GERALD SCHNEIDER: All right. I hope you're all intending to learn neuroanatomy. This is 9.14, Brain Structure and its Origins. I recognize some of you from my fall term class. This class is very different from that class the Animal Behavior class. One similarity, though, is that we talk about evolution in both classes.

The class, for me, is quite different this year. It's changed once before. I started it as a class on brain, basically, models for studying development of the brain and nervous system generally. So we looked at the various models and focused in on the neuroanatomy you need to understand those models. But other classes were studying development, especially from a cell and molecular biology point of view, so I shifted more to a brain evolution and brain structure class, and that's the way it's been for the last few years.

What's different this year is that while in previous years, we had no real textbook-- we had some readings that would supplement the lectures, but you were very dependent on the lectures for understanding what I was trying to teach-- that's still true, except this year I've been writing it all down, because I'm going to, one way or another, get a book out within the next year or so. I've written 29 chapters. I'm working on chapter 30. That's roughly one per class.

So I've already posted chapter 1 online. Many of you have seen it. And some of you may have noticed, I reposted it this morning. This is going to happen various times, because I read it myself, I wrote the chapter a long time ago, it was a first draft, and I made a number of changes. Corrections, mostly. So it's probably a little bit better than it was before.

But I do want your feedback. Maybe I should put in a few really obvious mistakes

and I'll find out if you're reading it or not, because you'll tell me. I want you to tell me. I need the feedback. And that will help you, too. It'll give you a chance to interact with me. And please go to the web and search for things. I know that searching for neuroanatomy things on the web right now is very difficult for you because you don't know the language, you don't know how to talk about the brain, and so forth. At least that's true for most of you. But that's my job here, is to teach you to do that.

So let's start to introduce some terms and talk a little bit about neurons. That'll be a review for most of you, because I think most of you have had 9.01. I do allow people to take this that haven't had 9.01. They just have to work a little harder, particularly at the beginning.

I want you to learn an outline of neuroanatomy, particularly vertebrate neuroanatomy. I know we'll certainly focus on mammals more than other vertebrates. And we'll be studying origins from both development and comparative anatomy and evolution. The evolution ideas are more secular, of course, but there's a lot of progress that's been made in that area, primarily because now molecular genetics is giving us a lot more information. Those cladograms we draw, the branching structures that show what came earlier, what came later-- we have more confirmation and we can alter them now according to the genetics we find in surviving animals. And of course we can also get DNA from some extinct animals.

Adaptive function is what drives evolutions. It's because something is more adaptive, helps the animal function better, so he passes his genes on better. That's why the brain changes. The brain's determining that behavior. So function is the driver of evolution, and we pay close attention to function. So again, that's going to make this neuroanatomy class a little different from many in that I will be more concerned with functions all the way through. That's not as much the focus as in, say, a neuropsychology class, Suzanne Corkin's class, or even 9.01, but it's still very important and will affect the way we go about our studies.

So let's go through some terminology and talk a bit about neurons. To talk about the

brain, we have to be able to form a map, and the map has to have directions. We're not going to talk about north, south, east, west. We're going to talk about rostral-caudal. Anterior-posterior in some cases, but usually rostral-caudal. Dorsal-ventral, superior-inferior, medial-lateral. These have very specific meanings. Let's just go through, and then we'll talk about different planes of section 2.

If we look at a fish or an amphibian or reptile this way, rostral always means-- in this case, it's the same as anterior-- towards the rostrum. You know what a rostrum is? This is the rostrum in this room. So towards this, towards the head end. Caudal, the word means tail. Towards the tail. Dorsal, it's always towards the back. Ventral always means in the direction of the belly.

Sorry. If you're listening to this recording, you just got a very loud noise on it. I hit this with the thing.

So if you put a human in this position, you can talk about the directions the same as you could here. This is a human in, we call this the quadruped position. So again, dorsal is this way, ventral is this way. They reversed the arrow there. Posterior towards the tail, not towards the feet. The legs are an outgrowth, lumbar region of the body, so there's still more body behind, where the limbs grew out. That's the sacral region.

