GERALD SCHNEIDER: Right, let's get started, guys. We were right at the last slide of class seven. I brought a few more of those printouts, in case you weren't here last time. But this is the very last one, and then we'll do class 8.

By endogenous activity, we generally mean in neurons. We mean neurons that are generating rhythmic changes in potential. So that means if you were recording the membrane potential, you would see it doing this, with a certain period. And it would have a regular rhythm usually. It wouldn't have to, but generally, it's a single rhythm.

This has been studied most extensively in invertebrate animals, how it was discovered. And it was-- this can happen without any action potentials, just slow potentials in the cell. Or if the potential difference is great enough to cause the threshold to be reached at the axon hillock, then you will get spike potentials. One, or you could get more than one, assuming the period is longer than the refractory period.

This kind of endogenous activity, generated by a single cell, and we know it is because you can isolate the cell and still get the potential change, is generated by specific molecular engines in the membrane. But these are proteins that are causing this oscillation in potential. We call those places-- we call such a place a pacemaker locus. So I put the plural up here, pacemaker lo-- "lo-se" or "lo-key" if you're a classical Latin.

We also know that such endogenous activity can be entrained, and you can shift the phase of the activity depending on inputs to the cell. And in fact, this kind of activity is the basis for what we call our biological clock. OK, and we'll talk about that when we talk about sleep and waking.

But I'll say only one other thing. And that is that, at least from a theoretical point of view, you could imagine a single cell, or perhaps a group of cells, generating activity like this, could generate any temporal pattern whatsoever, from a theoretical point of view. Why do we know that? Just from the mathematics of Fourier analysis. You can represent any wave form, arbitrary wave form, by a series of sine potentials, at different phases and different amplitudes.

OK. So now we're on to the next class, and we're going to start talking about multicellular organisms and their evolution. What I'm going to say about evolution is pretty speculative, but it's based on a lot of comparisons of different animals across many phyla.

We'll start by talking about intracellular conduction in these very simple multicellular organisms, the ctenophores and coelenterates. Coelenterates are animals like hydra, the hollow animals, the gelatinous animals. Ctenophores are also similar, even more primitive. And that leads to a generalized conception of the CNS that will allow us to define basic terms that we will use throughout the term, the next term also.

And then we'll start talking about our own phylum. I'll present what is really the simplest creature in our phylum, amphioxus. And we'll go through the simple body plan of that animal. And then finally, we'll talk about the elaboration of what we call the neural tube, our central nervous system as it appears in the embryo.

So if we look at many different creatures, as was done by George Parker at Yale in the early part of the 20th century, you see steps to a nervous system. Sponges are a simple multicellular animal that have contractile cells. So they're like muscle cells, but they're directly responsive to stimuli, not all of them, but they have these little openings. And around them, they have cells that will respond by contraction to things in the environment.

They also are able to conduct more widely within the organism, among contractile cells, which we would call myoid conduction, like muscles, or if it's neuroid conduction if it's conducting by some intermediate cell. You'd find that in sponges. There's also some evidence that these connections that look like synaptic connections are plastic. They're changing a lot. I've lost track of that, the paper. I read that, but I hope I can find that because it was pretty interesting because it would show that plasticity, in fact, a very primitive property of nervous systems.

OK, so let's talk about intracellular conduction. We'll look at Parker's work a little bit here. This is from the [INAUDIBLE] book. And he reprints or gets this from, took the figure from Parker's work.

Parker saw these three basic stages to a real nervous system. In the sea anemones, which are a plant-like animal, they have sensory cells. So they're like our primary sensory neurons. And they have contractile cells. They have muscle cells. And they directly connect with each other. So it's like a one cell nervous system, a real doorbell arrangement.

In the jellyfishes, some jellyfishes have something pretty similar, but they have an intervening neuron, which we will call a motor neuron because it's directly connected to a contractile cell, an output cell, and results in movement, without any intervening cells. But many jellyfishes and the mollusks also have cells in between the primary sensory neuron and the contractile-- and the motor neuron that causes the muscle cells to contract. Those are intermediate neurons, and we'll call that the intermediate network.

And that idea leads to a generalized conception of the nervous system. And I'll admit this is inspired by the reflex model. But it's very useful for talking about the nervous system. I don't if your printout shows this very well.

So what do we have there? At the top, I'm showing an epithelium, the surface of the animal. I've taken a section of it. And some of those cells in that epithelium are sensory cells. They are specialized for detecting something in the environment.

