Demystifying the Brain
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Lecture – 12
Maps in the Brain-Segment 2

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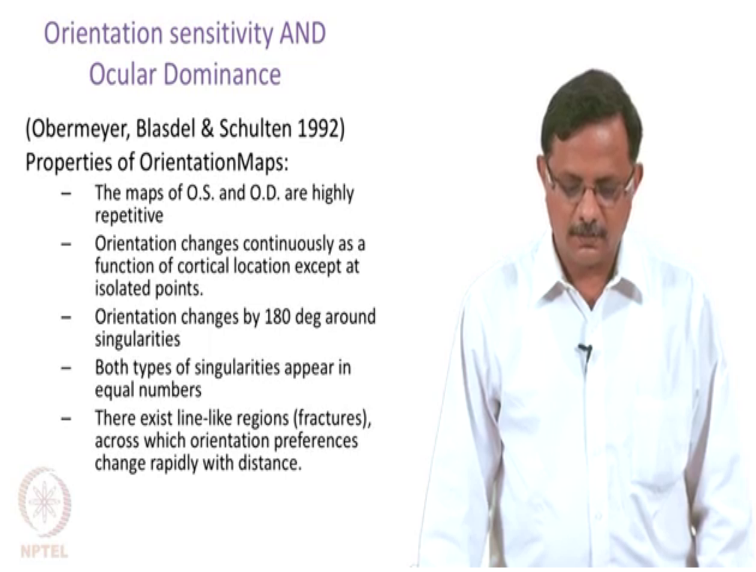

So, so far we have seen two kinds of maps in the primary visual cortex, the orientation maps and the ocular dominance maps. In the orientation maps we have seen that the orientation changes continuously as a function of cortical equations. So, as you probe the visual cortex you know along a line at various points, you will see that the orientation change over the full cycle from 0 to 180 degrees and it is periodic. So, therefore, once you reach 180 degrees, you start all over again from 0 and you progress towards 180 degrees again. And so, although the orientation changes continuously at most points at certain points isolated points, you do not have this kind of a continuous variation and such points are called singularities. So, let us see how they look like.

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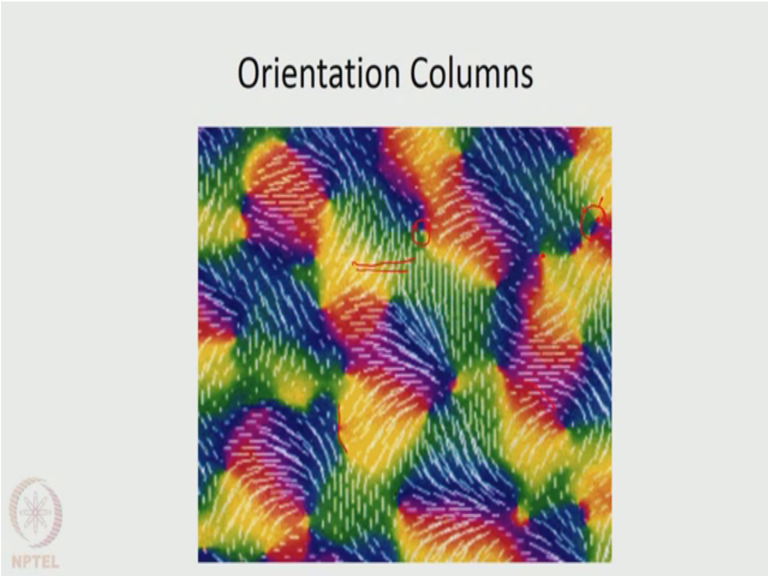

So, for example, here the orientation changes continuously from yellow to. So, so, yellow to green. So, that is yellow is 45 degrees and green is vertical 90 degrees, but at certain points they. So, lots of colors meet at certain points. So, these are those points, these points are mathematically called singularities and in visual signs they are called pinwheels because they look like you know wheels with spokes around them. So, at this point neurons respond to all sorts of angles. So, because at this point in the neighborhood you have red here, which is horizontal lines we have yellow here which is 45 degrees and green which is vertical and so on and so forth.

And again you have two kinds of pinwheels if you look at it here. So, there are two kinds of similarities or two kinds of pinwheels. So, for example, at this point you go from red if you go in the anticlock direction, you go from red to yellow to green to blue and right and back to red so, but whereas, if you look at other some other point if you take this point you go from clockwise direction you go from red, the yellow, green, blue ok. So, you see you encounter the same sequence of orientations, in one in at some points they encounter certain sequence orientation when you glow in the go in the clockwise direction at other points you encounter the same sequence and you going the anticlockwise direction ok.

So, pin these are the two kinds of pinwheels, and it turns out that both occur in about the same frequency in addition to the pinwheels they also these line like regions what are called fractures across which orientation changes drastically. So, if you go back to this plot right some places like I said it is it varies continuously, but some places it varies drastically you know you can see a kind of a line which separates two orientations. So, look at that you have very sharp transition from purple to red, look at the sharp transition from blue to yellow so, ok. So, you have continuous stretches, then you have sharp fractures where along cross a line the sharp change in orientation then you have singularities of pinwheels, where around a point you know in the neighborhood of a point there is a discontinuity and there again you have two kinds of pinwheels right as we have just described before.

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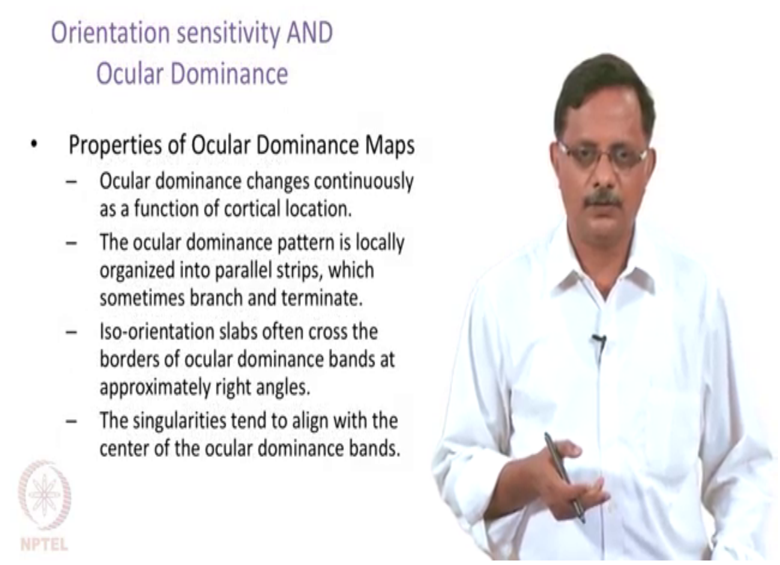

Now, if you look at ocular dominance, ocular dominance also changes continuously as a function of cortical location and they are organized in two parallel strips right which sometimes branch and terminates. So, if you look at this map this ocular dominance map.

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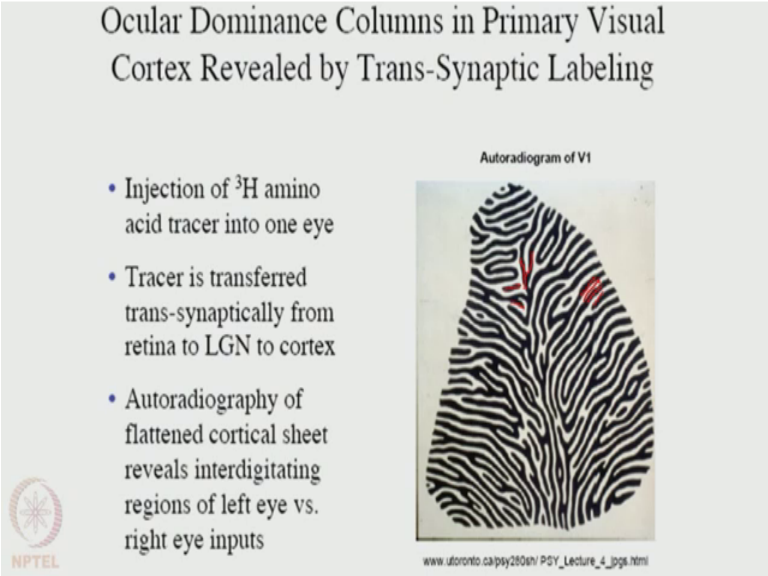

So, they are organized as parallel steps right you have this. So, you have black and white parallel strips, if you look at a small patch of the ocular dominance map, but sometimes these strips branch out like you see here right and also terminate. So, you see this little stretch terminating here or it is branch terminating here and so on. So, these are some of the properties of ocular dominance maps.

But the thing is both kinds of maps share the same space, same cortical space in the primary visual cortex right that. Now the question is; how are these two maps are related? Because if you overlay these two maps one on top of the other right, how are these two maps related. So, here there are two principles which people have observed how to describe the relationship between these two maps, one is that eyes orientation slabs often cross the borders of the ocular dominance bands at approximately 90 degrees ok.

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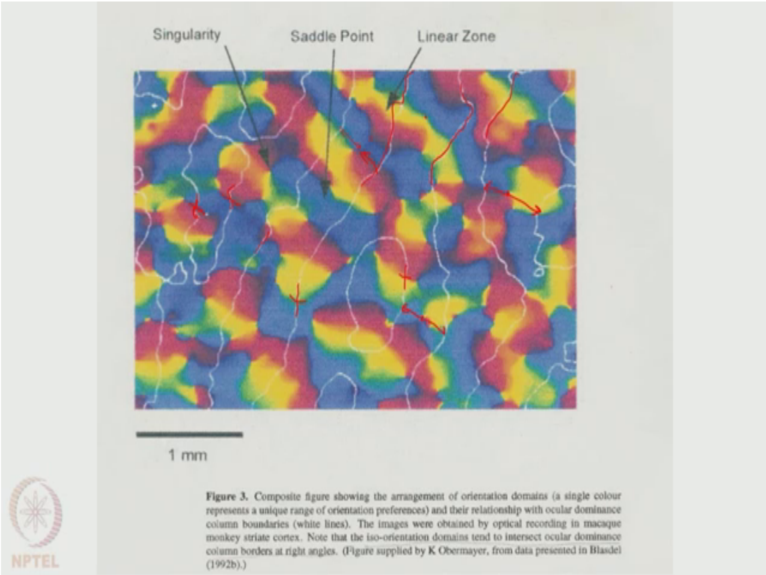

So, in this map where they have drawn these lines to indicate both maps in the in the same space; so these white lines indicate the borders of ocular dominance maps, and the colored patches right as we have seen before indicate the orientation maps.

Now, what the first principle says is iso orientations slabs often cross the borders of the ocular dominance bands at approximately 90 degrees. So, so these are the borders of the ocular dominance maps and they so, and for example, look at this part. So, there is a sharp change in orientation. So, size orientation line and the border cross this line at approximately 90 degrees. So, here it is it is not a great example, but if you look at this point right. So, the ocular dominance border right it crosses the iso orientation map at approximately 90 degrees. So, look at that ok.

