NANCY KANWISHER: So I'm going to talk today about a couple of things. I had a hell of a time constructing a nice clean narrative arc to everything I wanted to say. And so I finally just decided, the hell with it. I'm just going to be honest. There's several different pieces. They don't make a narrative arc. That's life.

I want to address what I see as a sort of macroscopic view of the organization of the human brain is giving us a kind of picture of what I'm going to call the architecture of human intelligence. We're trying to understand intelligence in this class. And so I think the overall organization of the human brain-- in which we've made a lot of progress in the last 20 years-- gives us a kind of macro picture of what the pieces of the system are. So I'll talk about that. And then I'll also-- if I talk fast enough-- do a kind of whirlwind introduction through the basic methods of human cognitive neuroscience using face recognition as an example to illustrate what each of the methods can and cannot do.

So that's the agenda. It's going to be pretty basic. So if you've heard me speak before, you've probably heard a lot of this. Anyway, the key question we're trying to address in this course is, how does the brain produce intelligent behavior? And how may we be able to replicate that intelligence in machines?

So there's, of course, a million different ways to go at that question. And you can go at it from a kind of computational angle, a coding perspective, from a fine-grained neural circuit perspective. But I'm going to do something that's kind of in between. because those are the things we can approach in human brains.

And it's really human intelligence we want to understand. It's a sum of human intelligences. A lot of it are things that we share with animals, but some of it is not. And so I think it's important to be able to approach this not just from the perspectives of animal research, magnificent as those methods are, but to also see what we can learn about human brains.

OK. So I'll talk a bit about the overall functional architecture of the human brain. What are the basic pieces of the system? And then I'll get into some different methods and what they tell us about face perception.

OK. So at the most general level, we can ask whether human intelligence-- as people have been asking for centuries, actually-- whether human intelligence is the product of a bunch of very special purpose components, each optimized to solve a specific problem, kind of like this device here, where you have a saw for cutting wood, scissors for cutting paper. Saws don't work that well on paper, and scissors don't work that well on wood. Or whether human intelligence is a product of some more generic, all-purpose computational power that makes us generically smart without optimizing us for any particular task.

And just to foreshadow the answer, as in all questions in psychology, the answer is both. But we'll do that in some detail. Before we get into that, who cares? And I'd say, first of all, this kind of macro level question about functional components of the human mind and brain matters for a bunch of reasons.

First of all, I just think it's one of the most basic questions we can ask about ourselves-- about who we are-- is to ask what the basic pieces are of our minds. Second, more pragmatically, this kind of divide and conquer research strategy has been effective in lots of different fields that are trying to understand a complex system. What do you do with this incredibly complex system, where you just can't even figure out how to get started? Well, one sensible way to get started is first figure out what its pieces are and then maybe try to figure out how each of the pieces work. And then maybe some day, maybe not in my lifetime, figure out how they all work together in some coordinated fashion.

And third, somewhat more subtly, of course, we want to know not just what the pieces are, but what the computations that are performed in each of those pieces and what the representations extracted in each piece are. And I think even just a functional characterization of the scope of a particular brain region already gives us some important clues about the kinds of computations that go on there. So if we find that there's a part of the brain that's primarily involved in face recognition, not in reading visually presented words, recognizing scenes, or recognizing objects, that already gives us some clues about the kinds of computations that would be appropriate for that scope of task. So if you tried to write the code to do that, you'd be writing very different code if it only had to do face recognition versus if it also had to be able to recognize words and scenes and objects presented visually.

OK. So that's my list of the main reasons. And of course, there are heaps of different ways to investigate this question, and I'll mention some of those in the second half. But I want to start with Spearman, who published a paper in 1904 in the *American Journal of Psychology.* This article was sandwiched between a discussion of the soul and an article on the psychology of the English sparrow.

And in this article, Spearman did the following low tech but fascinating thing. He tested a whole bunch of kids in two different schools on a wide variety of different tasks. And this included scholastic achievement type things. He got exam grades from each student in a bunch of different classes. And he measured a whole bunch of other kinds of psychological abilities, including some very psychophysical perceptual discrimination abilities. How well could people discriminate the loudness of two different tones, the brightness of two different flashes of light, the weight of two different pieces of stuff?

