PROFESSOR: This is 914, and the people in the back may sometimes have trouble hearing me. So you should always get-- maybe we should actually change tables in the future, so you can all sit closer. I don't have a real loud voice. I can ask them for an amplifier, but in a small class, that's sort of awkward.

AUDIENCE: [INAUDIBLE]?

PROFESSOR: Yeah, well, if you stop hearing me, just come closer. There's one there. And there's a few there that are closer. So this is the plan. I want you to acquire, and by acquire I mean in here in your mind, I want you to have an outline of vertebrate neuroanatomy, especially for mammals. But we'll learn enough about non-mammals that you'll have some understanding of them, too.

And neuroanatomy anatomy is not exactly an exciting topic. It's usually boring. But it doesn't stay that way if you know why it's like that and what it does. So that's why, and when I wrote the book that's the text for the class, I try to explain where this came from, how it develops, how it evolved. And for evolution, yes, I can use molecular data, but that's only in conjunction with comparative anatomy, look at a broad range of species, some of which are very primitive. That is, fossil record can trace them way, way back, like the sea lamprey, for example.

And as far as if you're going to talk about evolution, you've got to talk about function, because things don't evolve-- they evolve mainly to serve adaptive function, that is, by natural selection. And I'm assuming that, and I'm a Darwinian in that sense, and I recognize there are other mechanisms of evolution that result in change, but I believe the major things, especially for things like the CNS, which controls function, is due to selective survival of species.

So today, we'll start out with a little terminology. And then we're going to talk about cells. And the next time we'll be talking about the way some of the cellular mechanisms are used to study pathways, connections. And we'll hear a little bit about that today. You should be getting familiar with the Stellar site. And you go to the-- you log in, you go to this Materials section, and you'll see at the top the General section and a Resources section. You'll find there a book list.

Now, this year, I'm really only requiring as essential reading of my book, but there are some very interesting other books. And I post some of those readings as supplementary readings, and some of them are very helpful. If you get through with the reading and you haven't put your nine hours a week in yet, do some of the supplementary readings. The Allman book is a particularly interesting one. It's out of print. That was the problem with Freeman Press and *Scientific American*; books. They didn't keep books in print. Other publishers could pick them up, but so far, Allman hasn't been republished. And that's true also for [INAUDIBLE] and [INAUDIBLE] book. [INAUDIBLE] was my teacher in neuroanatomy, and he was a great neuroanatomist, and wrote a very interesting book that's still a good resource. So I will be posting those, too.

I'm not posting the Larry Swanson's book *Brain Architecture*. It's a book with similar goals to my book, but it's a very different book. It doesn't have the general kind of coverage that I have, but it's very unique in many things. And I did make use of that book in writing mine. So some people might want to pick that up. And I always list where the relevant things are in that book. You have a copy in the reserve room, I think.

AUDIENCE: Well, I have a personal copy.

PROFESSOR: OK, well, we should check. Well, check the reserve room and find out to make sure that they put the library's copy on reserve. So in case you have time and want to read some of that. That's fine. Now glossaries are important because you will soon find out there's a lot of terms in neuroanatomy. And they come from the Greek. They come from the Latin, or various combinations. And there's a lot of structures. A lot more than we have time to mention. I doubt if I will mention the bundle of Vicq d'azyr. I might mention habenulointerpeduncular tract. These are just, they're synonyms. They mean the very same thing.

The second way, that's easy. If you know what the habenula is, you know what the interpeduncular nucleus is because it's the habenulointerpeduncular tract. It goes from one to the other. And a lot of tracts, fortunately, are named that way, but not all. And there's a lot of synonyms. You will see some of that right away. So you just get used to it, a little suffering, especially earlier in the class. And it might make you feel a little lost once in awhile. But be patient with yourself, and just put the time in.

And I will go over things. The more important things I will return to a number of times to make it easier for you. I use the method in the book, and we'll use it in the class, because I'm basically-- the book originated from this class, from teaching here at MIT from a number of years.