So, you can find a lot of such examples, then the singularities tend to align with the center of the ocular dominance bands. So, so these are the ocular dominance bands, if you look at to approximately parallel white lines right they have stretches the stretches of the map between them are the ocular dominance bands and. So, the pinwheels often occur roughly in the center of these bands. So, let us look at some examples. So, here is a pinwheel, right here is a pinwheel it occurs roughly in the center right of this band. So, again here is a here is a pinwheel well let us look at a better example. Here is a pinwheel it roughly occurs right in the center of this band. So, here is another one occurs in the center.

So, so in lot of in varying the type frequency right these singularities tend to align with the center of the ocular dominance bands ok. So, we have seen different kinds of maps from the visual system, from somatosensory system and so on now the question is we just described them as they are found in real brains, and we also notice that they are dynamic because in case of ocular dominance maps have seen an example, but how the map changes when you change the stimulus right when you when the eye is sutured the neurons responding to the open eye or intact eye, but more in number then neurons which responded to the sutured or the closed eye. So, they are also dynamic ok.

So, now these are just observations, but what are the mechanisms, what are the underlying principles by which this maps form b?

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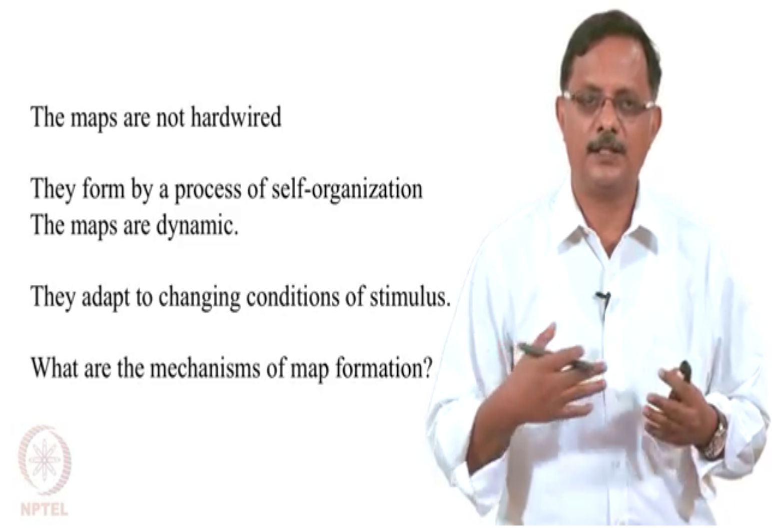

Because you have seen that the maps are not hardware, they form by process by which you can describe as self-organization. The maps are dynamic and they adapt to changing conditions of stimulus, we change stimulus the maps change what are these mechanisms?

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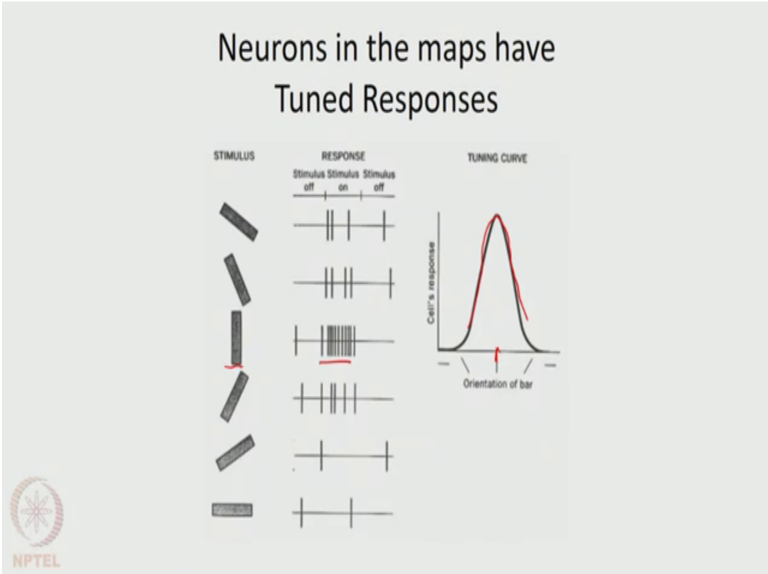

So, let us take registration right. So, first of all we know that since there are neurons which respond to certain oriented bar right? We have seen that given neuron responds the highest when it is shown a certain bar with certain orientation, but if you change the orientation neuron responds lesser and lesser. So that means, if you plot the response of the cell as a function of the orientation, it will look something like this you know like this bell curve right. High response is highest for certain orientation and as you as orientation changes from that optimal point response you know decreases.

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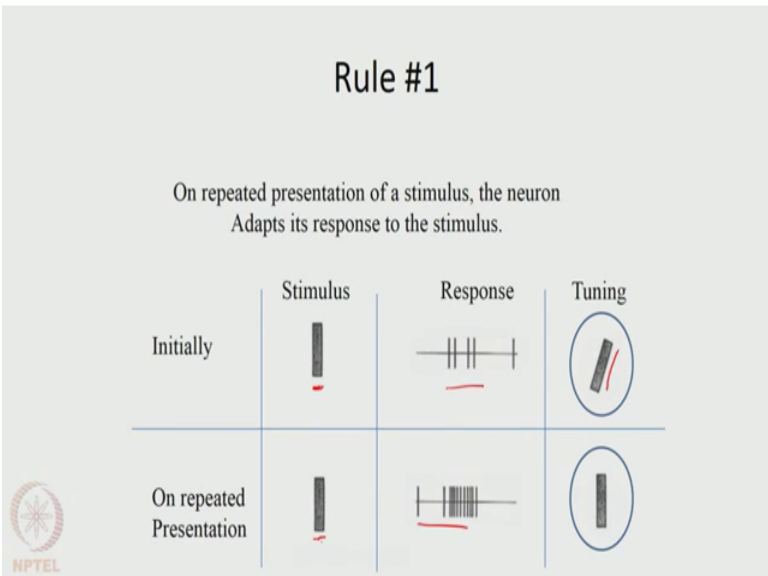

So, so, now, let us introduce the rule one of a map formation. So, let us assume that there is a neuron which responds to a stimulus like this a vertical vertically oriented bar right and. So, if you give present this stimulus in this neuron, it does not give a great response and. So, this response produced by the neuron ok. It is tuned to this orientation therefore, if you present this vertical bar is a stimulus; it produces a small response right. But then you present the same vertical bar again and again to the neuron right and so on repeated presentation right the same vertical bar will be successful in eliciting a stronger response in this neuron after some after some presentations.

That means at the end of that the tuning of the neuron changes from it is original angle you know this looks something like you know 70 or 80 degrees, right from this you know angle the orientation will probably change very close to the orientation of the stimulus which is the 90 degrees. So, the tuning also changes to approximately to 90 degrees right. So, on repeated presentation of a stimulus the to a given neuron the response of the neuron is likely to change in a way that, it the neuron gets tuned to the stimulus.

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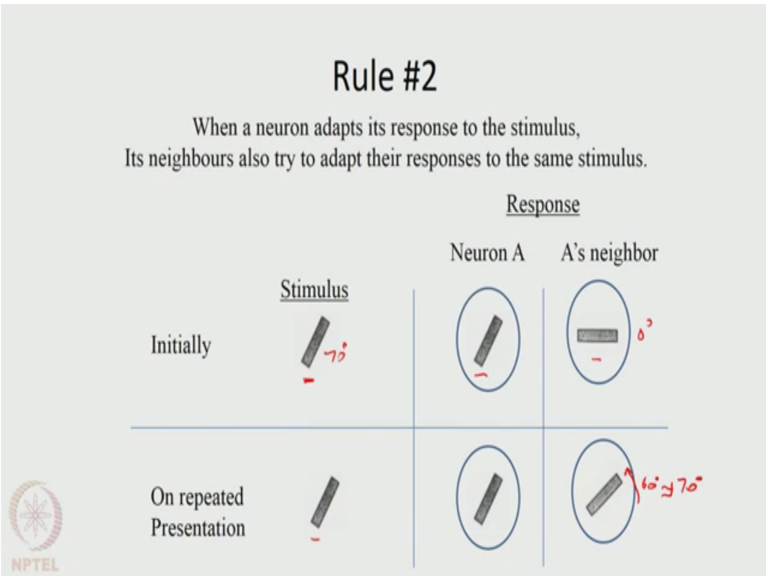

Now, let us look at rule 2. So, rule 1 talk about a given neuron and it is relationship to the stimulus and how it is response needs to stimulus. Rule 2 talks about how the neighbor of a neuron right response to a given stimulus. So, in this example let us assume that initially I give a stimulus, which is like a 70 degrees oriented bar and neuron A happens to have a tuning to the exactly equal to that are very close to that it is third stimulus, but then a s neighbor right happens to have very different orientation initially like this one responds to a horizontal bar

Now, on repeated presentation of this stimulus say your 80 degree or 70 degree stimulus right neuron it does not change much, and because anyway it is already tuned to that orientation. But neuron A now starts moving towards 80 degrees. So, this is 0 degrees. So, let us call this 70 degrees right and so, from 0 it might. So, it gradually turns right towards and becomes maybe 60 degrees. So, tending towards right 70 degrees ok. So, neuron A is now slowly changing which tuning towards that of the it is a neighbor, because neighbor is already tuned towards 70 degrees.

So, if you combine these rules right in a in a 2 dimensional sheet of neurons, right and we can actually implement these neurons and using mathematical equations and simulate them on a computer right.

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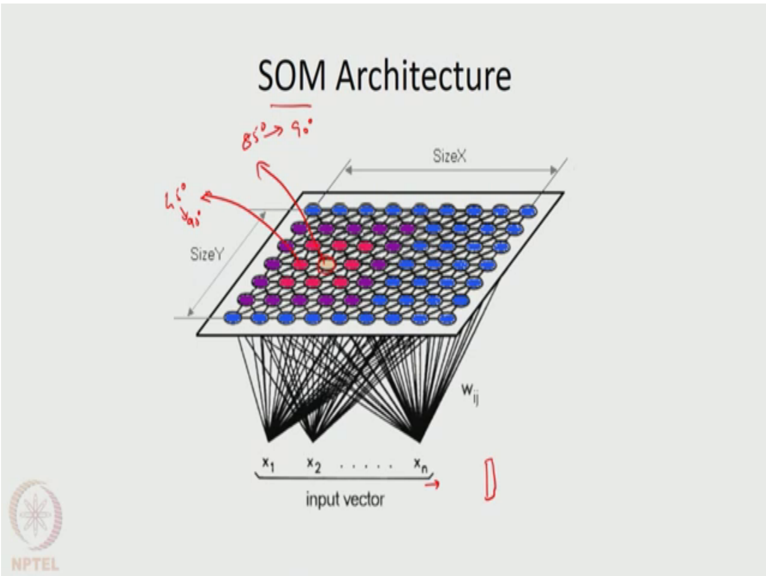

Let us see what happens if you do that, and that kind of a map model is called a self-organizing map or a som right and a lot of interesting map phenomena in the brain can be explained even using simple mathematical models like this. So, in a self-organizing map it consists of a two dimensional array of neurons like what you see in this slide, and then you can present your stimulus in the form of a vector right your stimulus is here. So, that could be like your no stimulus code to present maybe a vertical bar or a which is the visual stimulus or a frequency which is an auto racing stimulus and so on.