Of course, if you put a human this way, dorsal is now back here. It's the same as posterior. Ventral is the same as anterior. Well, that's very different than me talking about animals like this. So we're usually going to be using dorsal, ventral. Then we can talk about upright animals like these in the same language that we talk about the other, the quadrupeds.

Now, mediolateral-- that should be pretty obvious. If we're right in the median plane, we can measure distances from that point in terms of, say, millimeters, usually. Medial or lateral from the midline.

Now in planes of section, you should know all these. Sagittal, midsagittal and parasagittal. Let's define those. Coronal sections. There's a lot of synonyms in

neuroanatomy, not only for these directions, but for various structures, too. And I'll do my best to keep those limited. If I use a synonym sometime, you don't know what I'm talking about, just please stop me and we'll make the terms clear. Sometimes I will purposely teach you more than one way of naming something because in the literature, that's what's done, and you need to be able to understand these things.

So for coronal sections, we talk also about frontal sections or transverse sections. Sometimes we just say cross sections. Then and horizontal and oblique sections. If we take a cylinder, we can define these things. You can imagine here a cylinder or a banana. You're slicing across right angles to the long axis-- that's a transverse or frontal section. If you want a banana split, you're going to cut it either horizontally or midsagittally. If you nest the midsagittal plane, you're off, you don't need it a little more lateral to that, and we'll talk about a parasagittal section. But a lot of times, anatomists will still use the terms sagittal when they mean parasagittal. And oblique just is every section that's not in exactly in one of those standard planes.

So if we take here, I just did a sketch of a little rodent brain-- say a mouse or a hamster or a rat brain that we commonly use in neuroanatomical studies, or in physiological studies. I've drawn one horizontal section here, so in our brain, it would be a plane like this, and any plane above or below that is still a horizontal section. There is no mid-horizontal section. The frontal sections are at right angles, and they're usually approximately right angles to the surface of the cortex in these little rodents. For humans, it's always like this, but of course the angle can vary a little bit.

And then here I've shown the brain from the front. These are the olfactory bulbs you see from the front. And I've drawn parasagittal sections there. One right in the middle would be close to a midsagittal section.

Now we need to be able to name different parts of the nervous system. So let's, today, just name major parts. You've probably already used some of these terms, I hope so, in previous classes. They're going to be discussed repeatedly from various points of view, and you don't have to sit down and memorize them in one sitting.

You'll just keep hearing them, so they're going to sink in.

Here I've just mentioned, many of the terms come from not just English, but many of them from Latin or Greek, because many anatomists use those terms, and I'll try to define these things. It can get a little confusing because people will pronounce them differently, so try to use my pronunciations if you want to talk about it.

So what do we have here? On the left here, I've sketched not a section, but a dorsal view looking down on an embryonic vertebrate. Could be a mammal. A human at about less than three months after conception, say 2 to 2 and 1/2 months after conception would be roughly like this. The only difference here is up in front-- these are the cerebral hemispheres, and they sort of form outpouchings of this section of the brain, the tweenbrain, which ends up sort of between the two hemispheres, because it's the forwardmost of three brain vesicles. This is spinal cord down here, and then up to here the hindbrain, then there's the midbrain, and all the rest up there is forebrain. And the forebrain's got two parts-- diencephalon or tweenbrain, and then the outpouchings that grew so huge, and they are the major parts in the adult brain.

But what are these? You can imagine now-- this whole thing originated as a tube, and the walls of the tube, the lateral walls, in most cases, got thicker and thicker as cells proliferated. You can see that in the cross-section. Look at the spinal cord here. There's the ventricle in the middle, so you can see the tube with the thickened lateral walls, a thin roof plate and floor plate.

Then you get up into the hindbrain and the roof plate is stretched out. And that thin roof plate is what forms that thin membrane that I picture there in that rhombus shape. And that's where we get the name rhombencephalon, or hindbrain.