And what he found-- well, before I tell you what he found, what would you expect with this? Should we expect a correlation between your ability to discriminate two different loudnesses and, say, your math score in grade five on a math exam?

Spearman's main result is that most pairs of tasks were correlated with each other. That is, if you were good at one, you're good at the others-- even tasks that seemingly had very little to do with each other. And this is the basis of the whole idea of g, which is the general factor, which is what led to the whole idea of IQ and IQ testing. And in America, we're very uptight about the idea of IQ. Brits don't seem to have a problem with this idea. They're very enthusiastic about the idea and always have been.

But aside from all the social uses and misuses of IQ tests, the point is there's actually a deep discovery about psychology that Spearman made from the fact that all of these tasks were correlated with each other. He didn't know what it was, kind of like Gregor Mendel inferring genes without knowing anything about molecular biology. Spearman just inferred there's something general about the human intellect such that there are these strong correlations across tasks.

OK, so that's g. But less well known about Spearman's work is he also talked about the specific factor, s. And s was the fact that although the broad result of his experiments was that most pairs of tasks were correlated, there were some tasks that weren't so strongly correlated with others, and that you could factor those out and discover some mental abilities that weren't just broadly shared across subjects. And I think this kind of foreshadows everything that we see with functional MRI. There's a lot of specific s's, and there's also some g. And you can see those in different brain regions, as I will detail next.

Another method was invented by Franz Joseph Gall. And he argued that there are distinct mental faculties that live in different parts of the brain, which I think is more or less right, as I'll argue. But Gall lived in the 1700s, and he didn't have an MRI machine. So he did the best he could, which wasn't so hot. He invented the infamous method of phrenology.

He felt the bumps on the skull and tried to relate those to specific abilities of different individuals, and from this, inferred 27 mental faculties. My favorites are and amativeness, filial piety, and veneration. And so there's a kernel of the right idea, but kind of the wrong method.

And another method that was a very early one was the method of studying the loss of specific mental abilities after brain damage. And so Flourens, who's often credited as being the first experimental neuroscientist, went around making lesions in pigeons and rabbits and then tested them on various things. And he didn't really find much difference in what parts of the brain he took out for their mental abilities. Maybe that's because he wasn't such a hot experimental-- he didn't have great experimental methods.

In any case, he argued that all sensory and volitional faculties exist in the cerebral hemispheres and must be regarded as occupying concurrently the same seat in those structures. In other words, everything is on top of everything else in the brain. So that was a sort of dominant view for a while. People thought Gall was kind of a crackpot, even though he wrote very popular books and went around Europe giving popular lectures that huge numbers of people attended. The respectable intellectual society didn't take him seriously.

In fact, the whole idea of localization of function wasn't taken seriously until Paul Broca, a member of the French Academy, stood up in front of the Society of Anthropology in Paris in 1861 and announced that the left frontal lobe is the seat of speech. And this was based on his patient Tan, whose brain is shown here. Tan was named Tan because that was all he could say after damage to his left inferior frontal lobe. And Broca pointed out that Tan had lots of other mental faculties preserved, and it was simply speech that was disrupted. And from this was one of the first respectable people to argue for localization of function.

OK. So this research program goes on. And by the end of the 20th century, there's pretty much agreement that basic sensory and motor functions do exhibit localization of function in the brain. There are different regions for basic visual processing, auditory processing, and so forth. And that was no longer controversial. But the whole question of whether higher level mental functions were localized and distinct parts of the brain was controversial then and remains controversial now.

And so the method I'll focus on is functional MRI, because I think it's played a huge role in addressing this question at this macroscopic level. And I think you guys know what an MRI machine is. In case anybody has been on Mars for a while, the important part is its measure is a very indirect measure of neural activity by way of a long causal chain. Neurons fire, you incur metabolic cost, and blood flow changes to that region. Blood flow increase more than compensates for oxygen use, producing a local decrease rather than the expected increase in deoxyhemoglobin relative to oxyhemoglobin.