Now, let us assume that a given stimulus produces a lot of response in a in a certain neuron a high response in a certain neuron. So, then if you present the stimulus repeatedly right, let us assume that this neuron is initially only like at 85 degrees on repeated presentation right it gradually tends towards 90 degrees ok. And so, initially let us assume that the neighbors of this neuron are at a very different angles say 45 degrees. But on repeated presentation the neighbors also tend towards 90 degrees or maybe 85 degrees. So, so basically neurons tend to move towards stimulus in flux right.

If a central neuron moves towards the stimulus like or it is a it is input connection pattern moves towards the stimulus right the connection patterns of the neighbors also are dragged in the same direction so, that nearby neurons tend to respond to similar stimuli. So, that is why you get this kind of a continuous map structure.

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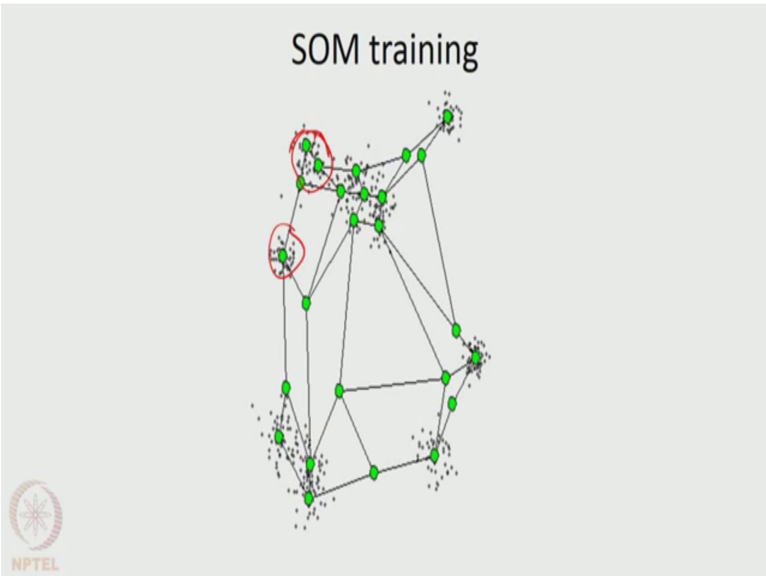

So, you can see that in this simple animation. So, here I have a 2 dimension array of neurons. So, what you are seeing here is? So, you have a bunch of dots, which represent represents the stimuli and stimuli are two dimensions these are vectors in two dimensions. So, these stimuli are clustered no in certain locations. So, you have lots of clusters ok. So, you have one here, one here and so on so forth.

So, you see that wherever there are clusters you know input stimuli occurring in clusters right the neurons in the map tend to respond to those clusters, and lot of neurons are clustered are moved towards points and input space, where there is a high density of know of points. So, these kinds of maps can be used to explain organized information in the in the artificial world in the in the world of engineering.

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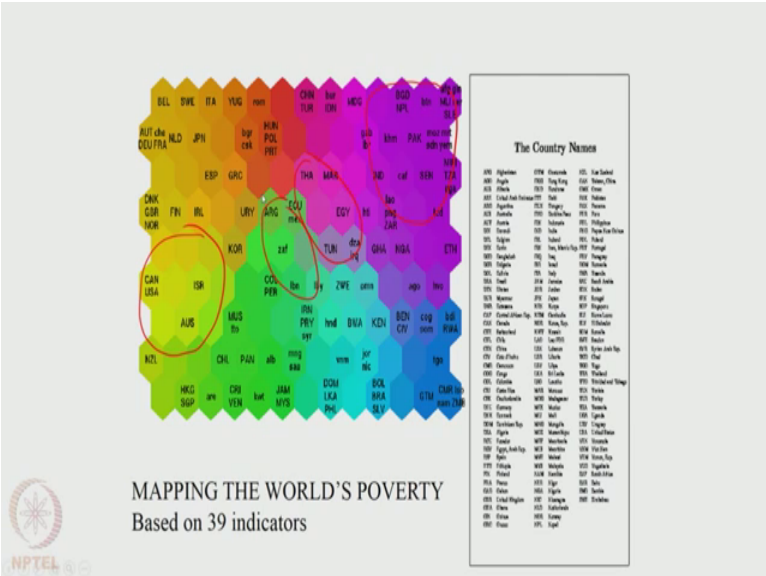

So, for example, in this simple example there they have map constructed a map of worlds poverty ok.

So, this map gives an idea of the poverty levels of different countries of the world. So, they have taken 39 indicators of poverty from various nations, and trained a map and the map that that got by this training looks something like this. So, you see that some of the poorest countries are you know are colored in the purple, look in this corner of the map. Some of the wealthiest nations are in a colored in yellow and then in this corner, for a countries with intermediate levels of poverty are somewhere in between and so on ok. So, all this happens automatically you know without any specific you know hand coding or you do not have to manipulate the map right.

All that you have to take is take a bunch of properties that indicate the poverty level these are the indicators, and you train the map a map.

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So, if you now once a map is trained you can superimpose the map on the on the real world map and you can apply the same color to the various countries on the map, and you can see where there are you know wealthiest countries, where there are poorest countries and so on. So, this part of the map represents right some of the poorer nations of African continent right and then. So, this part of the map indicates some of the nations of the developed world you know US, Canada, Australia, Britain and so on and so forth ok.

So, you can apply the maps to you know organizing information in the real world in artificial domain in many ways. So, now, let us look at how you can use the same kind of a map algorithms right to explain maps in the brain.

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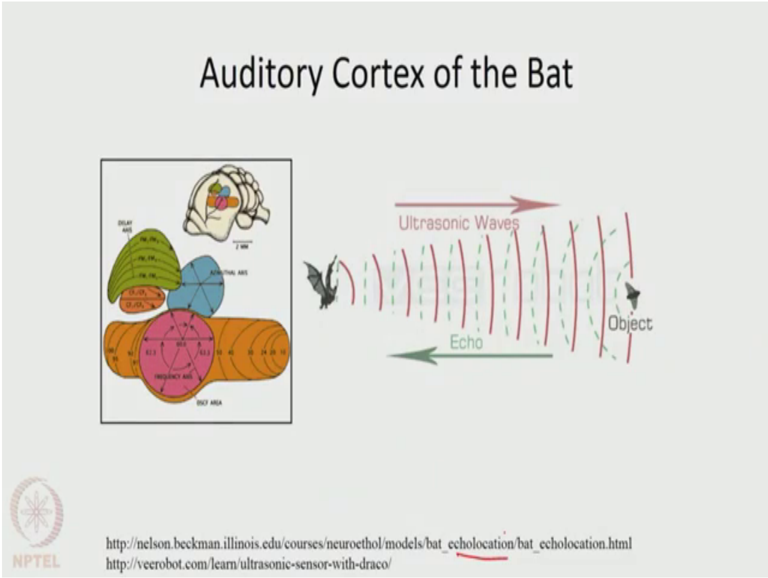

So, let us take the first example, and this example is from the auditory cortex of the bats. Now bats are interesting and they are blind visually, but they use sounds to navigate right in fact, they throw sounds out into the world and based on the echoes that I get from the world they navigate. So, this is and find out where various objects are. So, this process is called echolocation right. So, this is called echolocation and.

So, these sounds are ultrasound ultrasonic waves. So, the normal human range of sounds is somewhere between 20 hertz to 20 kilo hertz whereas, bats operate around 60 kilo hertz and so, when they send these out as impulses right from the time taken for the signal to come back after it hits a target right you can find out the bat finds out the distance of the object from itself. And also from the change in frequency that occurs after it bounces of a moving target, right it finds out the relative velocity of the target with respect to itself using the familiar phenomenon of Doppler’s so and so on.

So, bats brains like perform very complex event processing operations on the signals that they the return signals that they receive right from the world, and navigate through the three dimensional world.

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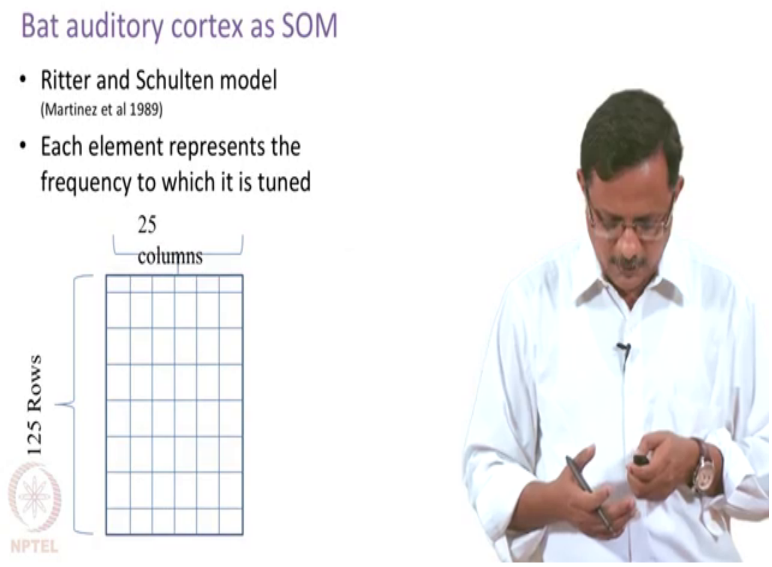

Now one; so there are lots of complex maps inside the bats brain, which have been explored by many neurobiologists right. One of the simplest aspects of it is there is a part of bats auditory cortex right where there is a simple map of the input frequency along a kind of a linear stretch of the auditory cortex.

