Bioelectricity
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Lecture – 28

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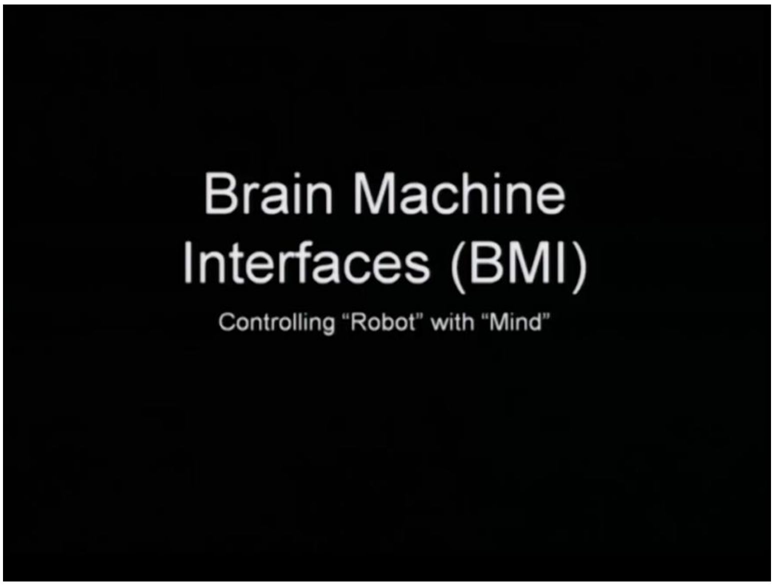

So, this lecture I will be talking about the man-machine interface. So as of now, we have talked about the how the different signal - bioelectrical signals are being transmitted, the action potential, the addition, summation, subtraction, inhibitory neurotransmitter, excitatory neurotransmitter. Then different circuits in the form of retinal circuits, cochlear circuits, the olfactory systems, the gustatory systems, the memory acquisition, the spinal cord signal, the stretch reflex arc, and so, and so forth. We have talked about several such circuits, and how the electrical impulses are being coordinated. So, one thing what I highlighted in one of the earlier classes what really is neural code.

So, say for example, I am seeing an apple, and I am calling it is an apple; or I am seeing oranges, and I am calling it an oranges. So, what essentially is happening is that my visual system is picking up those information, translating them into electrical signals, and that electrical signals is coded in the brain as an apple or as an orange or as hot or cold or whatsoever. I mean depending on any kind of signal what you are getting. So, assume that we know all those signals, and we could tune a robot with those signals, then a robot should be able to execute that action. If there is a wave, we could interface those signals, so essentially that means, is that suppose I am thinking something, and I want to do this. If I know those signals, and instead of me, say for example, I am sitting here, and so imagine like look at this, so I want to you know lift this fine. Now I am thinking that I have to lift this pen from here. So, this pen is sitting out here fine, you could see this pen.

Now, I am just thinking that I had to lift that pen. So, there is an electrical impulse which is going, and suppose my arms are not functional. Now I am thinking, and I have this robot from my thinking will be transmitted to the robot, and robot will exactly pick up the signal what I am thinking, and I will do the job, am I making sense? So, I want to pick up this pen. So, my best way to pick up the pen is like this, I pick up this pen. So, imagine that this is a normal situation. So, what I did I had to do something. So, I needed that pen. So, there is a thought process; I saw the pen, I went there, I picked up the pen, and then I start writing.

Now, situation two, my hands are not functional; I do not have my hands or some situation, imagine my hands are not there. Instead there is a robot, say for example, this mouse is the robot, imagine this mouse is a robot. I am thinking, and my thought process - my brain waves are connected to this robot,, and then this robot will go like this. Just imagine, it is not my hand, it is suppose the robot is going, robot will pick up the pen, and will move it. Is it making sense? So, this is essentially is brain machine interface, where a brain can crosstalk to the machine. So, the brain impulses could be configured in a machine, the machine can do that job. So, this class, and this is the concluding lecture in terms of that animal bioelectricity or from some of the insect bioelectricity, I will be dealing with later after the plans.