Those two are magnetically different. That's what the MRI machine detects. It's very indirect, so it's remarkable it works as well as it does. And it's currently the best noninvasive method we have in humans in terms of spatial resolution, not temporal resolution.

OK. So many of you are already diving into the details of some of the data we collected. But in case you're on other projects and are coming from other fields, the basic format of the data in a typical functional MRI study is you have tens of thousands of three dimensional pixels or voxels that you scan. And typically, you sample the whole set once every two seconds or so. You can push it and do it every second or less under special circumstances. You can have more voxels by sampling at higher resolution, but that's a ballpark of the format of the kind of movie you can get of brain activity.

OK. So a few things about the method and its limitations, because they're really important in terms of what you can learn from functional MRI and what you can't. So first of all, this is a timeline. My x-axis, even though it's invisible, is time in seconds. And so if you imagine looking at V1 and presenting a brief, say, tenth of a second high contrast flash of a checkerboard, what we know from neurophysiology is that neurons fire within 100 milliseconds of a visual onset. The information gets right up there really fast.

The BOLD, which stands for Blood Oxygenation Level Dependent, or functional MRI response, is way lagged behind this. So the neurons are firing way over here in this graph, essentially at time zero-- a tenth of a second. But the MRI response is six seconds later, OK? So it's really slow. And that has a bunch of implications about what we can and cannot learn from it.

So first of all, because it's so slow, we can't resolve the steps in a computation for fast systems like vision and hearing and language understanding-- systems for which we have dedicated machinery that's highly efficient where you can recognize the gist of a scene within a quarter of a second of one it flashes on a screen in front of you. And similarly, you understand the meaning of a sentence so rapidly that you've already parsed much of the sentence well before the sentence is over. So these are extremely efficient rapid mental processes. That means the component steps in those mental processes happen over a few tens of milliseconds.

And we're way off in temporal resolution with functional MRI. All of those things are squashed together on top of each other. That's a drag. That's just life. We can't see those individual components steps with functional MRI.

The second thing is that the spatial resolution is the best that we have in humans noninvasively right now, but it's absolutely awful compared to what you can do in animals. So I missed Jim DiCarlo's talk yesterday, but those methods are spectacular. You can record from individual neurons, record their precise activity with beautiful time information.

In contrast, functional MRI is like the dark ages. We have, typically, hundreds of thousands of neurons in each voxel. So the real miracle of functional MRI is that we ever see anything at all rather than just garbage, because you're summing over so many neurons at once. And it's just a lucky fact of the organization of the human brain that you have clusterings of neurons with similar responsal activities and similar functions at such a macro grain that you can see some stuff with functional MRI, although you miss a lot as well.

The third important limit of functional MRI that comes out of just a consideration of what the method measures is that you can only really see differences between conditions with functional MRI. The magnitude of the MRI response in a voxel at a time point is meaningless. It might be 563, and that's all it means. Nothing, right? It means nothing. It's just the intensity of the MRI signal.

The only way to make it mean something is to compare it to something else-- usually two different tasks or two different stimuli. And so you can go far with that, but it's important to realize you can't train translate it into any kind of absolute measure of neural activity. It's only a relative measure of strength of neural activity between two or more different conditions.

OK. And the final deep limitation of functional MRI is that we use this convenient phrase "neural activity." It's very convenient, because it's extremely vague. And fittingly so, because we don't know exactly what kind of neural activity is driving the BOLD response. It could be spikes or action potentials. It could be synaptic activity that doesn't lead to spikes. It could be tonic inhibition. It could be all kinds of different things. Anything that's metabolically expensive is likely to increase the blood flow response.

In practice, when people have looked at it, it's very nicely correlated with firing rate-- with some bumps and caveats, so you can never be totally sure. But it's a pretty good proxy for firing rate. You just need to remember in the back of your mind that it could be other stuff too.

The final, very important caveat is that functional MRI-- like most other methods where you're just recording neural activity in a variety of different ways-- you're just watching. You're not intervening. And that means you're not measuring the causal role of the things you measure.

