GERALD SCHNEIDER: We have to finish our discussion of evolution. And then we'll start talking about anatomy. Question?

AUDIENCE: What is the function of the notochord?

GERALD SCHNEIDER: The function of the notochord.

AUDIENCE: [INAUDIBLE]

GERALD SCHNEIDER: That's a good question. Why did it evolve in the first place? It gives the body some rigidity. But I'd just be making it up. What is an animal-- what would it be like if it didn't have the notochord? It would be a worm. And it looks like a worm when it first evolves, but it's a chordate. It's got a notochord.

We can say a lot more than that about it. Its roles-- it plays clear roles in the evolution of the brain. There are inductive influences from the notochord that affect the overlying nervous system. And we'll talk about that when we talk about development. OK.

Let's just go back a little bit. We were talking about evolution of the brain. Remember where we looked at the simplest possible neural tube in a chordate [INAUDIBLE]. Then we talked about the evolution of forward locomotion. That led to the need for head receptors. As head receptors involved, they led to an enlargement of the anterior ends. We call that the brain. There were expansions of structures in the brain that received inputs from the head receptors. Give me an example of inputs that come in through a cranial nerve rather than a spinal nerve. Condition, yes, would be one. What's the one that comes in most interior, way up at the rostral end?

AUDIENCE: [INAUDIBLE]

GERALD SCHNEIDER: Olfactory, you see it here. And that's where we'll start today. The forebrain expanded initially-- we're talking about forebrain, not the whole brain, because of the influence of olfaction, and the importance of olfaction, or approach-and-avoidance functions, feeding, mating behavior, predator avoidance, and so forth. The links to the locomotor system were not made by direct connections. Initially, they were made through links through the midbrain. We're guessing that from studies of primitive animals, primitive vertebrates. So that's what we're showing here. I added those words at the top.

As the expansions continued, then, with the development of structures in between sensory and motor structures for various functions, maintaining stabilities, stability and space, approach-and-avoidance functions, that led to the evolution of these specialized structures, particularly in the midbrain. Showing, here, a fish with an expanded midbrain, as well as cerebellum, important for-- the midbrain was connected to the cerebellum for coordinating movements. And the midbrain expanded with the evolution of distance receptors other than olfaction. The olfaction could be called a distance receptor, but the real distance receptors are vision and audition, which has many advantages for speed and sensory acuity, early warning, and for anticipating things that are about to happen.

So when that evolved, on the motor side, you have to be able to turn the receptors, which means orienting movements. And the midbrain became particularly important for that. And I'm showing here, in the picture, fibers coming from the eye, coming into the midbrain.

It's interesting. The eye did not evolve, initially, from the midbrain. It originated as an out-poaching of the tween brain and probably played even more-- had more primitive functions, initially, coordinating activity with the day/night cycle, just detecting light. But once the connection to the midbrain was formed, then it took on the role that required an expansion, the sensory analyzers of the midbrain tectum. And the midbrain then became the major-- you could call it a sentinel detecting predators. It also played an important role in orienting and feeding. OK.

Then, finally, my fifth stage here, expansion of the forebrain again, but now, not because of olfaction anymore, but because non-olfactory systems invaded the brain. And they did so not just-- they initially invaded the corpus striatum, a very important structure in plasticity, of habit formation, and so forth, important in both feeding and approach-and-avoidance functions and feeding and predator avoidance. But in learning--

But then something very interesting happened. The corpus striatum was not a cortical structure, was not a layered structure at the surface of the brain like the cortex of the olfactory system was. But when that cortex began to be invaded by these other sensory systems-- vision, and audition, and somatic sensation-- it led to a great expansion of the forebrain at the endbrain part of the forebrain, the very rostral end of the brain.

I'm showing here a projection from the tectum carrying visual and auditory information into the forebrain through the tween brain, a short connection there in the tween brain, then a connection into the endbrain. Now, that kind of connection initially went into the corpus striatum. OK? And I mention here that the-- what was happening on the motor side, but that didn't happen so much until the endbrain expanded.