In animal bioelectricity, this is one of the most beautiful successes stories of last century, where man has been able to translate the information of the brain to the machine. So, in other word, man has been successful, if you read through this first slide what it says, man has been successful in controlling the robot with mind. And this is the story of a monkey called belle, and I will be discussing this how that was feasible.

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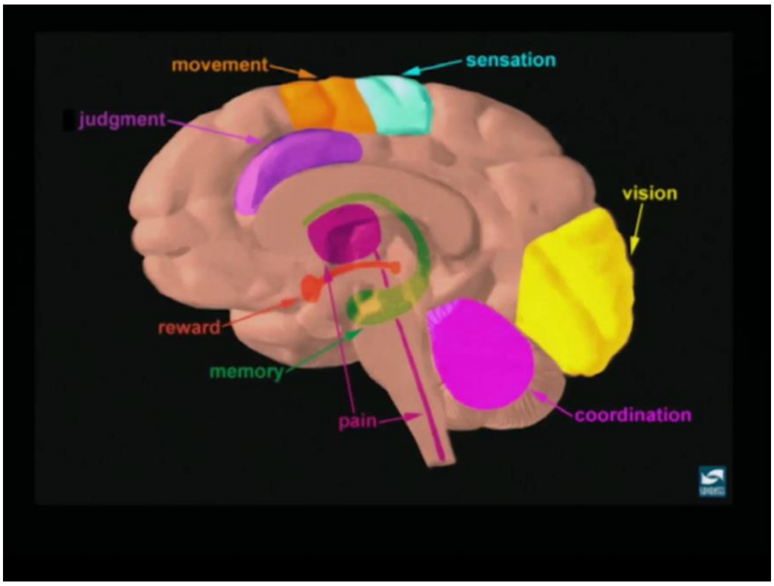

So, before doing that let us see this slide, where I was repeatedly told you in several classes that the brain has different areas which are involved in different functions. So, if you look at it, you have the moment area out here, you have the judgment area out here, you have the sensation, all the sensor inputs are coming out here. The any of the hippocampus, which is this seahorse like structure sitting out here, which is involved in your memory acquisition. And we have talked about what happened to those patients in those case this hippocampus region was removed. Then you have the reward area, this the area which ensures that if I perform well in the class, I will get an award or you know if I do this, I will have reward given to me, and so on, and so forth.

Then you have the coordination area, which ensures all the coordination motions of your body, all the different coordination - visual coordination, eye coordination, and hearing coordination likewise, and so on, and so forth that you have the visual cortex, which is in back of the brain out here. The complete visual fields, and how to judge all those things. So, this whole structure what you see in front of you which is just part of it or a small fragment of it, a small minuscule of the whole ability of it. Work in coordination, and they all work as a pool of cells bathed in a pool of electrolytic fluid, where the electrical impulses are travelling in a certain pattern. And decoding those pattern is the journey of the modern neural engineering or the bioelectricity. To understand those wonderful motions those fluxes, and everything what ensures, what we exactly see or what we are observing color perception, the movement, thought, and consciousness, and everything.

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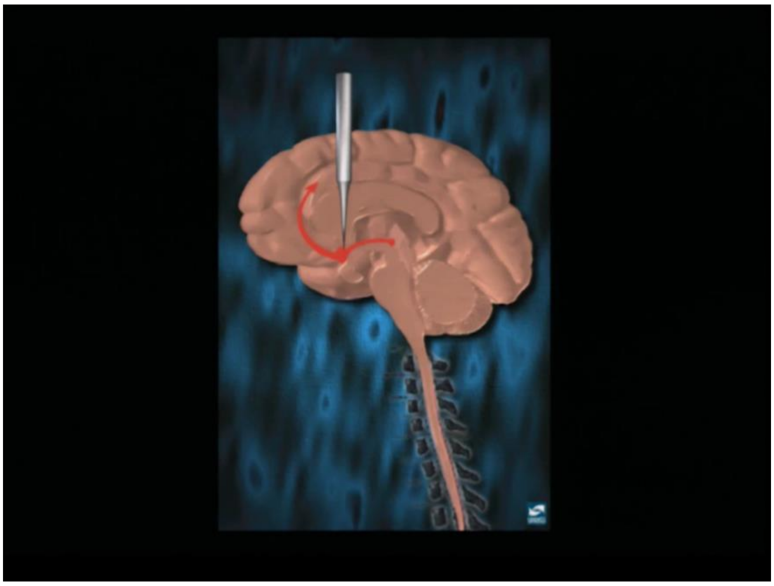