Then in the midbrain, the ventricle is shaped differently again. In the adult, there's just this small little fluid channel going through the middle of it, the cerebral aqueduct. And then we get into the forebrain, the endbrain component, or telencephalon, and the tweenbrain component, or diencephalon. And you see the different shapes of the ventricle.

Much of it has, again, just a thin medial wall. And I've taken two hemispheres and pushed them out to the side, pretty much like in the earliest developmental period, it looks like this. I've taken a somewhat later stage, but I've pulled the hemispheres apart so that we can see the logic of this. But as a matter of fact, those hemispheres grow out from the forebrain, then they come together and they fold back over the tweenbrain. So we'll encounter that again and again.

You have to understand this kind of topology if you want to understand how the nervous system is shaped, how it's put together. But every structure we're going to talk about in the class, I can show you exactly where it is on a diagram like this, and we'll try to do that.

What's happened to the cerebellum? Why is there no cerebellum here? Well, this is very early in development, and the cerebellum is just starting to form. Perhaps by this stage it should be a little further along. It's right from this region. This is where the cerebellum will grow, by an enormous proliferation of cells in the roof plate. They migrate into the roof plate. And the cerebellum ends up having probably at least ten to the 11th neurons, which is sometimes given as the estimate for the total number of neurons in the nervous system. It's a huge number.

So what's the nature of this CNS? I know Richard Gregory in England, a psychologist who, back in 1966, made this statement. He said, "One of the difficulties in understanding the brain-- it's like nothing so much as a lump of porridge." Because when you open the skull, that's what it's like. Unless it's been fixed with a fixative like formaldehyde or an alcohol, it has the consistency of some puddings. OK?

And you're not going to see, when you just open a brain up like that, you won't make out structures that we're talking about here. To see those structures, we have to fix the brain. We have to use stains or we have to use recordings in order to get any evidence of what this thing is all about and how it's connected. So it's a very soft tissue made up of cells that are pretty transparent.

What kind of tissue, other than being a soft tissue, is it? What part of the early embryo does the nervous system develop from? Anybody know? You have the three germ layers-- ectoderm, mesoderm, and endoderm. The endoderm forms the gut, the mesoderm forms skeleton and muscles, and then the ectoderm forms, among other things, skin. And it's that surface layer, the same layer that gives rise to the skin, that the nervous system comes from. We call it the neuroectoderm. So it's ectodermal tissue.

What kind of cells are there? What are the two major kinds of cells we talk about in the CNS? Neurons and glial cells. There's multiple kinds of glial cells, but there's also multiple kinds of neurons. And we'll see various types of neurons throughout the course, though it won't be our major emphasis on the details of neuronal shape, we will certainly consider that.

But how can we see them? What do we have to do to see them? I already mentioned, you have to fix them, which means a fixative, some way to preserve them. We could preserve them by putting them in a microwave and frying them, but that might mess them up a little bit. You're doing that all the time when you cook. But when an anatomist wants to see it, we want a fluid fixative that will soak into the tissue and preserve the structure.

And it used to be alcohols, but then the development of aldehyde fixatives, they've proven to be the best. And we use formaldehyde and glutaraldehyde most commonly, but there are other fixatives now that they use. Partly it's for safety reasons. Formaldehydes are mildly carcinogenic.

I always think of this horrible story. I heard it from a guy who wrote a text in electron microscopy. It's about a guy who committed suicide by drinking formaldehyde. And it was the first time they got really good electron microscope pictures the stomach lining, because they got to fix the stomach of that person.

Sorry. Most of my stories are not that gruesome.

So to see them, we have to fix them well, and then commonly for light microscopic

study, we use various stains so that we can visualize them. And different stains do different things, and we'll see some of those pictures throughout the course of the term and in some of the readings. And they're easy to find on the web, as well. And we'll mention various techniques. We'll do some of that next time. And different levels of observation. Today if I go fast enough, we'll get to some electron microscopic results, because I want to have a look at some synapses. But most of it will be light microscopic levels.