And I've shown little sensory hairs protruding. When the hair gets bent, it's going to respond, fire action potentials. So those are primary sensory neurons. That's what that says there, primary sensory.

They connect with the secondary sensory cells. And those secondary sensory cells are inside what we're going to call central nervous system. I've shown there, at the left. The CNS has all those cells, not including the muscle cells and not including the primary sensory neurons, everything else.

OK, so these are the secondary sensory cells that I'm marking here. In the spinal cord, we find them in what we call the dorsal horn. We also find them in the brain, connected to head receptors. Those are the secondary sensory cells. They're really part of the intermediate network, but we're giving them-- we're singling them out, separate them.

Now, at the bottom, these cells are the motor neurons, which we define, with the previous slide, as those cells that are connected to the contractile cells. Or they may be connected to an intervening cell, to the gut or to a gland tissue. OK, that's a separate part of our nervous system, peripheral nervous system, the autonomic nervous system.

So you can have two kinds of, basic kinds of motor neurons. But in every case, the axon goes out of the central nervous system. That's the defining feature of the motor neuron, a neuron in the CNS with an axon that goes out and causes action of some sort.

So everything else here, and I've only shown a few of them, are part of that intervening, intermediate network. I've only shown a few, but, in fact, that, of course, is the most numerous type of neuron, the great intermediate network. And those cells have local connections, as you see here.

Or they might have connections through distant parts of the intermediate network, like this one. It's going to some other place, and then there are other connections coming from a place like the brain. So that's the nature of the intermediate network.

Sometimes, we call those motor neurons the final common path. It was called at by Sherrington, the great physiologist in the years around 1900. And remember, he worked on cats' spinal cord, worked out reflex properties and many properties of synapses, in fact, without directly seeing them or recording from neurons directly-- singly. He didn't use micro electrodes.

Why did he call it the final common path? Why would he use such a word? Well, in the reflex model, if you're going to move it all, you've got to go through a motor neuron. So all that activity in the nervous system won't do anything for you, in the way of action, unless you go through a motor neuron.

So we may have relatively small numbers of motor neurons and huge numbers of intermediate network neurons, probably 10 to the 12th in the brain. And motor neurons, there are only a few million, but they're still the final common path.

So let's just go over these terms. We've defined, now, pri-- you should know these terms, primary sensory neuron. They're also on the list that I posted on the web for the [? flashcube ?] program. Primary sensory neurons, secondary sensory neuron, the interneuron, the motor neuron-- those are-- the secondary sensory neuron and interneuron and motor neuron are all in the CNS, remember. These are all CNS.

And in the CNS, if we see groups of cells that are obviously separate from others because they look different, we'll call them cell groups. Sometimes we call them nuclei. So the term nucleus, plural, nuclei, is used in a couple of different ways. It can be-- if we're talking about a cell, the nucleus of the cell. But it can mean a group of cells in the central nervous system. You have to get used to these terms.

Whereas, if we're talking about the peripheral nervous system, we don't call collections of cells nuclei. We call them ganglia. So the dorsal root ganglion, there's many of them next to the spinal cord. Dorsal root ganglia are clumps of cells of the peripheral nervous system-- question.

Secondary sensory neurons are those interneurons that are directly connected to primary sensory neurons. So we've separated them because of that. And sometimes we talk about tertiary sensory are the next one in line.

Now for the axons, we also have names, the next three names on the right there. In the peripheral nervous system, we'll talk about nerves, of course. But usually, in the central nervous system, we don't talk about nerves.

The bundles of axons within the central nervous system, we'll refer to as tracts or [? fascili. ?] The singular would be fasciculus for a ribbon of fibers. A funiculus-- there's various terms, OK? They come from the Latin and Greek. So don't be surprised when you see a number of terms that are more or less synonymous in neuroanatomy. I'll try to define them when we encounter them. These are the ones I'd like you to learn now.

The last two terms, they are the notochord and the neural tube now, applied to our phylum, the Chordata, the chordate phylum. And that's what we'll talk about now. We'll go over the body plan of the amphioxus.

I've drawn him here as if he's transparent, showing two things, his nervous system and the notochord. The notochord, the name means sharp at both ends because you can see it doesn't have an obvious head. All of members of the chordate phylum have a dorsal nerve cord that's above this cartilaginous rod, along the dorsal side of the organism, the notochord. That's the CNS, which, in the embryo, is a neural tube, a tube of neurons.