And that's very important, because it could be that everything you measure is just completely epiphenomenal and has absolutely nothing to do with behavior. So in practice, that's unlikely that you have all this systematic stuff for no reason, but you need to keep in mind that functional MRI affords no window at all into the causal role of different regions. For that, you need to complement it with other methods.

So despite all these limitations, I think functional MRI has had a huge impact on the field. And admittedly, I'm biased, but I think it's one of these things where as it happens, we get so used to a result the minute it gets published. It was like, oh, yeah, right. One of these, one of those, so what? But I think it's important to step back, so I made a bunch of pictures to show you why I think this is important.

OK. Here is Penfield's functional map of the human brain, published in 1957, a year before I was born. And he has six-- count them, six-- functional regions labeled in there. You probably can't see them. But it's the basic sensory and motor regions, visual cortex, auditory cortex, motor cortex, speech appear in Broca's area, and then my favorite is this word that says interpretive. Nice.

OK. Anyway, this was based on electrical recording and stimulation in patients with epilepsy who were undergoing brain surgery. Actually a very powerful method, but that's where it got him. He published this near the end of his career. And that's nice, but it's pretty rudimentary.

OK, now, cut to 1990, immediately before the advent of functional MRI. And this is really crude-- the black outlines are the basic sensory and motor regions. And I've added a couple of big colored blobs for regions that had been identified by studying patients with brain damage.

So even from Broca and Wernicke, it was known that approximately these regions were involved in language, because people with damage there lost their language abilities. You get whacked in your parietal lobe, you have weird attentional problems, like neglecting the left half of space and stuff like that. If you have damage somewhere to the back end of the right hemisphere, you might lose face recognition ability. These things were known by around 1990, not much else. That's basically the functional map of the brain in 1990. That probably seems like ancient history to a lot of you, but not to me.

OK. Here we are today. There's a lot of stuff we've learned, right? There a lot of particular parts of the human brain whose function has been characterized quite precisely. Not in the sense that we know the precise circuits in there or that we can very precisely characterize the representations or computations, but to the sense that we know that a region may be very selectively involved, for example, in thinking about what other people are thinking. A totally remarkable result that Rebecca Saxe who discovered it will tell you about when she's here next week. So that was completely unknown even 15 years ago, let alone back in 1990.

And likewise, most of these other regions were either known in the blurriest sense or not with this precision. So I think even though this is very limited, and it's kind of step zero in trying to understand the human brain, I think it's important progress. And I think to push a little farther, I'd like to see this as an admittedly very blurry but still a picture of the architecture of human intelligence. What are the basic pieces? What is it we have in here to work with when we think? We have these basic pieces-- a bunch more that haven't been discovered yet, and a lot more that we need to know about each of these and how they interact and all of that, but a reasonable beginning.

So that's my story here for fun. This is me with a bunch of functional regions identified in my brain. And so the argument I'm making here is that the human mind and brain contains a set of highly specialized components, each solving a different specific problem, and that each of these regions is present in essentially every normal person. It's just part of the basic architecture of the human mind and brain.

Now, this view is pretty simple. But nonetheless, it's often confused with a whole bunch of other things that people think are the same thing and that aren't, so it's starting to drive me insane. So I'm going to take five minutes and go through the things this does not mean. And I hope this doesn't insult your intelligence, but it's amazing how in the current literature in the field people conflate these things.

So I'm talking about functional specificity, which is the question of whether this particular region right here is engaged in pretty selectively in just that particular mental process and not lots of other mental process. That's what I mean by functional specificity. That's a different idea than anatomical specificity.

Anatomical specificity would say it is only this region that's involved, and nothing else is involved. That's a different question. How specific is this region versus are there other regions that do something similar? Also an interesting question, but a different one. I'm going to go through this fast. So if any of it doesn't make sense, just raise your hand and I'll explain it more.

Yet another idea is the necessity of a brain region for a particular function. That's actually what we really want to know with the functional specificity question-- is not just does it only turn on when you do x, but do you absolutely need it for x? And so that's actually a central question that's closely connected. It's really part of functional specificities. It's the causal question.