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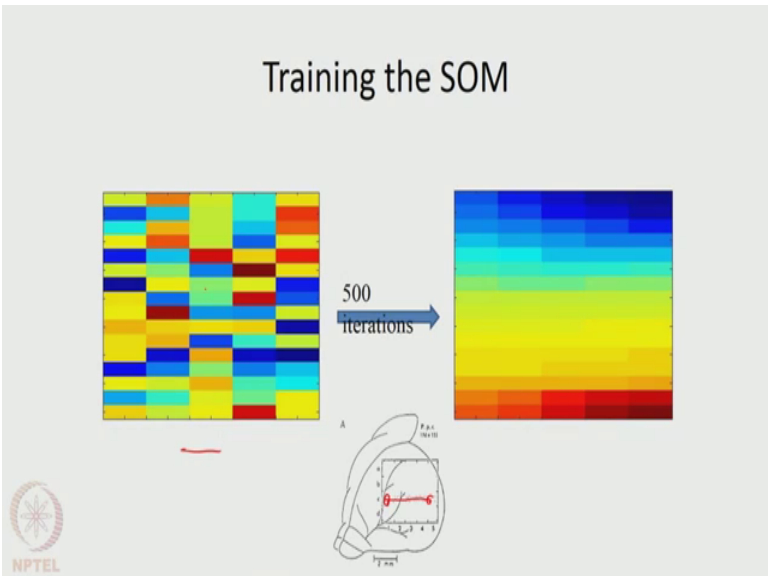

So, it is almost this part of the bats brain is performing some kind of a furrier transform in the 50 of the input frequencies, that is you have lowest frequencies right processed in one end of the map and higher frequency is processed in the other end of the map, with a continuous variation frequency along the length of the stretch of the cortex.

So, this phenomena has been similar has been simulated in this study by Martinez et al right using the same self-organizing map model. So, they have taken an array of neurons of size 125 by 25 and initially at least neuron is tuned a certain frequency, initially that the tuning frequency is random. So, it looks something like the picture on the left side right. So, hereby neurons in this map do not respond to similar frequencies in this map because. So, you can see the colors are all in a jumbled.

But whereas, as you train the map using a bunch of frequencies from around the frequencies of interest for the map, that is around a band around reticular hertz alright. The map or self organizes and you see there is a gradual transition, how frequencies from one end of the map to the other just like what you find in the bats auditory cortex ok.

So, that is a fairly simple phenomenon, let us look at a slightly more interesting slightly more complex phenomenon. This is from the domain of somatosense somatosensory cortex or touch.

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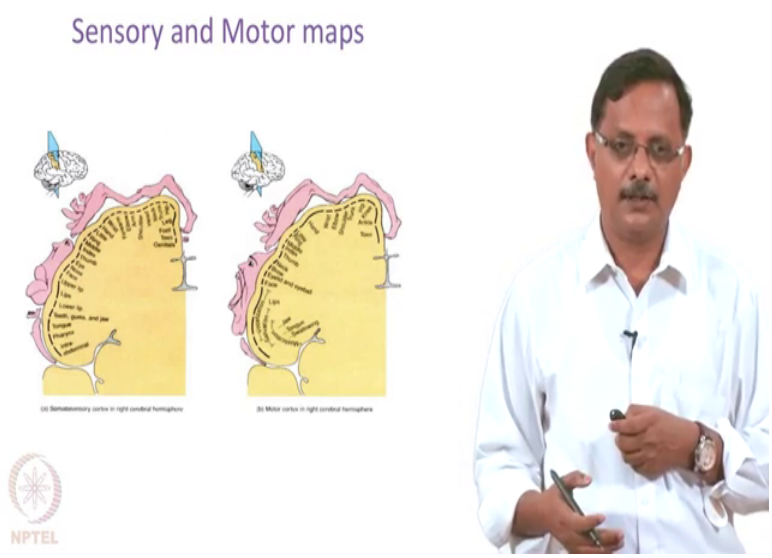

So, we have seen these maps before right and on the left you see the somatosensory cortex of humans and the somatosensory map in humans and on the right you see the motor map ok.

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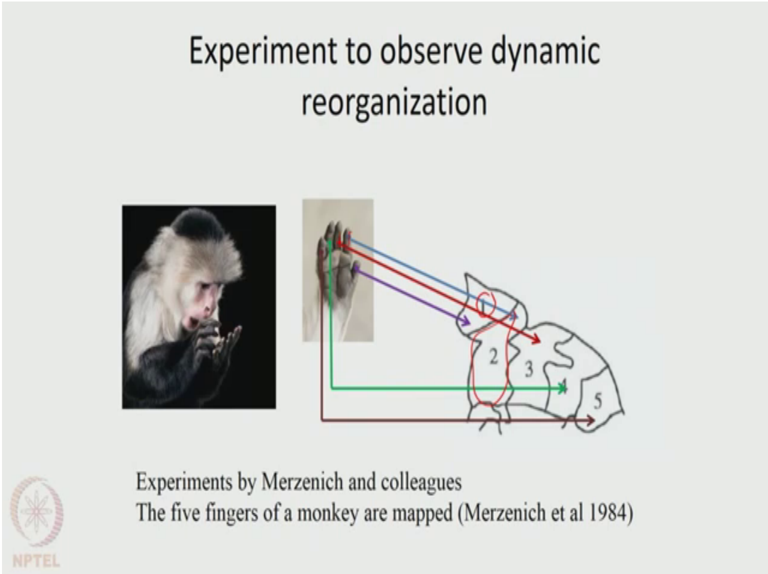

So, these kinds of maps are also been explored in monkeys. So, in this experiment by Merzenich and colleagues, they have taken a monkey and mapped the fingers of the monkey right and you see in this schematic the maps of different fingers of the monkey. So, one is it is you know it is index finger and two you know corresponds to it is middle finger and so on so forth ok.

So, this is the part of the somatosensory cortex of the monkey right and which responds to the corresponding finger of the monkey's hand.

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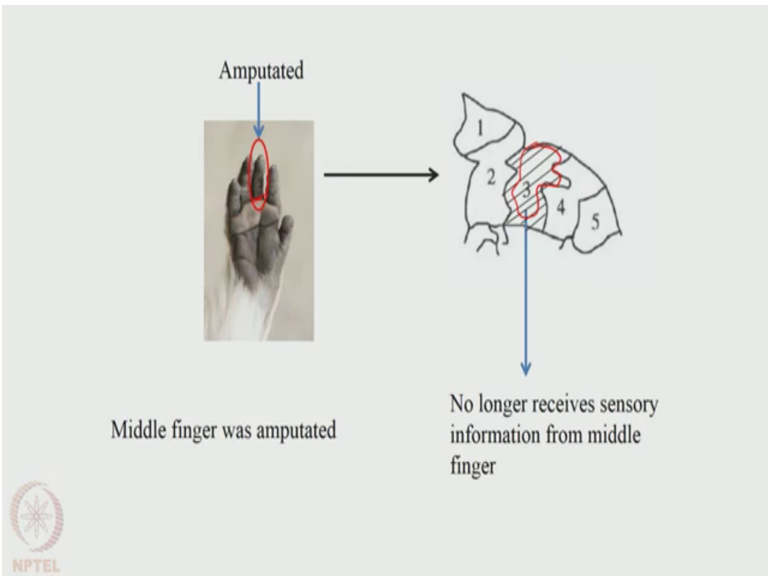

So, once the fingers are mapped they amputated the middle finger. So, this finger is amputated and therefore, after amputation the neurons which were earlier responding to the middle finger right, all these neurons they have nothing they respond to. So, initially they remain silent because finger is amputated, but after several weeks something interesting happened.

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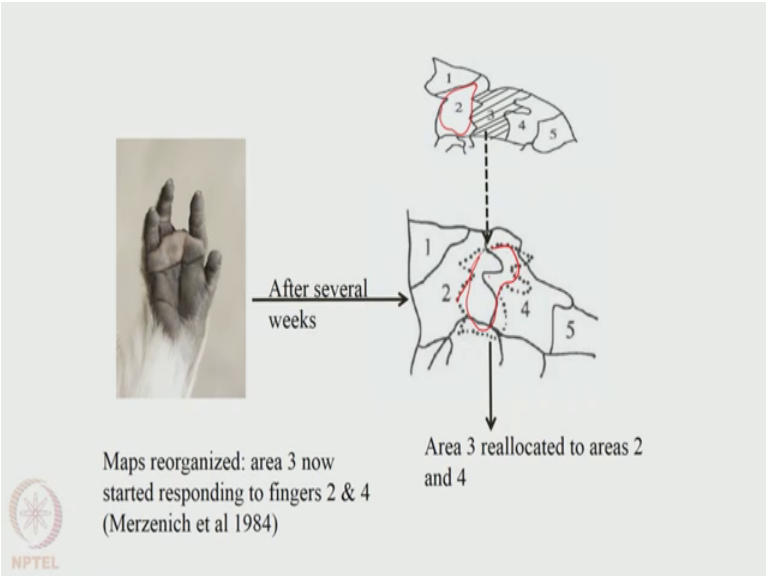

So, the neurons are initially silent because the finger is missing, these neurons slowly started to respond to the neighboring fingers. So, for example, the area to right which corresponded to index finger, right now started responding to the middle finger partly.

Neurons of the region three or the middle finger which was earlier responding to the middle finger; now began to respond partly to the index finger, that is area this is finger to and partly to the ring finger which is finger 4 ok. So, it is like you know what happens in a imagine? What happens in a big company, when a whole division is fired all the people in a big division is fired they are fired. So, these people now maybe are relocated or you know to different other divisions there of the company. So, that they do not lose their job. So, this what is happening here. The area three neurons which lost their job in the sense like which cannot respond to the finger.

Now, part of them are now doing the job of responding to a finger 2 and the rest are responding to finger 4.

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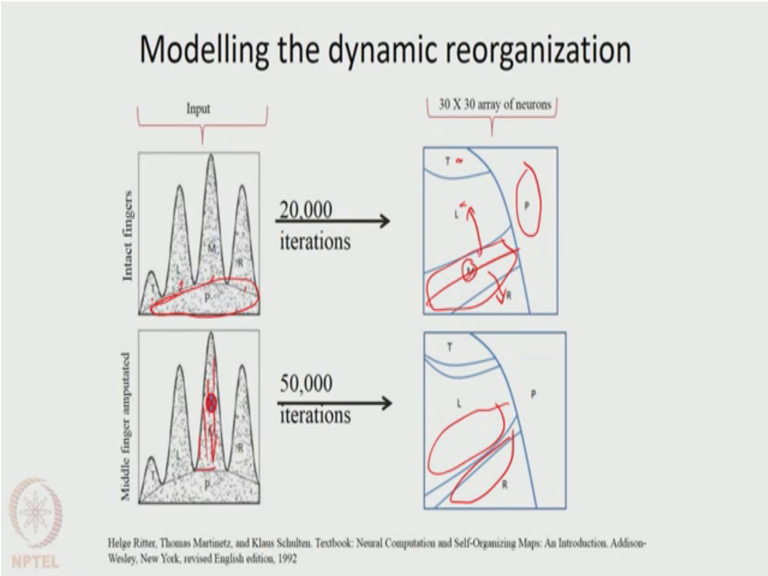

So, these phenomena can be simulated very easily using a self-organizing map model. So, this was done in a study by you know retire Martinez and Schulten you know described in this reference. So, they have taken a simple model of the hand which is shown here, basically it is a simple two dimensional geometric pattern where you have the fingers. So, this is the thumb, this is the index finger and middle finger ring finger and there is no pinkie, you know the little finger is omitted in this simulation and this is the palm this whole region is the palm, and they trained the map on this is distribution of points, and they found that the certain parts of the map respond to certain parts of their hand.