We'll treat the CNS as a system, a communication system that's involved in information handling, information flow. The nervous system is more than that. It's also a secretory organ. Now, we think of the endocrine system as the collection of secretory organs, but in fact, the brain also secretes substances into the bloodstream. Some are pretty well known and some are less well known. It also secretes substances-- and this hasn't been studied as much, but substances are secreted into the cerebral spinal fluid, that fluid inside the ventricular system. And that's something that we don't even know what some of those molecules are, but it's something that could be studied a lot more. And I think the whole area of general states of the brain that are determined by some kind of more diffuse action has been an understudied area, but it's one that's increasingly of interest to some neuroscientists.

And then of course we're concerned with functional architecture. And I will, just in these first classes, give you the initial overview of what I mean by that.

But let's talk about the basic elements of the CNS now-- the cells. Before we do that, let's just take a quick look at gross anatomy. We call this gross anatomy not because it's gross, but because it's-- gross. The gross view. Meaning not the microscopic view. That's what we mean. We're looking at a gross level, a microscopic level, or submicroscopic level, or electron microscopic level, or molecular level.

The brain you don't really see here well, because it's still ensheathed in the dura mater, the canvas-like covering in the human brain. This is a very young human.

These are all from people that have died of diseases or accidents that these brains come to the pathologist, and some of them are well enough preserved to be used in studies.

But what all these things? Well, that's not central nervous system. Here we have the central nervous system, the brain, and the spinal cord. The spinal cord actually ends about here. And then the rest is all spinal nerves. And there you see the nerves. What are all those nerves? They're part of the peripheral nervous system, and we'll separate peripheral and central nervous system very carefully as we go through this. There are also some nerves that are attached at the brain level. We call those cranial nerves. Whereas these below this are all spinal nerves. Usually 32 pairs of them.

Here's the brain of a rodent. And this is one of my pictures where I've pictured a newborn hamster and an adult hamster with the skull removed-- the newborn, it's completely removed from the skull-- just so you can see the incredible growth that occurs postnatally in many animals. This is relatively greater growth postnatally than in the human. This newborn hamster is at a stage of nervous system development that's like a human a little less than three months after conception, the end of the first trimester.

And we can see the cerebral hemispheres here and the olfactory bulbs up in front. We also see the roof of the midbrain exposed. Now, if this were human, the hemispheres are so big that the midbrain here would be totally buried underneath the hemispheres. They've grown back in this direction much more. So the cerebellum is sort of tucked under the caudal end there of the hemispheres. But here's the cerebellum, the caudal end of the hindbrain. We call that medulla oblongata, but that's just the caudal hindbrain. It's synonymous with that. Cerebellum's is part of the rostral end of the hindbrain. And then the spinal cord.

So now when we talk about single cells, we can start with evolution and talk about primitive cellular mechanisms, because these things are properties of one-cell organisms that function quite well. They live their lives out as single cells. They

show all of these properties.

They have irritability. All that means is when you stimulate them, they will respond in some way. And the response often will spread from one part of the cell to another part of the cell. And of course that's what neurons do. And the spread, we call conduction. Of the effect-- and of course, neurons are specialized for conduction, because they leave out action potentials, which we'll talk about in a minute.

Also, parts of the membrane of single cell organisms are specialized for certain kinds of mechanical stimulation or responding to certain chemicals. And of course the nervous systems have developed these kinds of specializations, too. They move. That's another specialization, or another primitive mechanism. Movement involves contractile proteins of various sorts. And of course, we know the muscle cells are specialized for that, but neurons, during development, have to move, too. So they also have that property, at least for parts of their lives.

Secretion. Single-cell organisms secrete things in order to eat, for example. They can kill prey, or immobilize them by chemical secretions. Prey that's even smaller than them, usually. And they do that by secretory mechanisms. Most neurons can do that not to poison things, but to communicate.

