**Demystifying the Brain**
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Lecture - 04
Understanding Brain's Shape - Segment 3 – Brain Evolution

Hello, welcome to lecture 2, as you remember this lecture is about understanding brain shape. So, how can we understand brain shape? Why is it like that? Why is it like you know brain has 2 hemispheres and there is a spinal cord and cerebellum how has brain evolved in this fashion?

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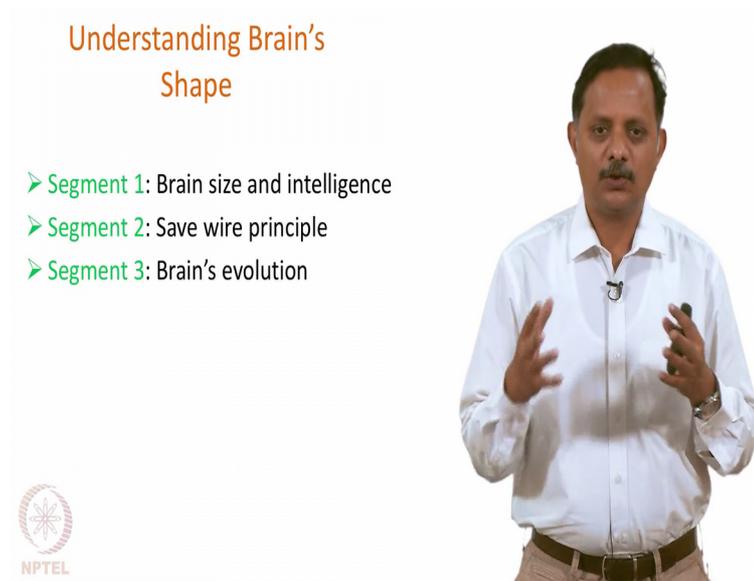
So, the first segment of this lecture we began with the general question of brains overall shape intelligence, we began with the case of Einstein's brain and nobody look at all these anatomical studies and finally, we concluded that gross and I mean anatomy does not tell you much about intelligence.

So, then we went on to look at maybe brains mass or brain mass to body weight ratio or any of these things correlate well with intelligence and none of them were really working very well then we came up with this measure called encephalization quotient and so we found that that number is highest for human species compared to other species, but even that was not very satisfactory because it seems seem to be some kind of a fit, right we

came up with some figure which is highest for humans, so that is not really very convincing.

So, in the second segment we looked at the save wire principle. So, we found that lots of brains satisfy this constraint of wire minimization and we also said that that kind of a constraint arises, so in our electrical engineering, when you design large circuits.

So, now, but that also did not did not really answer the question of the connection between brain structure and intelligence. So, now, let us look at slightly different question, we look at how brains evolution has occurred. So, that is what we will see in the segment 3. So, basically we look at these questions in this segment.

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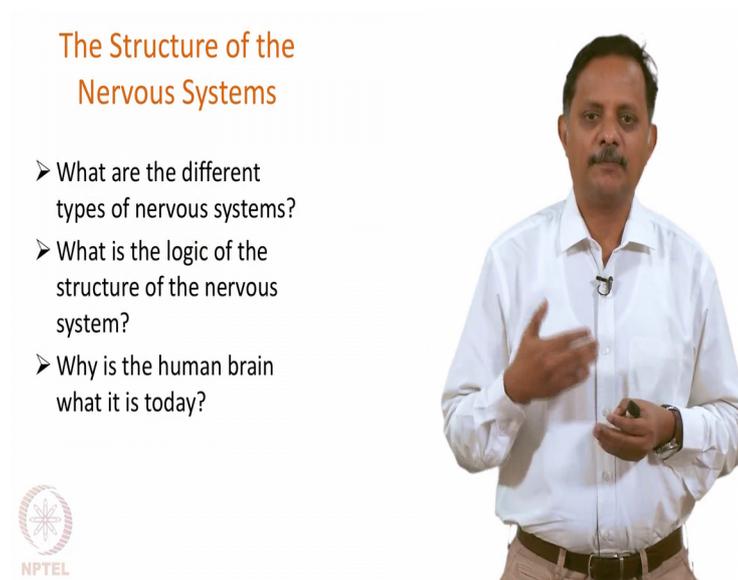
So, what are different types of nervous systems and when we started off in the earliest organisms of and evolution? They do not have a brain spinal cord, they have something called a diffuse nerve, they have just a bunch of neurons scattered all over the body. So, a brain spinal cord comes much later in evolution. So, why has it evolved like that? Has it got anything to do with intelligence that kind of a species are exhibits? So, what is the logic of this kind of structure? What kind of a forces? What kind of logic shapes nervous systems from the primitive condition of a diffuse nerve net to the current condition in humans with a brain in the spinal cord?

So, then will also see if what is the correlation between the type of nervous system that an organism has or a species has and the kind of intelligence that the species exhibits.

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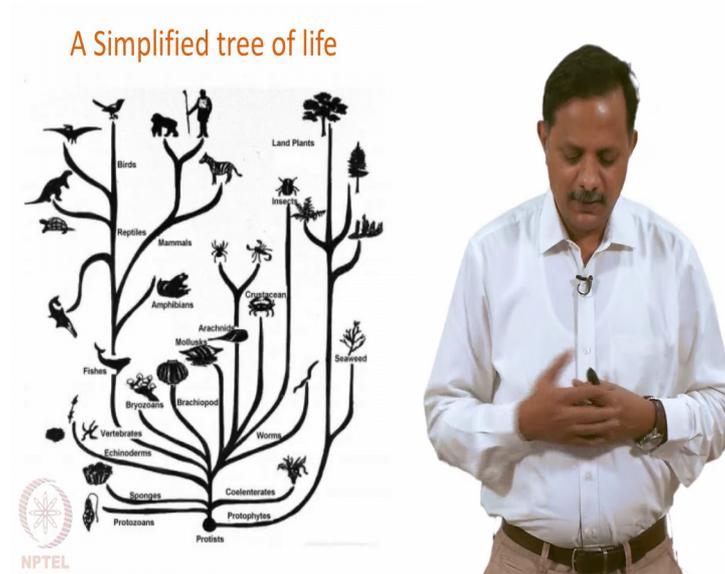
So, let us begin with the simplified evolutionary tree. So, the tree what is called the tree of life, tree of life there are very complex versions I am taking a very simple version to present some are you know preliminary arguments. So, let us look at this tree of life at the bottom of it you have what are called protists, these are single cell organism very primitive and 1 of the first branches from protist is what is called proto fights and these proto fights go on to become what we know as plants and trees.

Then, on the left side you can see these protists 1, which are also single cell organisms and if we go slightly further up you have on the right side in a branching out you have coelenterates and all of the good example of that is a hydra and we look at that in a moment and on the left branch again you see sponges, right now both sponges and coelenterates are multicellular organisms, but sponges do not have any nervous system per say right and whereas, coelenterates do have nervous system.

Then, as you go higher up now you have worms and you have insects, then crustaceans like crabs, then you have arachnids spiders, then you have mollusks, a good example of mollusk is an octopus or a more familiar example is a snail that you see everywhere, then you have on the left side you have a echinoderms, these are like they are very nice

symmetries like a starfish is an example of an echinoderm, then you have this great branch of vertebrates that nerve which we have emerged; humans have emerged.

So, on the vertebrate branch you have the fishes, then fishes move out of the water and enter the land and become amphibians right like frogs and alligators and all that and then, we have then 2 great branches from the 1 branch is reptiles, snakes and lizards and so on and dinosaurs are prominent and a classic example of reptiles, from reptiles some other flying dinosaurs you have birds right, at the end of it you have birds, then the other great branch other than reptiles is mammals and after that you have you see all these 4 legged animals that you see everywhere and 1 of the branches of mammals is apes and then humans.
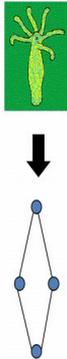
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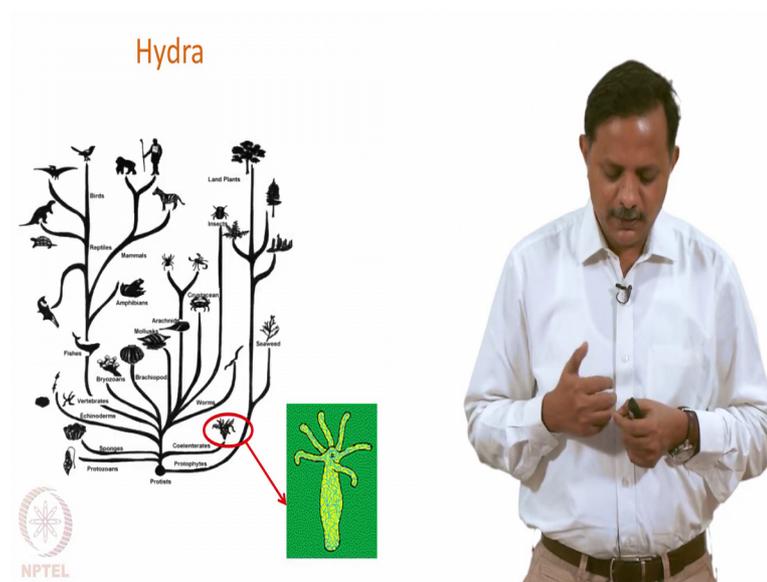
So, let us look at an example from coelenterates hydra. Hydra you see the picture of hydra on the right side and it has a kind of a stem like structure and at the top of it you have a bunch of finger like extensions and you also see a small orifice, right at the, in the middle of that those finger like structures.