So, this big region corresponds to the palm and so, this is this corresponds to the thumb and this corresponds to the ring finger and this is the middle finger and so on and so forth.

So, once the map is trained right for the normal hand, then they amputated the map which means that they basically removed all these points from the training data set and then train the map further. So, when they did that what happened is. So, these neurons initially have nothing to respond to, but after some training the same neurons in the same location, now began to respond to the index finger on one side and the ring finger on the other side ok.

So,. So, part of this right mood over to the job of responding to the ring finger, parts of these are responded mood over to the job of responding to the index finger ok. So, so, you can show that maps are dynamic and they reorganize, and you can explain the experiment is as very simply using a map model like this.

Now, let us look at a more interesting phenomenon, very intriguing and you know which challenge neuroscientist for a long time and finally, the phenomenon found an explanation in terms of very simple map the reorganization processes. So, this study is from the book phantoms in the brain by you know VS Ramachandra.

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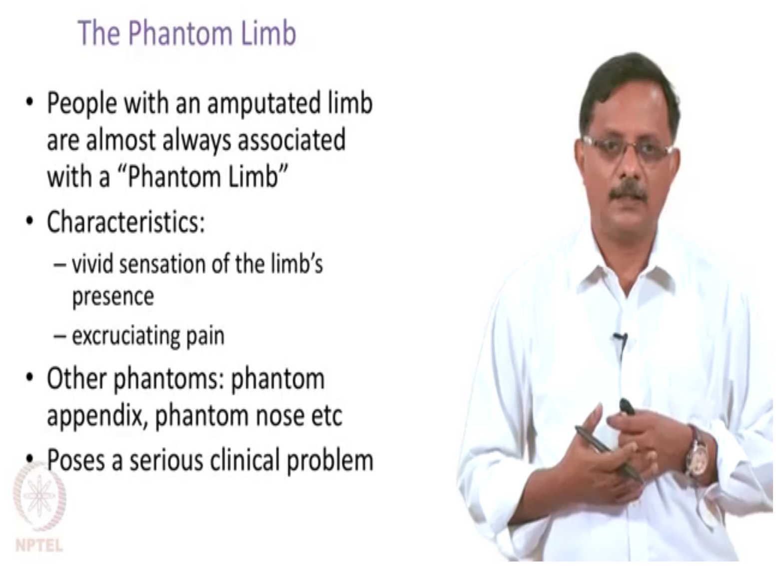

So, a phantom limb is a very intriguing neurological phenomenon. So, people who undergo an amputation of the limb, they very often have the sensation that the missing link limb is still there the field at the limb is there only thing is they cannot see, but it is also the; an invisible missing limb is still present this is called the phantom limb and. So, they feel the hand and also very often there is a lot of pain associated with this phantom limb and in. So, it is not just a limb, but this phantom experience is associated with other organs also for example, there are people who had phantom appendix after appendicitis and appendectomy when the appendix was removed. So, and they could have phantom nose because the nose is amputated and so on so forth.

And it was a clinical problem particularly because of the pain associated with it.

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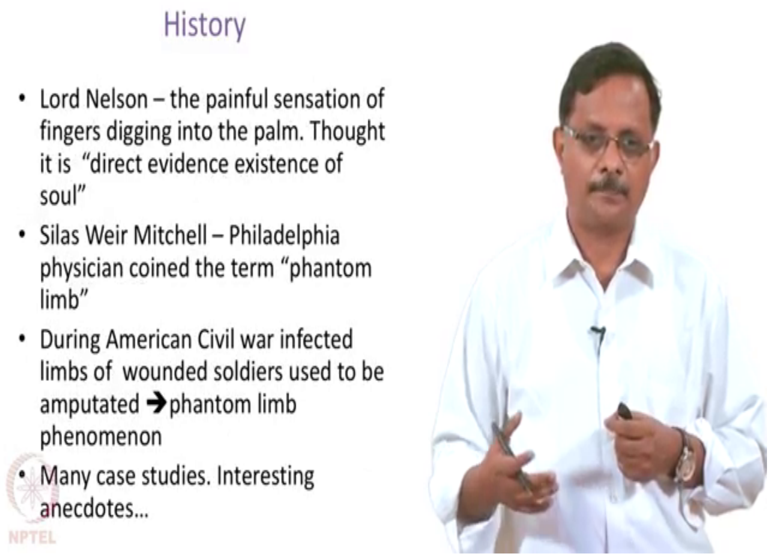

There is a long history to the phenomenon of phantom limb. So, for example, lord nelson the famous British general lost his hand in one of the battles, and he had the experience of sensation of phantom limb, and he thought that it is a direct evidence for existence of soul. Because I mean it is if you think about it the you cannot see the arm, but you can still feel it far it is a win invisible ghost like presence of the arm is still there. So, he thought that it proves that there is such a thing called soul.

Then Philadelphia physician called Silas Weir Mitchell rightly coined the term phantom limb, because during the American civil war and this doctor who was treating a lot of you know war victims. A lot of these soldiers came with you know with infected arms and so, therefore, they had to be amputated and they experienced and you know phantom limb phenomena sensation there was lots of interesting case studies. So, because this phenomenon was known, but people did not understand what is causing this kind of an experience or a sensation? So, the lot of folklore and interesting anecdotes that went with this phenomenon.

For example one story goes like this. So, there was this guy who had this amputated and he went back home after amputation and he had the sensation of phantom limb, but it did not end there it became you know slightly you know weird beyond that. So, he had this feeling that maggots were you know gnawing away at his hand ok. So, the phantom limb is you know itself was like weird enough on top of that he had this feeling that maggots were eating it away. So, he went back to his doctor who amputated it and complained about this experience, doctors thought it is you know gets crazy and he just backed him and not doing anything about it.

So, after some days of the sensation continued and then this guy goes back to the doctor, and then this time doctor takes him seriously and he had a thought to find out what happened to that arm once it is amputated. So, usually after amputation the arm is sent to the morgue, where it is incinerated or burnt by it. So, happens that for in this particular case when the arm was taken sent to the morgue and the person was in charge of incineration he somehow neglected it, and then just left it somewhere in the arm began to rot and so, it was filled with maggots and which was eating it away. So, it is as though the maggots which are eating the dead arm right you know somehow that sensation was felt by this guy was far away.

So, I am sure these are just you know some cockamamie stories, which were made up just to you know to entertain people and this is because it is totally unscientific and probably not true.

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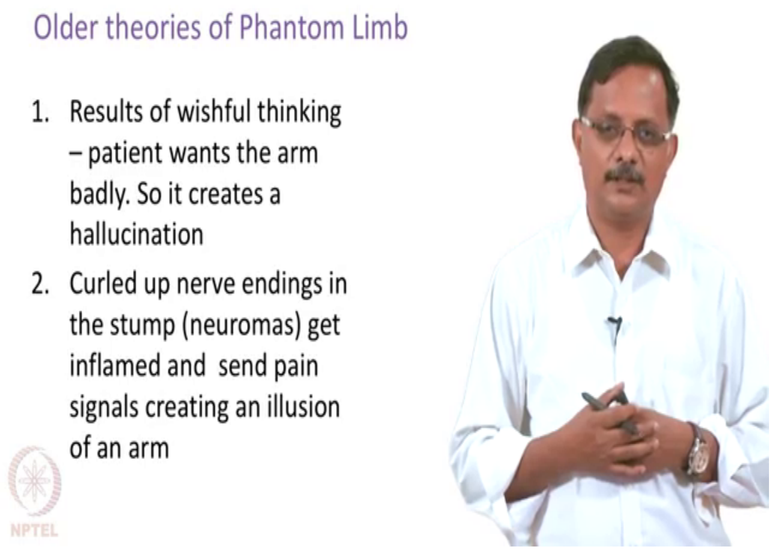

So there on a on a serious note the people have also made up theories to explain phantom limb, one of the earliest theories was just in terms of wishful thinking. So, people said that you know the patients miss the arm so badly, and that created this hallucination of a sensation a false sensation of the missing arm and that is all (Refer Time: 26:02). Then there were more neurologically oriented theories one of them explained that there when you when the arm is amputated, the nerve endings right are also cut at the point of this section right they develop what are called neuromas and where the nerve endings become inflamed, but and start sending pain signals on their own and these signals are created in illusion of the arm. So, this was another theory which is more neurobiologically grounded ok.

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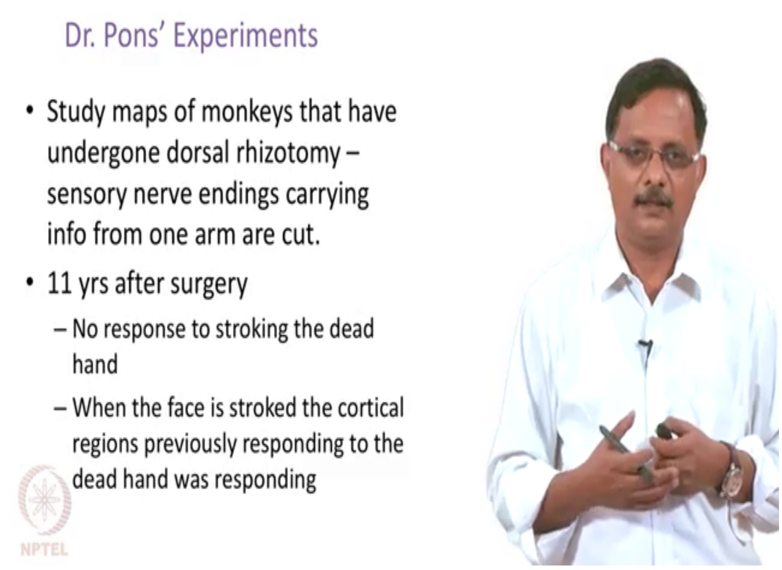

So, but interesting turn to this whole study of phantom limbs or search for neurological; basis the neurobiological basis to the phantom limb phenomenon. Came with the work of one doctor at national institute of health in the US, his name is doctor Tim Pons right then; his group doctor Bons group studied the monkeys, that have undergone dorsal rhizotomy. So, this is surgery basically where you cut the nerve fibers which carry information from the hand to the spinal cord. So, they did that and then after le eleven years after the surgery, when they explored the you know monkeys again. So, they found that the dead hand that is in hand for which the no inputs are cut out right when they stoke that hand there were no neurons in the somatosensory cortex of the of the monkey to respond to that ok, which is not surprising because the hand was not sending any signals to the cortex.

But what is interesting is when the face of the animal was stroke right the cortical regions which are previously responding to the to the hand right for the dead hand, was now responding to the to the face to stimulus from the face of the animal which is a bit strange.