I'm posting not only the readings for each class, but I'm posting questions on the readings. I want you to read before the class. Don't just come here and expect me to feed it all to you. We will answer questions in this class. And you will have a chance to ask me questions. But to make sure you're reading, I am sometimes just going to say, what's the answer to that question? You'll all be embarrassed from time to time, but it gets you to read. I can also use quizzes for that, but that takes up class time, takes up discussion time. So we're not going to have time to do too many quizzes. I will let in advance when we're going to have one.

So let's go through the questions. And I know this is the first class. We had a little trouble getting the book online. MIT Press was going to do it, as you probably know. And they ended up not being satisfied with their set-up for textbooks for a specific class. They have a deal with the libraries to make their books, their ebooks-- but mine isn't actually even out yet, so that will come. March 28 is when we can actually get the book, the print book. And after a few classes, I'll get all the names of you who expect to stay in the class or for other reasons want the book. And I will give that list to the guy at the MIT Press bookstore, to make sure he holds those for you guys. And then, anybody else that comes in, he'll have to have extra copies for them.

Should brain structures and their organization make sense to you? Because it seems a little arbitrary a lot of times when you're studying brain structure. What kind of sense should it make? What kind of sense do you want it to make? How would you answer that? I want it to make sense in terms of evolution and in terms of development and in terms of function. I want the connections we talk about, most of them, to make some kind of functional sense. It will help you remember it. And you will build, gradually, this outline in your mind.

And if it doesn't seem to make any sense, bring it up. Just tell me, it doesn't make any sense, OK? Put me on the spot. So, could somebody define central nervous system for me? Yes.

AUDIENCE: [INAUDIBLE]. .

PROFESSOR: So brain and spinal cord. The brain is in the skull. The word encephalon means in the skull. So we talk about the different main parts of the brain as prosencephalon, mesencephalon, rhombencephalon, the different three major brain vesicles in the skull. And then the marrow, the center of the spinal column, enclosed by the vertebrae there's the spinal cord or the medulla spinalis. That's why the caudal end of the hindbrain is actually the medulla oblongata, the elongated center medulla of the spinal cord.

So here are pictures of it. This is one from [INAUDIBLE]. This is from a dissection at a medical school museum in [INAUDIBLE], Switzerland that I visited. They have a wonderful museum there. And this is a dissection of a child who died. And they have exposed the whole spinal cord and the roots and the brain, where they sectioned part of it there.

This is one where-- you know why that looks so different from this one? What's different there? It's encased by the dura mater. The dura is the tough mother, the canvas-like covering of the brain, the outer meningeal layer. And we found this picture after my book. I would have liked to use this in my book. I've actually used these, but this one probably will be in the next edition because it's such a beautiful dissection of the adult human spinal cord and attached to the brain with the nerve roots, of course, all cut off. These would lead to the whole network of the peripheral nervous system.

So now, beginning at the caudal end of the CNS, what are the names of all the major subdivisions? Let's name them-- the most caudal, spinal cord. So what's just above it? I've already mentioned it in class. I've actually mentioned all the main answers here. But I want to see now. You've had 901. You've had brain pics before. You should know all these. So don't be too embarrassed if you forget. The neuroanatomy doesn't stick with some people very well, but that's why you're taking the class, right?

So what's above the spinal cord? The brain stem. The brain stem is a general name for everything in the encephalon, inside the skull, that's not cerebral hemispheres. These are cerebral hemispheres. There's the cerebellum. Those are the cortical areas. It's everything else that's not those two things. So let's start at the bottom and name the most caudal one, simplest in English; hindbrain, midbrain, forebrain.

The hindbrain, the lower part, is the medulla oblongata. The rostral part is often called the pons, just because of the structure called the pons that's located there. And we'll be talking about that and its connections. And then above the hindbrain, the midbrain. And we'll be studying that in a special unit, and it will come back in various chapters of the book. And then, the forebrain, but what are the major parts of the forebrain?

