Demystifying the Brain
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Lecture – 11
Maps in the Brain-Segment 1

Ah This is lecture number 6; this lecture is on maps in the brain. So, even in the very first lecture we mentioned that there are these maps in the brain. So, information is often laid out in the form of for two dimensional maps on brain surface. We talked about the somatosensory map or the touch map, how the surface of the body is mapped on to this somatosensory map where nearby points on the on the body surface are mapped on to nearby points on the cortical surface.

Ah We also talked about the motor maps, where ah the entire body is controlled by this maps in the in the motor cortex. So, the left part of the brain controls a you know right part of the body ah. So, if you activate the nearby points in the motor map, you produce movement in the nearby parts on the on the body.

In this lecture we will talk about how these maps are formed as what are the mechanisms. It turns out that although the maps are pretty complex and they are found in many modalities, not just in touch and motor or movement, they can be explained using very simple mechanisms actually the only two rules by which you can explain lot of this map phenomena and that is what we will be looking at in this lecture.

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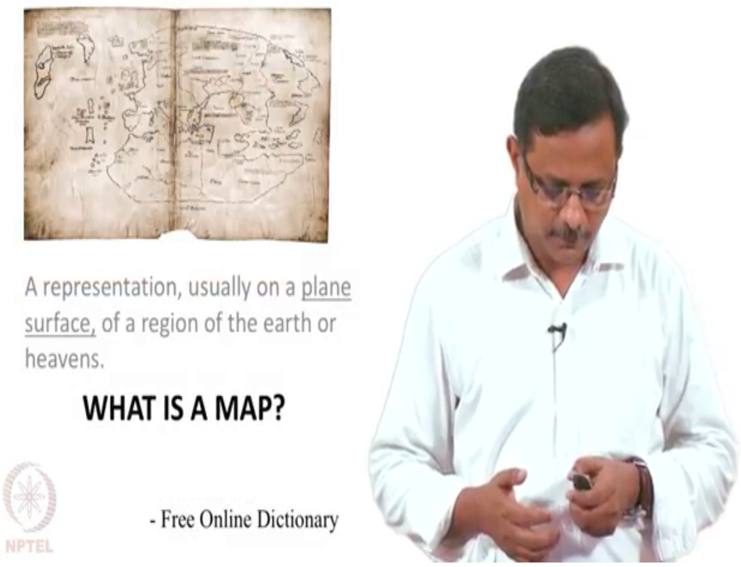

So, first of all let us talk about what is a map right. If you look at the dictionary definition, it is a representation usually on a planar surface of a region of the earth or heavens right. In fact, in this map is a map of the there is a world map right that was popular in Europe in the you know during the dark ages. So, because in those days they did not know much about the rest of the world, they knew that there is Europe and then you only a part of the Africa, the northern parts of Africa they knew that there is China and India in it somewhere towards the east, but right and around and all around they thought there is a large you know world ocean.

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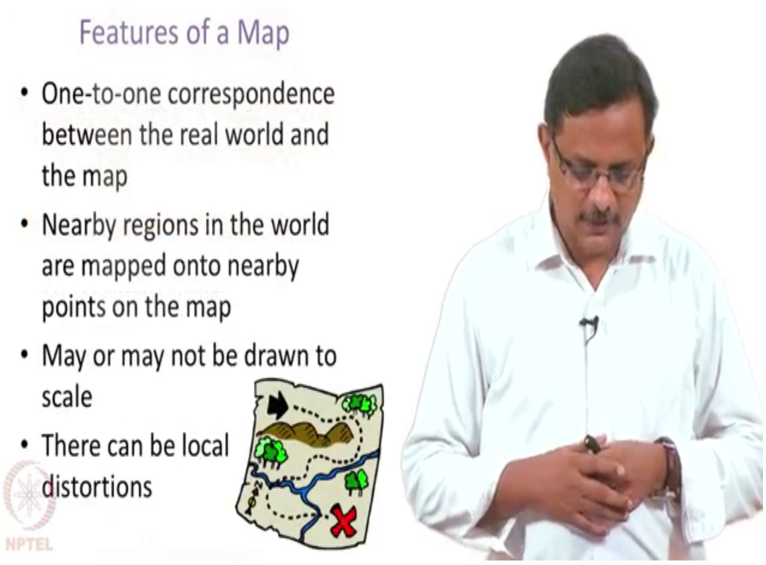

So, ah. So, let us talk about what are the features of them of any map. So, in the map it consists of a one to one correspondence between the real world and the map, and nearby regions in the map are mapped on to a nearby points on the maps map surface. Map may or may not be drawn to scale and also there can be local distortions depending upon your emphasis.

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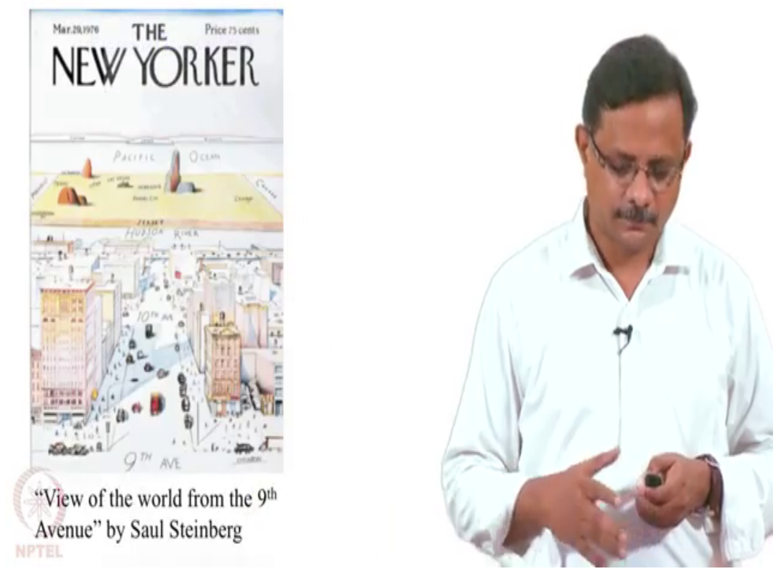

But if you want to emphasize and expand certain parts right then you will introduce a local distortion. A good example of such a distortion which is quite dramatic and even funny is this a map of the world from the ninth avenue of New York this was done by Saul Steinberg.

So, New York has generally you know they think no end of this the city and the thing that is the end of the world. So, in this picture there you can see the ninth avenue in the foreground and behind it you see the tenth avenue, and after that very quickly you see the you know Hudson river and beyond that you see new jersey and you know you see various the American state cities like Las Vegas and states like Utah and you can see Chicago right towards the right and then beyond that you see Pacific Ocean and beyond that you see the eastern world, China and so, on so.

So the point is in this extremely warped picture of the world right the ninth state of New York Manhattan occupies a big area and the entire world is organized around it. So, this is this is a funny illustration of how maps can be very distorted.