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So, hydra do have a nervous system, but it is basically a bunch of neurons scattered all over it is body and this kind of nerve net is called a diffuse nerve net and lots of neurons are concentrated around this orifice, which is actually the mouth of the hydra of the organism. So, it injures put through this mouth and also whatever is I just said is excluded back to the same orifice. So, and it has a strange kind of locomotive behavior.

So, with these tentacles which act like hands and feet right moves around through a kind of a strange; somersaulting movement, so and there are no ganglia like some of the higher organisms will see soon have process of neurons on which are called ganglia, but hydra does not have any ganglia, it just has this refuse nerve net and it also has specialized cells for touch and chemical detection.
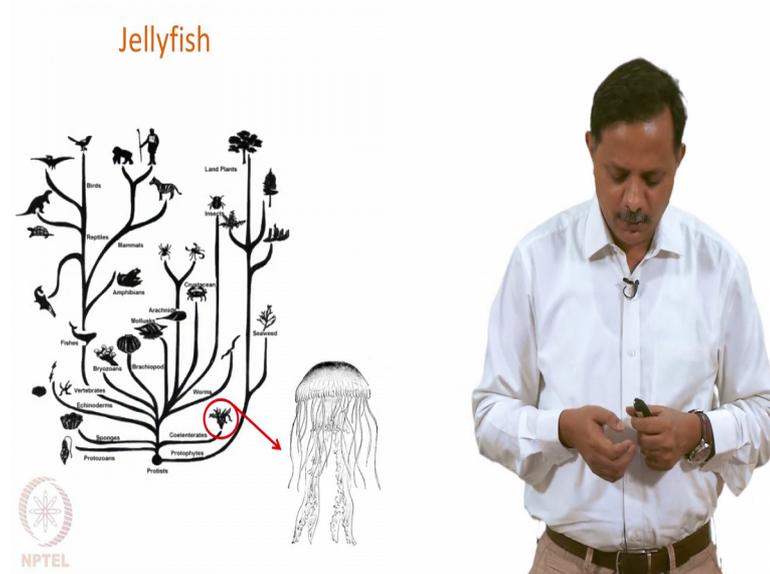
Then, let us look at jellyfish which is also another example of coelenterates, it has a nice symmetrical structure it looks like a kind of a umbrella with strands hanging down and the jellyfish also has a nerve net, which is of the type diffuse nerve net.

So, these nerve net conveys or conducts neural impulses around entire body of the jellyfish, it has tentacles for hunting, it has used stomach you know, the kind of vibrations of the stomach or for locomotion for vertical locomotion and so it has structures called rhopalia, which are you know act like and sensory organs. So, they can

sense and then they have light sensing structures called ocelli and then, there can sense balance through what are called statocysts, they can detect chemicals, so they have some primitive kind of olfaction and they can sense, touch through structures called lappets.

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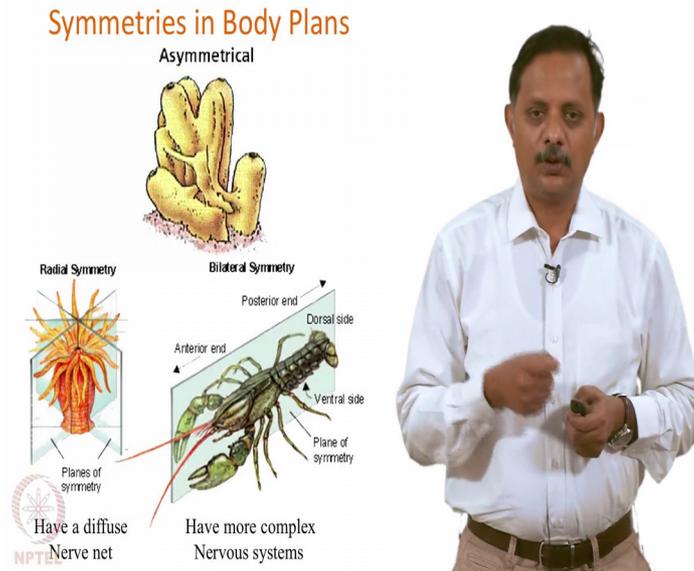
So, thing is both the example that we have seen which are you know examples of coelenterates have very interesting kind of symmetric, this is called radial symmetry they look like a flower part. So, there are organism's exhibit different kinds of body plants and the overall organization of the body. So, the for example, something like a sponge, which does not have any specific symmetry these are asymmetrical. So, you see the example, then the 2 examples we have seen of coelenterates the exhibit radial symmetry.

So, around an axis they are equally distributed in all directions approximately. So, in these kinds of organisms typically have a diffuse nerve net; now, which is interesting, that means, the body structure and the kind of nerve system the organism has, has some connection, but beyond that, if you go beyond coelenterates very quickly you run into organisms which have what is called a bilateral symmetry.

So, there is a kind of a box like structure and then there's a left side to it and right side to it. So, then it has a, so the front is called anterior side and back is called a posterior and the upper part which becomes the back of the animal you know, higher animals is called the dorsal side and the lower part is the ventral side.

So, there is a plane of symmetry which passes through the middle of the organism in the anterior posterior direction and this is a vertical plane and on both sides of the plane the animal body is roughly symmetric see it is roughly equivalent on both sides. So, what is interesting is organisms which radial kind of symmetry they do not move much, they do not have a very extreme kind of locomotory capabilities, whereas animals with different body plan, the bilateral the symmetric body plan move lot more.

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So, let us look at 1 more example the earthworm, so which comes into the in the branch of worms.
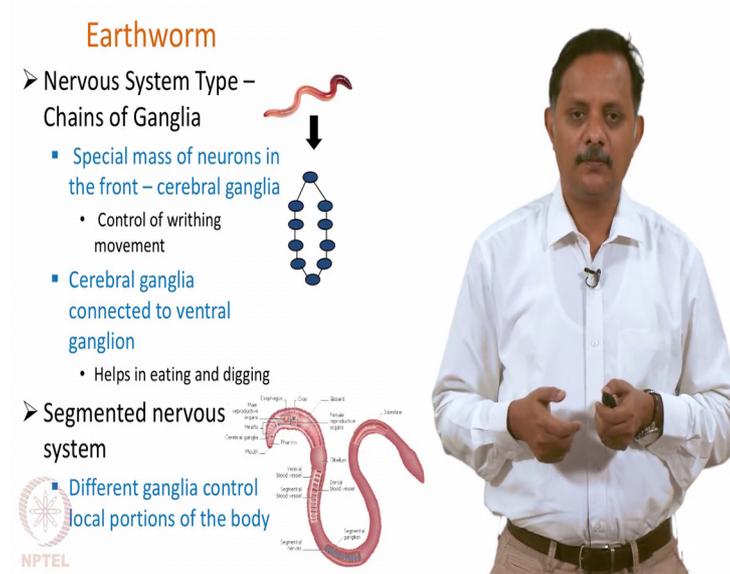
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So, earthworm also has a nervous system, but now the nervous system slightly of a higher kind in evolution and these are called the chains of ganglia. So, here you do not have a diffuse individual neurons distribute all over the body and you know a loosely connected, but these neurons are clumped together into small masses and these masses are called ganglia and they form a chain and you have chains of ganglia kind of nervous system.

So, these ganglia controlled the writhing moments of the earthworm and then typically there is a slightly larger and permanent set of pair of ganglia in the front of the animal close to what you call the head and this helps the organism in eating and digging and then all over the body of the organism there is a chain of ganglia which controls the locomotion, the local control the movements of the local parts of the body.