Then this property is a more complex one. Parallel channels of information flow with some kind of integrated activity. A single cell can have multiple things affecting it. It can be responding to the temperature of the water, to the chemistry of the water, to things touching it, to other one-celled organisms around it. And if it let every one of them act independently, it could go off in different directions. Even an amoeba can't do that. It would have to break up to do it. It would have to integrate in some way.

And when multicell organisms develop more than one cell, then you have a special problem. Because now we have a lot of cells, and different things are happening to different cells in that organism. How does it integrate that? That's what the nervous system is about.

And finally, we have endogenous activity, which we won't talk much about today, but

that means activity generated from within the cells, instead of from the outside. Not responding to something coming from the outside, but responding to something going on within the cell. We have, for example, an endogenous clock, and that single cell generates rhythms that affect our activity.

So if protozoa do all those things, why do we need neurons at all? And it's of course because being a single cell is pretty limited because of the small size. And the evolution, then, of multicellular organisms was almost inevitable to take advantage of things that size can give.

Let's talk about specializations for irritability. We've mentioned now protozoa respond to stimulation. By the time you get to simple metazoans like sponges, you have specialized cells that are responsive to mechanical stimulation or chemicals. And in Parker's st-- Parker was at Yale University, and I'll show one of his pictures. He studied especially coelenterates and ctenophores, and worked out the earliest stages of nervous system evolution simply by looking at the variety of nervous system structures he saw in these animals.

For example, primary sensory neurons. A primary sensory neuron is always a neuron in the epithelial layer that responds to some kind of stimulation. And then, of course, other neurons respond to other neurons, and not to input from the outside. It's not that they couldn't respond to anything from the outside, but they're not located on the surface. And all those things can be seen in coelenterates.

Then when you get to animals like worms that locomote in a particular direction, they develop specialized receptors at the head end. And of course that was major factor in leading to evolution of a brain-- enlargement at the front end of the nervous system. And that was a major consequence of forward locomotion. The head receptors and the enlargement of the head ganglia, or the brain.

So I'm going to just take these two neurons, familiar to many of you. This at the bottom is a motor neuron. Here's the neuron inside the CNS, central nervous system. It has this long extension, the axon. Leaves the central nervous system, travels to these endings on muscle cells. So here's the striated muscle cell, which

when the results of activation of this motor neuron results in a potential travelling down that axon ending up at the muscle cell, and then through a synaptic contact with the muscle cell will cause activation of the muscle cell, which results in contraction.

I ask here, what are the three functionally distinct parts of the neuron? We can name them for either the motor neuron or the sensory neuron, there's a receptive area. These are the dendrites of the motor neuron. These are dendrites, but there's no cell body right there. But don't let that fool you. Its function is the same. It's responding to inputs there like to pressure on the skin.

Then this is the functionally conductive region with the specialization, the great specialization of neurons that starts at one particular point here called the axon hillock-- that's where the action potential is initiated. It travels in an all-or-none way all the way down the axon to the ending. The conduction here out in the receptive region, this dendritic region, is not all-or-none like that. It's decremental. The greater the stimulation, the more the depolarization of the membrane. What's critical is what happens at the axon hillock there, the starting point of the axon. Then it reaches the transmissive end here, the synapses. So that's what I mean by functionally distinct parts of the neuron.

The cell body just happens to be at a different place. The cell body here is part of the receptive region. Here for the DRG cell, dorsal root ganglion cell, named for the ganglion that sits in the dorsal root, next to the spinal cord in the dorsal roots, isn't part of the receptive area of the neuron at all. It's simply supporting the cell, and it's connected through a little process there. It is invaded by the action potential, but that doesn't have any-- well, let's put it this way. We haven't studied much of what function that might have.

Now, this position of the dorsal root ganglion cell has been varied a lot in evolution This pseudounipolar shape-- that's what this is called-- so the cell seems to have only one pole, that is, one process coming out of it. That's fairly recent in evolution. And I want to show you a picture from Ramon y Cajal, who pictured these sensory

neurons in an earthworm, a mollusk, lower fish, and then animals with a dorsal root ganglion, which not only mammals, but amphibians, reptiles, and birds have dorsal root ganglia.