Let's look at now, we'll just make a cross section through him here, transfer section through amphioxus. And you see the notochord here, and you see the neural tube. And that little space in the middle is fluid filled. That's the ventricle, basically, neurons forming a tube around the fluid space, the ventricle in the middle.

And the peripheral nerves sensory come in through dorsal roots, just like they do in the mammals. At least, it's mostly sensory. [CHUCKLES] And there are motor neurons within that nerve neural tube that send axons out and go to the muscle cells in the body of the animal.

So the law of roots applies, pretty much, to this simple creature too, except that in any one segment, there's only one dorsal root on one side and a ventral root on the other. So whereas, all the mammals have-- these are in pairs. So every time there's one on one side, there's also one on the other side.

So that's the very simplest type of central nervous system in a chordate that's what gets elaborated in evolution. It gets elaborated because of behavioral demands. So I want to talk about what then-- what are the priorities? What are the behavioral priorities that caused all this evolution? Because that's important to understand because they result in the progressive evolutionary changes in the neural tube.

H. Chandler Elliott wrote a very challenging phrase in his book on neural-- on brain evolution. He said, "every brain system grows logically from the tube. He meant that under the behavioral demands that animals were faced with, once you had that simple central nervous system, that neural tube in the primitive chordates, the rest was sort of inevitable. So we're going to try to follow that logic just for fun.

Many of you have studied evolution a little bit. We mean processes of change in the way descendants function and the way their bodies and various organs look and function. And the changes occur because of natural selection, as defined originally by Darwin. Because certain genotypes produce more offspring than others, and so the genes increase in-- some genes increase in frequency, and others disappear or decrease. That's the way evolution works.

The changes are genetic. They result from genetic variations. And genetic variations are enhanced by sexual selection. And it involves, of course, the chance resorting of genes, expression of those genes. So you get more [? rate ?] variation in the phenotype that way.

You can get more changes in a species just by the selection from the variation that's already there in the genotype. So that's what I call rapid evolution. But you also get, of course, gene mutations.

And students have argued with me when I say that results in slower evolution. It's slower in a sense that they don't occur very often. That once you already have a lot of variation in genes, you will get selection among them currently, by what's happening now.

To get gene mutations to have an effect, that, of course, requires reproduction. And since they don't occur very often, it will take longer. Of course, a gene mutation, most of them are not adaptive and won't lead to anything. But occasionally, one of them is preserved because it does something good. And occasionally, it does something big in a hurry when it does occur.

So remember that it's function, including behavior-- I said behavior. I should have used the broader term, function, before, as the driver of evolution. And functional changes result in this process of successive elaborations of the basic plan of the neural tube in its simplest form, as we see illustrated by this little creature amphioxus.

So what are those behavioral demands? This is the way I'm going to characterize them. First of all, there's an ongoing background support, and I'll define that in a minute. Survival and reproduction is critical. It's often what's talked about when we talk about evolution.

And for these things to work, you need, along with them, the sensory and motor interfaces with the outside world. So let's go over these, the ongoing background support. By this, I mean the internal environment has to be kept stable. And as demands changed, there will be changes in the demands on the systems that do that.

What do we mean by internal environment in us? What's your internal environment? Your blood, blood sugar, electrolytes, salts, glucose levels-- what is stability in space? That's something else. That's background. It's happening all the time.

They're functions supported by our reflexes. We sometimes call it the mantle of reflexes because we wear it like a cloak. It's happening all the time.

I'm not thinking about it here, but I'm being kept upright. I maintain some stability in space. If I lose that, I stumble and fall, if something goes wrong with that system. It means much more than just maintaining balance, but it's still a kind of background support for the other functions.

Survival and reproduction-- the big things. It involves motivational systems that cause an animal to approach or avoid things. Anti-predator behavior-- to avoid predators, you need-- we need-- animals have evolved all kinds of specific patterns of behavior, specific sensory abilities, motor abilities.

Eating and drinking is necessary, of course, to maintain life. So there's a-- that's the second big demand in evolution. These, of course, are all simultaneous. But that also involves, of course, approach and avoidance mechanisms, mostly approach, but avoidance to things that are bad for us.

Reproductive behavior, of course, is critical, or we can't evolve at all. They say we evolve, we survive in order to reproduce. And we evolve to pass on genes, not to be happy. EO Wilson says we didn't evolve to be happy. We evolve to reproduce. That explains some of the conflicts we go through.