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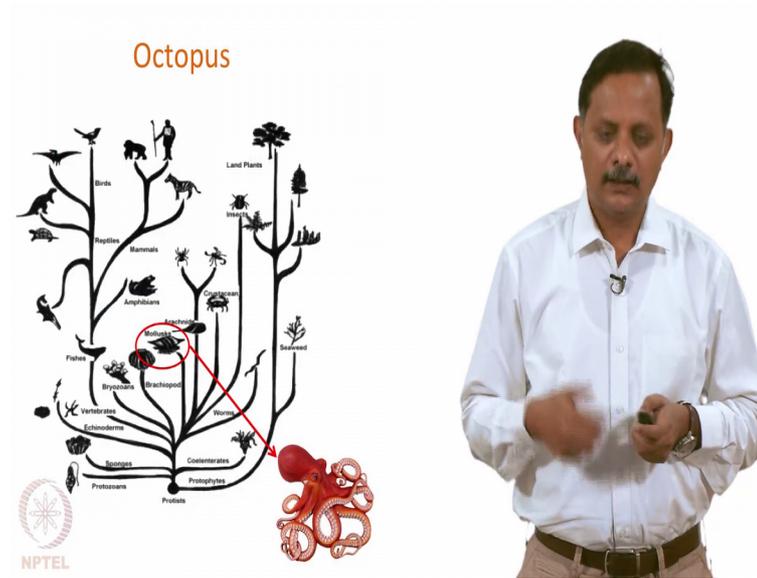
Then, let us look at octopus; octopus is an example of a mollusk.

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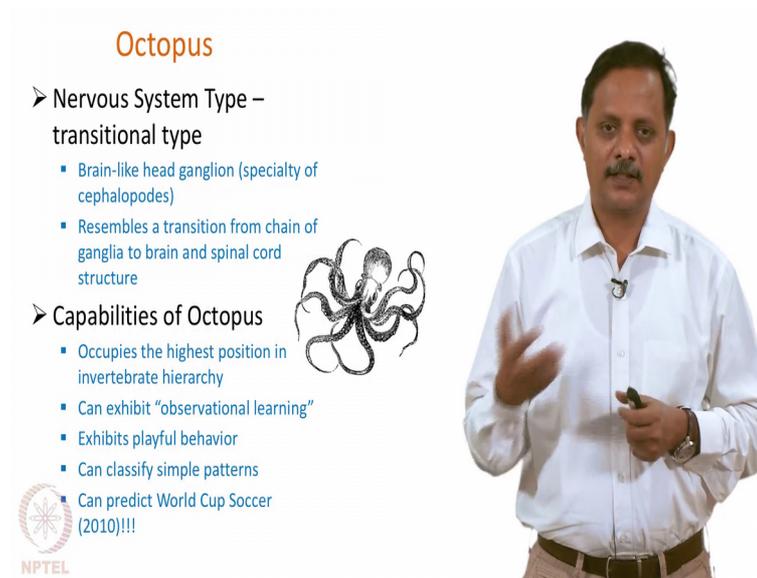
It is a very interesting animal, it is actually pretty smart animal and so the kind nervous system it has is actually a transition between now the previous type of a nervous system where we saw a chain of ganglia and the next kind of our nervous system, where you find a huge clump of neurons forming something like a precursor to the brain that turn on as we know it right. So, it is it has a brain like head ganglia this big and we know it has

the head is called head ganglion and then this seems we represent the transition from the chains of ganglia to the brain like nervous system.

And octopus have exhibit very interesting capabilities; in fact, it is called it occupies highest position there, but invertebrate hierarchy. So, it is a probably one of the smartest organisms in the invertebrate hierarchy, they can exhibit observation learning. So, people have studied behavior of octopuses; in one study they found that they thought 1 or 1 octopus to distinguish between 2 colored balls say red and white.

So, whenever it picked the red ball they gave it a little reward and whenever I picked the white ball to give it a punishment. So, after some exposure to this kind of stimuli, the organism learned to pick up always the red ball; then they allowed another octopus to observe this whole training process.

So, after that, then they presented this 2 balls to the new animal which is has been only observing, but never got directly trained and the new animal also started choosing the red over the white balls. So, this called observation learning, it is considered a very high form of learning and octopuses do observe that, I do exhibit that. Now, they also exhibit playful behavior, so people have shown observed octopuses for example, they throw an object into flowing water and then pick it up back, again with tentacles throw it again pick it up back, so this kind of have activity does not serve any purpose.

So, that is like playing, the octopus is just having fun and then they can classify simple patterns and an extreme example of this kind of a thing actually or even an absurd example; as octopuses have been used to predict the winners of world cup soccer in 2010 and in this octopus called Paul, had actually predicted the winner quite correctly. So, that might be you know just a joke, but they do exhibit very interesting and very intelligent behavior.
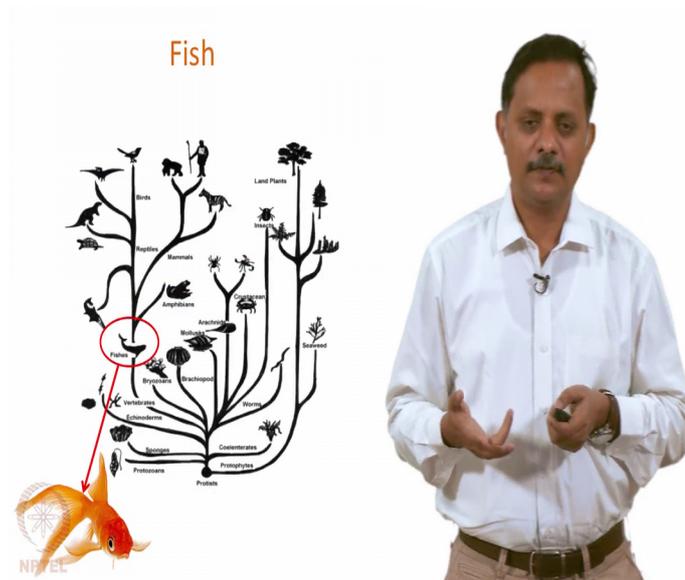
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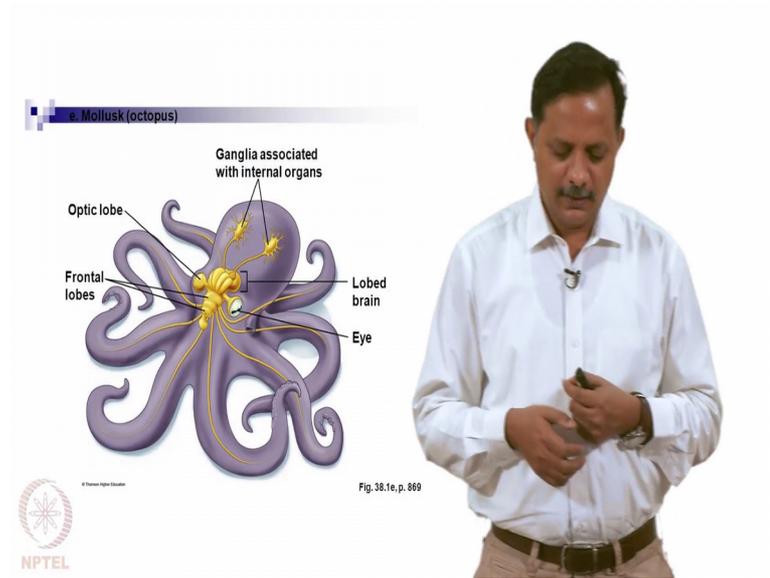
So, this is the, this picture shows the kind of nervous some organization of opposite it has, a brain like central mass of neurons right whether you do not have, you do not see those kind of chains of little ganglia all over the body, but they all come together into a big concentrated mass of neurons and from there you have you know strands of neural tissue, these are reminiscent of what we now know as spinal cord in higher animals and these trends have nerve neural tissue run along the end all the tentacles are in control the movements of the tentacles.