I mentioned this before, elaboration of other things that were going on, elaboration of complex programs for goal-directed activities, the so-called fixed-action patterns. If I put a red star here, it probably means I've changed the slide a little bit, since you have your printout. I probably added here. This phrase, the great mammalian elaboration, is just the stress that the additions to the brain that happen for reward-driven learning and habit formation in the corpus striatum, which was closely linked to neocortex, was something that happened in mammals, especially because of the evolution of neocortex. OK.

AUDIENCE: [INAUDIBLE]

GERALD SCHNEIDER: Oh, yes, there's certainly reward functions in non-mammalian animals also, but it was the expansion of the neocortex, which elaborated the possibilities of input to those structures, that led to the biggest expansion.

AUDIENCE: [INAUDIBLE]

GERALD SCHNEIDER: That's a good question. He asked me if non-mammals go for things like cocaine, which is a-- these kinds of addictions, you could say their acquired pathologies of the reward system, the motivational system. It's a good question. I'm not sure, but I would guess they probably do. OK.

So what systems evolved to modulate other brain systems for motivational control, visceral and social needs? These are the structures that you should think of there. I put them in blue here. These are the functions we're talking about, control of motivation, elaboration of hierarchies of goals, and communication of needs to other members of the species. And the main structures that evolved here were the hypothalamus, which were connected to the lower structures that did that, and then the structures in the endbrain that were most closely connected to the hypothalamus. And we call those structures the limbic system of the forebrain.

And then, along with that, the further elaboration of the endbrain. And this happened, really, only with neocortex systems for anticipating and predicting things on the sensory side, images that could simulate objects and events, on the motor side, planning the actions. These were non-reflex functions that I talked about at the end of the introductory lectures.

And here, it was the neocortex that played the primary of the role. In fact, these higher functions, cognitive functions, the structures that expanded the most in the neocortex were the so-called association areas. Those were the areas that, in us, occupy the largest part of our neocortex.

Along with that, all parts of the neocortex are connected to the corpus striatum. OK? And the parts that get those connections from neocortex have expanded, also. So it's not just one thing that expands. Many things expand in parallel. And before that, the endbrain of the animals leading to mammals was dominated by olfaction, the paleo cortex, and more ancient parts of the corpus striatum. I mean, you can see that by looking at the brains of these various species.

And I'm showing here this expansion of the end brain. I put here a picture, based on brains of fish, showing the smaller enbrain, little tween brain, and then a larger brainstem, midbrain and hindbrain larger than enbrain. But then, in mammals, you have the evolution of neocortex. That's the structure that's pretty much unique with mammals. Although, higher birds also have structures like neocortex, but it doesn't have the same structure as the neocortex of mammals. But they do have-- they have structures we don't have that are similarly connected.

The relative size of structures I'm showing here would be, well, in proportion about the brain of a rodent. OK? This is just an earlier expansion of the cortex. And then I'm showing here, along with it, expanded the cerebellum, OK, the more lateral parts of the cerebellum. OK. And also, I'm not showing here, at all, the neostriatum. OK.

Now, before we go to a more systematic coverage of neuroanatomy, just talk a little bit about what's happening to the brain evolution. If we just look at the weight, first of all, we don't have the heaviest brains. The heaviest brains are in animals that are larger than us, especially much larger, like whales, elephants.

If you look at here, brain weight is on the ordinate here. See, we here have, at the top, the blue whale, also the elephant, the porpoise. And here's modern humans. OK? But if we were-- it's plotted here on a-- against body weight. OK? And if you look at that graph, you'll see that humans are the furthest from this line here. In proportion to body weight, the brain is larger in humans OK.