Now notice here, we were going in this direction for normal conduction. Sorry, but this is turned around. Now we're going in this direction. So here is the surface layer of the body of the animal, and you see that the primary sensory neuron is right in the ectoderm. So there's the cell body.

In the mollusk, It's below the surface ectoderm, and it's a bipolar shape. That's true for fish, too, except the ganglion is closer to the CNS. It's more like a dorsal root ganglion, except it's still bipolar in shape. And then here's the pseudounipolar shape in these animals.

Now if we look in mammals, including ourselves, we find all those shapes. This is true for all the sensory neurons coming from our body's surface, but in the cranium, we find these types of bipolar cells in the auditory and vestibular systems, and we find primary sensory neurons right in the surface ectoderm, the nasal epithelium, the olfactory system. We still find all those types. But if we look in evolution, we see it in different animals for the entire body surface. Yes?

AUDIENCE: On the diagrams, is it big A or little A, big D or little D? On the second one, there is this E at the end, around the cell body, for lower fish and amphibians and reptiles, is the E standing for a structure that the cell body is located in?

GERALD SCHNEIDER: E is naming the ganglion. Yeah, Cajal sometimes neglected to define some of his letters because he used these pictures for different purposes, I guess, sometimes. They didn't all get defined. That just stands for the ganglion. It means a collection of cells. Whereas in the mollusk here, the cells tend to be more scattered along the nerve, whereas in the lower fish, they're collected in a ganglion.

Here's Cajal. He didn't even have a binocular microscope, but he saw more through this little primitive microscope than most people even now can see with their fancy microscopes. And not only that, but when he studied, he often didn't have that

pencil in his hand. He just studied the neurons. And then he stopped looking through the microscope and drew from memory.

You develop that talent. I can do that now, but I certainly couldn't do that without years of being a neuroanatomist.

OK. So you should review this kind of slide. You should know now the major parts of the cell. The word "soma" is used for the cell body. The branches are called dendrites, except for the one branch, the axon. At the axon, we talk about telodendria-- the end branches. So here you see telodendria inside the central nervous system, here and here and here, and here. That's not the same as-- when we just use dendrite by itself, we don't call them telodendria, and we're talking about the receptive part of the cell, usually near the cell body.

When we talk about the irritability of the cell, we're talking about what causes the membrane to be depolarized. And we talk about excitations of the cell. That always means depolarization of the membrane. Something that makes the cell more likely to fire an action potential.

And then at the other end of the axon where you have the synaptic contacts with other neurons or with muscle or gland cells, you should notice that the axonal membrane is specialized for conduction of action potentials-- I'll say a little more about that-- and that this type of conduction is very different than in the dendrites. In the dendrites and in the cell body, you have non-decremental conduction. There are a few dendrites in a few parts of the nervous system that do conduct action potentials, but it's fairly rare. Most of them conduct decrementally, whereas the action potential is non-decremental.

This is just a little cartoon, how the membrane functions. This is a section through a dendrite or an axon. The axon would be the one where I'm representing here. If we take an electrode and plunk it through the membrane and look inside, we'll record a potential of about minus 70 millivolts on the inside with respect to the outside. The reason for that is the distribution of ions. There's more especially sodium here on the outside, a lot more sodium ions on the outside. There are also more chloride

ions. Whereas on the inside, we have more potassium ions, but the major thing is these large, negatively charged protein ions that are-- just call them the large anions.

Now, the membrane is semipermeable. Sodium and potassium can't get through that membrane real easily. Not as easily as the chloride ions can. The anions, the big ones, can't get through at all, so they're trapped inside. And when we fire action potentials, the sodium moves in, and when it recovers, it does move out too, but to maintain an equilibrium, the resting potential, we need to make up for these changes that would deplete this distribution, and it would eventually stop firing action potentials.