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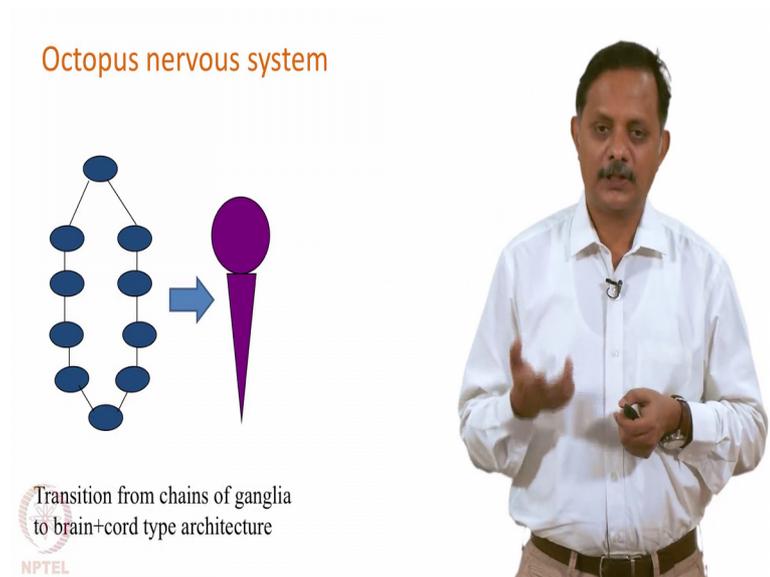
So, octopus nervous system presents a transition from the chains of ganglia to what is called a brain and spinal cord like type nervous system.

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Now, let us look at fish. So, in fish you have entered the vertebrate branch and one of the lowest organisms in the vertebrate scale.

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You do not think much of a fish's intelligence, but that is what people thought for a long time, but recent studies have shown that fish also are very intelligent for example; they can learn to navigate mazes. So, maze learning is something that we attribute to higher

mammals. So, there is a lot of maze learning studies that are done on rats and mice for example, so if you leave a rat in a complicated maze and it runs around for a little while and then learns their route to escape from the maze outside. So, a lot of studies have been done in a part of the brain called hippocampus in refuges there in mammals is thought to contribute to this kind of a learning.

But even goldfish were shown to be able to learn mazes and find the way around in mazes, so the exhibit spatial learning which is thought to be present only in higher mammals.

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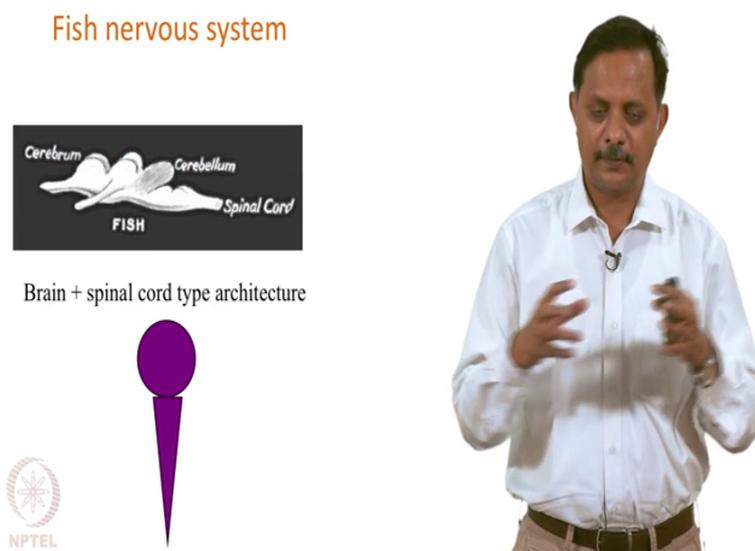
So, in fish nervous system again you see an brain spinal cord, kind of structure obviously, the brain is very small, the fish itself is very small, but in the brain you see again small sub structures appearing, it is not just like 1 big mass of neurons, but you see the little bumps right the 2 bumps and then the very front of it the anterior end and there the form the cerebrum right which bit, which is what we understand is brain in a higher in humans and then after that you see the another bigger bump called the cerebellum, which is which you see all through the a mammalian hierarchies in the nervous system and at the end you have a spinal cord.
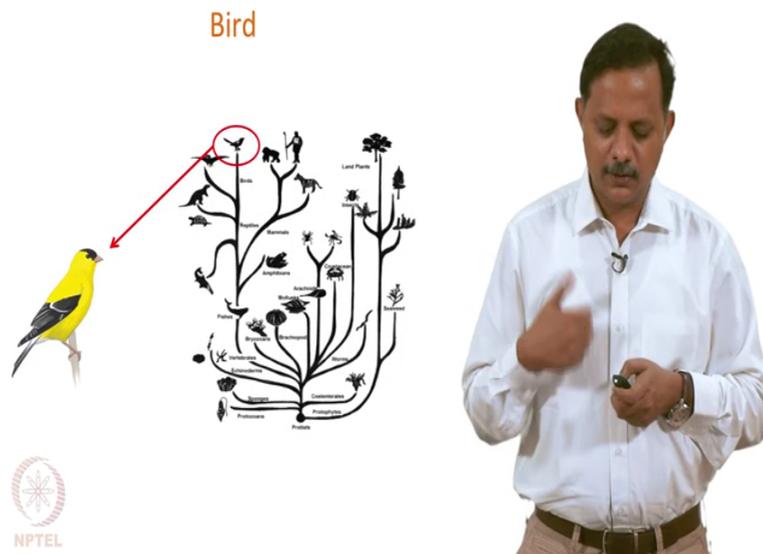
So, then let us go up a little bit along the vertebrate hierarchy and go where the reptile branch and then go to the end of it and we have birds. Now, birds are also generally not thought to be very intelligent. In fact, we want to insult somebody you say the person has a bird brain.

But, actually that is also not quite true and you know studies over the last few decades have shown that birds are very intelligent and they have a great in spinal cord kind of a nervous system, one thing is the brain is small and as small bird and when multiple

proportions is larger because as you go to higher mammals you will find that the relative mass of brain increases with respect to spinal cord. So, it does not have what is like structure like cortex which is there in mammalian brains, but equivalent to that it has what is called a pallium, a kind of expanded portion of the brain in the forebrain.

So, you can see that this is the cerebellum, where this call the pallium and then birds exhibit a very complex intelligent behaviors for example, birds can sing and also teach, they can teach singing to their young. So, this is what is called a deuter bird, which can be a parent bird or some other elder bird which teaches a young bird how to sing and the young birds also can improvise.

So, they learn a few syllables and then they can string the syllables together in various sequences and come up with new songs, songs that are not taught by their elders, it is almost like a in a classical musician improvising and the singing in alap, they can imitate each other what is called duetting, when they have very rich pattern classification capabilities for example, pigeons were found to classify over 700 patterns, which is a very large number and birds also can count.

So, for example, crows were found to count up to 3, which is not much when parrots up to 6, cormorants up to 8 and a green heron it was found can throw a piece of bread as a bait to catch fish. So, to use a third object to interact with the second object in certain way is considered very smart.

So, or a wedge tailed eagle can use stones to break eggs, again we see the same thing use the 3rd object to act on a second object, that is called tool use and tool use is something that is, that marks a very great stage in human evolution and people have learned to make weapons by sharpening sticks or stones and that was considered a great stage in human evolution. Well, later on people found that even chimps can show that kind of behavior they show tool use, the tool use is continually considered a sign of intelligence in the animal world. So, even birds can show tool use.

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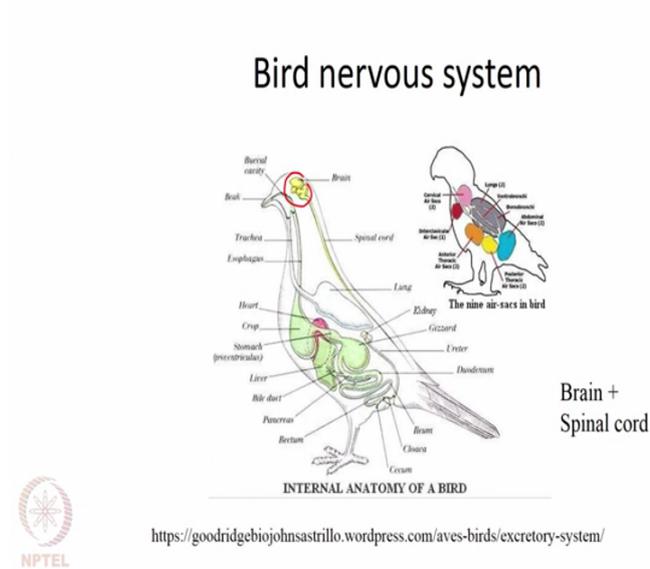
So, again you can see here that the brain of the bird, nervous system of the birds have this brain and this cord kind of a structure. So, if you look at the brains of this last 3 organisms that we have encountered the fish, reptile and a bird.