The hemispheres we've already named, cerebral hemispheres. That's the endbrain. It contains a little more than the hemispheres. It contains the olfactory bulbs and what we call the basal forebrain. And what's in between the endbrain and the midbrain? The tween brain, of course. The between brain. Sure, it's between the midbrain and the endbrain. It's also between the hemispheres. The hemispheres kind of blossom out of the tween brain.

All right, so here's a picture of the embryonic neural tube, where I've taken the developing hemispheres and I've sort of pushed them apart. So you can see the thin of what we call the roof plate here on the rhombencephalon. There you see the hindbrain right there. And you see how it's got that sort of one-cell thick membrane across the top? It's a tube. The whole nervous system is a tube. But the walls get very thick with development. This is early in development. They're not that thick yet. But that roof plate never gets thick in much of the hindbrain, only in the rostral part where the cerebellum develop. Then it gets huge. Sorry?

AUDIENCE: [INAUDIBLE]?

PROFESSOR: The tween brain.

AUDIENCE: Is that your term?

PROFESSOR: No, no, that's what di-encephalon means.

AUDIENCE: Oh.

PROFESSOR: I'm just giving you here the equivalent English and classical names. These are basically Greek. And the Romans imported a lot of the terms from the Greek language, and they have their own. So the other question is here, why is the hindbrain called the rhombencephalon. Hindbrain, rhombencephalon-- well, rhombencephalon doesn't mean hindbrain. Sorry? For that rhombic shape there. It's the shape of the roof plate seen from the top. And that stretches out like that when the development of the two develops flexures, bends. It's like a peapod that you've bent and it stretches out part of the top there.

So what are the coordinates we use now? We want directions when we're looking at brain sections, and we want to know what the common planes of section are. Of course, we talk about anterior and posterior, rostral and caudal. Do those always mean the same thing? No, not for humans. They do for most animals. Now here, anterior and posterior, same as rostral and caudal.

Do you have trouble remembering those names? Rostrum, do you know the term rostrum? He's at the rostrum. He's at the front. Caudal actually means tail. Dorsal, ventral-- dorsal towards the back, ventral towards the belly.

But look at the human here. The only way the terms are really equivalent for the human is when he's in that position. Because if he's standing up, now ventral is also anterior, you see? Not so here. And it's similar for the bird. And so that's the reason we normally-- and by the way, you can use the term oral, too, instead of rostral. But that's why I prefer just the dorsal, ventral, rostral, caudal terms because you can use them right across all the vertebrates, and even for invertebrates.

And for the planes of section, very simple. But just notice the synonymous terms. And I will sometimes, without even thinking, switch from one of these to the other. Transverse, frontal, coronal-- the all mean the same thing. Horizontal always means horizontal. You have midsaggital and parasaggital. But parasaggital, people don't bother with that. They still just call them all saggital, whether they're midsaggital or parasaggital, at the midline or off the midline.

And then, oblique sections are just used for special purposes in order to get certain axons all in the plane of sections and so forth. And here I'm just showing-- what you see here are the drawings that I based the textbook figures on. We did redraw a lot of them for the book. But here I just sketched the brains used in the lab the most, the mouse, rat, or hamster, from the side. And showing if you make a series of frontal sections and cut like that, this would be the horizontal plane. And then I turn the brain around. You're looking at it from the front. The olfactory bulbs in front. And the sagittal sections would look like that.

So what kind of education tissue makes up the CNS? It's not really a lump of porridge. It just looks like that if it's not fixed. So what kind of tissue is it? You can say it's ectodermal tissue because it arises from the embryonic ectoderm. And part of that ectoderm fronds the central nervous system and peripheral nervous system. And we will see that because one of our early topics is spinal cord development. When you do histology of nervous system tissue, it's very much like histology of skin because the skin is ectodermal.

So how do we define and recognize cell groups? Anybody? What do we do? How were they initially named? Well, of course dissection, but you can't see a lot of detail with dissection that you can see with anatomical methods. Well, what kind of anatomical methods? Yeah? Yeah, you. You were indicating you were going to tell me. Speak louder. Anybody, give me some methods. Sorry? I can't hear very well. I can't hear well with any background noise. I have more trouble than you do, I think, in hearing me.