It's different from the question of sufficiency. Is a given brain region sufficient for a mental process? Well, I think that's just kind of a wrong headed question, because nothing's ever sufficient. It's just kind of a confused idea. What would that mean? That would mean we excise my face area, we put it in a dish, keep all the neurons alive. Let's pretend we can do that. I'm sure Ed Boyden could figure out how to do that in a weekend.

And so we have this thing alive in a dish, can it do face recognition? Well, of course not. You got to get the information in there in the right format. And if information doesn't get out and inform the rest of a brain, it doesn't house a face percept, right? So you need things to be connected up, and you need lots of other brain regions to be involved.

So let's distinguish whether this brain region is functionally specific for a process from whether it's sufficient for the whole process. Of course it's not sufficient. All right. I know you guys would never say anything so dumb.

OK. A question of connectivity-- so people often say, oh, well, this region is part of a network, period. And my reaction is, duh. Of course it's part of a network. Everything's part of a network. In no way does that engage with the question of whether that region is functionally specific.

A functionally specific region of course is part of a network. It talks to other brain regions. Those other brain regions may play an important role in its processing, sure. At the very least, they're necessary for getting the information in and out and using it. OK? OK.

All right. The final thing that people confuse it with functional specificity is innateness. This is a very different concept. Just because we have some particular part of the brain for which we make it really strong evidence that it's very specifically involved in mental process x, that's cool. That's important. That's completely orthogonal to how it got wired up and whether it's innately specified in the genome that whole circuit-- or whether that circuit is instructed by experience over development, or as in the usual case, very complicated combinations of those two. So just to remind you that functional specificity is a different question from innateness.

And one way you can see that very clearly is to consider the case of the visual word form area, about which I'll show you some data in a moment. The visual word form area responds selectively to words and letter strings in an orthography you know, not an orthography you don't know. It's very anatomically stereotyped. Mine is approximately right there, and so is yours in your brain. And it responds to orthographies you know.

If you can read Arabic and Hebrew, yours also responds when you look at words in Arabic and Hebrew. If you can't, it doesn't, or it responds a whole lot less. So that's a function of your individual experience, not your ancestor's experience. It has strong functional specificity, and yet, its functional specificity is not innate.

So this idea that I'm staking out here has become kind of unpopular. It's very trendy to say, of course we know the brain doesn't have specialized components. So for example, here's from a textbook. Scott Huettel-- unlike the phrenologists who believe this very stupid idea that very complex traits are associated with discrete brain regions, modern researchers recognize that a single brain region may participate in more than one function. Well, he built in the hedge word "may," so we can't really have a fight. But he's trying to stake out this different view .

Lisa Feldman Barrett-- I haven't met her, but she's driving me insane, most recently by proclaiming all kinds of things in *The New York Times* just a few weeks ago. Quote, "in general, the workings of the brain are not one to one, whereby a given region has a distinct psychological purpose." Well, she's got hedge words "in general." We all have hedge words.

But basically, what she's reasoning from is the fact that her data suggests that specific emotions don't inhabit specific brain regions from the idea that the whole brain has no localization of function. Well, that's idiotic. It's just idiotic, right? So I hope that people will stop these fast and lose arguments.

But here's my favorite-- this old coot Uttal. I know this is going to be on the web, and here I am carrying on as if we are-- anyway, whatever. This guy cracks me up. He's been publishing. Every year, he publishes another book going after functional MRI. Any studies using brain images that report single areas of activation exclusively associated with a particular cognitive process should be a priori considered to be artifacts of the arbitrary threshold set by the investigators and seriously questioned. You go.

So anyway, that's fun. Anyway, my point is just that we should engage in the data, right? This isn't like an ideology, where we can just proclaim our opinions. There are data that speak to it. So let me show you some of mine.

OK. So what would be evidence of functional specificity? There are lots of ways of doing it. The way I like to do it is something called a functional region of interest method. The problem is that although there are very systematic regularities in the functional organization of the brain, each of these regions that I'm talking about is in approximately the same location in each normal subject. Their actual location varies a bit from subject to subject. So if you do the standard thing of aligning brains and averaging across them, you get a lot of mush, and yet there isn't much mush in each subject individually.