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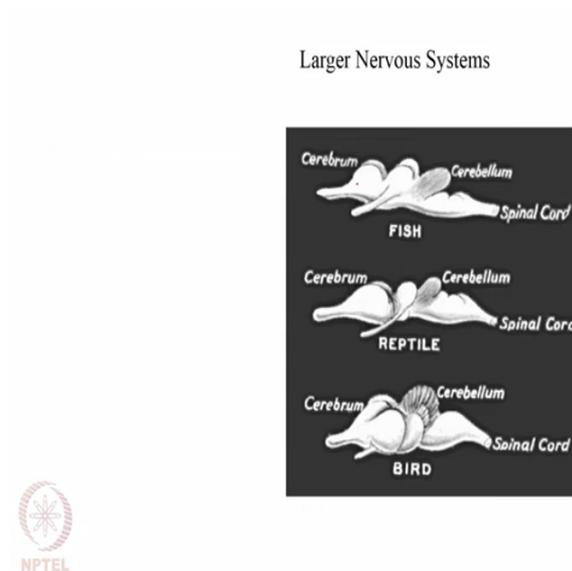
So, you see all of them have a brain spinal cord kind of a nervous system and if you go higher and higher up you see that the cerebrum part of the nervous system gets bigger and bigger, so will see that more as you go to mammals.

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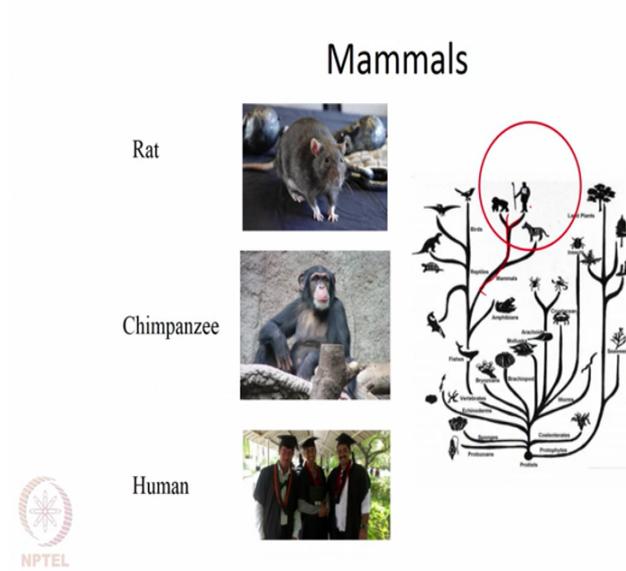
So, let us look at some mammals. So, we have rats, chimpanzee and the humans. So, these are located in this branch of there were tree of life.

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So, rats again they have a brain spinal cord, kind of a nervous system they are very complex, they can expert very complex capabilities, they can learn mazes, the they can distinguish between cardinality and ordinality. So, cardinalities numbers that is 1, 2, 3 it is a question of magnitude, whereas ordinality 1st, 2nd, 3rd is a question of sequence, as you for example, a 1st house or a 2nd house or a 3rd house in a street, that is ordinality.

Cardinality is basically like 1 apple, 2 apples, 3 apples is this cardinality. So, rats were able to distinguish between these 2 kinds of concepts; some rats also were shown were found to use pesticide some kind of a chemical, which will keep bugs off the beds. So, that is a some example of a tool use.

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Volume: Comparative Data

	Proportion by Volume (%)	
	Rat	Human
Cerebral Cortex	31	77
Diencephalon	7	4
Midbrain	6	4
Hindbrain	7	2
Cerebellum	10	10
Spinal Cord	35	2

(Trends in Neuroscience, November 1995)

Now, when you go from rats to humans one thing that you notice is the they there both have obviously, the brain and spinal cord kind of structure, but in rats the relative volume of brain is smaller than in humans for example, the volume of cerebral cortex, the surface of the brain is 31 percent in rat, well humans had 77 percent.

So you see although both have brain spinal cord kind of structure, the brain part gets larger in humans compared to rats. So, chimpanzee house has also a brain span caught, but the nervous brain volume starts increasing that compared to it is lower mammalian cousins.

So, capabilities you know chimpanzee use to show tool use and in fact, this was discovered almost half a century ago by Jane Goodall, who traveled from Europe to Africa to study the behavior of chimpanzees. When she first saw a chimpanzee sticking a kind a piece of twig, a twig into a pit an ant pit and a termite pit and so, when the chimpanzee pulled out that twig and there were termites stuck to the entire twig and it could eat the termites. So, it is using a twig as a tool to access the termites.

So, that is an example of tool use and was a big revelation at the time when she discovered that and later on (Refer Time: 20:18) was discovered and chimpanzees also have an excellent working memory capabilities, they could learn sign language because they do not have the vocal apparatus to produce human like sounds, but they can learn sign language by signing with their hands and by gestures.

So, 1 particular animal which was trained on sign language it is called Washoe could learn 132 words using signs and Washoe was also allowed to adopt a smaller chimp and the then this. So, the Washoe was able to teach the smaller chimp; the adopted chimp a lot of these words without any human intervention. Therefore, that is bordering on what a human being or a civilized human being is capable of doing.
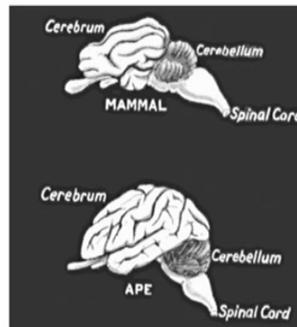
So, if you look at this cerebrum in an organism which is below the mammalian branch it looks very smooth where have been well rounded, whereas the cerebral cerebrum in mammals starts showing all this convolution this force. So, this force increase the surface area of the brain and surface area of the brain in mammals as this sheet of neurons called the cortex and the more greater the number of force the bigger the area of this sheet and that seems to be correlated with the kind of intelligence that the organism which own which has it is capable of expensive. So, whereas, in ape again there is a cerebrum, but it has greater force and it is bigger in volume and yet this trend continues all the way up to humans.

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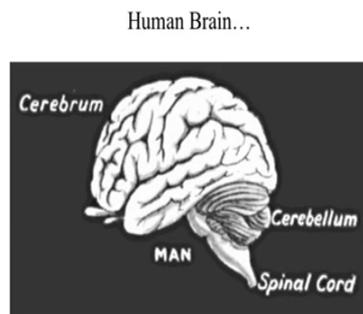
So, in humans again there is cerebrum and so on when their folds and the folds are lot thicker and deeper and more complex giving us a very high cortical area.

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So, here again the minimum wire principal is satisfied. So, if you apply the minimum wire principal to this these brains, can we explain the organization or the emergence of these different types of nervous systems.

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So, that is some people working the minimum wire principle can we show how we can go from the nerve nets or the diffused nerve nets, when you have a small number of

neurons in nervous system, whereas as you add more and more neurons as nervous system grows in size with more and more neurons, nervous system does it actually evolve into chains of ganglia and cortices and brains and cords and so on so forth, let us look at that.

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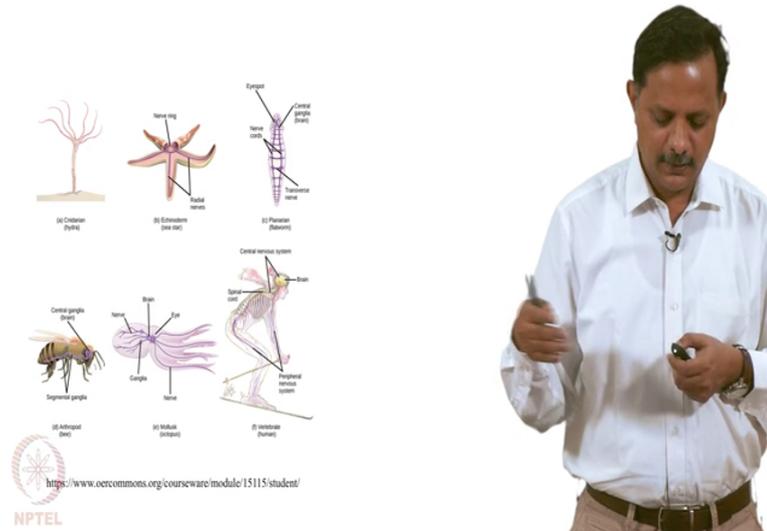
So, some of the different organizations that we have seen, in the discussion so far is in hydra which is a cnidarians, which has a diffuse nerve net, then a sea star which has a central ring, but does not have a kind of a brain proper, does not have a concentrated mass in the center, just as a ring like structure of neurons and then there are these strings of strands of nerve tissue going out, in order into it is along it is tentacles, then you have planarian which has chains of ganglia. So, then bee also has a segmental ganglia, a mollusk has a beginning of a centralized brain and then if you look at other birds and fish and reptiles they all have a centralized brain spinal cord and then, mammals also have some similar a nervous system.