AUDIENCE: Stains, we can look at stains.

PROFESSOR: Stains, one word, histological stains. Give me an example of a-- a Nissl stain. What does it stain for? Well, a Nissl substance. Where is the Nissl substance? In the cell body. Not very much of it gets into the dendrites, maybe the large proximal dendrites get a little of it. And it doesn't enter much of the axon either. So when we stain for Nissl substance, we're seeing the cell bodies. So you'll see whether the neurons are big or small, and whether they have a lot of Nissl substance or less, so there'll be dark staining or lighter staining. And just those properties help us define different cell groups, and they help us define layers. So we will see more pictures of that. There's many pictures in the book of these things. And you will see more pictures next time and in chapter two. Some of you have read it already.

What other kinds of stains? Well, Golgi, but if you just take a more general stain, other than the Nissl stain, we could stain for fibers. And the fiber stains might just stain for myelin, so that's only the thicker myelinated fibers, but they might stain for all the fibers, like silver stains for axons. That gives you a different picture. Like for example, when I wanted to map the whole neocortex of the hamster, I found the Nissl substances not to be all that clear. I could see boundaries, but it was pretty hard to make out. So I used a silver stain for axons, and found suddenly I could really see clear boundaries. And I was able to map, using a lot of quantitative care in the histology, I was able to map the cortical areas. And you'll see results of both of those kinds of methods applied to mapping different parts of the brain.

If we use the term primitive cellular mechanisms, the way I do in the book, what's it mean when we're talking about nervous system? What is a primitive cellular mechanism? Basically, I'm talking about mechanisms that we see in single-celled animals, that we still see in neurons. And here I list them, as the way I list them and discuss them in chapter one. They're all present in one-celled organisms. They're retained in the evolution of neurons.

Irritability and conduction-- irritability means it responds in some way to stimulation, like even just simple mechanical stimulation, but also other kinds of stimulation, chemical stimulation, electrical stimulation. Something changes in the membrane, and it conducts those changes to other parts of the cell. It happens in the amoeba. It happens in other protozoa. It happens in neurons.

And then we get specializations. That happens in single-celled organisms, too. Parts of the membrane respond better to some stimuli. And we see that in neurons, of course. Specializations at the synapse, of course, specializations for responding to stimulation from the outside world, movements themselves, specialize in movement. You say, well, that applies only to muscle cells. No, it applies to neurons, too. They have to move a lot when they develop. And they still use contractile proteins, just like the muscle cells.

And then secretion, single-cell organisms secrete. They use that in catching prey, for example. Secretions-- many neurons specialize. And even central nervous system neurons, some of them don't just secrete chemicals at at the synapses, but they secrete into the bloodstream. They are neurosecretory cells.

And then parallel channels of information is some way to integrate different information coming in different parts. Single-cell organisms, it's easier for them because they're all one cell. When you get a multicellular organism, especially if it's big, then it becomes a real problem. How do you integrate different things? Different stimuli can be contradictory. Your left hand might be touching one thing, and the right hand something that doesn't make any sense in terms of what's in your left hand. How do you solve a problem? How do you integrate? Well, you need connections, the soul of what we'll be dealing with.

And then the last property, endogenous activity-- we'll come back to that one. Can someone answer question 11 for me? Contrast the meaning of synapse and boutons in descriptions of neuronal structures. You find both of them. You find a bouton near the axon ending, or at the axon ending. Often many boutons associated with one axon because it branches and has many ending. And we talk about synapses. What is the difference in the way we use those two terms?

AUDIENCE: [INAUDIBLE].

PROFESSOR: Yeah, let's make an even simpler answer. Sorry? You know, I can hardly hear any of you.

AUDIENCE: Is a synapse different after the gap?

