GERALD SCHNEIDER: All right, this is what we were talking about last time and we're going to continue today, the recurring goals that people trying to relate brain and behavior have pursued.

We talked last time mainly about the first one, specific neural circuits which underlie behavior. Their prime example was the concept and discovery of the reflex arc, which led to the philosophy of life called reflexology.

I mentioned that even the discovery of reflexes was probably inspired by human machines, and theory in this field has been influenced by machines for a long time. For example, when homeostatic governors were developed, it seemed like machines were showing purposive behavior. And that actually was a big surprise to many people at that time. They didn't think a machine could possibly show purposive behavior.

But, of course, homeostatic governors and [INAUDIBLE] mechanisms and homing devices, which you're all very familiar with because you grew up with them-- it wasn't always so obvious to people that these machines could show purposive behavior. Homeostatic governors are still a model for homeostatic control of visceral states by physiologists.

Now, of course, the major machine that serves as an inspiration to models, the computer. And you'll see that as we come to some simple models for explaining behavior in this class. Flow diagrams, information flow diagrams, are similar to what engineers use.

OK, now, I mentioned Descartes and showed his picture. I didn't read anything from him. I won't read you the whole quote, but he talks about these as little filaments in tubes connected to tubes. And he ends with an analogy after he describes the circuit, which, as you know, wasn't completely accurate anatomically.

But his concept of the reflex was accurate. He said this happens just as, by pulling one of the ends of the cord, you cause a bell attached to the other end to ring at the same time. So that's the basic idea of a reflex. A simple stimulus leads inevitably to a certain response, and it's a fixed relationship.

It didn't say anything about the anatomy. And the beginnings of understanding the anatomy of a reflex was the discovery of the law of roots. Somebody asked me at the end of the class what exactly is the law of roots. Well, how can you remember that?

Every spinal nerve, as it approaches the cord, separates into two major divisions, one entering the cord dorsally and the other ventrally. The dorsal root is sensory. The ventral root is motor. Input dorsally, output ventrally--

How can you remember that? Think of a pain in the back. The pain is towards the back. This is dorsal. This is ventral. Pain in the back summarizes what the law of roots is. And these were the people that first discovered it.

Then I talked a little bit about reflexology and how it originated with people reading the writings of Sechenov, Ivan Sechenov, in Russia. Now, before that, let me describe La Mettrie. What did I say that La Mettrie's concept of the uniqueness of the human was?

AUDIENCE: [INAUDIBLE].

GERALD SCHNEIDER: Right. Differed from other animals simply in the complexity of the reflexes underlying his behavior. He is well known for a phrase that is in the following quote. Let me just read you one sentence from La Mettrie, translated of course. "Since all the faculties of the soul depend to such a degree on the proper organization of the brain and of the whole body, that apparently they are but this organization itself, the soul is clearly an enlightened machine."

And that phrase, the enlightened machine, has been repeated many times, even in modern neuroscience. He continued by saying "the soul is, therefore, but an empty word." I don't agree with that, but that is the view of some people. We'll say a little more about that in a minute.

How did Pavlov change that whole picture and make the influence of reflexology much more marked in America, especially the American educational system, which was based on the idea, plasticity, changeability of the reflexes. That is, the stimulus-response model was accepted.

Often, we think of the stimulus-response model as a generalization of the reflex idea, that all behavior can be explained by stimuli leading to responses. But the idea that they could be plastic-- that, in other words, learning could occur-- became very important in educational theory in America, where it was believed that, OK, animals have instincts. But people are plastic, and everything can be changed by learning.

It' not, actually, completely true. Most things are-- there's a large, instinctive component. And some of those aspects of the instincts are not very changeable. But, in fact, most behaviors, there's some influence of experience as well as of built-in connections.

I mentioned [? Makai, ?] and I posted one paper by him on the web, who argued that a strict determinism-- determinism he could accept. But then he said, in the strict sense, it's logically impossible because it doesn't allow you to say a person isn't responsible for his actions, since I'm asking you some questions about that here that I've added.

Does this mean that some things are not determined by lawful cause-effect relationships? No, that's not what he means. Well, then, why should a person be held responsible for something that necessarily had to occur, once the conditions were there, once the stage was set?