This is the cartoon showing say for example, this is a reward area. If we will go back, so this is the reward area. So, this is what you are doing that you implanted electrode in the reward area. So, this is now we are slowly entering into that experiment what I wanted to show you people. So, what is this being done, before I really get into the experiment. So, there these monkeys were trained in a way that if they do certain act, they will get an reward. Say for example, if imagine this is a liver this pen what you see out here this pen, this is the liver. So, I tell the monkey, you hold this liver, and you move it in one direction like this, like this. If you move it in this direction, you will get some say juice;, and if you move it in the other direction, you would not get a juice.

So say for example, if it moves in this direction, it will see a green light coming in front of it, or if it moves in this direction, it would not see that. So, this liver so I am training the monkey to move the liver in one direction; so if it moves in this direction, it will get a juice;, and if it moves, in the other direction it would not get a juice. Or if it moves in this direction, it will see another green light as well as the juice;, and in the other direction it will see a red light, and you would not get a juice.

So, if it has to get a juice or if it has to get a reward, it has to move in this direction. So, these kind of trainings could be done, and when you are doing those kinds of trainings if you look at this slide now, so this is reward area. So, your reward is very simple. If you move in your direction, you will get a reward. So, the reward area get activated, here the reward area is getting activated. So, you can pick up the signals from the reward by putting an electrode there, what is the signal generated when you get a reward.

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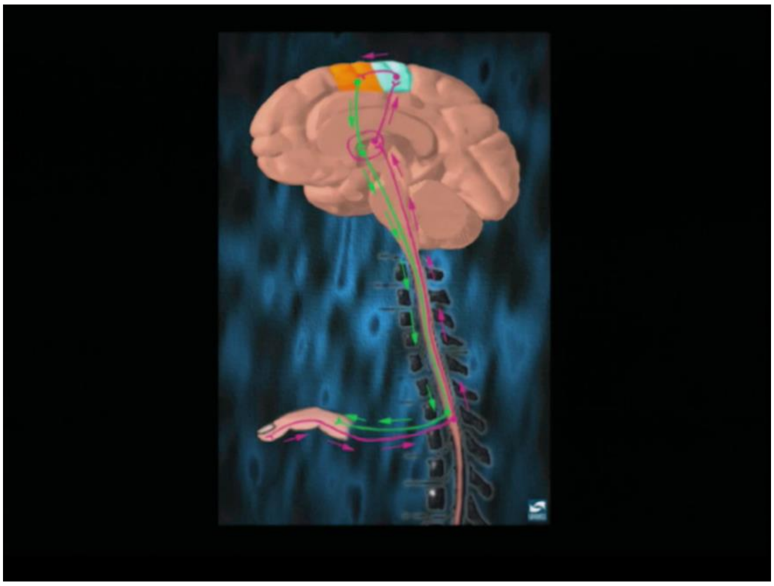

So, now coming back into the circuit, so this is the most primitive way or the simplest way to put the circuit. So, this is the finger which is ensuring. So, look at my finger. So, this is my finger which is ensuring that it moves in one direction, this is my finger which is ensuring that this either moves like this or it moves like this. So, whenever I am doing say if I move like this, so the signal now if you look at the slide, the signal the one in the pink color, these signals are all travelling along this all the way to the brain. And in the brain, the reward area or hippocampus reward, and all this areas, there are whole range of competitions part of the signal goes all the way up into the sensation area, and the movement area, so this area, the reward area, sensational area, movement area.