PROFESSOR: Yeah, but you're still not getting the major point. You're looking at details. I want the main picture. What's the difference between a bouton and a synapse? A bouton can have a lot of synapses. The synapse is just one little area of the membrane that's specialized for it's content and communication with another cell. The bouton is the enlargement of part of the axon where most synapses occur. So let's say it's an axon going along like this, and along its way, it has an enlargement, and then it just keeps going. And at that enlargement, that would be the place to look for synapses. They're called boutons en passage, boutons in passage. Often we use the French because it sounds so nice. And that's where the word, of course, bouton is a French word; bouton, terminal, the terminal bouton. Now we talked about a bouton a passage. So it's where synapses are formed usually.

Do all axons end in boutons and synapses? No, you will see, we'll talk about this different types of ending. But we're talking about even peripheral nervous system, an axon going to a muscle cell, it ends in a type of enlargement, but there it's more specialized. It's the endplate, the muscle endplate. It's a flat structure, but it has all the synapses on the muscles.

Next question there, what membrane structure had to evolve in order for action potentials in axons to evolve? You know that dendrites, most of them, don't conduct action potentials. A few of them actually do, but not very many. They conduct differently from axons. Axons conduct by action potentials. Now I want to know what membrane structure had to evolve for this to happen? Sorry?

AUDIENCE: Myelin?

PROFESSOR: No, no, no, no, myelin didn't exist when axons first evolved and when action potentials evolved. I'm talking about a molecular structure in the membrane.

AUDIENCE: Ion channel?

PROFESSOR: Exactly, a particular type of ion channel, a voltage-gated ion channel. It appeared in even jellyfish, which have been around longer than any chordate. And that just means that when the membrane potential changes-- remember the cell is irritable. It responds to input. And what's the usual response of a neuron to stimulation? Or an axon-- take an axon in my arm and I pinch it, especially if I pinch right here, I get an effect. I'm causing depolarization, simple word. Think in terms of the main thing here. Depolarization, the main response of a neuronal membrane to stimulation.

So now, what about let's deal with these, and you'll see examples of that in a minute here. I want you to be able to contrast excitatory and inhibitory postsynaptic potential, you should all be able to do that by now with the studies you've done. Unless you're from another department amd you just wondered what the brain is all about, and you're here. Well, we'll teach you, but I don't expect you to be able answer here.

Contrast the nature of conduction in a dendrite and an axon; just what we were talking about. And what's the functional purpose of an active pumping mechanism in the axonal membrane? Usually people say, oh, action potentials. And the answer is, no. It's not its purpose. So first of all, excitatory, inhibitory post synaptic potentials, this is from an introductory biological psychology textbook. It shows intracellular recordings with a microelectrode, where they record from this axon. I'm wondering here. Yeah.

So the presynaptic recording shows the action potential, big potential that goes from minus 60, minus 70, becomes momentarily positive and then the membrane potential recovers. And if you record on the other side of the synapse, you get a little bit of depolarization. If you're getting depolarization, it's excitatory. Why are those two things are equivalent? Because it moves. There's one point here where the axon begins, where if the depolarization, reaches a critical level, it triggers the action potential.

And these little EPSPs summate at the beginning of the axon, the axon hillock, we call it. So the more of them there-- and the conduction in the cell body is decrimental. So if it's happening way over here, and there's a depolarization, it has less effect on the axon hillock here than something happening right there. So it makes a big difference where the terminal is on the axon. But the EPSPs look the same everywhere. They might be a little bigger, or a little smaller, but they're conducted decrementally by the dendrites and cell body membrane.

Inhibitory post synaptic potential is opposite. It's when there's a hyperpolarization, as you see here. The membrane, if it was polarized as minus 70, might go to minus 80. And it's inhibitory because it takes the membrane further from the point where an action potential will be triggered. So let's talk a little bit more about that difference in conduction in dendrites and axon. Looking this picture, I drew it without myelin for a reason. Axons don't need myelin to conduct. So here I'm drawing functionally equivalent parts of two neurons, a dorsal root ganglion cell that conducts from the body surface, where there are endings here, and then the long axon goes right by the cell body into the central nervous system, where it ends in terminals with synapses on the cells, secondary sensory neurons. So it's a sensory neuron.