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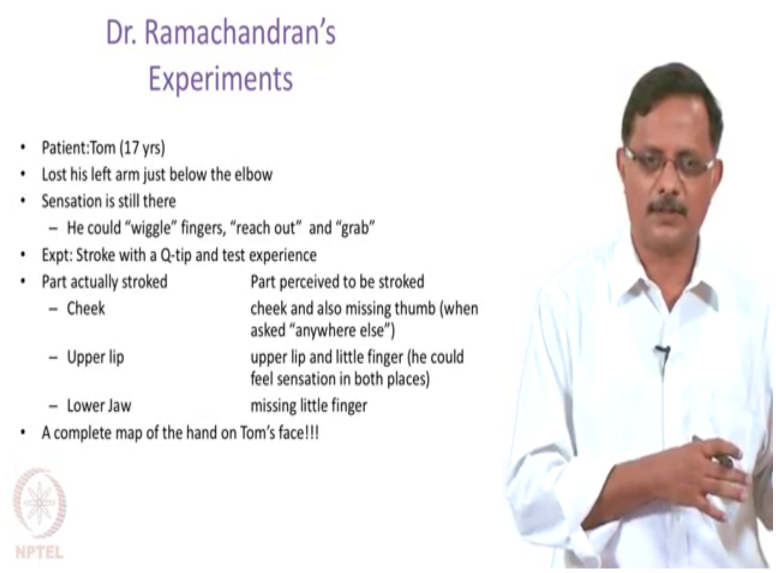

Now doctor Ramachandran has taken the results from you know doctor pons studies a starting point right and here the interesting idea and he applied this idea on a patient on a phantom limb patient who visited him. This first patient was called tom and he is a seventeen year old young champ a tom lost his left arm just below the elbow and she he had the sensation of phantom limb, and what is strange is he could feel that he could wiggle the fingers of the phantom limb and you could reach out and grab objects and so on so forth.

So,. So, the experiment goes like this, this doctor has taken a kind of a cotton swab a q tip right and touched various points on the surface of body surface of tom, and asked him to report which part of his body is being touched. So, while the experiment is going on. So, this is the patient and is he was actually blindfolded in the experiment ok. So, when the patients a cheek was touched, and then when the patient was asked in which part is being touched. The patient reported that the cheek was being pressed and also the missing limb the thumb and missing thumb of the phantom limb.

So, similarly when the patient's upper lip was touched, the patient agreed that upper lip is being touched and also the little finger right of the phantom limb that was being touched. So, similarly when the lower jaw is touched the patient reported that the missing little finger was touched. So, therefore, stimulation of the face right is somehow being combined with the stimulation of the different parts of the phantom limb ok. So, so this simple experiment led to the discovery that there is a whole map of the patients of phantom limb on the face. So, for example, here you have the index finger, here you have the thumb and so on so forth. So, this all map the hand on the face.

Now, in addition to the map of the hand on the face similar maps were found in two other locations. For example, this whole map on the right shoulder and when you the other places there are no dual sensation for example, when you submit the chest no there is only experience of touching the chest, but there is no other dual location.

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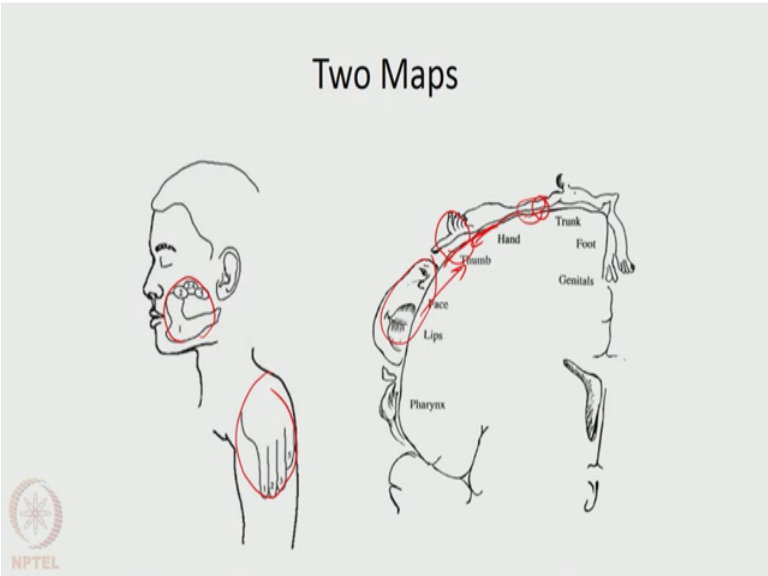

In the upper left arm right it was founded as the whole map of the hand. So, map of the hand is located in two places, one is on the face here and another is on the upper shoulder now why is this happening?

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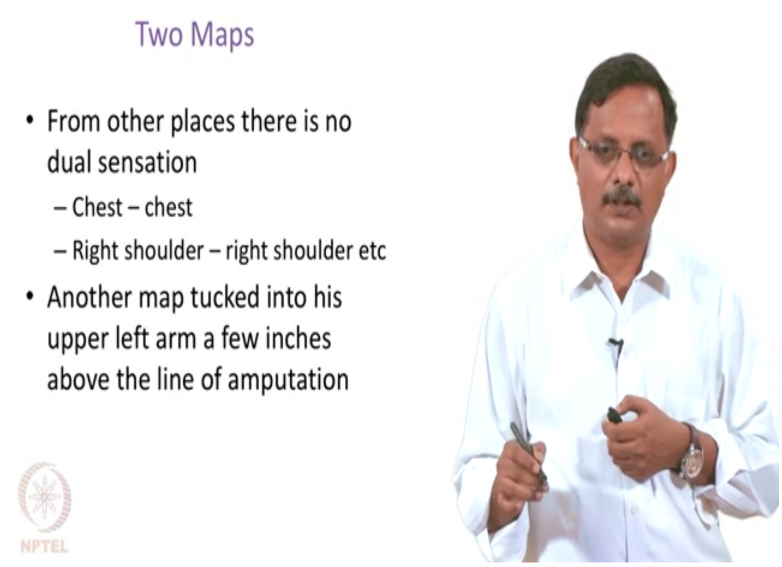

So, from what all we have seen about map reorganization right how when a part of the map you uses stimulation. So, they it does not receive any stimulation.

So, neurons in that part of the map sort of get reorganized and reallocated to responding to neighboring regions. So, and if you look at the somatosensory map. So, we know that. So, this is the hand region, and here you have this shoulder and so, here you have the face. So, neurons in the hand region do not get any input right because a nerves are cut. So, therefore, the shoulder region now kind of encroaches into this the hand region and the face region also now encroaches into the hand region. This is the reason why there is a whole map of the hand on the face and also on the upper shoulder.

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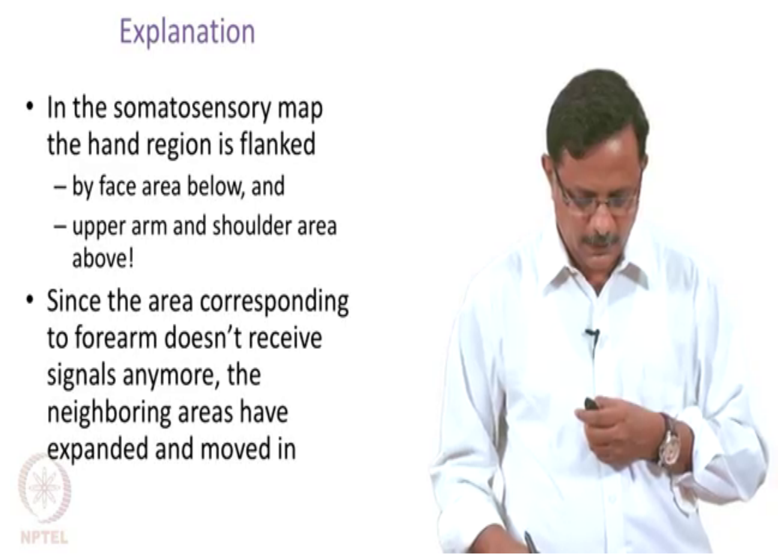

Right. So, the right. So, the somatosensory map region like I just explained is flanked on one side by the face area and other side by the upper arm in the shoulder area. So, therefore, when the area corresponds to the forearm does not receive any signals the neighboring area just expanded and kind of encroach into this area.

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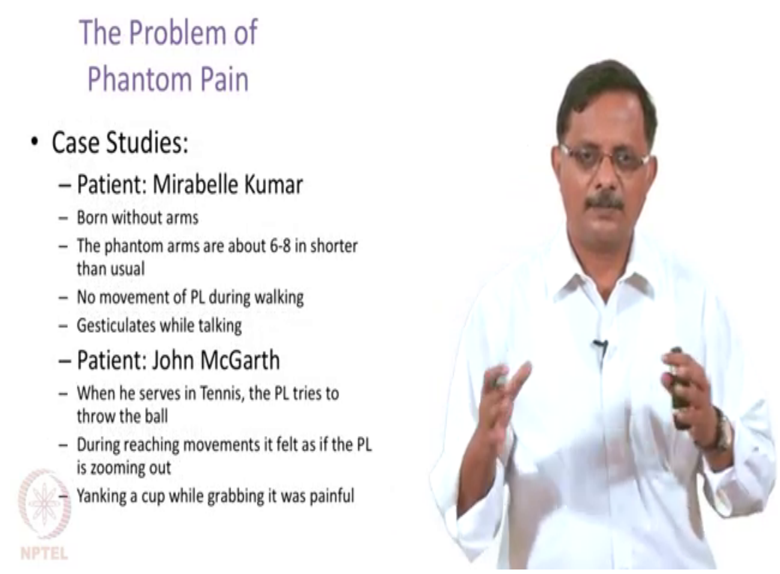

So,. So, that gives an explanation of why there is a phantom limb sensation, but there is a real problem the clinical problem associated with the phantom limb which is the phantom pain. So, there were several case studies which doctor Ramachandran has you know looked at and reported in his book one of them is a patient called Mirabelle kumar; she was born without arms and her phantom arms are about six to eight inches shorter than normal arms, and there is no movement of you know of the phantom limb during walking, but when the patient gesticulates right during talking the arm right the arm moves. So, the arm can gesticulate phantom limb and gesticulate.

Then the and the other patient called John McGrath right and this guy in the phantom limb can also throw the ball when the patient serves in tennis and during reaching movements. So, thing it feels as if the phantom limb is zooming out, that is like the target which are trying to grasp is too far away it is as though the phantom limb can stretch itself out right, but what is interesting is in one interactions interaction with the patient alright the doctor asks him to you know pick up a cup with his phantom limb the cup is on the table. And just when the patient is trying to grab the cup the doctor pulled the cup away and in that process I do not know the patient must have felt an extra stitching of his phantom limb, and the that get a lot of pain. So, the grabbing was felt to be painful.

So, the again and again the pendulum patients report pain in the phantom limb. So, the question is, how do you treat it? So, this is a very strange situation because the phantom sensation itself is you know is ordinal right and how do you treat the panting pain ok.