And so to deal with that problem-- and to deal with a bunch of other problems-- we use something called a functional region of interest method. And that means if you want to study a given region, you find it in that subject individually. And then once you've found it with a simple contrast-- you want to find a face region, you find a region that responds more when people look at faces than when they look at objects.

Now you found it in that subject. It's these 85 voxels right there in that subject. Now we run a new experiment to test more interesting questions about it, and we measure the response in those voxels. OK? That also has the advantage that the data you plot and look at is independent of the way you found those voxels-- a very important problem in a lot of functional neuroimaging, where people have non-independent statistical problems with their data analysis. If you have a functional region of interest that's localized independently of the data you look at in it, you get out of that problem.

It's also a huge benefit, because one of the central problems with functional brain imaging, which I think has led to the fact that a large percent of the published neuroimaging findings are probably noise, is that there are just too many degrees of freedom. You have tens of thousands of voxels. You have loads of different places to look and ways to analyze your data.

One of the things I love dearly about the functional region of interest method is that you tie your hands in a really good way, right? So you specify in advance exactly where you're going to look, and you specify exactly how you're going to quantify the response. And so you have no degrees of freedom, and that gives you a huge statistical advantage. And it means you're less likely to be inadvertently publishing papers on noise.

OK. So that's the functional region of interest method. We've done loads of these experiments. Here's just from a current experiment in my lab being conducted by Zeynep Saygin. She's actually looking at connectivity of different brain regions using a different method I probably won't have time to talk about. It's very cool. But in the process, she's run a whole bunch of functional localizers. And so we can look in her data at the response of the fusiform face area to a whole bunch of different conditions.

So these are a bunch of auditory language conditions, so, OK, not too surprising. It doesn't respond very much to those. They're presented auditorily, but these are all visual stimuli here. The two yellow bars are faces. This is line drawings of faces. This is color video clips of faces-- strong responses to both. And all of these other conditions-- line drawings of objects, movies of objects, movies of scenes, scrambled objects, words, scrambled words, bodies-- all produce much lower responses. OK?

So I would say this is pretty strong selectivity. It's been tested against lots of alternatives, only a tiny percent of which are shown here. As I mentioned before, it's present in more or less the same place and pretty much every normal subject. I think it's just a basic piece of mental architecture.

Now, this is a very simple univariate measure. We're just measuring the very crude thing of the overall magnitude of MRI response in that region to these conditions. There are legitimate counter-arguments to the simple-minded view I'm putting forth, and we should consider them. I think the most important one comes from pattern analysis methods, which I will talk about if I get there. And importantly, these data don't tell us about the causal role of that region. We'll return to those.

However, the point is, before we blithely say it's not fashionable to talk about functional specificity, we need counterarguments to data like this. They're pretty strong. And that's just one example, to show you just a few others from Zeynep's paper. OK, so this is what I just showed you, but I'm in the same experiment. We can look at other brain regions.

OK. So this is a bottom surface of the brain there, so this is the occipital pole, front of the head, bottom of the temporal lobe. That face area is the region in yellow in this subject. This purple region is that visual word form area that I mentioned, and here is its response magnitude across a whole bunch of subjects, localizing and then independently testing. The purple bars are when subjects are looking at visually presented words. And again, all these other conditions-- faces, objects, bodies, scenes, listening to words, all of those things-- much lower response.

In the same experiment, we can also look at a set of regions that respond to speech. I mentioned those very briefly in my introduction a few days ago. These are regions a number of people have found. In this case, they're immediately below or lateral to primary auditory cortex in humans, interestingly situated right between primary auditory cortex and language sensitive regions. Right between is the set of regions that respond to the sounds of speech-- not to the content of language, but the sounds of speech.

And so this is when people are saying stuff like, "ba da ga ba da ga." So they're just lying in the scanner, saying, "ba da ga ba da ga." And here's when they're tapping their fingers in a systematic order. Here's when they're listening to sentences. Importantly, this is when they're listening to jabberwocky gobbledygook that's meaningless. So no meaning, but phonemes-- same response. That's what tells us that this region is involved in processing the sounds of speech, not the content of language, and load everything else.