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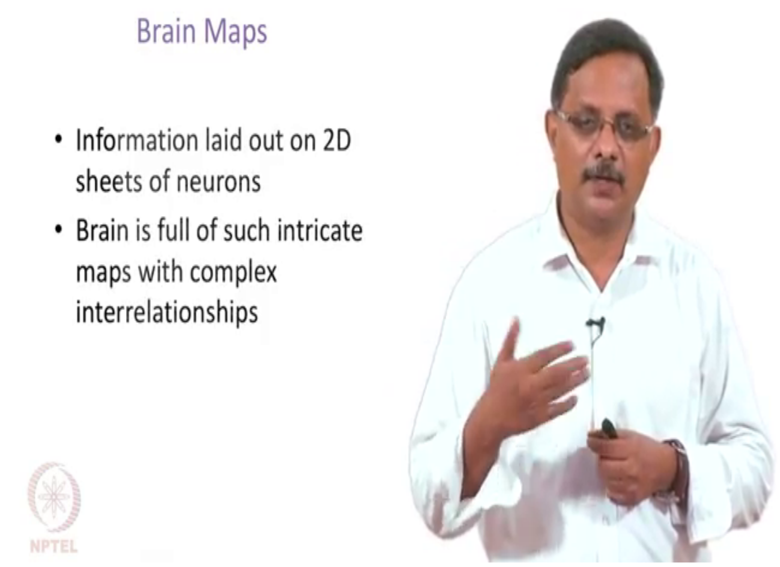

I interestingly see such distortions even in the brain maps different for various reasons. So, brain maps consists of information laid out on 2 D sheets of neurons, they can be they can be cortical maps in fact, the kind of maps we have encountered. So, far are mostly cortical maps, but they can be subcortical map there are many such maps in the brain and very often these maps are interconnected right in complex fashions.

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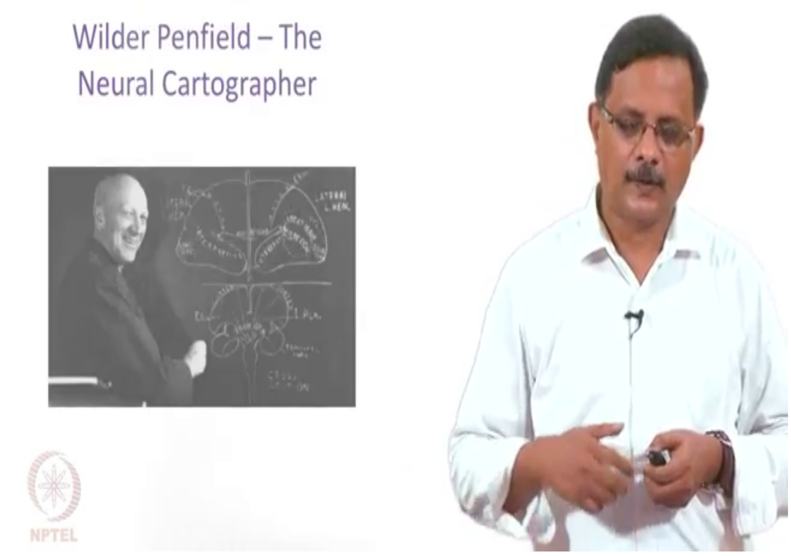

I think we once mentioned before in one of the introductory , maps is build up and field a Canadian neurosurgeon right who is often called the neural cartographer or a neural map maker. So, he did is you know he started his career based on studying certain brain simulation experiments. So, basically lot of his surgeries were addressing the problem of epilepsy, where there is this abnormal activity which starts from a part of the brain and spreads to the you know entire brain, and often the source of this kind of activity is in the temporal lobe.

So, ah; so, the point which is called epileptic focus, now this tissue which acts as a focus anatomically and structure looks similar to the surrounding tissue. So, the only way you can expose the tissue is by you know by functional stimulation.

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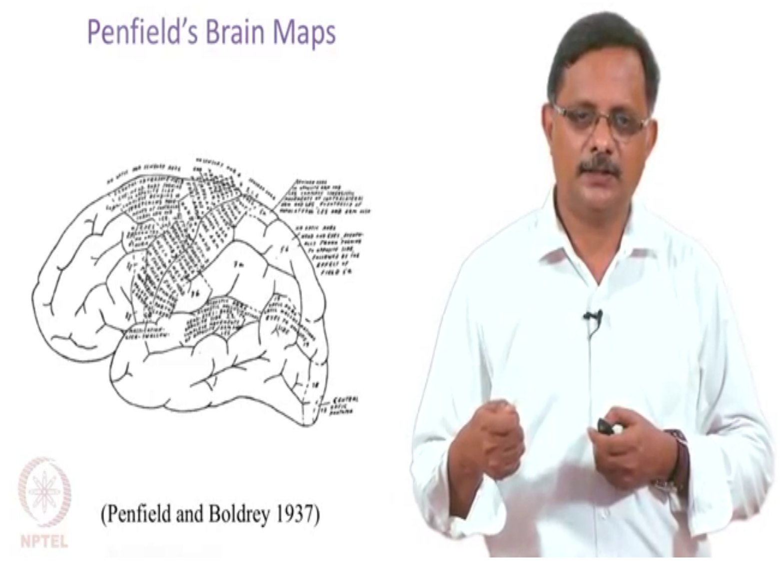

So, a pen feed would go in expose a part of the brain stimulated right to see if stimulation of the given spot gives rise to triggers the epileptic seizures. So, in the process is similar to various parts of the brain and found that very often information is laid out or organized in the form of maps and he would draw pictures like this right.

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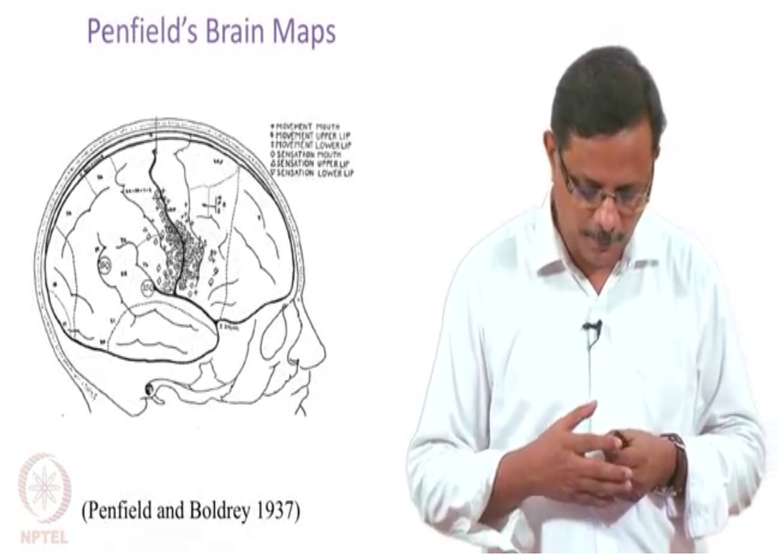

So, so in this picture you can see know some somatosensory maps, the auditory maps in the superior temporal area then the motor maps and you know and so on so forth.

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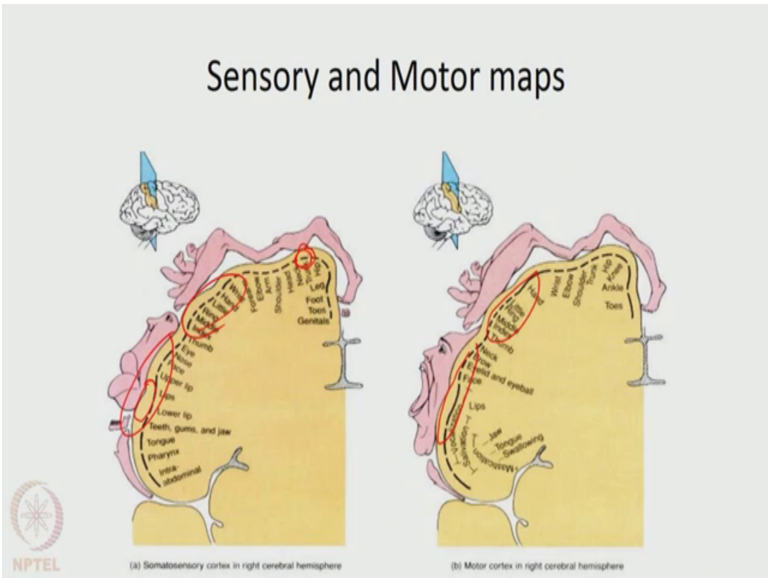

So, more modern portraits of the maps look something like this. So, on the left ear you see the somatosensory cortex, and you see how the whole body surface is mapped on to the brain surface here the somatosensory cortex as we have once mentioned before is in the postcentral gyrus. So, here you see the hand is mapped and on to on this region an entire face is mapped onto this region and what is interesting is, the trunk which is a very big area right is only this small region right and so on and so forth.