Now, see the circuit sensation area, movement area. From here it moves to the movement area, and the signal comes back, and now if you look at my finger, now I can move my finger after this whole processing I can move my finger like this. So, this whole process of movement of the liver is involving, if we had to get a reward, if I move in this direction like this, the liver is back now I put this, and bring the liver like this. So, in order to do that there are three different circuits; now if you look at the slide, so this is the level of complex circuit which is involved in it. So, there is a reward area, there is a sensation area, there is a movement area. If I go back to this picture now, and if I could collect all the signals what is happening, and if I could decipher these signals,, and then what I do that I translate those signal to a machine. So, this is what the next slide is about from theory to practice.

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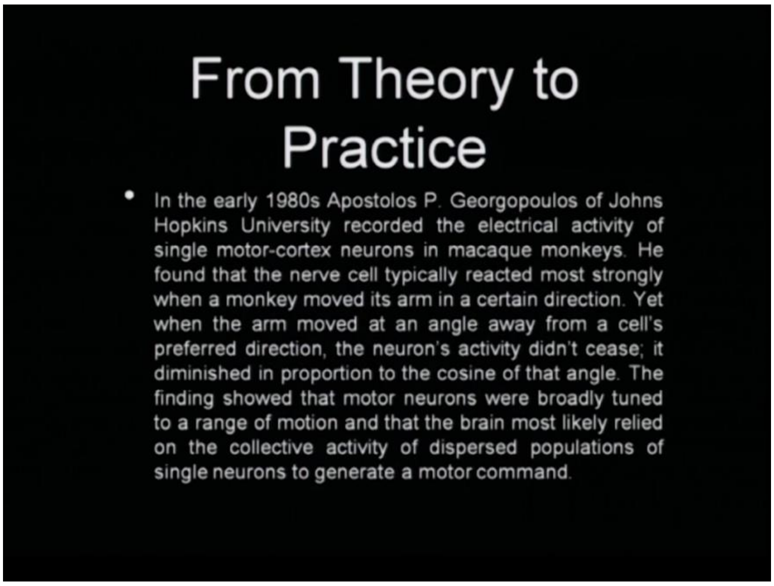

In early 1980s Apostolos P Georgopaulos of Johns Hopkins University recorded the electrical activity of the single motor-cortex neuron in macaque monkeys. He found that the nerve cells typically reacted most strongly when a monkey moves it arm in certain direction that is exactly what I was trying to tell you. If it moves in a certain direction, there is typically very high electrical activity. Now, if you read further, yet when the arm moved at an angle away from the cell’s preferred direction, the neuron’s activity did not cease. It diminished in proportion to the cosine of that angle. The finding showed that motor neurons were broadly tuned to a range of motions, and that the brain most likely relied on the collective activity of dispersed populations of single neurons to generate a motor command. This is very important please read through this paragraph, this is pretty much the bases of some of these successful experiments.

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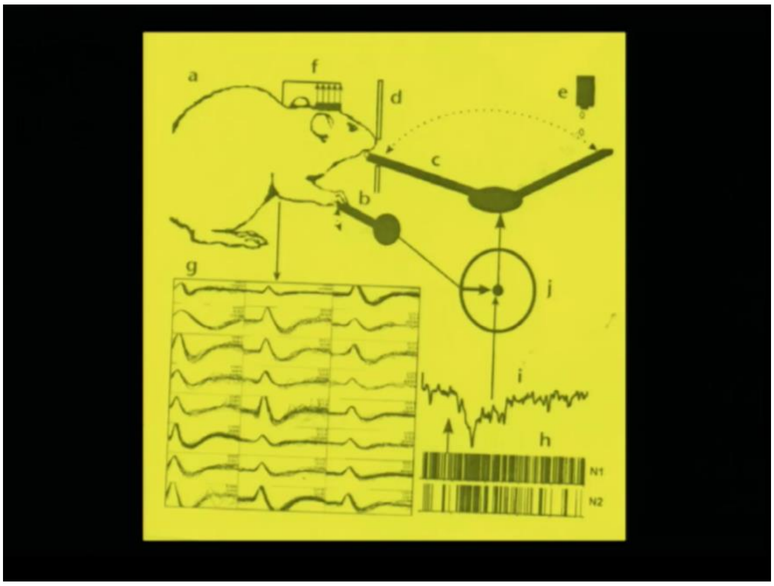