So other things-- moving outside of perceptual regions, you might say, OK, fine. Perception is an inherently modular process. There's different kinds of perceptual problems, that make sense. But high level cognition-- we wouldn't really have functional specificity for that. But oh, yes, we do.

Here are some language regions. There's a bunch of them in the temporal and frontal lobe that have been known since Wernicke and Broca. But now, with functional MRI, we can identify them in individual subjects and go back and repeatedly query them and say, are they involved in all of these other mental processes?

So this is now the response in a language region-- so identified, here's the response when you're listening to sentences. This is when you're listening to jabberwocky nonsense strings. Here's when you're saying "ba da ga ba da ga." It's not just speech sounds. Here's when you're listening to synthetically decomposed speech sounds that are acoustically very similar to the jabberwocky speech. It's just not interested in those things. It seems to be interested in something more like the meaning of a sentence.

And just to show you some other data we have on this, this is data from Ev Fedorenko, who has tested this region. Now, this is sort of roughly Broca's area, the main mental functions that people have argued overlap in the brain with language. Namely-- sorry, this is probably hard to see here, but arithmetic, so we have difficult and easy mental arithmetic. Intact and scrambled music in pink. A bunch of working memory tasks-- spatial working memory and verbal working memory-- and a bunch of cognitive control tasks-- just kind of an attention demanding task where you have to switch between tasks and stuff like that.

And here is the response profile in that region. Reading sentences, reading non-word strings. All of those other tasks, both the difficult and the easy version-- no response at all. That's extreme functional specificity, right? It's not that we've tested everything, there's more to be done. But the first pass querying of do those language regions engage in all of these other things that people thought might overlap with language? The answer is no, they don't.

And I think that's really deep and interesting, because it means that this basic question that we all start asking ourselves when we're young is, what is the relationship between language and thought? I know Liz disagrees with me somewhat on this. That's because she's very articulate, and she doesn't feel the difference between an idea and its articulation. I'm less articulate. It's very obvious to me they're different things. No, it's not the only reason. She has data, too, and it'd be fun to discuss.

But I think there's a vast gulf between the two in that many different aspects of cognition can proceed just fine without language regions. And actually, the stronger evidence for that comes not from these functional MRI data, striking as I think they are, but from patient data. So Rosemary Varley in England has been testing patients with global aphasia.

This is this very tragic, horrible thing that happens in patients who have massive left hemisphere strokes that pretty much take out essentially all of their language abilities. Those people she has shown are intact in their navigation abilities, their arithmetic abilities, their ability to solve logic problems, their ability to think about what other people are thinking, their ability to appreciate music, and so on and so forth. So I think there's really a very big difference between a major part of the system that you need to understand the meaning of a sentence and all of those other aspects of thought.

This is just showing you what I mean by functional specificity-- what the basic first order evidence is. And these are just the regions that we happen to have in this study so I could make a new slide. But for lots of other perceptual and cognitive functions, people have found quite specific brain regions for perceiving bodies and scenes, of course, motion.

The area MT has been studied for a long time-- regions that are quite specifically involved in processing shape. We've been studying color processing regions recently. They're not as selective for color as some of these other regions, but they're very anatomically consistent. And things I mentioned before in my brief introduction-- regions that are specifically involved in processing pitch information and music information, and as you'll hear next week from Rebecca Saxe, theory of mind or thinking about other people's thoughts.

And so there's quite a litany of mental functions that have brain regions that are quite specifically engaged to that mental function. And each of these-- to varying degrees, but to some appreciable degree-- have corroborating evidence from patients who have that specific deficit. So that shows that each of these is likely to be not only activated during, but causally involved in its mental function.

And as I mentioned, there are actually good counter-arguments to some of the things I've been making that are worth discussing. I think the pattern analysis data is the strongest. Oh, and I do need to take a few more minutes. Just like five or something? OK. So all of that's to say, so here's roughly where we are now. There are counter-arguments, but loose talk about, oh, there's no localization of function in the brain. You got to engage with us at first and give me a serious counter-argument.