This is a question in forensic psychiatry. That's why psychiatrists are asked to come in the courtroom sometimes and testify that someone was too crazy to be responsible for his actions or he had some other problem. But I would argue that, if everything is determined, then the culpability and the punishments are also determined, and they also must necessarily occur by the same kind of deterministic laws.

So you can't have part of one, you see, without the other. So I like [? Makai's ?] argument. Even though some people don't, I think it helps us. It points out a logical conundrum that we are always faced with in this field.

Why did people move to a different kind of goal, giving up the idea of specific neural circuits underlying behavior? It's because they thought the first goal was a pipe dream. It was impossible. How could we ever trace the connections between the input and the output, stimulus and response?

In the human brain, where there's 10 billion nerve cells, at least-- there's actually many more than that. That was the number always given. Then they discovered there were more than that just in the cerebellum. And that says the number of connections is much, much greater.

One study was done some years ago with the electron microscope looking at the monkey motor cortex. In the monkey motor cortex, where it was found-- we'll mention motor cortex in a few minutes-- it was found that, on the average, one neuron had 60,000 inputs. That is 60,000 synapses on its surfaces. In the monkey visual cortex, it was 4,000. Those are probably the extremes in the neocortex, but it gives you an idea, enormous numbers of connections.

The task of specifying circuitry is pretty formidable even in the spinal cord. But, there, reflex ideas can explain many reactions, and that's been known since the detailed studies of Charles Scott Sherrington around the turn of the previous century, 1900, the man that coined the term synapse.

So what else can we do if it's so difficult to trace connections from S to R, connections that underlie behavior? Well, many people have simply pursued a very different kind of goal, localizing function in specific parts of the central nervous system, brain and spinal cord, without necessarily any specification of circuitry within a functional subdivision. Or even, sometimes, not even between them, although the modern synthesis often tries to at least specify connections between the major functional divisions of the brain.

This kind of goal started out with simple arguments about where the seat of the soul was. But then we'll see how localization took on a very different form, and detailed mosaic maps of the brain were developed.

But there was an opposing type of idea that we'll cover also. I don't know if we'll get to it today. It is sometimes called anti-localization because they didn't believe that you could localize function so easily in different parts of the brain. But they did have a kind of general localization, and I'll explain what that means.

The seat of the soul is exemplified by a quote from Shakespeare in*The Merchant of Venice,* who asked, tell me where is fancy bred, in the heart or in the head? But the idea was, well, is it in the brain, or is it in the heart that we have feeling or that we have imagination or whatever?

It wasn't always so clear to people. Although there were many, many people that correctly assumed it was in something in the head in many different cultures. But there were many arguments because we seem to feel feelings in particular not here, but here, or throughout our body.

This is a picture from Leonardo, Leonardo da Vinci, who has this picture, an outline of the brain, very large, but he's stressing the ventricles. The ventricles are the fluid-filled cavities in the center part of the brain and spinal cord.

And to many people, it seemed appropriate that-- they didn't know they were filled with fluid. They thought they might be filled with a kind of gas, and they thought that was very appropriate for the soul. You see, it didn't seem so physical. In fact, Descartes was influenced by that kind of idea.

The idea of localizing functions, and specifically in different parts of the brain, really got its first strong impetus from what we now would call a false science, the science called phrenology. Franz Joseph Gall was a neuroanatomist. Well, let's say an anatomist. He wasn't really a neuroanatomist. But he's known for being the first one to separate gray and white matter in his dissections of the brain.

And a follower of his in America, Spurzheim, helped to popularize the ideas that the shape of the skull somehow represents character because it corresponds to different parts of the underlying brain. And here's one of their maps.

This became very popular and not just in the 19th century, but it continued into the 20th century. And you'll find books of phrenology on some of your parents' or grandparents' shelves. And they also sold these little models that look something like this, with the skull divided up.

What they claim was that, simply by feeling the prominences and the bumps on your skull, you could say something about character. Well, what on earth was that based on? This is another one of the pictures where they're depicting the various functions in this graphical format.

Well, they made certain assumptions, and we don't argue with all of those assumptions now. They said the brain is the sole organ of the mind. It's not in the heart. It's not elsewhere. It's all in the brain. And we don't argue with that now, for the most part.

They also argued that basic character traits were innate. They're something we're born with. Well, there's a large degree of truth to that, too. We may be shaped by experience, but in fact, basic character traits are built in. They're genetic, as the brain structure, the basic structure of the brain, is inherited.