So, the; so, it is a highly distorted map because the hand which is actually has a very small area is mapped onto a very large cortical surface whereas, trunk which is actually a very large area is mapped onto a very small part of the cortical surface and so on and also in the face. A face occupies have big area here even within the face the lips occupy a huge area right which is a very interesting. So, so then again on the motor side you see the motor map on the right side, you see the face here in this area. So, in motor map of the phase involves movement of moments of your jaw, your tongue, your lips and other you know facial muscles.

So, the hand also even the motor map and is allocated a very big area in the motor map. So, specifically as far as motor maps are concerned although this maps look very clean and you know point to point maps from the body to the to the brain. On the motor side actually maps are not that clean that somewhat more fragmented right compared to the maps of the body surface on the on the side of somatosensory maps.

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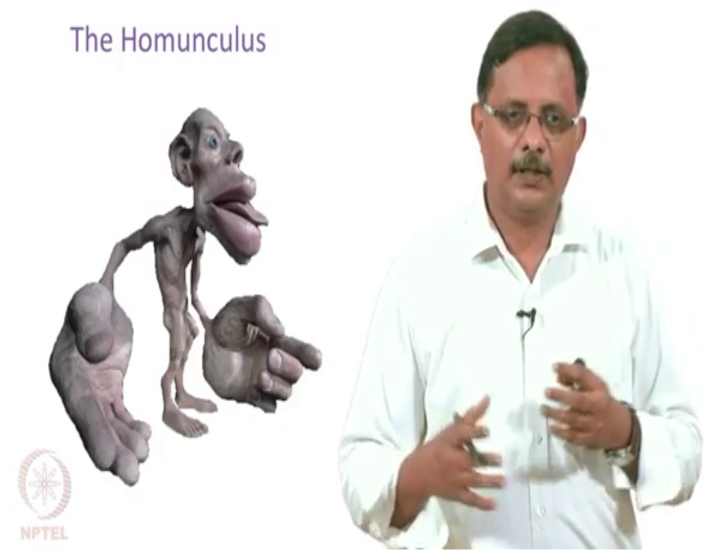

So, people would made all these maps you know after the early discoveries of a pen field, and then they thought that inside the brain there is some kind of a little man right which is which these maps embody and this man this little man is receiving all the input from the external world and operating on them. So, they called this kind of imaginary little man, homunculus homunculus means a little man and they would make little figurines of this kind of imaginary imaginary ah persons right and this these figurines would decorate the tables of neuroscientists, and this kind of thinking about how maps work became very popular, but this is definitely a lower simplification of what the map means.

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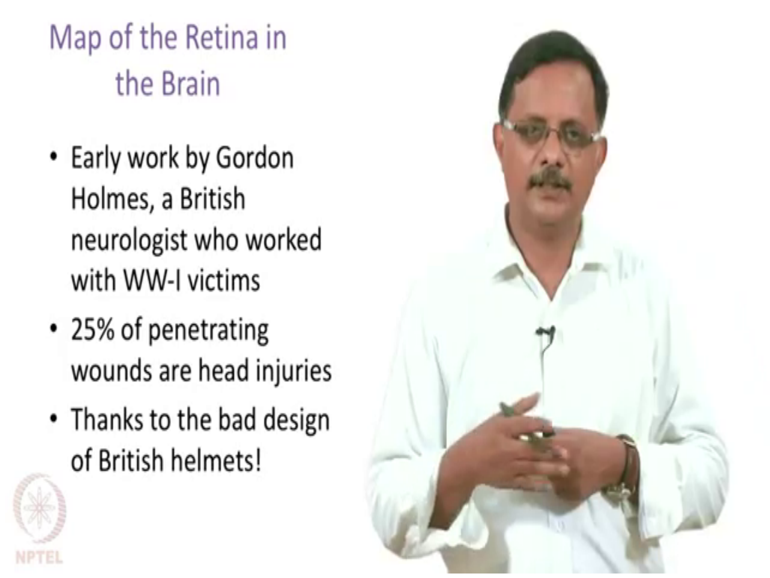

We talked about the maps in the somatosnsory area and the motor maps, but maps can be found in you know any other every other modality. So, for example, there is a visual maps of the retinal image onto the visual cortex. Like some of the ideas work on the visual maps in the brain you know came out of the work of neurologists called Gordon Holmes right he is a British neurologist who worked on World War 1 victims. So, a lot of these soldiers and who are wounded in the war, came back with penetrating wounds you know produced by the shrapnel right of the war and 25 percent of these wounds were head injuries, and you know part of the reason was the bad design of British helmets.

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So, in this figure you can see the British helmet on the top and the German helmet on the in the bottom. So, you can see very clearly that the German helmet is better designed as far as a protection it offers to the you know back of the head. So, you see that exchanged part of the helmet in the bottom right and that really covers the nape of your neck, and whereas, on the British side in the British helmet you do not have that kind of an extension. So, therefore, a lot of these wounds right would affect the back of the head and injured the occipital lobe, which is where you have no visual area.

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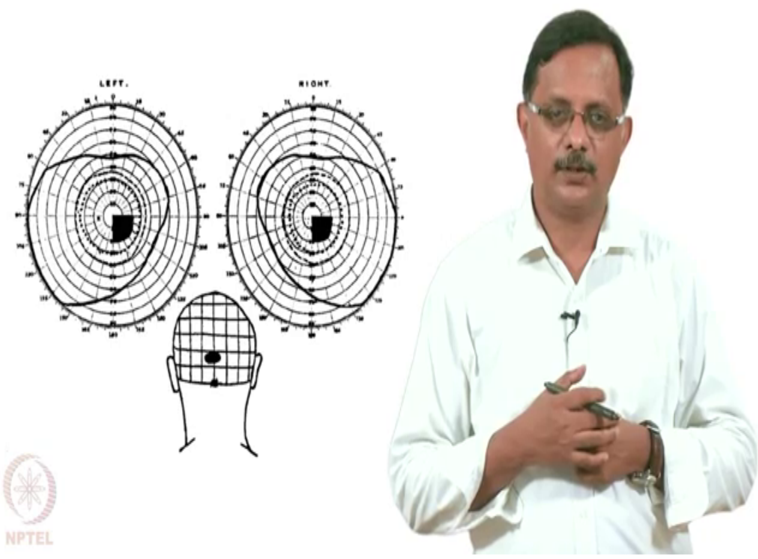

So he would study these patients and look at you know how the vision is impaired because of the wounds that they have in the brain right because of sharpness stuck in the visual cortex and what you found is the, shrapnel is very small right and often like a almost like a pinprick ah.

There is a corresponding deficit in the visual field. So, they would just see a kind of a black dot or a black patch a dark patch in the visual field. So, it is as though the input coming from that part of the image is not being processed by the brain by the visual cortex.