There are actually a few exceptions. Porpoises are probably very close to us, partly because they don't have limbs. So their spinal cords don't have the enlargements with the extra neurons supporting the limbs. OK, so that distorts that picture a little bit. And there are some little rodent-like animals that have a pretty brain-to-body-weight ratio, but we don't talk much about them. Here, if you look at the various animal groups on that kind of graph, you'll see that the mammals are different. Although, there's overlap with birds, and other animals, and the more primitive vertebrates, the furthest to the lower right, here.

Now, we know some of the factors that affect brain size, not just intelligence, by a long shot. OK? And I'll say a little bit more about that in a minute here. First of all. these terms, the notochord, you see it spelled in both these ways, with the H or without the H. And I'll accept either one, but the first one is actually the-- supposedly, the proper one. But don't spell spinal cord with the H. OK? Only the-- it is a cord, OK, C-O-R-D.

Let's say a little bit about the relationship of development or ontogeny, the development of the individual. Comparing that to difference in species, phylogeny, we want to know whether development can tell us anything about evolution. There's a popular phrase, that ontogeny recapitulates phylogeny. What does that mean? OK? What it means is that the earlier the stage of embryonic development, the greater the resemblance of different species. OK? So if you take, say, the brain of a pig or the brain of a monkey, compared to the brain of humans, at very early stages of development, they all look the same. OK? But as you get later, you get more and more divergence. OK?

Let's look at the pictures from Romanis, 1901. OK? Here is showing, at a very early stage, a fish, salamander, a tortoise, a chick, a hog, a calf, a rabbit, and a human . We see very similar appearances in all these different vertebrates, in early stages.

But now, in the middle stages, a little later, you see that, already, the fish and the salamander are looking very different. OK? But the reptile here, the bird, and all the mammals still look pretty similar. There are some small differences beginning to appear.

And then when we get much later in development and we're still here, pretty early in gestation, for humans, we see more differences. And now, if we had a monkey in there or an ape, we would say that at this stage, the human still looks pretty much the same, next to these primates. OK? It seems that they diverge later in development if they diverged later in evolution. That's the correlation that seems to hold. OK.

This, just to remind you that my outline of high-priority behavioral demands, it's based mainly on studies of evolution and behavior-- comparative studies of behavior. And I've correlated that with changes in anatomy. I emphasize that it's speculative here, but it is based on a lot of information. And I support it with the illustrations from comparative anatomy.

These are the various stages. We've already reviewed that today, so I won't go over this now. I just want to remind you that we have these data that I showed you before, that show the importance of relative size for specialized functions. Remember the expansions of the hindbrain here with specialized taste functions and these fish.

But I just want to mention some other specializations, so you won't assume that it's only these fish that give us this. Some fish have electroreception. We don't have that, but they-- many fish have this. They can detect disturbances in the electric field that they generate around their body with the electric organs.

In the Mormyridae fish, this has led to an enormous expansion of the cerebellum. So if you'll open the skull, you see a cerebellum. It covers everything. It's like when you open a human skull, all you see is the neocortex, OK? We still don't fully understand exactly what the cerebellum is doing in those animals, or even in us, although we have some ideas about it.

Let's look at another specialization. What is a pit viper? It's a snake that has a specialized pit organ, OK, on its head, OK, beneath it. It has infrared detectors, those pit organs. So in total darkness, a snake can detect your presence or the presence of anything warm, OK, because it can detect infrared radiation, OK?

And we can do that, too, but only if we invent a machine to do it, OK? Bats and porpoises have echolocation, so that's another specialized sense that's led to an expansion in their auditory system and midbrain, controlling orientation movements. They also have expanded-- there are some studies of bat neocortex wingspan and auditory regions in the neocortex as well.

Primates-- what's most characteristic of primates? Vision, high visual acuity, learned object recognition. That's led to expansion of visual cortical areas. If you look at the brain of a rhesus monkey, I mean, it looks like more than half of the brain is occupied by areas related to vision. In rodents, the comparable thing would be representation of the whiskers. Their face-- their [INAUDIBLE] OK? They have specialized somatosensory systems, and they're frequently studied in neuroscience because of this.