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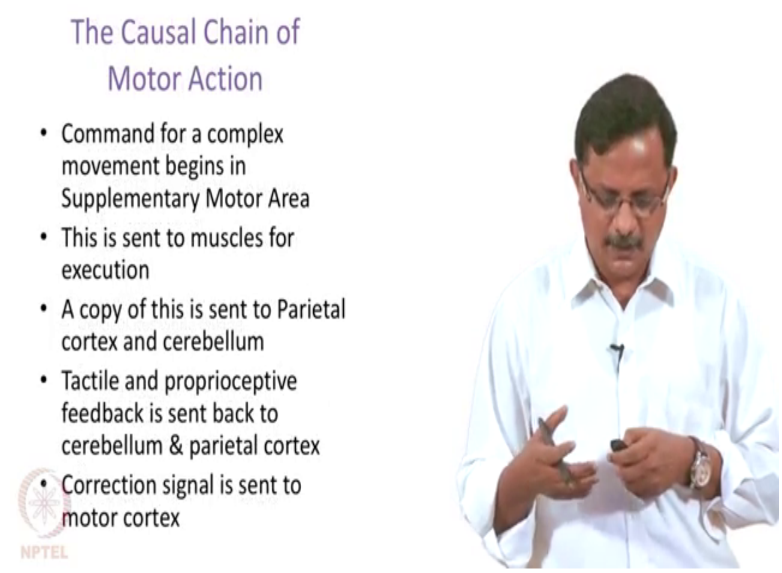

So, to understand why they are feeling the phantom pain right here is a theory proposed by doctor Ramachandran. So, it goes something like this

So, if you look at this there is this kind of schematic.

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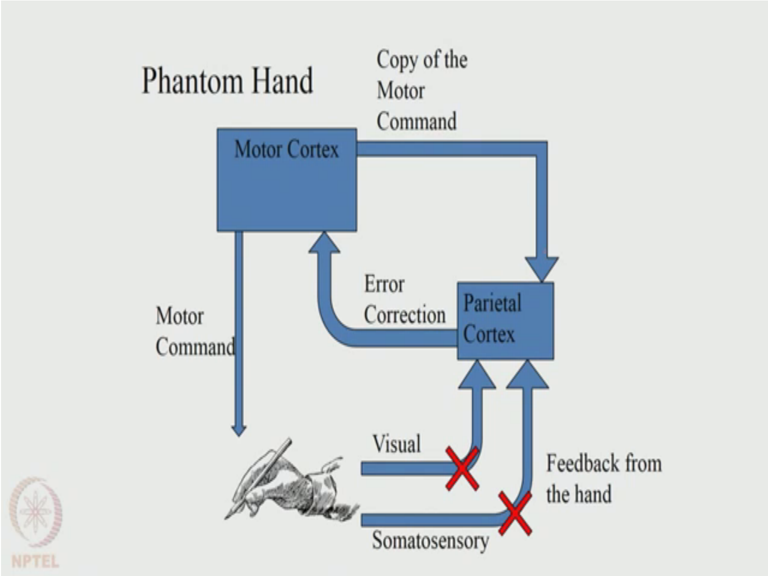

So, we know that motor cortex originates some motor commands and the motor commands go to the spinal cord in here and way down and then spinal cord sends commands to the muscles of the arm and then arm moves. So, at the same time it turns out that the motor cortex sends copies of it is command to other parts of the brain. So, we have seen earlier that sends a copy to this cerebellum for example. It also sends a copy to the parietal cortex right and now this is called a referent copy of the motor command; then parietal cortex also receives sensory feedback. So, it receives input visual and somatosensory cortex.

So, visual information tells you know where the arm is located and how it looks it is appearance. The somatosensory, feedback gives you information about the arm configuration that is what are the joint angles of the fingers and of the you know wrist and so on and so forth. So, using that also the parietal cortex can judge where the arm is and you know with respect to the body. So, now, when the parietal cortex receives the copy of the motor command right it kind of calculates, what would be the expected position of the arm when this motor command is executed ok. So, this is what is called a forward model. So, the parietal cortex computes a forward model and estimates where the arm would be.

And it also receives the sensory feedback from the visual and somatosensory and other sources. So, it compares it is estimated position of the arm it with the actual position, and if there is a mismatch between these two there is an error and this error is fed back right to the motor cortex and. So, asking the motor cortex to adjust it is command slightly so that, this mismatch is cleared and the actual version of the arm and the and measured position the expected position of the arm right are both the same ok.

So, this is what happens in a normal person, but the problem is in case of phantom limbs you know patient right there is no visual feedback because arm is not there and there is no somatosensory feedback, because in the arm is not there. So, therefore, what can happen in principle is the parietal cortex receives the motor command, right and estimates where the arm should be, but it does not receive any echoing feedback from the sensory organs. So, it thinks that there is a mismatch, it the arm is not able to reach the target location right and therefore, it is since an error correction back to the motor cortex. Asking it to strengthen the you know give even stronger command the arm. So, the arm can move to the desired location.

But this loop will never end because the there is no supportive or conforming feedback from the visual and somatosensory sources. So, therefore, this goes on and on and it as of this motor cortex and parietal cortical loop it is stuck in a kind of a frozen state, and which is give which probably is translated into some kind of a clenching of the arm and which is then associated with phantom limb pain.

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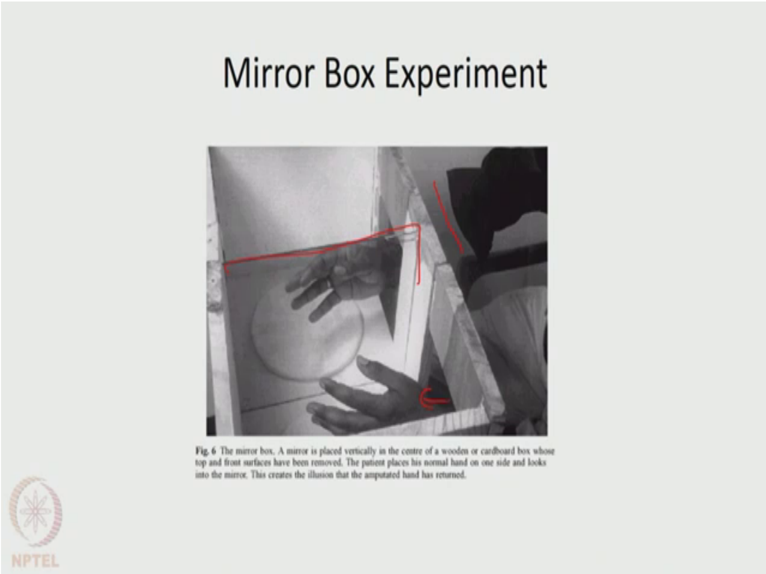

So, doctor Ramachandran suggested a very simple experiment to relieve this situation and relieve the pain, this called a mirror box experiment. In this experiment there is a box and which has two compartments; the two compartments are separated by a mirror in which you can see here right and the. So, there are two slots to the box into which you can you know the patient or subject can put the two arms when a phantom limb subject is using the box which is typically the case right the. So, in one of the slots the intact goes in the other slot there is nothing no because here in this case the right time was subject is missing that is amputated. So, nothing goes into the right slot only the left arm the intact arm goes into the left slot.

And then the mirror is placed so that, it faces the intact arm. So, in this kind of a configuration if you look at it, the it looks as if the patients the right hand is still visible and it is still there right. So, the patient gets a feeling that both arms are present right. So, in this kind of a situation. So, what happens is the patient can see his left arm because it is actually there, and patient gets sensation it is seeing the right arm because it because he is only the mirror image of the left arm.

So, a visual feedback is restored although somebody sensory feedback is still not there. So, because of this and the patient practiced on the box again and again something interesting happened. So, in case of this was first started on this patient called philip Martinez right who suffered from brachial evolution.

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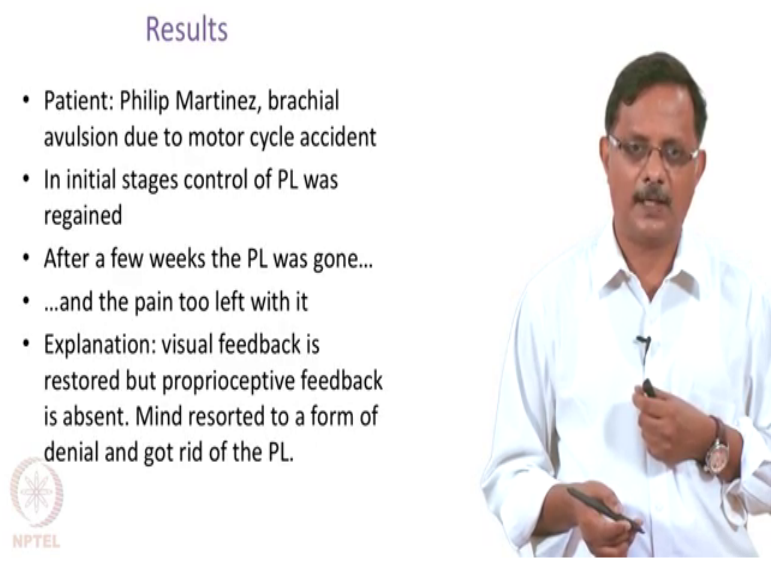

So, this brachial plexus is basically a kind of a bundle kind of a junction area, which connects the spinal cord with the arm and you know in a motorcycle accident the nerves were kind of yanked out of that nerve roots and. So, therefore, the patient had a phantom limb sensation. So, when the patient worked with the box after flu few weeks the phantom limb was completely gone since the limb itself was gone the pain also you know we left along with it ok. So, what happened in this case like I just explained his visual feedback is restored, but the somatosensory feedback is still not restored because there is no real physical arm. So, there is no touch and you know purpose of information coming from the phantom lim.b

So, probably brain got confused because it is getting mixed signals, because visually it looks like the arm is there, but in terms of touch there is nothing there. So, this conflict maybe created a problem and it kind of destroyed the illusion of the phantom limb in the process.

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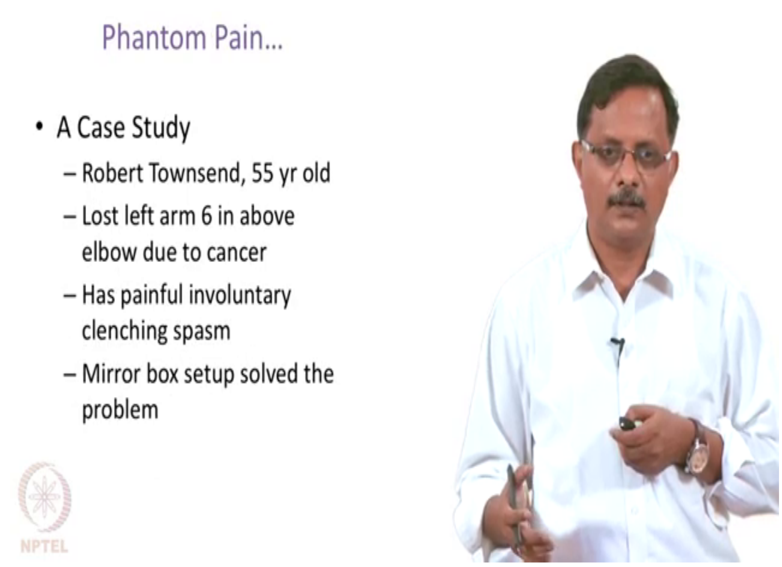

So, similar experiment was done also in another patient Robert Townsend he lost his arm he lost 6 left arm, a s6 inches above elbow due to cancer and he had this kind of the same clenching spasm and the pain along with it. So, when he walked on the mirror box right he also got it off his phantom limb and also his pain.