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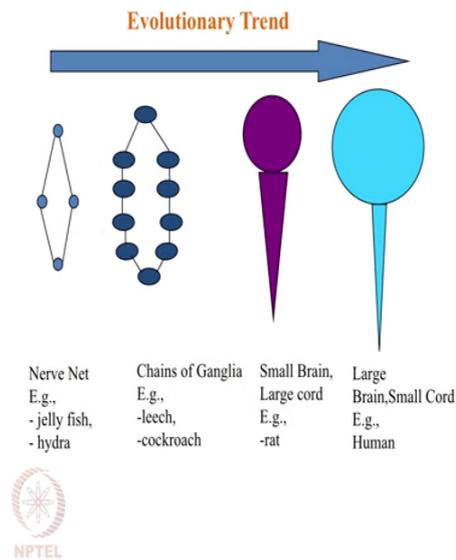
We have broadly seen 4 kinds of nervous system a chains of the diffuse nerve net chains of ganglia, brain spinal cord where this the brain part is smaller spine cord is bigger. So, a small brain large cord and later on it becomes a large brain and small cord.

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So, can we explain the evolution of these different types of nervous system by knowing the save wire principle.

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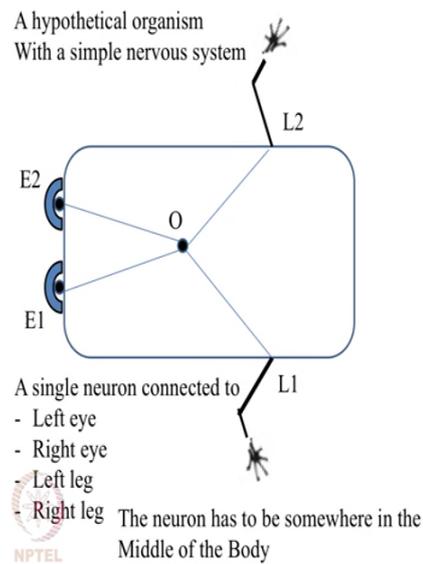
So, let us look at a kind of a hypothetical organism. So, you have just box like animal, which has 2 eyes in the front, in the anterior and it has 2 legs and will endow it with a single neuron, let us start with a very simple of simple nervous system which has single neuron and this neuron is connected to both the eyes E1 and E2 and is also connected to both the legs L1 and L2.

So, if you invoke the minimum wire principle, where would this neuron be? So, you can see that it should be somewhere in the middle. So, there is a total length of all the wires connecting neuron to the ends of the body that becomes minimum because if you take this neuron too close to the eyes and the length to the legs becomes longer. So, that would not be minimum or if on the other hand you take it too close to the legs length eyes becomes much longer and on the whole it would not minimum. So, it should be somewhere in the middle.

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A hypothetical organism
With a simple nervous system

L2

E2

O

E1

L1

A single neuron connected to
- Left eye (with 2 fibers)
- Right eye (with 2 fibers)
- Left leg (with 1 fiber)
- Right leg (with 1 fiber)   The neuron has to be Closer to
the eyes

NPTEL
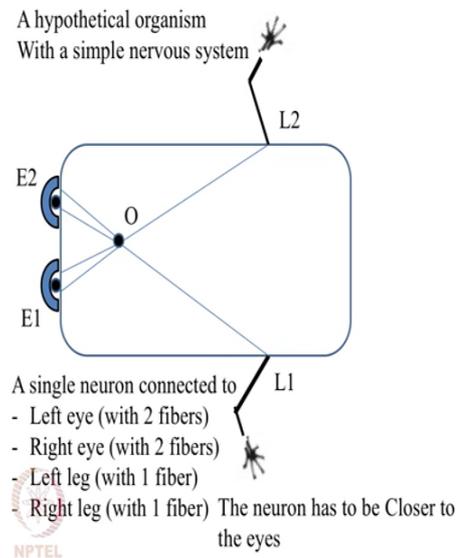
But then, what happens if you have more wires connecting the neuron to the eyes as opposed to the legs. So, we have seen this, this is kind of anterior posterior nerve fiber ratio generally much higher than 1.

So, for example, in humans we saw that it is about 5 in the previous segment of this lecture. So, like that if there are more wires connecting to the front as supposed to the legs. So, then what happens? So, since the more wires connecting to the eyes, right if the neuron is too far from the eyes you will end up with lots of wire. So, you have to move the neuron as far as possible as close as possible to the eyes. So, that the overall wire length is minimized. So, you see it starts saying some kind of a brain or some kind of a concentration of neurons close to the sense organs right, giving rise to some kind of brain like structure in the head.

A hypothetical organism
With a simple nervous system

L2

E2

0

E1

Two neurons, each connected to
- Left eye (with 2 fibers)
- Right eye (with 2 fibers)
- Left leg (with 1 fiber)
- Right leg (with 1 fiber)

L1

The two neurons Clump together
Close to the eyes

NPTEL
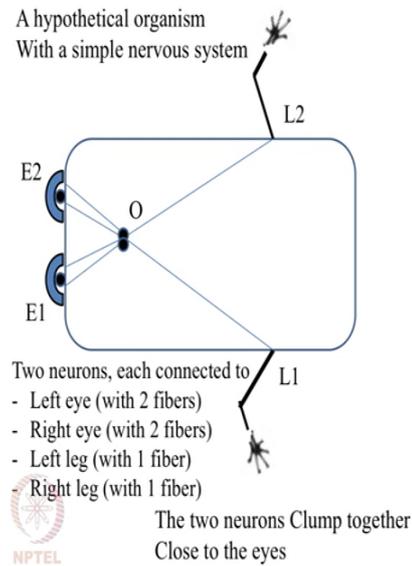
Now, imagine that you saw 1 neuron which is very silly, let us have more neurons, let us have 2 neurons there are 2 neurons, but both neurons have the same kind of connectivity. So, both neurons are connected to both the eyes in the same way, each eye each neuron is connected to each eye with 2 wires and each neuron is connected to both the legs with only 1 wire each. So, then again since the problem is same as the previous problem it is just that we are repeating it; we are posing it 2 times. So, the same solution applicable to both the neurons, so, both neurons will be at the same location.

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L2

E2

0

E1

There are two neurons:
Neuron #1: connected to
- Left eye (with 1 fibers)
- Right eye (with 1 fibers)
- Neuron #2 (with 1 fiber)
Neuron #2: connected to
- Left leg (with 1 fibers)
- Right leg (with 1 fibers)
- Neuron #1 (with 1 fiber)

L1
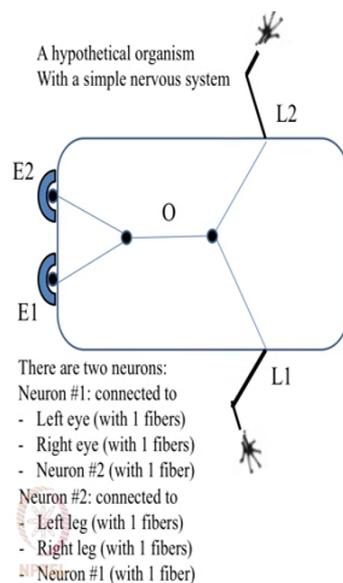
So, you see that then this they start clumping, so that is how ganglia start emerging, then look at let us just we have decide different situation you have 2 neurons, but the 2 are connected differently to the 2 different parts of the body.

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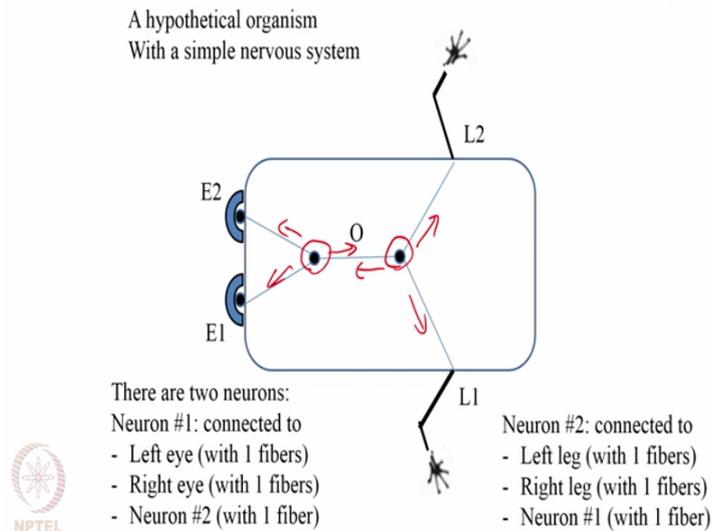
So, there is 1 neuron here, right here, right which is connected to the 2 eyes with 1 fiber each and then there is another neuron which is connected to the 2 legs at 1 fiber each and this 2 neurons are connected again. So, with this kind of a nervous system we how would you, where would you place the neurons.