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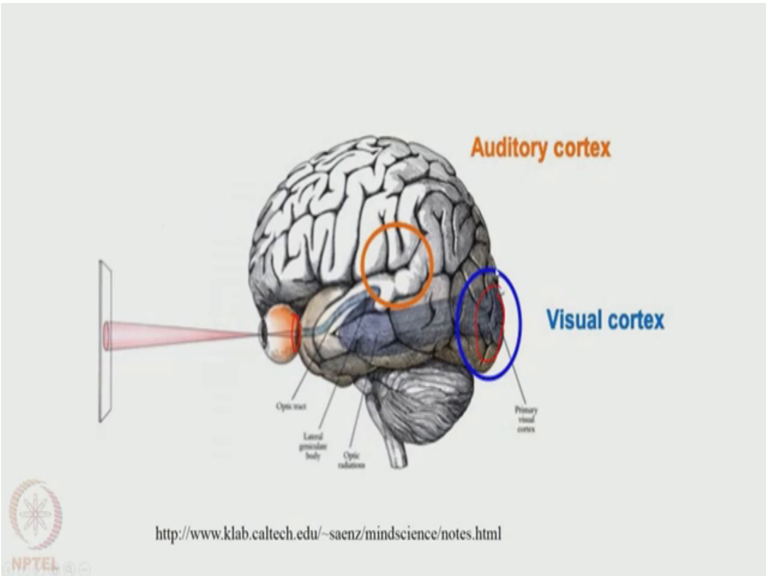

And he also noticed a very interesting relationship between the location of this black spot which is called scotoma and the location of the wound in the visual cortex.

So, if you look at this picture no we have looked at the organization of visual system earlier in some of the earlier lectures. So, if we know that the image now goes to the retina and falls his form is formed on the retina, from there it goes to the thalamus right and from there it goes to the primary visual cortex in the occipital lobe here.

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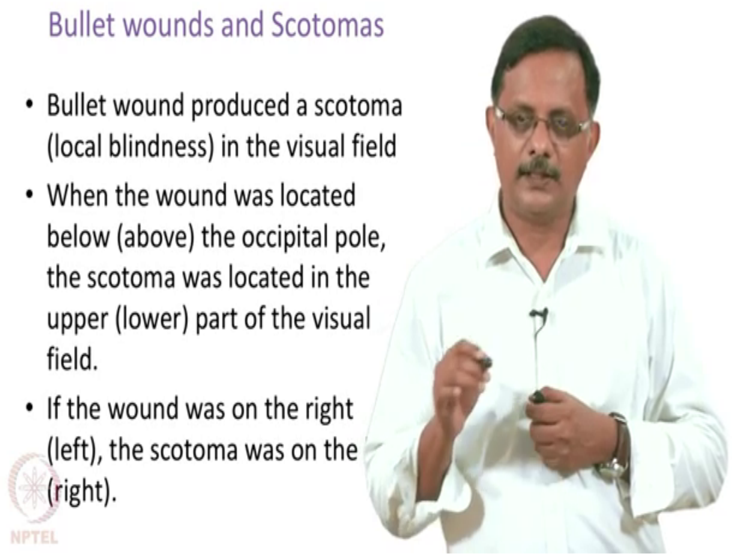

So, what he has noticed is a wound produced in the lower part of the occipital lobe right then the then the corres the corresponding scotoma was located in the upper part of the visual field.

So, if the wound is in the lower part especially below the occipital pole. Occipital pole is basically this tip of this occipital lobe, where there is a sharp extension right. If the wound happens below that then the deficits that you see this scotoma is located in the upper part of the visual field, and if the wound is in the left part of the brain then scotoma was on the right.

So, there is a interesting mapping between the external visual field and the location of the wound in the in the occipital lobe in the cortex. So, later on people studied this mapping between the retinal image, and the visual field and the in the brain surface and these maps are called retinotopic maps. To calculate these maps or to measure these maps people use this kind of interesting grid patterns.

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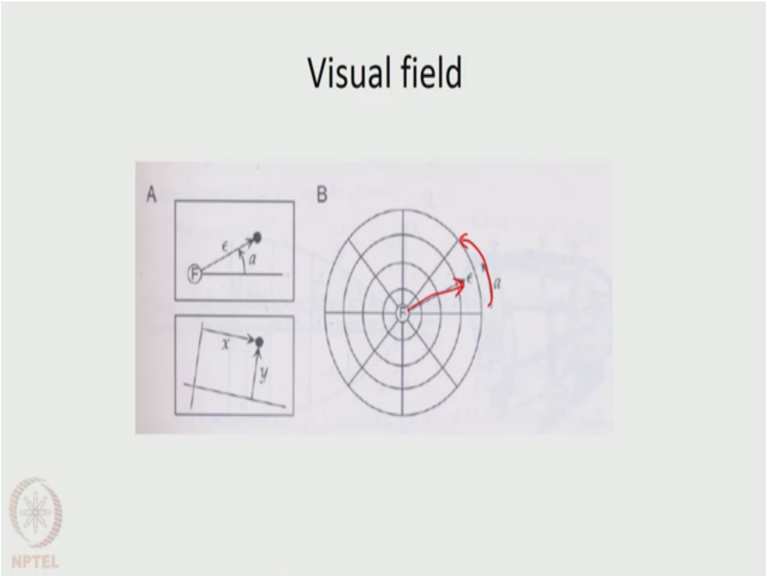

So, in this grid pattern you can see a bunch of concentric circles. So, there are two dimensions with which you can characterize this a given represent any point on these concentric circles. So, there is a radius here which is called eccentricity or denoted by epsilon and then the angle around that goes around the circle which is called azimuth ok.

So, in simple high school mathematics technology, the eccentricity is like the radius and the azimuth is like the angle is like polar coordinates of the visual field.

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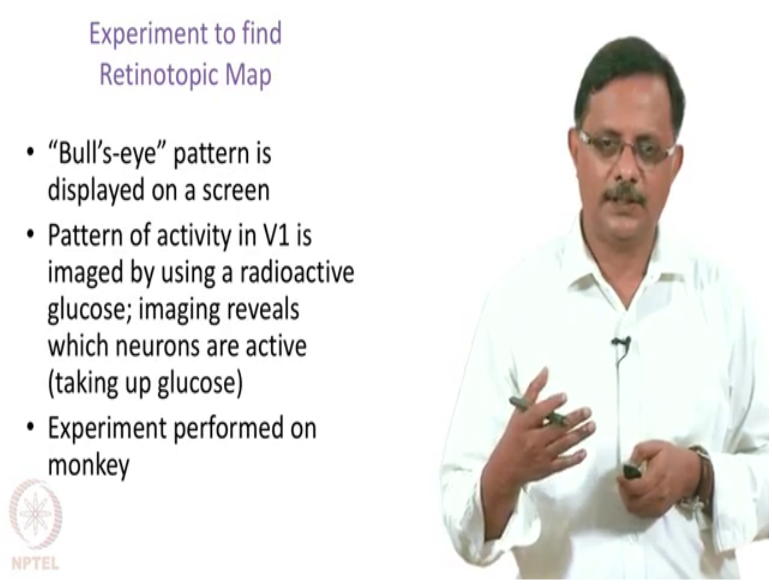

So, this kind of a black and white picture is flashed in front of the animal so, some of these recordings were taken from monkeys monkeys has monkeys have very rich a visual system, which is quite close to human visual system so, very often monkeys or primates are used that exploited animals for studying the visual system.