So there are other examples. I'll mention a few other behavioral specializations. These are all correlated with elaborations in the brain. The hand-- we mentioned vision in the primates, but also they have specialized hands, OK? But so do raccoons, OK? And humans, of course, especially, which requires a lot of tactile acuity and fine motor control, both. And these lead to expansions-- or correlated with expansions in the somatic sensory motor cortex and in the cerebellar hemispheres connected with those areas of the hemispheres.

Other animals have this-- this monkey also has a specialized tail, a prehensile tail. And he's got something we don't have at all, expanded tail representations in sensory and motor cortex, OK? And both the motor control of that tail and the sensory detection with the tail, the specialized glaborous skin, like the skin of our fingers and palm, that he has on his tail. Yes?

AUDIENCE: [INAUDIBLE]

GERALD SCHNEIDER: Spider monkeys? You've never seen a movie of spider monkey and the way they use their tail? They use their tail like we use our hands. When they go through the trees, they're using their hands, too. They're using the tail and the hands, OK? And they can-- when they touch things with the tail, they can-- it's like touching with our hands. They have good acuity.

And I just want to point out here that in humans, language is a specialization, and that's led to expansions also-- or it's correlated with expansions of the polymodal association cortex, the parietal, temporal, and frontal lobes. It's also led to hemispheric specialization. There may be other reasons, though, that lead to hemispheric specialization, OK?

And finally, I don't know if you'll hear about this in other classes, but the elaborate social organization and planning and problem solving that you have in social animals, social mammals, OK? That has representation in the brain, too, especially prefrontal, neocortical areas in the primates, OK? It's huge in us, OK? And a lot of it has to do with planning and problem solving, anticipating what we're going to do, OK?

Because females are so good at that, I would probably say the female brain expanded first and the male had to catch up, OK? OK, sorry. But there are more women in this class. I've got to say a few things they've had. It's probably true. OK, there is actually a theory of brain evolution that takes that view.

OK, let's now start talking about-- going back to brain connections, OK? Let's talk about basic subdivisions of the brain, basic types of neurons. We introduced that before, OK? Basic channels of conduction of sensory information through and into the brain. And then I'll give you an overview of the cephalic structures. And finally, we'll talk about the specialized connections that evolved with the elaboration of neocortex in the mammals.

I'm going to use the Shmoo brain for this. So I'll have to tell you what a Shmoo is, and then we'll identify the basic structures. And we learned some definitions. Here's a Shmoo here in the corner. I got this. He's a very cute little animal. He evolved in the brain of Al Capp, who was a cartoonist in Chicago. And this describes-- people used to read this every time he published the little cartoon series in the Chicago newspapers.

Yeah, it's just to remind you a little bit about Shmoo because he loves all course 9 students. Instinctively and without fail, no matter what-- well, you can read these. You're also serious. Gosh, Shmoo is-- oh, the Shmoo is sort of serious, too, but he also makes you laugh. OK.

So what is it? It's a pedagogical device, of course. It was invented by Nauta, the great neuroanatomist, who finished his career here at MIT. He invented it to illustrate some basic principles of the anatomical organization of the brain of animals suggested to be ancestral to mammals. The first Shmoo could represent a generalized amphibian brain. He usually described it that way. It was based on the work of C Judson Herrick, OK, an American comparative anatomist, and then more recent anatomical studies as well, studies of connections that Herrick did not know so well because he didn't use experimental studies to study connections the way Nauta and his students did.

Now, why do we study primitive-- why do I introduce the brain by talking about primitive brains? Why don't I just save time and go right to the human brain like they do in medical school? OK. Well, you'll appreciate more and more why I do that as we go on. But it's also relevant because it not only helps you learn, but it's-- we still have all those parts because when the brain evolved, we don't just throw things out and replace it with something new. We just add to what we had before, OK?