From here, so this is what Georgopaulos experiment was being done. So, they were training. So, look at this, they are training this rat, you know they move it in a certain direction, and and they were recording. These are the electrodes which are implanted here, you see this. So, these are the electrodes the in f, you will see. All these field potentials, all these electrodes are being stored. And depending on from which electrode it is coming, this is the impulses, and this is the raster plot, these are the different raster plots which are getting generated out here. So, the overall field potential changes what are taking place during this whole process of its motion using the finger. So, essentially what the rat is doing, the exactly the same thing what I am trying to do out here. So, I hold this, and I move it in a direction like this.

Now if you go back to the figure this is how it looks like. So, if somebody puts in my brain all those electrodes like this, they should be able to trace the whole motor action which is taking place. If you go back to this picture, you will see, it is all in the sensation, and the moment area where this whole process is taking place, which is essentially part of the motor-cortex.

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Now, from here the experiment was designed that this is very interesting experiment, which is done in Durham. So, if you look at the American map, so this is where North Carolina Durham Duke University, and here you have Massachusetts - the state of Massachusetts. So, this experiment was done, there was monkey which was sitting here in North Carolina, and this was controlling a robot which was sitting in Massachusetts. And how this experiment was done this is what is all about the man-machine interface one of the most successful stories of the last century.

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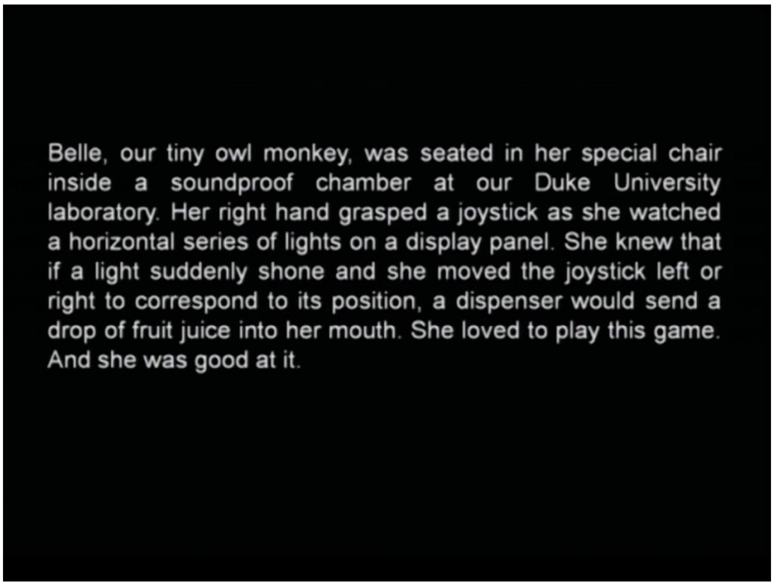

Belle, so this was the monkey this is called an owl monkey which was seated in a special chair inside a soundproof chamber at our duke university, this is all taken from the discoverer's website Soundproof at our duke university laboratory which is essentially out here in North Carolina (( )) Durham sorry her right hand grasped a joystick as she watched the horizontal series of light on the display panel. So, imagine, so if you look at me now, the way I am holding it. So, I am holding grasping a joystick as an I am seeing lots of lights in front of me, and this monkey knew. So, if you see the slide now this monkey knew that if a suddenly that if a if a light suddenly shown she moved the joystick left or right to correspond to its position a dispenser would send a drop of fruit juice into her mouth she loved to play this game, and she was good at it,

So, look at it how they have trained the monkey. So, basically what, then this monkey knew that if suddenly if light suddenly shown, and she moved the joystick left or right to correspond to its position. So, imagine if you will look at me. So, so here the light is moving. So, this knows certain light is shown like a, and if it could really you know follow that light in a way, then this monkey is going to get a get the fruit juice it is pretty much like that. So, this monkey this belle was trained in a way that it could you know follow the light like wise, and it will get a reward.

