we said before, nearby bits of cortex respond to similar things, in this case, to similar directions of motion.

So here's a little diagram. As you move across the cortex, you see a systematic change in the direction selectivity of neurons as you move across the cortex. So in MT, we have a map of direction preference, just as we had a map of spatial location in primary visual cortex. Make sense?

OK, now because those neurons are clustered like that-- I forget what my next point was. No. Never mind. We'll get that in a second. OK, what about humans? OK, so here's a monkey brain. Here's a neuron in a monkey brain. What about humans? Can we record from single neurons in humans? What do you think? Do we ever get to do that? Yeah?

**AUDIENCE:** Like neurosurgeons.

**NANCY**  
**KANWISHER:** Yeah. Yeah. Neurosurgeons, very occasionally, enable us to record from individual neurons in human brains. It's the most awesome data ever. Of course, we only do it when the neurosurgeons have decided, for clinical reasons, to put electrodes in human brains.

They need to do this to map out epilepsy before surgery. And sometimes those patients are super nice and say, yes, I'll look at your stimuli or listen to your stimuli while you record from my neurons. And then we get the most awesome data ever. But it's very, very rare. I don't know of any data where people have reported individual neurons in area MT in humans. Yeah?

**AUDIENCE:** So how powerful should an fMRI be to be able to record such information?

**NANCY** Oh, we're getting there. OK, so given that we, very rarely, get to record from individual neurons in humans and  
**KANWISHER:** we want to more generally if there is an MT in humans, what do we do? We pop subjects in an MRI scanner. And we show them moving dots or stationary dots.

And we scan them with functional MRI. We'll go through the details of how this works more in future lectures. But what you see, basically, is this is a slice through the brain like this. And you see this region right here responds more to the moving dots. This is the response. This is time here. This is when the moving dots are on high response. And then when it switches to stationary dots, the response drops.

OK, so with functional MRI, you can also find the visual area empty by the higher response to moving than stationary dots. Does that make sense, more or less? I mean, I'm not giving you any of the details. But for now, they don't really matter. OK, so that's cool. But does that tell us that neurons in human MT are specific for the direction of motion? Yes?

**AUDIENCE:** Are the moving dots moving to a specific location?

**NANCY** They're moving in all the directions you see here. No, it doesn't. It tells us it's sensitive to the presence of motion  
**KANWISHER:** but not the direction of motion. OK? So if we want to really know, is human MT like monkey MT or is this really human MT, we want to know, are the neurons in there not just responsive to motion but are neurons specific for particular directions of motion, OK?

So how would we do that? OK, well, there's lots of ways of doing that. But actually, one of the charming things is you can do that without an MRI scanner. That is it won't tell you whether it's MT you're looking at. But we can ask the question of whether your brains have neurons that are tuned for particular directions.

So for this demo, I want you to fixate right in the center. And do not move your eyes from that dot. And I'm going to keep talking for a while, while you keep fixating right on that dot.

And so what I'm going to show you is something called an after effect. This is also known as the psychophysicist's electrode. Psychophysicists are people who just measure behavior. And from behavior, they can infer how individual neurons work.

And that is about as awesome as it gets. That's much more impressive than just recording from the damn neuron. Inferring from very indirect data how the neuron works from behavior, now, that is pretty-- oops. OK, sorry. Look directly at my face.

You see anything? I didn't see it stop. OK, we're going to-- oh, here we go. Oh, right. OK, just fixate on the center again. Sorry. I forgot this guy was going to stop. So keep looking at the center. And then when it stops in a little bit, then keep your eyes right on that dot. And you can see what happens.

**AUDIENCE:** [INAUDIBLE]

**NANCY** Oh, that's right. Good point. Yes, right now, it's alternating. Nothing's going to happen. But that's OK. We're going  
**KANWISHER:** to have the whole experience. Keep fixating on the dot. It's good the TAs are on the ball.

OK, fixate on the dot. Anybody see anything? Not really. That's OK. You're not supposed to. That's the control condition. It was alternating directions. OK?

So I think it's going to start moving again. I'm not sure. Let's go back. Let's just start it again. OK, I'm sorry I blew it the first time. But let's just get this right. OK, fixate on the center and just keep your eyes right on that center.

So this one, it's not alternating. And it's going to do this for around 30 seconds. And so the whole point of this is a way with behavior to ask the question of whether you have neurons in your brain tuned to specific directions of motion. And something as low-tech and simple as an aftereffect can tell you that.

Keep looking. Did you guys see anything? What did you see? What happened?

**AUDIENCE:** It wasn't moving exactly [INAUDIBLE]

**NANCY**  
**KANWISHER:** Uh huh. Well, it actually should-- well, now it's doing something else. But it should shrink at the end. Did you guys see it shrink? OK, so that's an after effect.

And the simple version of the story is that you are tiring out your neurons that are sensitive to outward motion while you stare at all that outward motion. And after you kind of burn them out and exhaust them, then when you look at something stationary, it looks like it's going inward. OK? And the general idea is you have pools of neuron-- the easiest way to account for that is you have pools of neurons tuned for different directions. And that's why, if you tire out one batch, you have a net signal in the other direction. Does that make sense?