So, basically what is happening here is, when you try to minimize a wire with wire length to some target yeah, right you are trying to move towards the target. So, in this case the given neuron is basically is attracted right, by the eyes. So, the neuron here is attracted by the 2 eyes in some sense because it is trying to minimize a wire length and it is also attracted towards other neuron because it is trying to minimize this wire length also.

So, it is under these conflicting forces, it will try to attain some kind of equilibrium position. The same thing is being done by the other neuron also; it is being attracted to the 2 legs and is also attracted to the other neurons. So, this what happens generally in nervous systems 1 of the neurons are connected to each other therefore, they try to be as suppose as possible to each other, but they are also connected to the end organs, the sense organs are motor organs on the surface of the body. So, they also try to move closer

to the surface of the body. So, these 2 forces shape the overall organization of the body of the nervous system.

So, if you have, some more neurons right and then with a slightly different connectivity for example, here we are introducing bilaterality, the effects of bilaterality of the body on the nervous system.

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A hypothetical organism
With a simple nervous system
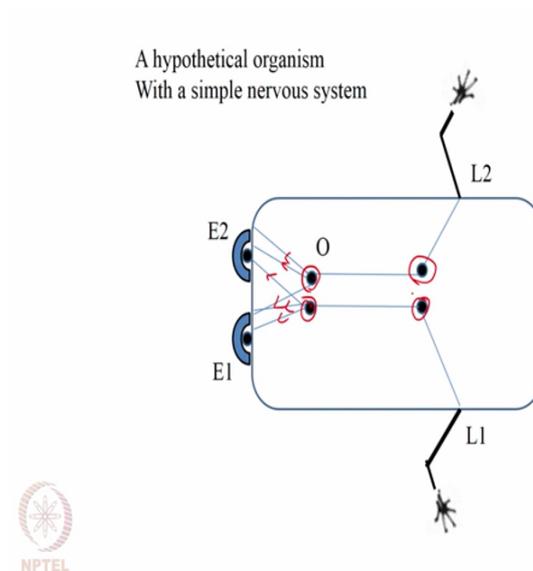
So, in this case I have 2 neurons here, this nerve is connected to the E2, eye E2 with 2 fibers and like this and which is connected to the eye E1 with only 1 fiber and similarly, this eye, this neuron is connected to E2 with only 1 fiber, but it is connected to E1 with 2 fibers. So, therefore, this need not be try to stay closer to E1, but slightly further away from E2 and this one will try to stay closer to E2, but further from E1.

So, you see that both neurons will start moving slightly to the sides of the body giving the nervous system a kind of a bilateral structure. So, the bilateral organization of the body seems to lead to a bilateral organization of the brain also. So, similarly you can see some kind of a bilaterality, even in the neurons which control the legs.

➢ When the Save Wire Principle is applied:
➢ Depending on the number of neurons and
➢ Their connectivity to:
  ▪ Other neurons, and
  ▪ To sensory and motor organs
➢ The nervous system takes on a certain organization

Well, these are very simple, highly simplified artificial situations so, but you can imagine how the same kind of principles could be operating in the evolution of and in the shaping the dual nervous systems in real organisms. So, we did some simple simulations to know, to make the type of this point most strongly.

Diffuse net
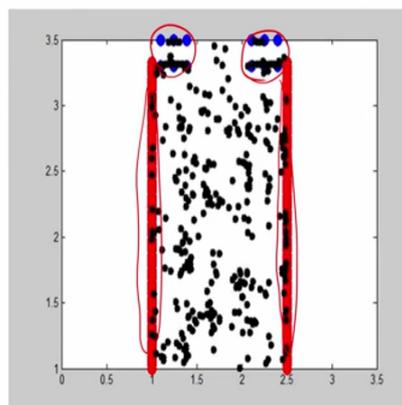
$$\sigma_x = 0.08$$
$$\sigma_y = 0.08$$

So, in this simulations, which was done by my student Karthik. So, we have taken this kind of a simplified ideal organisms like a box a like a rectangle and the blue dots in the front are like the sense organs can call them whatever you can call them eyes, ears,

whatever and the red dots on the right on both sides are like legs of example the caterpillars legs, you have legs now along the body of length of the body on both sides.

Now, the black dots in the center are like neurons, there lots of neurons and then we have 2 parameters sigma x and sigma y, which you can see on the right side, I am not going to explain the equations and because in this course I promise that I am not going to use much mathematics.

So, we start off with some random initial locations of the neurons and let them run around, let them follow these 2 constraints that is each neuron is attracted towards the sense organs in the front and towards the motor organs on the right and left and towards each other and then wherever these attractions lead them and the and lead to some kind of liquid even for the equilibrium position, that is where the simulation stops.

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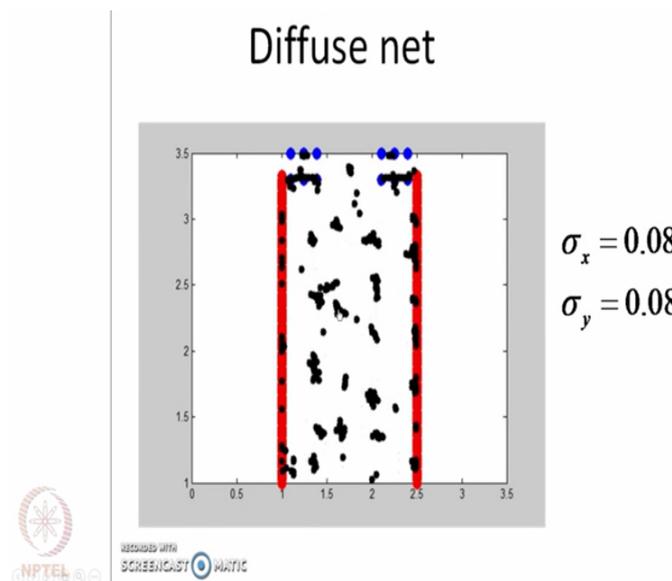
So, let us see what happens. So, you see that neurons have come together they form clumps, but these clumps are all over the place, it is like a diffuse nerve net. So, then let us look at the next example.

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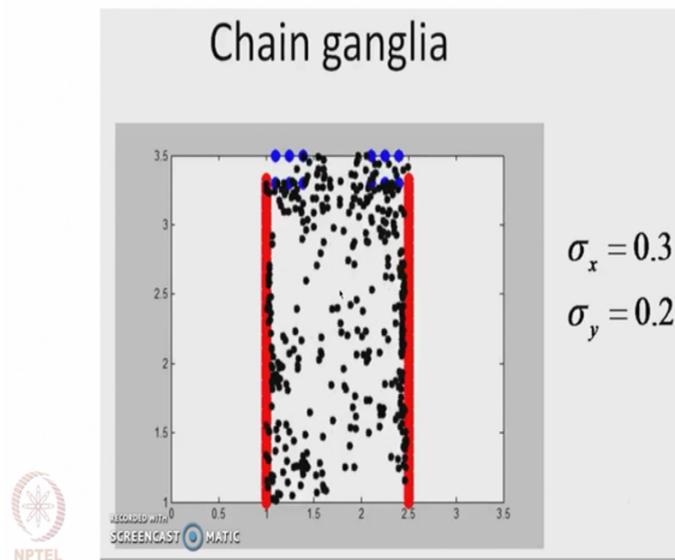
So, here again we change this sigma x sigma y slightly and same did the same simulation again in this case something interesting happens.