The third assumption was that differences in characters and ability imply differences in structure. And just going that far, I think, many people in neuroscience would still agree with that.

But then they said that that was manifested mainly as differences in size. Well, there are a number of examples where functional differences are correlated with differences in size. And I talk about a few of those later in the class and in the second term also. But there are many exceptions to that also.

The final assumption, and this is the one that was the most wrong, the shape of the brain is correlated with the shape of the skull. But, wait a minute. I mean, our brain is shaped pretty much like our skull. But what about details? Well, we're a very thick-skulled species, and we can't tell too much about details of shape by looking at the outside of the skull.

But if we look at the inside of the skull, and people in anthropology use that, this method of making what they call an endocranial cast, a cast made from the inside of a skull, you can actually see quite a bit about major features of the external surface of the brain. We can tell where certain major vessels were located, major fissures in people who have not existed for many thousands of years.

Well, so their assumptions were true, or partially true, but their methods were not what we would call scientific. They practiced what, I suppose, you could call newspaper science. They collected anecdotes and then used it to argue immediately for the generality of the phenomenon.

For example, you would read in their book about a student who is discovered to be torturing animals, and he was found to have prominence above his years. So they concluded that that area, if it's prominent, corresponds to that character trait. That's an anecdote, and, of course, there's nothing general about it. They didn't do the statistics you would need.

I'm not saying that there might not be some correlates that could be found like that, and there are people that still pursue that kind of thing. But their methods were simply anecdotal and can't be depended on.

So why do we talk about it then? It was very important in the history of the field because it drew attention to brain-behavior relationships. And it made successors who talked about more believable data correlating structure and function, it made them conservative. It made it easier to believe. So it was a popular thing that called attention to brain-behavior relationships and then made it easier for what followed.

Let's talk about some of the later discoveries, beginning with the speech areas. Paul Broca, in 1861, published cases. And I'm not showing his cases. But what Broca said was he had certain-- he was a neurologist. He said, I had certain patients that could not speak after suffering brain damage. They had strokes, and they were rendered speechless. They couldn't get any words out. And yet they seemed to be able to understand speech, but they couldn't speak.

He found that there was some consistency in more than one patient that he looked at. They had damage in the left hemisphere, in the frontal lobe, in the ventral part. And you can see here, in these more recently done-- these are about, oh, I don't know, 20 years old now, when functional imaging first began to become popular.

And Marcus Raichle at St. Louis University was one of the people that pioneered in this area. He noted that when a person spoke, and here he had them generating verbs, this area showed more tissue oxygenation or blood flow. And there are different methods for imaging based on one of those two things.

The imaging people will say it's activated, this area in the frontal lobe on the left side, the lower part of the left side. Well, that was the area where Broca found the damage to be centered. There was variability in patient to patient, but that was the area that was consistently damaged in the people with aphasia. That's the word for the lack of speech after brain damage, aphasia or dysphagia.

You can see that other aspects of language were differently localized. Hearing verbs activated an area there that we know to be auditory in function, here. I think this one stopped working there. This here. OK, so that's not going to work.

Just seeing the words, not hearing them, in the upper right there, activated an area we now know to be concerned with vision. And reading, of course, involves not only seeing the words, but also uttering them, speaking them. And that activated sensory motor cortex.

Now, you say, well, if he's seeing the words, why isn't it activating the visual system also, as in the upper right there? And that points out something that's very important about these imaging, that they're always using thresholding techniques. So the engineers and the mathematicians are in between the data and the people that are getting the data and interpreting it, and they have to choose a cutoff.

So all it means is the area with the greatest tissue oxygenation, or the greatest blood flow, or sometimes it's even temperature change they're looking at, that's what they're showing. So you're not seeing all of the data in these imaging pictures. And that method often is not discussed adequately, and there's not enough variety, in my view, of the methods being used.

Let's talk about another discovery that came not that long afterwards, the discovery of the motor cortex. Fritsch and Hitzig were two German physiologists who did studies of dogs, initially, using what, at that time, was fairly newly developing methods for studying the brain, electrical stimulation. And they systematically studied the exposed surface of dog brains.