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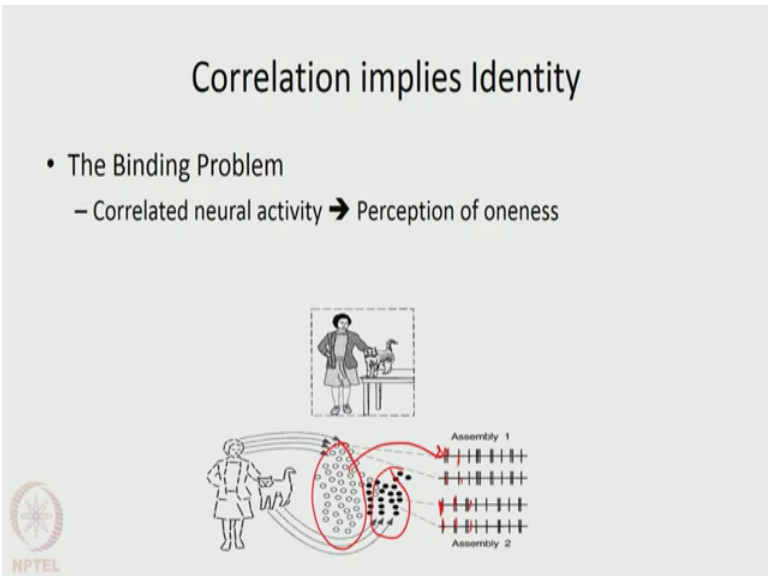

So, now let us look at an interesting aspect of phantom limb and also the question of experience and how neural activity is related to experience. So, there is a problem called the binding problem. So, which basically state if two sets of neurons or two pools of neurons respond to two different objects? So, in this simple schematic, there is a woman in this scene and there is also cat, and we assume that different neurons respond to the woman and then the cat. And neurons which respond to the cat right they all fire in synchrony. So, as you can see right here and neurons which respond to the woman right also fire in synchrony and neurons responding to the woman and neurons responding to the cat they are out of sink ok.

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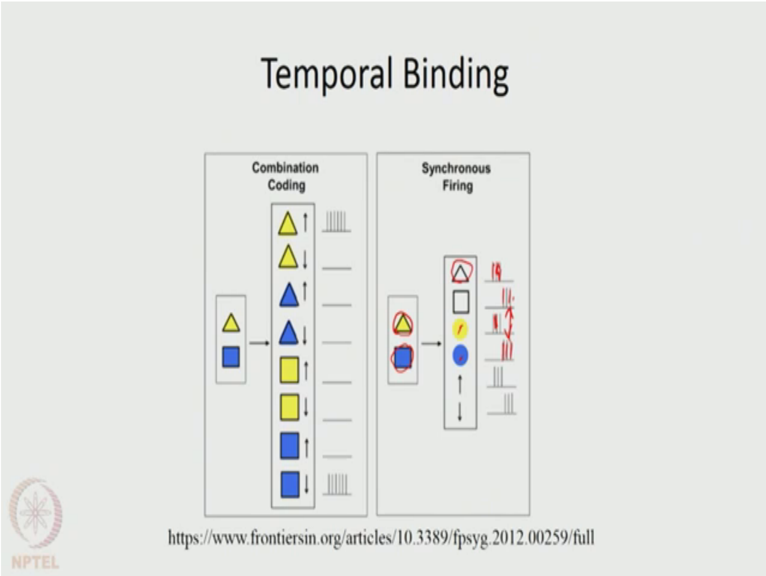

So,. So, these and these are out of sink, but during with respond to the same object they are the firing sink ok. So, the basically this is a schematic, but these kinds of schematics have the roots in experimental data, some of the earliest work on this was done by gray and singer on cats visual cortex.

So, where they found that when a moving bar shown to the cat neurons which respond to the bar right are all firing high in great synchrony, but when two bars are shown and two with two bars move in opposite directions, neurons which respond to one of the bars firing synchrony neurons respond to other, but also fire in synchrony among themselves, but there is no synchrony between these two pools of neurons ok. So, this is called a temporal binding.

So, basically you bind all the neurons which respond to a given object together, you know by allowing them to fire in synchrony ok. So, this way you are using the time dimension to express the identity of a of a given object or identity or you combine all the features of a given object right into an identity of an object through the time dimension. So, a classical way of achieving this kind of a binding is by having in the separate neurons that respond to different combinations of feature as you see on the left side of the side whereas in synchronous you know firing.

So, if you look at the example. So, there is a yellow triangle and a blue square. So, here you have two color properties yellow and blue, and two shape properties that is triangle and square. So, so imagine that there are separate pools of neurons which respond to each of these features. So, there are these triangle neurons which see whenever they see a triangle, the square neurons which respond to a square and then there is a yellow neurons and you know blue neurons right.

When you are looking at a yellow triangle neurons which respond to yellow and neurons which respond to the triangle right will be firing in synchrony right which is what you see here. Similarly when you if you since you are looking at a blue square here, neurons which respond to blue which was these neurons, neurons which respond to the square which are these neurons. So, they are in synchrony ok. So, this is called temporal binding and there is lot of evidence for this kind of binding occurring in the real brain.

So, because of this binding. So, when 2 neurons are fire and sync to given two different features, brain tends to believe that these two features come from the same object. So, this you know this feature of the brain has been exploit exploited right to create very interesting illusions. So, one of them is called a rubber hand illusion.

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So, in this illusion or this subject right and he places both his hands on a table and there is a separator right, which will ensure that the subject cannot see his left hand. But in place of the left hand which is invisible to the subject and they place a rubber hand, which kind of looks like this his left hand right and then the experimenter stimulates the left hand of this object right and the rubber hand right simultaneously.

So, that for example, he is taken brushes and simulating the index finger of the actual left hand and index finger of the rubber hand simultaneously right in a correlated fashion; that means, you have the pattern of stimulation on these two fingers is exactly correlated. It should not be strictly periodic should be slightly irregular, but we should the rhythm should be the same right on these two points and when they did that for maybe a few you know maybe a 10 minutes or so, right the subject had the feeling that the rubber hand actually belonged to him like he had the feeling that when this simulation is going on the rubber hand, he felt that it is in the his real hand is actually being stimulated.

In fact, in one dramatic variation of the experiment of the experiment, the experimenter tried to hit the rubber hand with the hammer right and the patient was so shocked, he jumped up in any alarm when that happened because they he was. So, deeply identified with the rubber hand because of the way in which the simulation was given to the subjects brain. So, that gives rise to a very interesting philosophical angle to this whole idea of a temporal binding.

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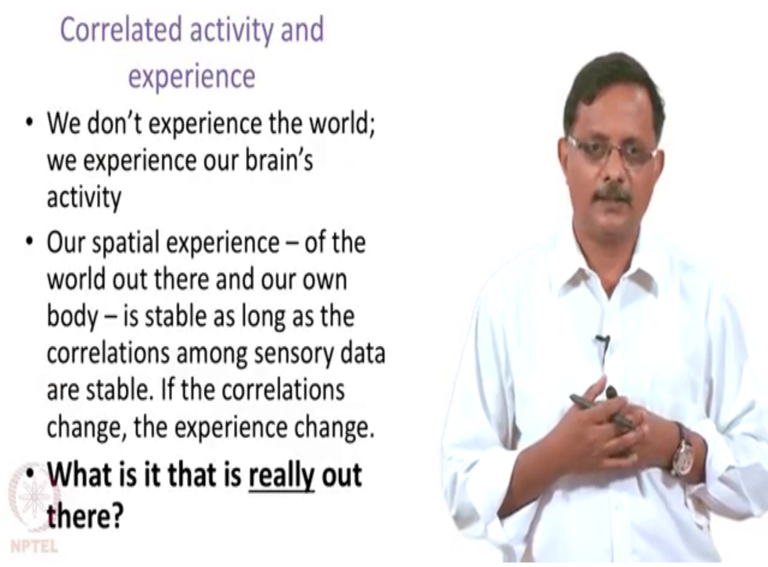

So, what it looks like that what we experienced is not really the world, but we only experience our brains activity right. Now to the extent that the world produces as a reliable response in the brain right we had experienced the what in a reliable fashion. But by artificial manipulation if you can manipulate the activity in the brain right then you can change the experience. So, that you know gives rise to a whole deep philosophical question of what is really out there ok. So, we will we will stop at this point.

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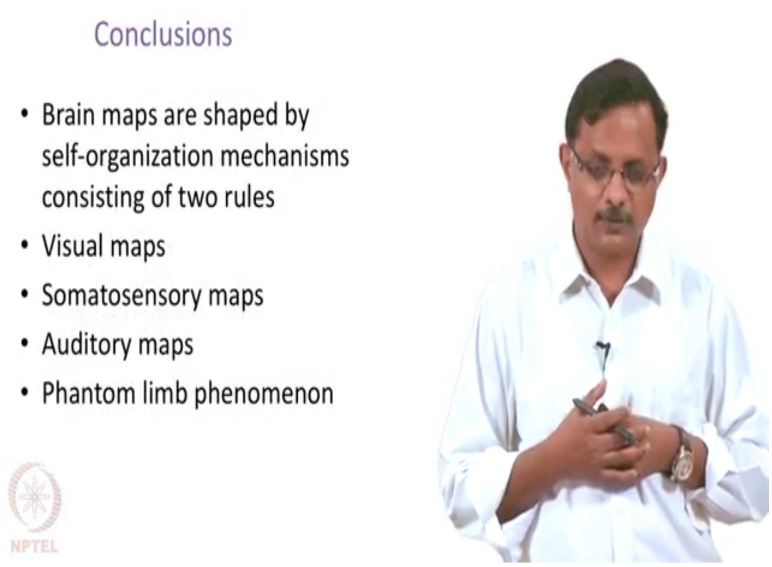

So, to summarize in this lecture, we have seen that in the different kinds of brain maps and brain maps are governed by two important self-organizing mechanisms and with that we could we were able to explain several kinds of maps, visual maps, somatosensory maps auditory maps and finally, we also looked at the phantom limb phenomenon.

Thank you.