And here I have a motor neuron. So here, you're inside the CNS, and there is the cell body. There is the axon going to a muscle cell. So this part of both of those cells is the receptive part. This part, where I show the arrows, is the conductive part. And here transmissions occur in, the transmission part. And so now let's take a little piece of that.

First of all, the conduction here-- now, in some cases, the axon might begin further out. But here, I have it at the beginning right here. You get decremental conduction there. What are the characteristics of decremental conduction, other than the fact that gets less and less the further away from the sight of stimulation you get? The other characteristic you should know is it's very, very fast, almost instantaneous. Not like light, but it's close, very fast.

And then the point where the action potential begins, what is an action potential? Here I pictured it. I've taken a snapshot of it at one little plane and enlarged the tube or the axon, and I'm just showing how ion distributions are polarizing the membrane, positive on the outside, mainly because of the accumulation of sodium ions, negative on the inside. There are potassium ions in there that are positive also. But a lot of name are going to be charged anions, large ones, and [INAUDIBLE] here.

What happens when, at the beginning of the action potential, there's an implosion of sodium ions? Momentarily reverses the potential. This curve matches that piece of axon. So there's the beginning of the action potential. The sodium ions rush in, an implosion of sodium ions. The potential, remember, reverses, momentarily, and then it rapidly recovers. And the first reason it starts recovering is potassium ion channels are also voltage-gated, and so potassium, which is in high concentration inside, rushes out. The channels open up. You see, it's a semipermeable membrane. It's not-- all these ions can't get through very rapidly, unless the channels open up. So that's why the voltage-gated ion channels are so important.

And then so then, the membrane recovers. And there's another way to look at that membrane, where I show the polarization indicated a lot of sodium ions on the outside. There's also chloride ions. And then, in the inside the negatively charged anions, the big ones that don't pass through the membrane at all, and the positively charged potassium ions. But there are molecules in the membrane, I'm just showing a couple of sites here, we call the sodium potassium pump. It's always moving sodium ions out and potassium ions in. Because with a lot of action potentials, you basically lose that concentration of sodium on the outside and potassium on the inside if you get a lot of action potentials. So eventually, it'll just stop. Unless, you use energy to redistribute those ions. And that's why we need an active pumping mechanism.

So now we've answered those questions, at least tried to. Where's the dorsal root ganglia? I've mentioned it here. Actually, I said a dorsal root ganglia cell. Let's answer that a little better, talk about the oligodendrocytes and Schwann cells. Somebody already mentioned myelin. These are the cells that make myelin. And then I want to talk about the main function of the myelin sheath.

First of all, what's the dorsal root ganglia? This is a picture from [INAUDIBLE] that I put in the book. Here you see in an earthworm and mollusk, primary sensory neurons, the neurons responding to the outside world. These are neurons at the surface layer of the body, so in the skin of the animal. Here are the cell primary sensory neurons right in the epothelium. Here, the cell body below the epothelium, but it extends right out into the epothelium. But as soon as you get to the vertebrates-- this is the central ganglion here. We don't talk really about a CNS, but sometimes we do, just because of similarity to the vertebrates.

Here's a fish and amphibian, reptile, bird, or mammal. The fish has these bipolar cells that contain the primary sensory neuron, and they are collected in a ganglia. You talk about a collection of cells outside the central nervous system as ganglia. So here, in us and in these other mammals and also amphibians and reptiles, the primary sensory neurons carry input from the skin are in a dorsal root ganglion. From the dorsal roots because the roots of the spinal nerves that enter the CNS will always divide. The more dorsal one contains the sensory axons, the more ventral ones, the motor axons going to the muscles.