This is all very relevant to your assignment which is due tomorrow night at 6:00. This phenomenon was used in the scanner for that experiment. You can think about how you would use this phenomenon to ask whether there's direction selectivity, not just responses to motion, in human MT. Yeah?

**AUDIENCE:** I'm just a little bit confused. So even when an image is completely still, like even if you're not detecting motion, those neurons are still firing?

**NANCY**  
**KANWISHER:** That's a good question. But most likely, the simple cases-- this may have not worked beautifully, in part, because I screwed it up and didn't notice when it stopped. But if it works well, you should get a pretty powerful sense that after you see it expanding, then when it's still, it should seem to be contracting.

So when that happens-- the reading assigned for today, tomorrow night tells you what happens in your brain during that time when you are looking at stationary stimuli but experiencing motion. So there's no motion in the stimulus. But there's motion in your percept. OK? So that's the question. All right? So read the paper and find out. Yeah?

All right, so all of that tells us just that there are neurons someplace in your brain that are sensitive to the direction of motion. It doesn't tell us that they're in MT in particular. But the assigned reading will talk about that. OK?

Right, a further bit of evidence is remember I said how, in monkeys, next door bits in MT have similar direction selectivity. That means you can also inject an electrical signal in a little patch of MT and give the monkey a net percept of a direction of motion. OK? If all the neurons were scrambled around spatially, so that there was no clustering of neurons sensitive to, say, this direction of motion, then stimulation wouldn't do anything.

But if you train a monkey to tell you what direction of motion he's seeing and you show him just random dots that aren't moving in any direction and you stimulate one little patch, it'll tell you the direction of motion of the neurons in that little patch. And that is much more powerful evidence that that region is not only responsive to motion but causally involved in your perception of motion. OK? I'm a little obsessed with this distinction between recording responses and establishing causality. So we'll go over this in more detail later. But I want you to start getting used to that idea.

Another way to test the causal role of area MT in motion is with patients with brain damage in area MT. So there's one famous patient who had brain damage right there, which is right where MT usually is. And she could not see motion. And she reports all kinds of things like difficulty crossing the street, difficulty catching balls, difficulty pouring water into a cup, OK, just as you guys saw earlier. That's called akinetopsia, right? Kinetics, motion. A, not motion, right? Opsia, eyes. OK.

All right, so I started with these criteria for what makes something a distinct area. And one piece of evidence is function. And I just give you a whole bunch of different kinds of evidence for distinct function and visual area MT, that it's specifically involved in motion processing.

And the two other criteria, which are getting short shrift, but I'll just toss them off. And we'll return to them. One is the distinct connectivity of that region. OK, so you may have seen this horrific wiring diagram of visual cortex in monkeys. I think it comes up in like half the talks in classes in my field.

This is the one down here. And so there's lots and lots of different visual areas. And there's a whole fancy wiring diagram. And smack in the middle of this diagram, that's visual area MT.

And if you blow this up and stare at it, you'll see that MT has a particular set of connections to other visual regions in cortex. And its particular set of connections are different from the connections of any of those other regions. It's part of its connectivity fingerprint or signature. And that's another piece of evidence that it's a thing. OK? It's not just another like amorphous bit of cortex. It's a particular thing in the brain.

And finally, you might wonder, is that bit of cortex physically different? Are the cells in there different? Are the layers of cortex different in any way? And you may remember, from probably 900, about Brodmann areas. Like this dude Korbinian Brodmann sliced up lots of dead brains, looked at them under a microscope, and argued that there were 52 different parts just from what it looked like if you slice them up under a microscope. OK?

So we called those Brodmann areas. And area 17, this primary visual cortex, comes from Brodmann's terminology. And so he argued that there-- he thought these were distinct organs in the brain.

And he even inferred the specific histological differentiation of the cortical areas proves irrefutably their specific functional differentiation. Well, it doesn't. But never mind. Kind of sounded good. Anyway, that was his idea.

And these kinds of distinct, kind of cellular, physical, anatomical differences are very salient for primary cortical areas for vision and audition and touch and motor cortex. But they're much muckier for lots of other areas. One important exception, which is why we chose this, is area MT.

And so I'll end in one minute. But just to tell you where this is going, this is a flattened piece of monkey cortex rolled out like with a baking roller. No. I don't know. Something like that.

So here's monkey cortex. And there's V1 and V2. And it's a big mess. But that big dark blob, this bit of cortex is stained with something called cytochrome oxidase. And that indicates metabolic activity.

MT neurons are very highly metabolically active. And so here's a map of visual cortex. And that exactly is area MT. So area MT actually is histologically or cytoarchitecturally different from its neighbors and fits all of the criteria for a cortical area. OK?

I went one minute over. I realize I threw out a lot of terminology. I don't want you to memorize too much. So I made a list of the kinds of things that you should understand from this lecture, the things that I think are important.