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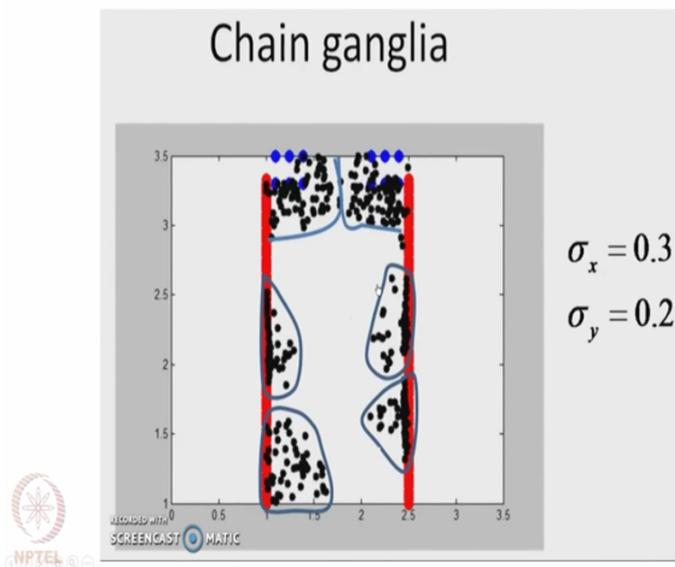
This clumps are formed, but they did not get considered in this middle of the body, they kind of move to the sides of the body. In fact, the lining up into small clusters along on the 2 sides of the body, which is vaguely reminiscent of the chains of ganglia that you see in a lot of invertebrates, the 2 parallel chains of ganglia 1 and which are bilaterally organized right 1 on the left and 1 on the right.

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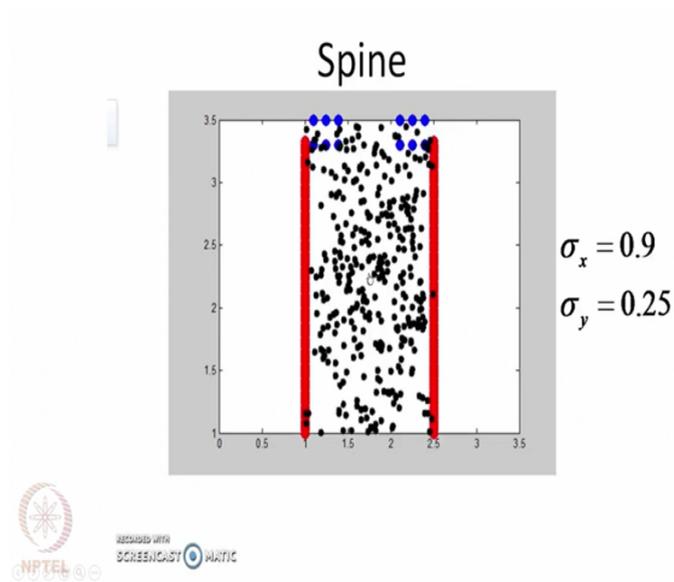
Then, let us look at the 3rd kind with brain spinal cord kind of thing.

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So, in this case again we change a parameter slightly, in this case instead of going the neurons instead of clumping to the 2 walls to the sides of the organism, they come to the middle right forming some which is a va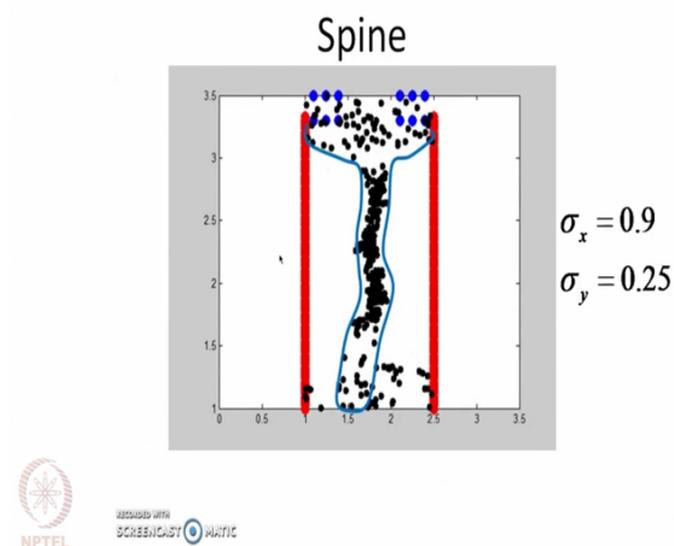guely reminiscent of some kind of a spinal cord, at the top you have another big distribution or a cluster of neurons, so these black dots right and that is reminiscent of our brain. So, let us look at a simulation 1 more time. So, I said you have all this agglomeration center, which looks like a spine and big mass

which is at the top which looks like the brain. So, you can kind of anticipate how the real nervous system are evolved, simply by trying to minimize the wire length for the given organism.

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Summary

- Nervous systems serve as <u>communication network</u> that enables the body to respond as a WHOLE and react to the shocks of the world efficiently.
- Nervous systems evolved through 4 broad architectures in evolution.
  - Diffuse nerve net → chains of ganglia → small brain, large spinal cod → large brain spinal cord
- Organisms endowed with "higher" type of nervous system architecture, can exhibit a greater "intelligence."
- Traditional evolutionary scales and the hierarchies of nervous system architecture, are not tightly correlated.
- Therefore, it is not easy to make a more precise statement about the link between nervous system architecture and intelligence

To summarize, we have said in the very beginning of this lecture in the in segment 1, the nervous system basically act as communication networks that enable the body to act as a whole to respond as a whole to the inputs coming from the environment. So, they evolved through 4 broad architectures, a diffuse nerve net, then chains of ganglia kind of a nervous system, then a small brain and a large spinal cord and a large brain, small spinal cord.

So, the organisms with the higher type of a nervous system can exhibit greater intelligence; what is higher type? So, for example, a large brain spinal cord, large brain in a small spinal cord is better than a small brain and a large spinal cord and then which is better than it is chains of ganglia kind of nervous system, which again is better than diffuse nerve net.

So, it is a question of what kind of a nervous system an organism has, that will determine what kind of intelligence the organism can exhibit. So, that seems to be a more deciding factor rather than the simple evolutionary scale because I will in evolutionary scales and the hierarchies of nervous system architecture are not tightly correlated, because we have seen that right in the evolution tree, we have seen that that an octopus which is a

mollusk, which is much lower than even vertebrates, can again show intelligent behavior just like a fish or a bird.

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Octopus
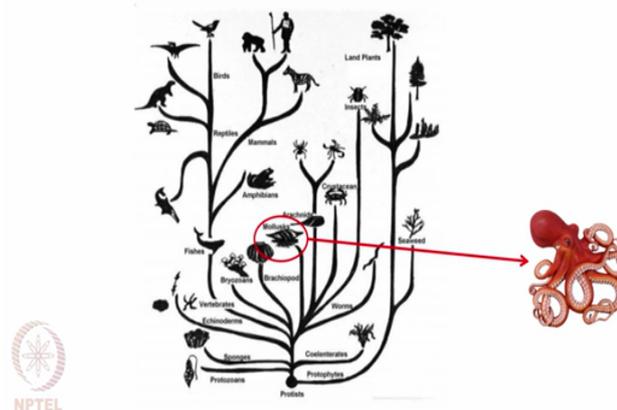
So, the evolutionary hierarchies are not that important, it is the this broad class of nervous systems, the architecture nerve nervous system that determines what can intelligent behavior that organism can exhibit, but having said that it is not easy to make a very precise statement about the link between nervous system architecture and intelligence because first of all what is intelligent is very relative, it depends upon the context the milieu of the petal organism right and so therefore, and it is difficult to quantify that.

So, and then given the complexity of a nervous system, we can we have just seen some patterns, but even that is very hard to quantify and kind of a draw a plot between that number that characterizes the complexity of a brain and a number that characterizes the level of intelligence.

So, because first of all, so we tried to and probably began with a kind of difficult question maybe an impossible question, which is can we understand intelligence completely by a structural analysis of the brain. So, we try to do whatever we can, we try to our best, we have discovered some interesting answers, but it is not enough, probably because it is not a question of gross structure, but something else because if we look at the computer language or computer metaphor, what a computer can do is not determined

by it is hardware, which is also necessary, should we have enough ram, enough hard disk space and then enough sufficiently a powerful processor and so on, but that itself is not enough you need to have software.

So, it comes to a computer we distinguish between a hardware and software. So, in brain also we should learn to distinguish between this true although it is not appropriate to just carry out the same idea. So, brain because in brain the difference between hardware and software is it is not very clear. So, unless we know for the more about brain it is very hard to understand, what makes a very intelligent? So, for that, we need to get into neural activity in the activity of neurons which means the electrical activity of the neurons. So, let us move on to that in the next lecture.

Thank you.