So, this kind of Bull's-eye pattern was displayed on the screen and the corresponding activity in the primary visual cortex or V 1 is measured using a radioactive glucose. So, basically what they do is they do is they inject radioactive glucose into the bloodstream of the animal ah. So, we; so we know that the neurons of need glucose from the bloodstream to run their firing activity. So, this radioactive of glucose is picked up by active neurons and therefore, wherever neurons are active and they take this tracer know this reductive glucose, which can be seen auto radiograph right. So, that radiograph looks something like this.

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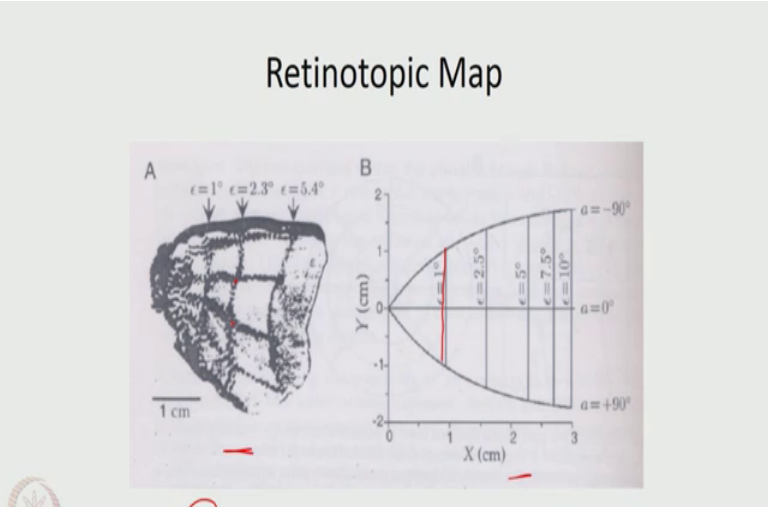

$$Z = \lambda \ln(z); \quad z = (\varepsilon / \varepsilon_0)\exp(-ia)$$

So, on the you know this image on the left side ah. So, the. So, this type bar patterns that you see the grid like you know intersecting lines that you see this radiograph indicate where the neurons are activated because this is these are the points in the brain surface where neurons have taken up the reductive glucose.

So, what is interesting is the image shown to the animal and the pattern of firing of neurons in the in the visual cortex, they do not look very similar you can see a grid like pattern; but it does not look like a kind of a carbon copy of the image that you see in the external world. So in fact, what this x 1 tells you is that the activity pattern of neurons in the in the individual cortex right it does not duplicate what you see out there in the real world, it really transforms it in a very profound ways and then this transformation gets more and more complicated as you go to higher visual areas, which we will you know which we cannot discuss at this point.

. So, ah. So, this grid like pattern can be mathematically presented in a simpler graph like this what you see on the right side. So, what you see here is the eccentricity which is the radius in the input space, in the visual space turns out to be some kind of X coordinate and the azimuth right which is la like the which is the theta or the angle in the power coordinates happens to be the y y coordinate in this space so.

So, the what is radius in the polar becomes x axis in the cortex and what is the angle theta in the polar coordinates becomes y axis in this space in the cortical space. So, this can be expressed using a very interesting formula ah. So, this. So, here z is a complex number, you know those of you who had studied complex algebra in your high school can recollect you know some of this information about complex numbers. So, if z z is a complex number here defined in terms of the eccentricity E epsilon and the azimuth in both a. So, i is the imaginary number purely image number right and so, this formula defines a quantity called z, and z is a complex number which defines a point on the visuals in a visual space.

And given that point this capital Z is a point on the cortical space which you can see like these are this is the points on the cortical space. So, the visual space the cortical space mapping can be defined by this formula lambda lawn Z. So, lawn here is the natural logarithm, but it is a complex lawn function. So, it is a complex transformation from the visual space to cortical space and experimentally people have found that this formula with a small you know with small variation right can explain the retinotopic maps of a large number of species. So, which is very interesting. So, this is one more example how mathematics and the two such an esoteric mathematics you know like complex algebra can be used to explain something. So, deeply biological. So, this is an interesting example of that.

So, now a retinotopic map basically tells you how the visual space is mapped onto the cortical space in the occipital lobe in the primary visual cortex. Now let us look at the response of single neurons and how what kind of maps they found right about the visual about the visual input.

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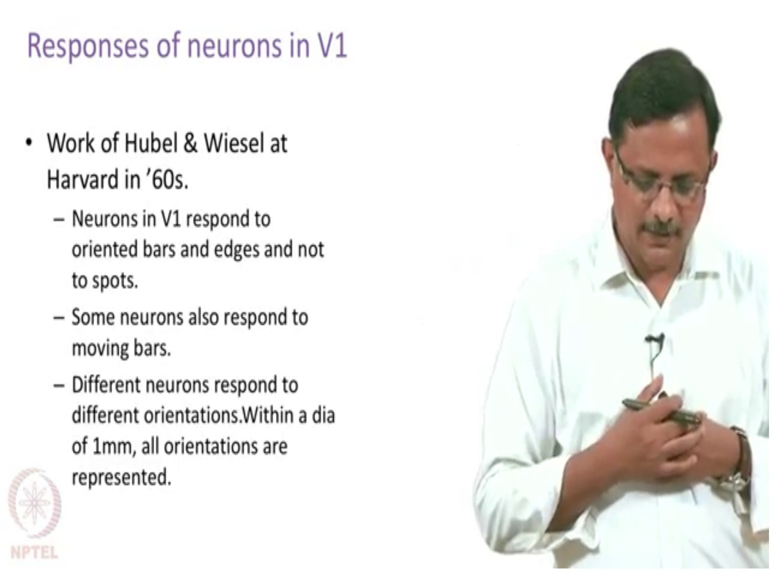

So, Hubel and Wiesel know these two people who are working in Harvard in the 60s on the response of visual cortical neurons. And what they found is so, neurons in V 1 respond to bars and edges. So, some of this experiments goes like this ah.

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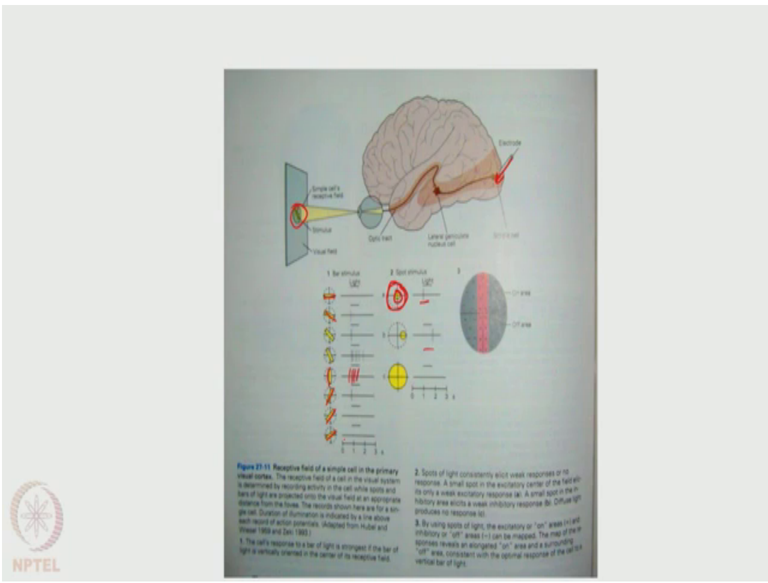

So, you have you know a pattern or a picture that you present on a screen right and record from various parts of the visual cortex by poking the neurons with micro electrodes. So, the experiment will typically tries to figure out what kind of a pattern shown on the screen produces a and in a strong response and in the neuron from which you are recording. For example, if we show a you know flash of light at a dot on the screen of neuron respond strongly to that input, it means it means it recognizes that that pattern and it is tuned to that pattern the idea of tuning is very important and will return to that concept later on in this class.