Trying to put out of our minds for a moment that they didn't have anesthetics at that time, they found that they could get movements from many different parts of the brain. But there was one region where they could get the movement at the lowest thresholds, the least amount of current, and they call that the motor cortex. And they found that when they stimulated different parts of this strip of tissue, different parts of the body moved, and that it was very systematic.

And the area they were talking about is called, in this picture of the human brain, primary motor cortex, the strip of cortex right in front of the central fissure. Other parts of it are called premotor, where you also get movements, but they're involving larger parts of the body, more organized movements.

The topography of that system is expressed in this kind of-- there's many different versions of that. This is one for the motor cortex. The term homunculus means little man, so this is the little man in the head.

So there you see the map of movements laid out in a, more or less, frontal section of the human brain that cuts through that precentral gyrus in front of the central fissure in the brain. And they're simply depicting, both with words and then with pictures, different parts of the body will move when you stimulate different parts.

And you find a much greater representation, much more tissue representing, say, the hands, the lips, the tongue, than other parts of the body. And notice in the motor cortex, some things don't appear to be represented at all.

This is another picture of the area, the gyrus, just behind the motor cortex, which responds to sensory input. Now, that was discovered later. If you stimulate the surface of different parts of the body, you will activate certain areas much more than others in the brain. And you'll see that it pretty much matches the motor cortex right in front of it.

Again, a much larger area representing lips and face and fingers and hands than other parts, and you always find the face, tongue, and throat located more ventrally. As you go up on top, you find first the hands and then lower parts of the body and the feet.

There's another way they represent it. You get all varieties of these pictures. This is another common way to show the homunculus to emphasize the distortions.

Now, remember, if you actually look at the tissue, you're not seeing anything like that. This is just a way to represent it. A way to represent something when we're talking about sensory cortex, we call the relative magnification of the sensory surfaces. But there's a corresponding concept for the motor areas.

AUDIENCE: [INAUDIBLE].

GERALD SCHNEIDER: There's a greater area of cortex representing a square centimeter of the skin on your finger than there is the skin on your back.

AUDIENCE: [INAUDIBLE]?

GERALD SCHNEIDER: Not if it's a sensory area-- it means, for the motor cortex, that you will get a response, say, of the finger over a bigger area of cortex than you will get, say, the twitch of a muscle in your back.

Well, shortly after the motor cortex had been mapped by Fritsch and Hitzig, a German anatomist named Betz was doing separate independent studies, and he noticed a very large neuron was consistently located in one part of the cortex. And it turns out that that cortex, where this very large pyramidal cell was located in the fifth layer of the cortex, was in the motor cortex. And that's remained true ever since that time.

It was a finding. It was very real. And we always find these largest pyramidal cells, the largest cells in the neocortex, located in the precentral gyrus, the motor cortex. We find them there in rats. We find them there in dogs. We find them there in humans. There was a question over here.

AUDIENCE: [INAUDIBLE]?

GERALD SCHNEIDER: Very good question, does the size correspond to sensitivity? Well, in fact, there's a very good correlation between sensory acuity and the area of cortex concerned with that part of the body.

Now, how do you measure sensory acuity? Well, one method would be what's called two-point discrimination. If you take two little needles, and you put them very close together and touch the back of my hand, I won't be able to tell that there's two. But if you make them further and further apart, you'll reach a point where I'll say there's two of them. That's two-point discrimination. It's a measure of acuity.

Well, you will be able to tell there's two when those two needles are much closer to each other on the tip of your finger than the back of your hand. And either of those, you'll have much higher acuity than, say, on the thigh or on the back. And we use that method as a measure of acuity, and the correspondence to the homunculus is very good. Yes.

AUDIENCE: [INAUDIBLE]?

GERALD SCHNEIDER: Does the tissue look different? No, it basically looks the same throughout. But it's a very interesting question because the relative growth of brain does affect the shape of the gyri, the way it folds.

And in animals that have developed larger representation of certain parts of their body, sometimes they develop separate gyri for each part, like the raccoon's hand. There's separate gyri for each finger. He also has a large magnification of the representation of his fingers. Yes.

AUDIENCE: [INAUDIBLE].

GERALD SCHNEIDER: Then why--

AUDIENCE: [INAUDIBLE]?