Very little is discarded. I mean, there are some things that get-- aren't as-- that might get smaller, but basically, we keep everything. So you still have that ancestral brain, the core of your human brain, OK? That little note you see crawling in the slime of the swamp or you might find in your basement has connections in his brain that you also have in yours. And when we get very angry, we probably use those a lot more.

OK, let's first give you the outline here. This is my outline of Shmoo one. And here are the subdivisions. I want you to know all of these. They're very basic. You know some of them already. This shows the spinal cord here at the caudal end. Here you see at the rostral end the olfactory bulb. Here's the midbrain-- sorry, the hindbrain and the midbrain. In the hindbrain, I've shown the cerebellum.

In the midbrain, the little bumps there represent pretectum of the midbrain. The more anterior one is often called the optic tectum. That's where those visual connections go. And this is all forebrain, and I've got it divided into different parts here. These lower part's-- the more caudal part's the 'tween brain, and I've got the two major divisions here, thalamus and hypothalamus. There are a couple of other divisions, too, OK?

But we know most about the two largest parts, the thalamus and the hypothalamus. And then the endbrain, corpus striatum, subcortical structure, other subcortical parts of the-- connected with that we call limbic because they're connected to the hypothalamus there. It's sort of at the fringes of the hemispheres. And then cortical structures related to olfaction and what we call limbic cortex-- some of that cortex that is not just olfactory, but it's connected to hypothalamus.

There's no neocortex in Shmoo one, OK? Now, in the most primitive amphibians that this is based on, there is very little anything that looks like neocortex. There's a little bit of cortex they call general cortex that's probably the predecessor of it. And here, I've shown some of the basic connections. It looks like a mishmash to you at the moment, but it won't as we proceed.

Now, here, I am showing you what the actual neural tube looks like, although I've exaggerated the thickness of the spinal cord and brain stem a bit here. Remember, it's a tube. It's a tube that then expands more in some regions than others. And on the right here, I've shown the cross sections of these various levels. There's a cross section through the embryonic spinal cord and the embryonic hindbrain, the embryonic midbrain, OK?

And then you see the 'tween brain and endbrain here. The 'tween brain has this heart shape in its cross section, and then the endbrain with the corpus statrum below the ventricle and the cortex above, OK? And I'm showing here, again, the basic subdivisions, which I would like to learn there, and I've given you that both the English, OK, and the Greek names.

So we'll keep repeating these. I'll mention this. I don't expect you to, like, learn it instantly, and I will repeat this a number of times to try to get you to relax a little bit. Neuroanatomy takes little time to acquire. You have to get it repeatedly. And so I will go over things repeatedly in the class. You'll also do some readings. Don't get too frustrated with yourself when you have trouble remembering it because you can connect it with-- if it takes on more meaning to you when you know a little bit more about connections and the function, and it'll grow on you.

OK, then we'll look at where these things are in the brain. Let's talk a little bit about the primary sensory neurons in different animals. This is a picture from Ramón y Cajal showing primary sensory neurons that carry input from the body surface, OK, in various species here. Here, he has a sensory cell in the earthworm that goes to a sensory ganglion in the earthworm. And notice that the primary sensory neuron is in the surface epithelium of the body surface, OK? This is the epithelium.

The derivative of the ectoderm, the surface layer the embryo. The entire nervous system, in fact, is a derivative of the ectoderm. Here, he shows a sensory cell in the mollusk, which is similar, but the cell body now has moved deep to the surface. But it's still connected with the surface, OK? So now it's become a bipolar neuron with the input side at the surface and then the output side here in the sense-- in the ganglion, or central nervous system, OK?

And then he gets to vertebrates here. And he's showing a sensory cell in a lower fish here, which is still a bipolar neuron receiving inputs from the surface, carrying it into the central nervous system-- the neural tube now, because now we're invertebrates. We're all chordates, OK?