So, they did that you know they flash different kinds of pattern and know recorded from lots of neurons and trying to see what they respond to. And what was known earlier before these kinds of studies based on recordings from the retina and the and thalamus for the lateral geniculate nucleus is that, neurons in these lower stages of visual system that respond only to dot patterns. So that means, you could if you have a white dot on a black background or a black dot on a white background typically these are the kinds of patterns or stimuli that elicit a strong response in neurons in the retina and in the lateral geniculate nucleus.

But the same kind of stimuli failed to elicit any interesting significant responses in the neurons of visual cortex. So, for example, if you look at this picture, if you show little light spot right ah. So, this is the receptive field of a of a neuron. So, I am recording from this neuron and so, this circle indicates where all you can give an input so, as to produce a response in this neuron. So, if you give an input outside that circle it will not be able to reach that neuron. So, whatever you do you have to do within that little circle.

So, any kind of a dot like pattern is symmetric circular you know stimulus failed to reduce produce much response right in the neuron right you could increase the size of the circle and all that not much response.

On the other hand when they showed a kind of a bar like pattern a linear pattern right that showed in you know significant response, particularly when the when the bar has a certain orientation. So, on the left you can see that when they showed a horizontal bar no response right when they showed bar at an angle no response and as a bar became more and more vertical right suddenly this said. So, there is a lot of response. So, these lines here indicate the strain of action potentials you know emitted by this neuron.

So, again when the bar is rotated further right as it is moved towards horizontal position there is not much response. So that means, this neuron is responding to oriented to bars first of all and not two dots, and further it is tuned to bars with certain orientation. So, each neuron here is tuned to such oriented bar. So, ah. So, that with that what is interesting about neurons of V 1 compared to neurons in the in the lower stages and they also found some neurons responding to moving bars. So, for example, there might be a neuron which are responds to a vertical bar, when it is not moving immobile and there are neurons which respond to a vertical bar when it moves to the right and similarly there are neurons which respond to a vertical bar when it moves to the left.

So, there are neurons that respond to all sorts of linear stimuli and not to circular or symmetric stimuli like dots or discs. Then there also different neurons respond to different kinds of orientations and within a small cortical area of about 1 millimeter right they found neurons which respond to all sorts of orientations. And further on here they found different subclasses of cells which respond to orientation in a slightly different in different ways.

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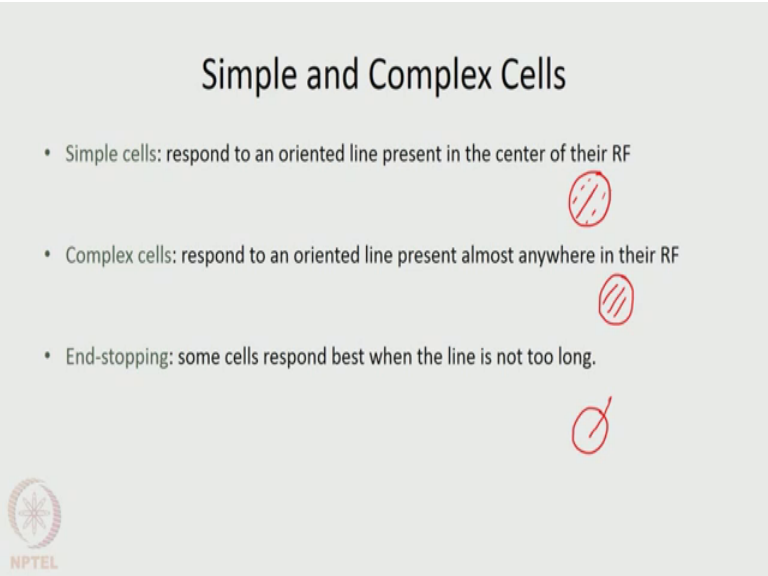

These are the simple cells right which respond to oriented bar only if the bar is located in the center. If the bar is located off center the response is somewhat weaker and then there are complex cells right, which respond when the bar is anywhere within the receptive field.

So, the orientation of the bar should be correct right and that is right for that neuron, but it can be anywhere within the receptive field. Then there end stopping cells right where the stimulus is should be present in the receptive field, but the line very often just stop somewhere in the center of that circle. So, it does not go through the entire receptive field these are called end stopping signs. So, they found different types of neurons which respond to different types of lines with specific orientation then they also found neurons which respond to edges. So, the example that we have seen before just a moment ago are examples of lines neurons which respond to lines.

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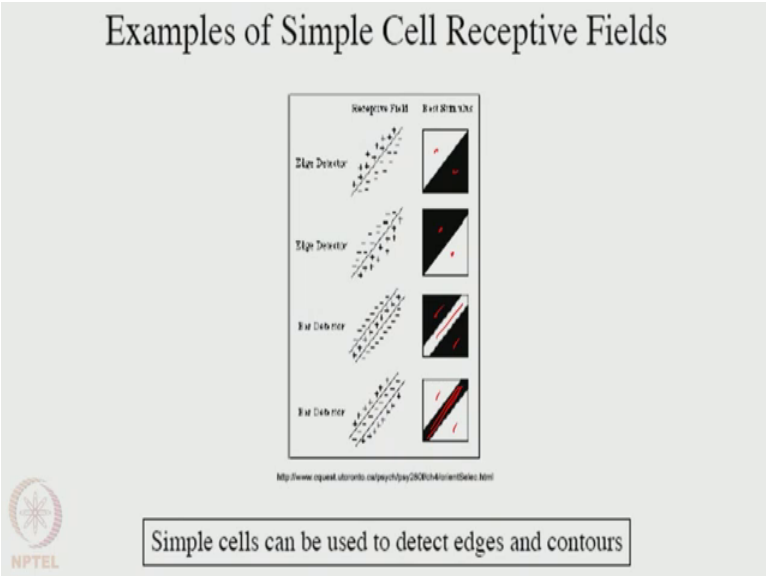

So, a line is basically like a bar with some service certain orientation and there is a contrast between the part of the line and it is you know and its surround. So, in this case I have a dark line with a white and surround, in this case I have a white line with a dark surround.

But both of them are like lines or bars and there are neurons which respond to these kinds of oriented bars. There are also neurons which respond to edges. So, it again has a has a is line linear boundary between two regions which where there is a contrast. So, in this case in the upper part of the edge there it is dark and lower part it is white and in this case at the upper part it is written in lower part it is black. So, these kinds of all these kinds of edges or bars right typically trigger responses in the neurons of V 1.

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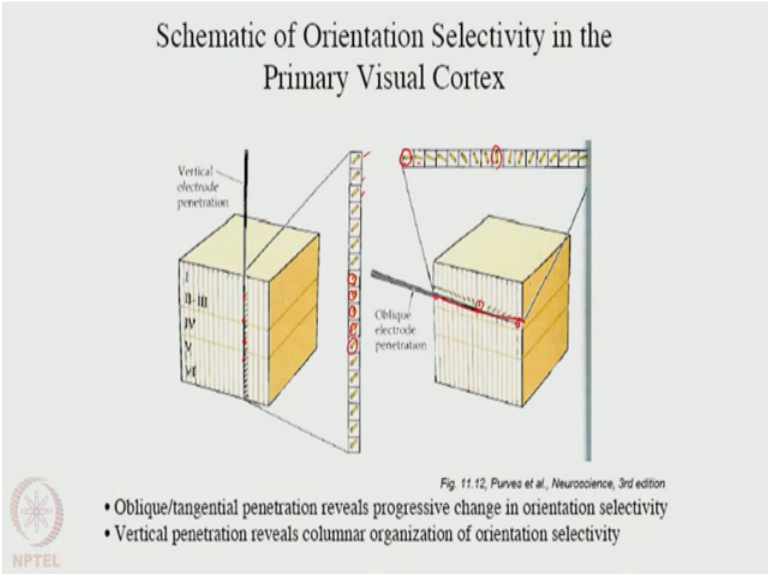

So, now the experimental also recorded from neurons at various depths inside the cortex. So, we know that cortex is a thick sheet of cells is a slab of cells and within this slab there are 6 layers. So, we talked about this before and they use a microelectrode and penetrated deeper deeper and deeper levels of this cortex and recorded from neurons, when they did that they found that neurons at various depths corresponded to the same orientation. So, which is what you see here in this nice schematic you see that neurons had various depths respond to the same orientation.