GERALD SCHNEIDER: That's a very good question. Why are the genitals so small in the picture? Well, in fact, our two-point discrimination, the same kind of sensory ability we measure in fingers or hands, are not that good in genitals. But they're very sensitive because there's another representation for these areas in an area more concerned with the motion and motivation, limbic system. That's separate from the sensory areas. Thank you for giving me an opportunity to introduce the limbic system so early in the class. Yes.

AUDIENCE: [INAUDIBLE]?

GERALD SCHNEIDER: Say that again?

AUDIENCE: [INAUDIBLE]?

GERALD SCHNEIDER: There are some differences between males and females, but not in these kinds of things, except the size of the brain tends to correspond to body weight. There's a very good correlation. So male brains tend to be a little bigger, but only because of the correlation with body weight and size. There are some other sex differences in the brain that I talk about more in the second term, but you will read a little bit about that later in the class. These are all very good questions.

OK, one more of the early localizationists, Carl Wernicke, who is the most modern of these people in the way he thought about brain function. Wernicke, whose theory was taken up again in the last century by Norman Geschwind, so we now call this the Wernicke-Geschwind connections model of speech.

Geschwind was really the founder of the Boston behavioral neurologist school, and his students still are very prominent in behavioral neurology. He used to teach with me here at MIT, I'm proud to say, but he died a number of years ago.

OK, so here is Broca's area, that we know is concerned with speech output. Here's the auditory area, shown in purple there. Here's visual cortex here. Wernicke discovered that there was an area in the posterior dorsal temporal region of the brain, of the left hemisphere in most people, that when damaged, caused a different kind of disturbance of language. They could still talk, but they didn't understand speech, nor could they read. We call that area Wernicke's area. And Wernicke showed a kind of connectionist model of speech that is still held to by many people, although there are arguments about it.

So when you hear a word, and you hear the word and then speak it, the input comes into the auditory area of cortex. Now, it comes into subcortical areas first, but it does reach the cortex first in this region, the upper part of the temporal lobe. The information, he said, passes from there to Wernicke's area. Not necessarily with a single synapse, it might take a couple. And the information then, to actually speak the word, has to go from there through long axons that go to Broca's area and then to the motor cortex.

And then he said for reading, if you have a written word, you see it and speak the word, the information comes into the visual cortex and has to go from there to an association area which connects to Wernicke's area. And then again, the rest of it's the same, goes to Broca's area and then to the motor cortex.

Now, that model has been supported by a number of lesion studies, including studies where people have suffered a disconnection with one of those pathways. So, for example, if people lose the connections between the posterior temporal region in the frontal cortex, some brain damage that severs what we call the arcuate fasciculus-- they can understand speech, and they can speak.

But when they speak, they speak sort of a word salad. It doesn't make sense because they don't have the normal connection between the area of comprehension and the area needed for producing the utterances.

These people use different words for talking about these than we do, especially Broca. He talked about this area being a depot of representations for speech articulation. But what happened afterwards was very interesting. Now neurologists, every time they had a patient with a specific brain damage that could be localized, they tried to specify the function that was disturbed. And these functional maps of the brain got more and more elaborate.

This is a little yellow because I took it out of a book of Alexander Luria, a Russian neuropsychologist. It was the only place I could find this map. And it shows many, many different details. And the functions sometimes do correspond to physiological functions, and sometimes they're more psychological functions, and that sometimes raises some difficulties.

But what the maps did is simply summarize neurological findings. If you look at this map, and you'll know that, OK, somebody that suffered a damage in that area had that disturbance of that function.

One problem is that lesions are often not very precisely localized. They could easily make mistakes. And sometimes the lesions would disturb connections between areas and not just the cells in that region. And by the time the first textbook in physiological psychology came out-- that's the word that was used for the field that now we just call neuroscience or behavioral neuroscience.

There was a book by Morgan and Stellar. It came out in 1950. Their maps were much, much simpler than the Kleist map. So just between 1935 and 1950, there was this regress. People became more critical and weren't so willing to accept these localizations because, by that time, many contradictions had appeared in the literature. So Morgan and Stellar felt that if you didn't do precise experiments with many cases, especially if it were backed up by animal studies, you couldn't really believe it.

OK, now, next time we're going to deal with this issue, how can you carve up the soul like this? Aren't we unified beings? Are we really just this collection of functions represented in different parts of the brain? Read this, bring your notes to class next time, and we'll continue with the discussion then.