Now, talking about the reward, if you will go back here this is this is the area which will get activated, and this activation is the function of these two situations, there is the sensation, because it is looking at those lights moving moving the eyes like this he is moving the eyes like this. So, there is a sensation is a moment, and there is this broad situation coming back to this.

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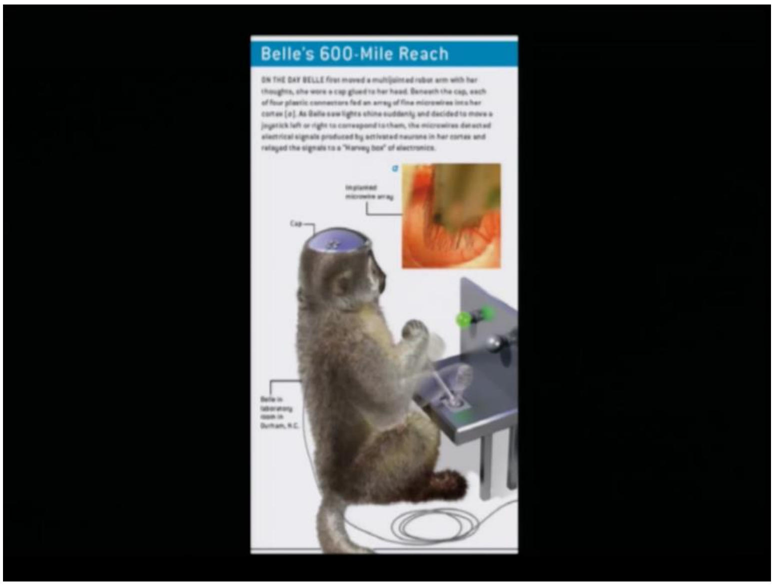

So this was what belle was trained with coming to. So, this is where belle is six hundred miles reach it means six hundred miles away. So, this is essentially wanted to tell you from North Carolina all the way to Massachusetts, this is what they are trying to highlight.

So, on the day belle first moved multi jointed robot arm with her thoughts as I was telling you in the beginning with your thought she wore a cap glued in her head, this is the cap which is glued in her head filled with all the electrodes all there beneath the cap each of the four plastic connectors fed an array of fine micro wears into her cortex. So, these are where the cortex if there are connected to the cortex.

As belle saw light shine suddenly, and decided to move a joystick left or right correspond to them the micro wears detected electrical signals produced by activated neurons in her cortex, and relayed the signals to a harvey box of electronics. So, this is belle in the laboratory room in durham north carolina here is the cap, and here is the implanted micro electrode this is just a underneath how the micro electrode ion implanted these are the micro electrodes. And this is the joystick which belle is holding, and playing depending on which light it is showing depending on the light it tries to correspond along with the light if the light is shown in the left it moves to the left if it is in the right it moves to right, and it loves to play this game, because it knows that if it does. So, it will get a reward get a reward for that.

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The box, and then you have the harvey box now coming to that harvey box of electronics. So, this before I proceed further please I will try to read through this scientific american exclusive online issue of may two thousand four which has talked about this particular story of belle the box collected filtered, and amplified the signals the harvey box what we talked about in the previous slide out here I am continuing from here electronics harvey box of electronics

So, the box collected filtered, and amplified the signals, and relayed them to a server computer in a room next door the signals received by the box can be displayed as a raster plot. So, this is where the raster plot is sitting. So, this is the similar raster plot as I was showing you here this is the raster plot which is sitting out here is basically showing essentially this raster plot is doing installing from which region of the cortex these signals are coming. So, basically a field potential plot it is learning this area is active this area is active which electrode from which electrode the signals are passing through.