OK. Finally, I want to say that it's not that the whole brain is like this, right? There are big gray patches where we haven't figured out what it's doing, but there are also substantial patches that have already been shown to be, in some sense, the opposite of this. Regions that are engaged in almost any difficult task you do at all. And I think this is a very interesting part of the whole story of the architecture of intelligence, so I'm going to take five minutes and tell you about it.

This work is primarily the work of John Duncan in England. And he's been pointing out for about 15 years that there are regions in the parietal and frontal lobe shown here that are engaged in pretty much any difficult task you do. Any time you increase the difficulty of a task-- whether it's perceptual or high level cognitive-- those regions turn on differentially. And so that's why he calls them multiple demand. They respond to multiple different kinds of demand.

Duncan argues that these regions are related to fluid intelligence. So remember Spearman, who I started with, who talks about the general factor, g. Well, Duncan thinks that basically, this is the seat of g-- these regions here-- to oversimplify his argument. There's multiple sources of evidence for that. And one is, well, they're strongly activated when you do classic g-loading tasks. That's not that surprising. They're activated in all different kinds of tasks.

More interestingly, he did a large patient study, where they found 80 or so neuropsych patients in their patient database. And they identified the locus of the brain damage in each of those patients. And what they did was they measured post-injury IQ. They estimated from a variety of sources pre-injury IQ. And they asked, how much does your IQ go down after brain damage as a function of one, the volume of tissue you lost in the brain damage, and two, the locus of tissue?

And basically, what he finds is if you lose tissue in these regions, your IQ goes down. If you lose tissue elsewhere, you may become paralyzed or aphasic or prosopagnosia. Your IQ does not go down. In fact, he made a kind of ghoulish calculation that you lose 6 and 1/2 IQ points for every 10 cubic centimeters of this region of cortex, and almost nothing for the rest of the brain.

So this is kind of crude. It's very imperfect what you can get from patient study, but I think it's intriguing. And so his suggestion is that in addition to these highly specialized cortical regions that we use for these particular important tasks, we also have this kind of general purpose machinery that makes us generically smart. And I'm going to skip around.

We've tested this more seriously. He did group analyses, which I don't like. We did it in collaboration with him with individual subject analyses, the most precise measurements we could make, and boy, is he right. I mean, even to the voxel you can find that these regions are engaged in seven or eight very, very different kinds of cognitive demand-- all activate the same voxel differentially.

So the basic story I'm putting forth here-- without the second half of my talk, I'm sorry about that-- is that at a macro scale, the architecture of human intelligence is that we have these special purpose bits for a smallish number of important mental functions, not all of them innate-- maybe some of them. In addition, we have some general purpose machinery. There's loads more that we don't know from the precise computations that go on in these things, to their connectivity, to the actual precise representations that you can see with the neural code if you could measure it, which we can't in humans, to the timing of these complex interactions, which of them are uniquely human, which of them are also present in monkeys.

And I don't have time to go find the slide, but one of the things we've been doing recently is looking in the ventral visual pathway at the organization of face, place, and color selectivity. And what we see is that-- we is me and Bevil Conway and Rosa Lafer-Sousa. Bevil and Rosa had previously shown that on the lateral surface in the monkey, you have three bands of selectivity. So it goes face selectivity, color selectivity, place selectivity, and three bands on the side of the temporal lobe in monkeys.

We find this in humans. You have exactly the same organization in the same order, but it's rolled around on the ventral surface of the brain in the same order-- face, color, place-- on the bottom of the brain. So we think that whole broad region is homologous between monkeys and humans. It just rolled around on the bottom. Maybe it got pushed over [AUDIO OUT] something.

And that's not exactly a novel argument. Actually, Winrich wrote a paper suggesting this a while back, and I think we're starting to see those homologies. And the reason that's important is that it means that all these questions we desperately want to answer about the causal role, connectivity, population codes, [AUDIO OUT] interactions between regions, development-- all of that that we can't answer very well in humans, Winrich can answer in monkeys. And after a break, he will tell you about all of that.

[APPLAUSE]