At some points you have neurons which are not orientation sensitive. So, for example, here they do not respond to any particular angle, but otherwise when they respond to an orientation, it is often to the same angle if you measured from various depths at the same position in the cortex.

But what happens if you recorded not along the depth, but along a parallel to the surface of the cortex? So, in this and the schematic on the right they recorded from various neurons right at various locations, and they proceeded along a straight line parallel to the cortical surface at certain fixed depth. When they did that they found that the different neurons responded to different orientations. So, here the orientation sensitivity seems to be changing along the length you know along the length of this path of the tragic path of the electrode and, but this variation is quite ordered. So, for example, at this extreme end you have a neuron which responds to horizontal bars as you move further and further along this path of the electrode you find that the orientation tuning of this neuron also rotates quite gradually, and somewhere here in the center you have a neuron that is here which responds to a vertical bar.

As they went further down, somewhere here you have a neuron which responds to a horizontal bar. So, you have come full circle ah. So, if you go further down you will find somewhere later right neuron responding to a small orientation like mean the small orientation. So, there is some kind of periodicity here because the angle is a periodic quantity. So, if you kept on measuring the orientation tuning of various neurons along a straight line in the cortical surface, you will find that the same angle from 0 to 180 degrees repeats right along the way, but now the ques question becomes very interesting because cortical suppose is a two dimensional surface, it is not a you know it is not a straight line.

So, if you went in different directions what is the orientation sensitivity change, how is this during angle the of orientation right change from neuron to neuron? As you know went around the cortical surface of the pa primary visual cortex.

So, people measure this kind of a now tuning and these are called orientation maps these are two dimensional maps, which tells which tell you what is the orientation angle right to which a given neuron responds at a given point on this two dimensional surface. And since they are maps you have to make 2 D pictures of them, and here is an interesting color chart or a colored map that indicates orientation of various neurons in this primary visual cortex.

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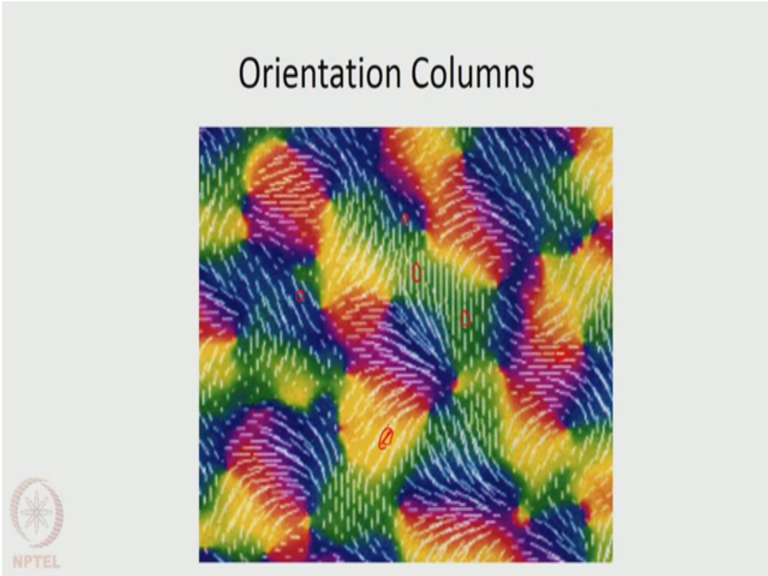

So, each color indicates a certain and orientation and if there is also you can see these you know short white lines right which indicates also indicates orientation.

So, for example, the red color indicates horizontal lines. So, neurons here respond to horizontal lines. So, similarly the green color indicates no vertical orientation; that means, neurons in this part of the map respond to vertical lines right and so on and so forth. So, yellow indicates an orientation of about 45 degrees right and so on and so forth. So, you see how different neurons respond to a different kind of ora orientation in this map, and there is a kind of a gradual variation of orientation from point to point as you go over this you know this cortical surface.

No there is a different kind of map which is also superimposed in the same space of primary visual cortex right. To understand these maps we should understand how the visual space is mapped onto the cortical surface. So, if we have seen this once before. So, each eye receives input from both the left part of the visual field, and right visual field and if you look at the right eye the right part of the eye which is called the temporal side right receives input from the left visual field and the left part of the eye receives input from the right visual field.

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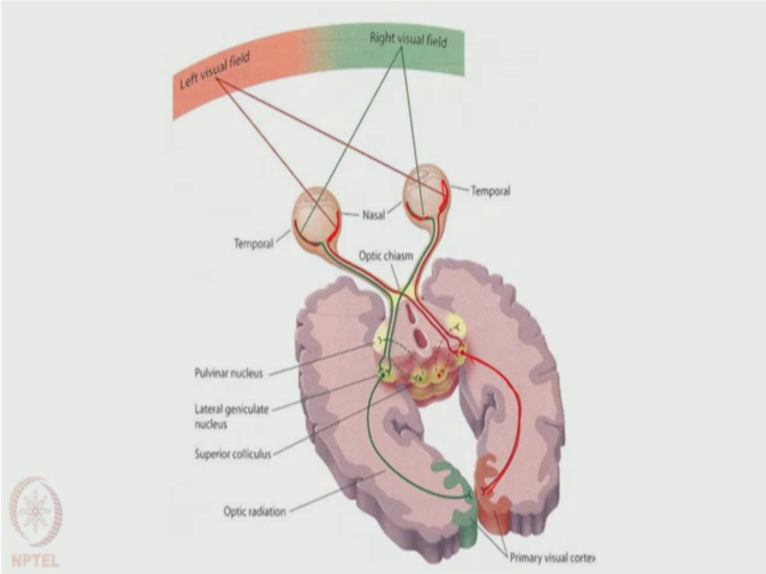

But similarly on the on the for the left eye its right part this is input from the left usual field and its left part which is called the temporal side receives input from the right visual field.

Now, you see that the way the information is propagated or projected backwards to lgn and you know further down to the primary visual cortex is very interesting. So, the information from the temporal part of the right eye and the nasal part of the left eye both of them correspond to the left visual field, both are sent to the same side of the brain which is the right brain.

So, the information about the left visual field is captured partly in the left eye and partly in the right eye, but both these chunks of information are sent by a complicated you know wiring patterns to the same part are combined and sent for the same part of the brain which is the opposite side to the right brain.

So, similarly information about the right visual field the is captured partly by the left eye and partly by the right eye ah, but both these chunks of information are com are combined and sent right to the left part of the brain to the left frontal visual cortex. So, the interesting kind of a regrouping of information happens right through this wiring pattern from the eyes to the primary visual cortex. So that means, a given part of the primary cortex this is input right partly from the right eye and partly from the right eye, but it receives input only from the left visual field.