And we need an interface with endocrine regulatory mechanisms in order for these functions to work. It's most obvious for reproductive behavior, but it's true for other kinds of behavior as well. And at a higher level, animals have to have built-in goal hierarchies. And of course, later, added to that, are cognitive functions that lead to a higher level of setting of priorities.

But by here, I mean things that are built in, like fleeing from predators gets priority over eating and drinking. An animal can be eating or drinking. If it detects a predator, everything has to stop because surviving is the most critical thing. Although, I don't know. If he wants to die happy, he might keep eating.

But OK, now the interfaces with the outside world-- we talked a little bit about sensory analysis and motor coordination before. But beyond that, we have also evolved systems for anticipating what we're going to sense, our expectancies. Remember, we talked about the model of the world. That's really evolved out of our sensory systems. We also evolved mechanisms for not just doing actions but planning them, anticipating, achieving our goals by planning them. And these are what we call our cognitive abilities.

OK, so now we're going to go to the nervous system. What did that-- what did all those things-- those were the behavioral demands, as I'm summarizing them for you. What did it lead to? The sensory analyzing mechanisms, corresponding motor apparatus-- it led to ways to relate the two, that some anatomists have simply called the correlation centers.

It also led to elaboration of complex programs for goal-directed activities. We talked-- I mentioned fixed-action patterns, instinctive-action patterns. But of course, we have many learned-action patterns as well.

We also have systems for modulating other brain systems in response to our needs, visceral social needs. Those are our motivational systems-- and finally, systems for modeling the world so we can anticipate and plan. So I'm just trying to get you to think about why the CNS evolved the way it did, what does it accomplish for an organism, and how is this expressed in the basic organization of the CNS.

And that last thing is what I want to go through with now, my way of looking at this. So we start with amphioxus, at the far left, the neural tube, simple neural tube. Remember, he's sharp at both ends. He doesn't even have a head.

Well, very early in evolution, worm-like creatures developed forward locomotion. And that led to the development of head receptors. And so I'm showing here, olfactory, olfactory at the front end here. I have a one by it because we call it the first cranial nerve.

I also show their visual somatosensory. I have a two because the optic nerve is the second, in mammals, somatosensory because the cranial nerve innervating our face is cranial nerve V. And then I also put the vestibular system since stability in space is so important. That's part of the eighth cranial nerve.

OK, and I've also shown that that led, very early, to enlargements. These specialized head receptors caused enlargements at the rostral end. Rostral means towards the rostrum, towards the front. Caudal means towards the tail.

So at the rostral end, we have enlargements. And initially, they're very simple. I've labelled them here, F forebrain. That's the F. M is the midbrain, H, hindbrain.

And sometimes, these are called-- and C is the cord, or spinal cord. Here, I'm just using the English, not the Latin. I'll use the Latin later. You practically have to know some of these things, or you can't understand what you're reading. But for right now, we'll just be [INAUDIBLE].

We call these the primary brain vesicles, the enlargements of the neural tube with a fluid-filled center. Forebrain, midbrain, hindbrain-- that happened very early with the evolution of head receptors and forward locomotion. So they had receptors cause this were part of the evolution in the brain.

We also, of course, had to develop means of controlling those receptors controlling the body, controlling body posture. All that evolved along with forward locomotion and head receptors. And here, I'm just summarizing what I just said, adding a little bit, telling you what's in the hindbrain and midbrain, sensory side, motor side, and then the forebrain, olfaction and the endocrine and visceral control. And in early evolution, these things occurred.

So now let's look slightly [INAUDIBLE] stage. I just want-- I'm separating it this way in order to emphasize certain points that I want you to remember. Expansion of some of these sensory analyzers, especially in the hindbrain-- but it, of course, occurred other areas too, but first let's just talk about the hindbrain sensory analyzers. It included the somatosensory receptors of the face, but also taste ability, vestibular ability, auditory, electroreception, which we don't have, but some animals do.

This all involved inputs to the hindbrain, and I'm showing there-- right here, I'm showing one organ. It represents the cochlea or the vestibular apparatus. And I'm showing [INAUDIBLE] innervated by a cranial nerve, going into the hindbrain. Then I'm also showing the input from the trigeminal nerve. It's called trigeminal because it has three main branches, go to different parts of the face. And I'm showing it as a cranial nerve coming into the hindbrain.

And there is a ganglion for both of those, where the primary sensory neurons are located, outside the CNS. But the idea here is expansion, expansion of the hindbrain. Let's look at how I know that. Let's look at a few brains of animals where the expansion has gone to an extreme.