And then finally, in amphibians, reptiles, birds, and mammals, the sensory cells innervating the body surface have this-- we call it a pseudounipolar shape, OK, with a cell body off to the side. Dendritic part of the cell is out here, and then the axon goes into the central nervous system this way. So these-- the outlines here show what we would call a peripheral ganglion-- collections of those kinds of cells.

OK, so now let's go back to the Shmoo brain. Now, where are the primary sensory neurons? I've shown just three of them here. Here is an example, only one, showing a cell that would be in the dorsal root ganglion-- in one of the dorsal root ganglia, OK, there, next to the spinal cord. So it's through the unipolar in shape. It has its dendritic endings out here in the skin. The axon starts there, goes into the central nervous system, where it connects with the secondary sensory neurons, OK?

Here's another one. This would be in the auditory vestibular system. Note that it has a bipolar shape. There are many fewer of these, OK, but in the auditory system, we have bipolar neurons. The sensory, enter dendritic end and out in the cochlea, or in the vestibular canals, OK?

And then the action potential has to go by the cell body. It sort of jumps over it. And the axon then continues into the central nervous system, where you have the cochlear nuclei and the vestibular nuclei, the secondary sensory cells of those systems.

And finally here, I show another primary sensory nueron, an olfactory neuron. An example of one olfactory neuron to note is, just like all the sensory cells in the worm, OK? The cell body is at the surface and the epithelial layer, OK? That's in the olfactory mucosa lining our nasal passages. Then it has a little dendritic part here in our mucus over these cells.

Responds to molecules dissolved in that substance. Those molecules that trigger action potentials will-- the actior potential goes through the primary olfactory neuron's axon into the brain-- part of the brain here we call the olfactory bulb, where it contacts secondary sensory cells of the olfactory system.

OK, so three examples of primary sensory neurons-- the secondary sensory neurons are the ones that get input tc it. Everything else is an interneuron. And of course, we want to understand how are those interneurons connected? What kind of systems do they form?

The only exception that we don't call interneuron here is the motor neuron, and I'm showing it here in the little black triangles that you see in the ventral part of the brain and the spinal cord but also in the hindbrain and in the midbrain, OK, where there are collections of these motor neurons. Motor neurons are defined as the neurons with an axon that goes out of the central nervous system, OK?

And we have two kinds of motor neurons there, and I've shown that two kinds here. One type, the axon goes to muscle cells. The striated muscle cells I've shown-- depicted the striations there to indicate it's a particular kind o muscle cell. It's not a smooth muscle.

The other kind of motor neuron connects with a ganglion. So we call it a preganglionic motor neuron of the autonomic nervous system. Now, the autonomic nervous system innervates smooth muscles and glands, OK? So there, the connection is different. It goes through a relay in a peripheral ganglion of the autonomic nervous system, and then those cells in those ganglia connect to smooth muscle and gland tissue, OK? So two kinds of motor neurons.

OK, so we've defined now a subdivision is the primary sensory neuron. The secondary sensory neurons, interneurons are the great intermediate net, two kinds of motor neurons, cranial nerves I and XIII. Well, cranial nerve I, you generally-- the cranial nerves are the nerves coming into the head-- sorry, in the head that come into the brain, above the spinal cord, and they're numbered from rostral to caudal, OK?

There's quite a few of them, well over 20, in fact. But there's only 12 major ones in humans, and so we usually think of just 12 cranial nerves. The first one, the rostral one, is the olfactory. The eighth one is the auditory and vestibular, OK? And those are the only ones I'm showing here, which is why I put it here to be identified in the Shmoo brain here.

OK, so now, what happens to the input when it comes in? And here we're going to focus on spinal cord initially. But the other sensory systems have similar channels of conduction. In every case, we can talk about a local reflex channel, a cerebellar channel, and lemniscal channels, plural. OK

And we're going to learn all these terms. We'lll first talk about segmental reflexes, OK? And we'll define dermatome and myotome. OK. Here would be-- we could call it also a local reflex channel. We can follow input through a primary sensory neuron in the Shmoo brain here. Contacts secondary sensory cells. And some of those have fairly short connections through interneurons reaching motor neurons.