So, now the thing is within the primary visual cortex on the right side you will have neurons, which respond to inputs coming from the left eye and there are neurons which respond to inputs coming from the right leg. Now the question is how are they organized spatially. So, if you can color the neurons as within you know black and white right black is neurons which respond to left eye and white neurons which respond to right eye right how are these two neurons organized specially on the visual cortex. So, what they found is here also they find they are organized in nice periodic fashion.

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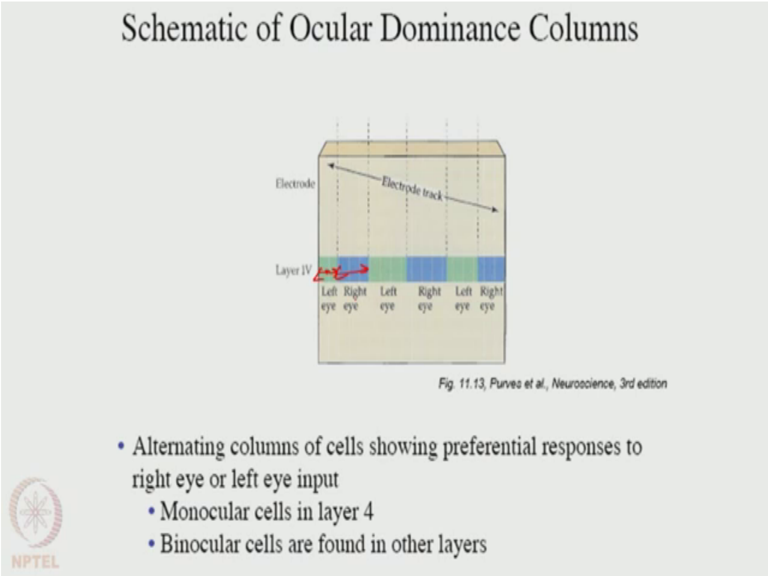

So, for example, in the in the cortex if you record from layer four right and you will find let us say neurons which respond to left eye here right over this whole stretch.

The after that again you will find a stretch where neurons respond to the right eye and so, on so forth. So, you have a simple repeating periodic pattern of neurons which respond to right eye and left eye. So, this map is still is one dimensional, but if since cortical surface is two dimensional, if you look at the same maps in two dimensions right looks more complicated.

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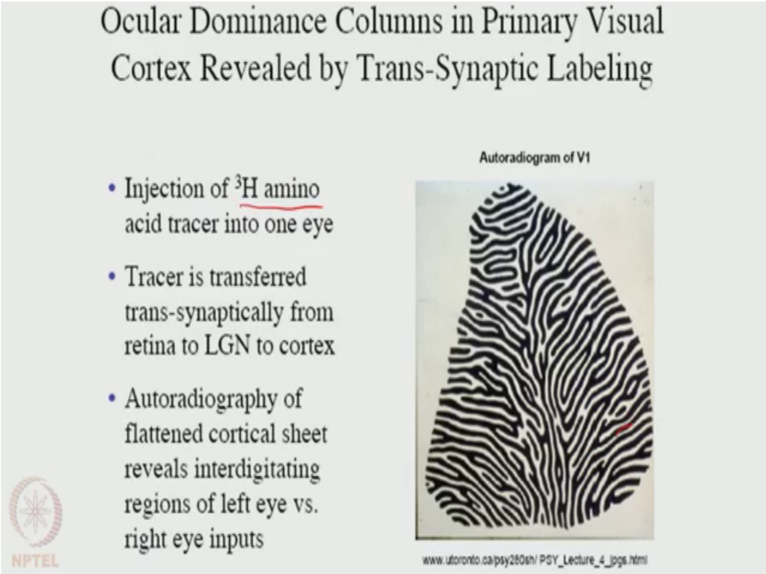

So, the on the in the image here shows a map of the neurons, which respond to right and left eye; in this case you can say that the black here corresponds to neurons responding to say right eye, then the white corresponds neurons which respond to left eye.

So, these kinds of patterns are you know are measured or produced by injecting a tracer a radioactive tracer like right tritium, amino acid tracer. They inject this laser into one eye and that and the signal goes through the pathway to optic nerve and crosses the lateral geniculate nucleus and reaches the visual cortex and activates only the neurons which receive input from that neuron in the retina. So, this is a map of one eye and you know bunch of neurons which are received from that eye.

So, what is missed out in the map has to be neurons that receiving from the remaining eye the other eye. So, you see very interesting is zebra zebra like patterns, and these patterns are called ocular dominance maps or ocular dominance columns and also these maps are not fixed. So, for example, if you they are driven by the external input and so, if we change the external input your visual stimulus, then the these maps reorganize and changed.

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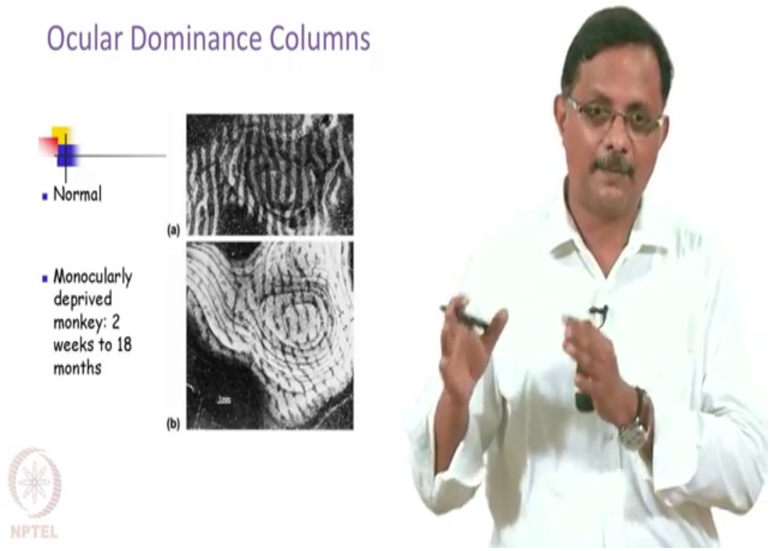

So, for example in this experiment which was done with monocular deprived monkey. So, they take this monkey at an age of about you know 2 weeks to 18 months, which is what is called a critical period. This is a period in which the brain of the baby monkey undergoes lots of you know changes in them in the map organization, but after that map stabilizer and you know there is not much you do not see much change after once a critical period is passed.

So, during the critical period they the monocular deprived that is the just shot of one eye by suturing the eyelids. So, that that eye cannot receive input receive light. When they did that they found that the maps form in such a way that neurons predominantly respond to the opposite or intact eye. So, there are very few neurons left to respond to the eye which is sutured. So, because of that even though the switches were removed at the end of this period right there are not many neurons left to respond to input coming from the light from the so, they say let us say the right eye is sutured, they are not mean neurons left to respond input from the right time.

So, it is act as though the brain is blind to the right eye. So, we have a very interesting situation here, the right eye is intact means right now there is open, but the maps right have formed such that the neurons which respond to the right eye right are know very few therefore, it is as the brain cannot receive input from the right eye. So, this is a situation of what is called cortical blindness. Normally blindness is associated with eye something is wrong with eyes, but here the eyes are fine, but the blindness is in the cortex because the maps, I have not formed of maps are totally skewed to one eye and other eye is functionally blind.

So in fact, there is a interesting. So, this raises lots of implications for you know blind people right. So, because the condition for seeing is not just intact eyes, but intact maps the visual maps in the visual cortex [noise].