We're going to look at these animals. I'll look at a fish without so much expansion first, the freshwater mooneye. And then we'll look at a buffalo fish that has a huge vagal lobe-- that's the 10th cranial nerve-- because he's got a specialized palatal organ that he can sense things in the water that he's filtering through his mouth and going out his gills.

The catfish that not only has the vagal lobe, but then he has another lobe there in the hindbrain because he's got another specialization, which I'll define for you, in the seventh cranial nerve. He's got taste senses that are normally innervated by the seventh cranial nerve, as well as the ninth and tenth. But the seventh is the critical thing here because it expands in the catfish and distributes over the whole body. So that results in changes.

So here's the mooneye, a very simple brain, where you see the forebrain, midbrain, and hindbrain expansions. So here you have the cord. Here you have the hindbrain. Here you have the midbrain. Here you have the forebrain.

Now look at the buffalo fish. What is that? Well, that's the hindbrain, part of it.

Here's the cord. Here's the hindbrain. This is also hindbrain. Here's the midbrain up here. Here's the little forebrain. You just see the end brain part of it because the tweenbrain is hidden.

So what has happened? Well, there's been a sensory analyzer that has-- they needed more apparatus to do the analysis of the water that's coming, the taste in the water that's coming through the mouth. So the apparatus expanded. It developed more machinery, like in the telephone company with all the relay and racks for handling the inputs and outputs.

So just like the phrenologist said, things get bigger when they're-- you need more function, at least when we take it to an extreme. Now, here's a catfish who does have the vagal lobe, but it's not as big there. But he's also got another big bulge. In fact, it's even bigger.

We call it the facial nerve because it's connected to the facial nerve. Now, why did the catfish have that? Well, here's a picture of one of the small catfish. And it shows the seventh cra-- you see the brain there, in-- this is brain. And in black there is the seventh cranial nerve and its ganglion.

Normally, the seventh cranial nerve innervates our tongue, taste receptors in the tongue. It also controls, on the motor side, much more facial muscles and everything. We're only talking about the sensory side here.

But in the catfish, that's expanded and distributes throughout the body, including these, the little, what we call whiskers in the catfish, little barbels. They're innervated. They have taste receptors on them.

So this animal is an animal that, in his feeding, makes special use of taste. And so he's expanded the distribution. And that's why he's developed an expansion of that part of the hindbrain, getting that nerve's input.

OK, now let's continue, still dealing, now, with forebrain, midbrain, and hindbrain. What caused the forebrain to begin to expand? We'll deal with forebrain. We'll also deal with midbrain, but first let's deal with the expansion of the forebrain because of the adaptive value of the olfactory sense for approach and avoidance functions, feeding, mating behavior, predator avoidance.

The outputs to locomotion, of course, were critical. And these links were made by the midbrain, as I've shown there. Here's the midbrain. This is all forebrain. You see the olfact-- here's the olfactory receptors. That's [? our ?] olfactory epithelium. The primary sensory neurons are sitting there, sending their axons into the olfactory bulb there, a little protrusion of the forebrain.

And there in the midbrain, there were neurons receiving some of the output of cells that connected to that olfactory system. And the midbrain cells, then, has descending connections to the hindbrain, which then, of course, reached the spinal cord, enables the animal to escape or to approach. Now, if olfaction hadn't evolved at the very end like that, it would have led to a different kind of expansion. But that's how it happened, and it's very ancient. And once it happened, it was maintained in evolution.

Well, we've talked about how sensory analyzing mechanisms can expand. You always get some corresponding changes in the motor apparatus. Let's talk a little bit about the correlation centers between them.

You need them to maintain stability in space, for example. And it led to evolution of structures, like parts of the cerebellum, the midbrain tectum, and other groups in the brain that I mentioned there. We'll show the ones we think of mostly are-- oops-- cerabe-- oops, sorry. Cerebellum-- midbrain tectum.

So there, I'm showing in the mooneye, again-- I'm showing the midbrain and cerebellum. The midbrain expanded. One of the reasons it expanded is it had a special connection to the eyes.

And I'm not saying that that's how vision initially evolved. In fact, it came as an outgrowth of the tweenbrain. But the first connection that became really large was the connection to the midbrain.