Now, if that all happens within one segment of the spinal cord, a segment being defined as the area connected with one spinal nerve, one dorsal root, OK? So there's about 32 segments in the cord. And if that then goes from a sensory to motor within one segment, contacts the motor neuron, we would call a segmental reflex, OK, or local reflex.

If it comes in at one segment here but the output through interneurons connects with other segments in the cord, then we would call it an intersegmental reflex. But if it involves these long axons going up into the brain, the lemniscal channels, before it comes back-- If we're going to call it still a reflex, we would call it a suprasegmental reflex, OK, because it involves conduction above-- supra-- above the segments of the spinal cord.

OK, now, if we're dealing with one dorsal root here, which is a collection of axons, of course, coming in through on spinal nerve, those axons originate on the body surface from in just a limited part of the skin. And we call the skin innervated by one spinal nerve-- we call it a dermatome. And this is a dermatome map, showing-- usually, there's no first cervical segment of the dorsal root. We start with C2 to C8, and then the thoracic segments, T1 through 12, five lumbar segments, and five sacral segments. OK.

Usually, the coccygeal segments are not even indicated on these dermatome maps because they're not very large or important, OK? If we put the human in a quadruped position, we can see why those dermatomes are the way they are, because in early development, of course, the limbs are very short and stubby, when these things first develop.

So the body is segmented the same way the spinal cord is segmented, if we look at it this way, OK? Now, why do we start the map with the C2 innovation here, in the middle of the head? Why? Yeah.

AUDIENCE: Everything else is cranial.

GERALD SCHNEIDER: Everything else is cranial nerve. That's right. OK, so the cranial nerves innervate the face, primarily the fifth cranial nerve. OK. Although the cranial nerves, too, but the skin surface of the face there-- forehead and face-- is the fifth cranial nerve. Then we have the cervical segments, OK? Then the thoracic, the lumbar, and the sacral.

So with this kind of map, if you look at the dermatomes, then we know that the caudal-most part is right around the anus, the very tail end, OK? And the reason for these funny ways divided up in the legs and arms is because of the way those nerves grew in development, OK? But basically, they follow the dermatome pattern that you see here.

Now, the innervation of adjacent dorsal roots here-- and here, the cartoon here on the right, they're showing-- they only show a single axon in each. They're showing a single peripheral nerve that may enter cerebral spinal nerves. So it goes in through several different dorsal roots. That's what they're showing there.

And they show that, out in the periphery, it can come-- there is some overlap, OK, of the way these innervate. But there's a limited amount of overlap. Now, how do those things-- how were they mapped? Well, there was two major methods. First of all, the regions that become hypersensitive when a single spinal route is irritated-- of course, you could stimulate it electrically, but we usually don't experiment like that with human beings.

But we don't have to because they have problems with backs, like in a vertebral disc and a slip and herniate and put pressure on the dorsal root. And they can even transect a dorsal root. Usually, they cause initially just irritation, and then we can map the area of the body that shows the irritation. The irritation, of course, results in action potentials. So it gives us feeling like it's coming from the skin, like if we hit a nerve, which you can hit a nerve in your elbow because it's very close to the surface there. So that's why we call it the funny bone. We can actually disturb it and fire action potentials there.

That's similar to this method of mapping a dermatome, because we can map the hypersensitive regions. We can also look at what happens in the rarer cases, where there's a severance of adjacent spinal nerves. There's the one nerve remaining, and it's sort of as an island. We'll see it in the area of remaining sensibility.

So that's how these were mapped. And sometimes, we talk about a myotome also, the corresponding muscles of the ventral root at the same segment. And there's a pretty good correspondence between the position of the dermatomes and myotomes. All right, and my timing was perfect today. We're right at the end of the hour.