So that's the dorsal root ganglia. So now what about oligodendrocytes and Scwann cells. When axons acquire myelin, it is the Schwann cell that myelinites these axons of the periphery, the peripheral nervous system. But as soon as you enter the central nervous system, it's really a very different type of tissue, and you get a different glial cell making the myelin. It's now an oligodendrocyte. There are other differences, too. One Schwann cell will form the myelin in one little stretch. And then there will be a little place with no myelin. And then another Schwann cell wil myelinate the next segment.

In the CNS, one oligodendrocyte can myelinate or form a segment of myelin in a whole bunch of axons nearby, so quite different. But the function is quite similar. What is the function? It's a kind of insulator. It prevents ion flow. The ions can't flow through the membrane where the myelin is there. It's a tight fit.

So if you get depolarization just before myelin begins-- if we're talking here about space, so at one end-- you get depolarization. What happens? It triggers the action potential right there on that little piece of bare axon. And then, the only way I can conduct down the axon is by a flow of ion by decremental conduction, until it reaches the next node where there's no myelin. And if the decrement of the depolarization isn't so great, it will depolarize that membrane, trigger an action potential there.

And then same thing will happen, and the conduction will go bloop, bloop, bloop, bloop, like jumps. That's what saltatory conduction is. So [INAUDIBLE] means dumps. OK And that's why it speeds up, because the decremental conduction is very fast, like I said before. The action potential is not so fast that it's self-regenerating. So in a picture like this, you just get this continuous movement of the action potential, all the way down the axon. But it's limited in how fast it can go. It goes faster if the axon's bigger.

So in animals without myelin, the axons get huge if they need rapid conduction, for an escape response. But we don't have-- mammals generally don't have such huge axons. It would be very-- it would cost too much energy and space. The myelin was the invention that solved that problem.

Receptor cells, I said many receptor cells are not actually neurons. So how do they differ from neurons? How do they interactive with neurons? They depolarize, just like neurons. But they don't have the membrane of an axon. They don't have any action potentials, but their depolarization affects neurons that contact them, and can trigger an action potential in those neurons. So that's a receptor cell. Some receptors, like in the nasal epithelium or olfactory receptors, the primary sensory cell is a receptor. You have the same thing in the retina, where the specialization is even greater.

And here's just a list of various specializations. You already should know about various kinds. Some of them here are mechanical in nature, also response to light, chemicals, to heat or cold are all specialized receptor cells, except in the case of chemicals, where it's the neuron itself. But it's still a specialized receptor.

What kind of molecules are actin and myosin? What kind of molecule is that that we're talking about? Contractal porteins. When is actin found most abundantly in neurons? During development, when the axon's growing. The axon has to move a lot. The growth cone is very active. And we will see that when we study development.

You should know about the Otto Loewi's discovery. Don't have time to describe his dream. I like to describe it. It's a lot of fun. But you should read. I have a little bit in the book about it. And you can find things online very easily. He discovered-- he didn't know he was discovering acetylcholine and norepinephrine, but that's what it was. That's what the molecules turned out to be. He was the one who settled a big argument in neuroscience in the early part of the 20th century about whether conduction in synapse was electrical or chemical. And there were a lot of arguments on both sides.

He proved that-- now we know they both exist, but for the most part, most synapses, the conduction is the transmission from one cell to the other is chemical. He discovered that in this experiment on frogs. By just stimulating the axon of a heart, and accelerator nerve, one heart in a Petri dish, taking a little fluid from that Petri dish and putting it in another Petri dish, here he hadn't stimulated a nerve, but the heart speeded up anyway.

The reason I said it is high and maybe a few of you want to go to the [INAUDIBLE]. [INAUDIBLE] didn't discover, didn't talk about--

I wanted you to read this and you ask me questions about it. If there's anything about the way I portrayed synapses and their various types in the central nervous system. The hardest thing is probably the concept of presynaptic facilitation and inhibition. So, see if you can get some understanding of that. The rest of this, I think, is quite clear from the book, endogenous activity also. Just read it in the book. You can look at the slides to know what I'm stressing here. And these concepts will recur later in the class.