Auditory also provided input to the midbrain, and that gave big advantages for-- that were better than olfaction, in many ways, for detecting predators, very good for early warning and anticipating bad things. So anti-predator behavior, very early, depended on visual and auditory connections to the midbrain tectum. It also, the tectum was involved in turning of the head and eyes, so it took on a wider role than just anti-predator behavior. It became important in approaching things too, orienting. Although we think it evolved, mainly, as sort of an early, early warning system.

OK, I have a couple. This is just the introduction to the fifth part here, involving evolution of fine control of movements and manipulation, where you had evolution of certain cortical functions and cerebellum. But early on, the-- something very interesting happened to that forebrain that was dominated by olfaction. Other sensory inputs moved in also.

Because, you see, olfaction was doing something really important for the animal. The forebrain was doing that. The midbrain was doing most of the visual things. But the midbrain had its connections too. And some of them went forward, and by way of the tweenbrain, invaded that endbrain structure, which was initially olfactory.

So we talk about an invasion of the non-olfactory input, which led to the neocortex. Olfactory cortex is not neocortex. It's a more primitive kind of cortex.

Now, that really oversimplifies how it happened because there were really two structures that evolved there, the corpus striatum and the cortex. And we'll be talking about those. And there, I'm showing some expansion of the cerebellum as well, as it gets, now, these distant receptors, the vision, somatosensory, auditory, in addition to the sense that was most important early on in cerebellar evolution, the vestibular sense.

So changes are happening in the cerebellum as well as in other parts of the brain as these head receptors are elaborated and their analyzing mechanisms are elaborated. So let's talk about some of these other things I mentioned as drivers of evolution, complex programs for goal-directed activities. We're calling those-- remember, I called them fixed-action patterns?

And I think we've already mentioned some of the examples in humans, where they're not quite the same as reflexes, which are simpler, which means segmental. Whereas, the fixed-action patterns involve a much wider part of the nervous system. What's a simple fixed-action pattern that I've probably done about 50 times since I've been standing up here? Swallowing.

It has its own input. You're not always aware of it. But when you swallow, you're stimulating the very back of the tongue, behind a little roll that can be defiant. You take a little-- you take your finger and slide it back. You won't swallow until all of a sudden, you reach a point where you'll trigger that fixed-action pattern.

Of course, you've got the finger in your mouth, so you'll gag, but actually, you're trying to swallow. Every time you swallow, you're not voluntarily swallowing. You're voluntarily moving, producing that stimulus in the back of your mouth. And that makes-- that triggers the fixed-action pattern involving at least 20 different muscle groups. It's a very complex pattern.

What are other fixed-action patterns of humans? I'm doing one of them right now. I'm walking. You say, but you learned to walk.

Well, actually, if no one had ever taught me, I would still walk. We say we're teaching our kids to walk, but actually, they're walking on their own. You just encourage them. But if you're never encouraged them, they would still walk. It's a fixed-action pattern.

I'm not saying it doesn't end up a little bit different from person to person because of learning. But in fact, it's a pretty small effect. In fact, there's certain characteristics of the way people walk that are inherited. And if you know the father, and you've never seen the son, and then you meet him, you might think, when you see him from a distance, by the way he moves, that it's the father because he's inherited these movement patterns or fixed-action patterns, inherited action patterns. And they do evolve a little bit differently but mostly the same.

Startle is another one. It's-- we often call the startle response a reflex, but, in fact, it could be called a simple fixed-action pattern because it does involve wildly different areas of the brain. In fact, a loud clap, like that, if it's loud enough-- I saw movements throughout the-- from about a third of you when I clapped my hands.

If it was really loud, your knees would buckle. Well, that's quite a distance from the input through the ears here, to part of the spinal cord that's controlling the leg flexors. Smiling is another one.

We find simple stimuli that will generally elicit smiling in infants. It appears very early. Infants also make a grimace that looks like a smile when they feel odd in their intestines. And so people often say look, he's smiling. But there are many fixed-action patterns like that, and there's a long list of them.

So these things also lead to structural elaborations. The hindbrain and spinal cord, especially, but then you also have motivational control. In fact, the [? ethologists ?] often define the fixed-action pattern as different from a reflex in that there's motivational control that's different. Motivation does-- can modulate threshold for reflexes. But fixed-action patterns, in fact, when motivation is very, very high, the threshold becomes so low that they will just, some of them anyway, will be generated without any noticeable input.

OK, and then finally, we have reward-driven learning and habit formation involving the corpus striatum neocortex that are linked to our motivational system. OK, we'll talk about these last few things next time.