So there's a molecular pump in the membrane, the sodium potassium pump. It uses ATP for energy and it moves three sodium ions out of the cell when it brings two potassiums in. And this is going on all the time. It is not necessary for the action potential. It has to do with maintaining the axons, maintaining that potential difference of about minus 70 millivolts. That's an equilibrium reached because of the combination of the properties of a semipermeable membrane, distribution of ions, including these big negatively charged ions that can't go through the membrane, and the pump.

So now let's just go back to this axon and talk about the action potential. We'll just take a little piece of the axon and enlarge it, and now if the action potential is going this direction and I take a snapshot and just freeze it, this is the kind of distribution I would see if I could record with my little micro electrode all along, I would see the resting potential out here in front of the action potential. Positive on the outside, negative on the inside.

Then when the depolarization occurs, the sodium ions implode. Now why does that happen? Why would sodium ions suddenly come rushing in? Well, they're rushing down their concentration gradient, right? So something happened. The membrane permeability changed when the depolarization of the membrane, due to the stimulation of the cell, reached a critical level, the threshold level.

So what is doing a change? Well, there had to be something that evolved, OK? A molecular channel. We call them the voltage gated ion channels. So the voltage gated sodium channels, when the membrane polarity reaches a certain level, it goes from minus 70, say, down to minus 40 or minus 35, whatever the threshold is for that cell, there's a change. These voltage gated ion channels open up, and the sodium rushes in, potassium moves out. The first step is sodium rushes in, and the result is this rapid change in membrane polarity. So in fact, the cell changes from negative on the inside to a little bit positive because of the implosion of the sodium ions.

But then if that happens, potassium ions begin moving out right away when the channels are still open, and you start to get a recovery. And then the channels close. And as that happens, you get a recovery. There's a little bit of oscillation there, as I'm showing you, as the recovery occurs.

So you can look at that, then, as a snapshot at a given point in time. But in fact, you would get exactly that picture if you just held the electrode at one point inside the axon and recorded an action potential that went rushing by. You would get that same picture, of course.

So we can say a little bit about specialization for the membrane for irritability, first of all at the post-synaptic site. They're special receptors for neurotransmitter molecules. Neurotransmitters are the chemicals released at the endings of the axon. We'll talk more about that, or you can look at pictures that follow this to see how that happens. Those molecules bind to molecules in the surface of the post-synaptic cell, and that change in potential, due to that binding, allows molecules to come in.

OK. Now, the primary sensory neurons are varied, and there are cells that are connected to the primary sensory neurons, in many cases, that are the more specialized ones at responding to a particular kind of energy. So for example, chemicals in the air or in the mouth for olfaction and taste. For olfaction, it's the primary sensory neuron itself that specifically responds to certain shapes of

molecules that are in the air. In the case of taste, it's cells that aren't the primary sensory neurons, but cells that attach to those cells that respond to the salty substances or the sweet substances or the bitter substances and trigger the depolarization of the membrane.

And of course we have cells specialized for light in the retina. They are a few other places, too, in animals. Many different kinds of mechanical stimulation result in special response to pressure, stretch, or sounds, all due to particular kinds of mechanoreceptors. So we get various specializations there. We have neurons that respond to cooling or to heating, and some primary sensory neurons can respond specifically to electrical potentials in the water. Some fish have electroreception. Some of the specializations occur with the evolution of modified cilia in the olfactory and visual systems, especially.

So we'll say a little more about these specializations next time. According to my computer, we've got to stop right now.

So normally, I would like you to read the chapter before the class. Now, chapter 2 I haven't posted yet, because I discovered last night that I had to revise chapter 1 a little bit. But I will try to get that one up by tonight so you can read it for Friday. Because neuroanatomy is a subject you have to go over multiple times for it to sink in. You haven't had that much neuroanatomy today, but it will come fairly heavy sometimes, and it would be very much better for you if you could read the chapter, then come to class, and any questions you have, if I don't answer them, you can insist on an answer. At least, I'll try to answer them. And I think you'll learn more that way. So good luck, and I'll see you again on Friday.