You can really draw the whole map looking at the complete raster plot coming back to the... So, each row of the raster plot represent activity of a single neuron recorded over time, and each colour bar indicate that the neuron was firing at a given moment. So, basically you are getting a spatiotemporal plot using a raster plot, because patio, because at which from which neurons this space is coming temporal means with respect to time you are getting it.

So, it is a spatiotemporal competition which a raster plot gives you at what time this is active. So, this neuron is active at this time this neuron is active at this time, and this neuron is active at this time, and based on the plots you can say neuron one to neuron two neuron three to neuron four likewise this signal is moving.

So, that is what the raster plot does raster plot gives you an overall spatiotemporal changes in the signal at a given point of time depending on where all the electrodes are being placed.

So, maximum nowhere electrodes, but the complex the raster plot becomes, and more intense signal you start getting. So, coming back to the slide again. So, each row of raster plot represent the activity of the single neuron recorded over time, and each colour bar indicates that the neuron was firing at a given moment. The computer in turn predicted the trajectory that belle's arm would take, and converted that information this is very important, and converted that commands for producing the same motion in a robotic arm this is the key out here.

So, these signals the computer in turn predicted these signals are feed to the computer the computer in turn predicted the trajectory that the belle's arm would take, and converted that information into commands for producing same motion in a robotic arm, then the computer send commands to a computer that operated a robot arm in a room across the hall at the same time at the same time it sent commands from our laboratory in durham north carolina to another robot in a laboratory hundred miles away in response both the robot's arms which was the one robot, which was sitting on the other side of this room the other robot which is sitting six hundred miles away in massachusetts both of them at the same time they respond, if you read through this in response both robot's are moved in synchrony with belle's own limb.

So, essentially now belle's thought process from the brain. So, belle is doing this act you can think of it. So, this is what belly is doing. So, you look at my arms now. So, so this is what belle is doing, but from the signal generated from the head of belle you could make the robot do that action for it. So, say for example, I want the robot should give you a glass of water I just think the robot will do the job, because my brain will be conveying the message to the robot sitting in by your side to tell you give that glass of water to the robot think of it this is something amazing, if you really become intense, and think over this whole situation you are telling the robot.

So, essentially a nurse has to think of in a in a medical situation a nurse suppose there is a nurse, and twenty patients who has to work. So, nurse will not go to the individual patient nurse will think, and the patient will get the medicine. So, this is what man machine interface is all about that where you are thinking process the robot is executing the task. So, this is something amazingly interesting, and years, and years, and century to come mankind will be keep on trying you know to integrate its taught processes with a robot, because that is amazing I mean if you really could achieve that kind of fate, then a lot of things what we can we can only think we cannot really do could be achieved in no time. So, now going through this going through this whole layout of this different thing.

So, this is where the computer on the left, and the robotic arm this is the robotic arm which is setting across the hall from belle, and this is the other robot in laboratory in cambridge in massachusetts where the second robot is sitting interface with the computer. So, the signal, and this is where the belle is sitting the harvey box for the ethernet these are sent to the computer from here the computer split the message rather duplicate the message split in two paths, and send one path send a copy of the message to massachusetts, and then send another copy of the message through the wires to the to through the other room, and the end result is both the robots where, and this is what you’re seeing the computer is translating translating the signal in terms of tri directional moment of what belle has done, and this is belle’s raster plot.

It was basically belle’s raster plot which is generated from here from these from these wonderful electrodes this raster plot is generated this raster plot is sent to this harvey box where sent to the computer where it basically decolbulated the whole signal, and send a copy of a signal to massachusetts via internet where as the other one was sent to the other room through wire, and both the robots at the same time.

While belle was drinking the juice or you know getting the juice belle’s brain was taking two robots to function in synchrony. So, if you think of this whole situation this was a landmark discovery of its time to…

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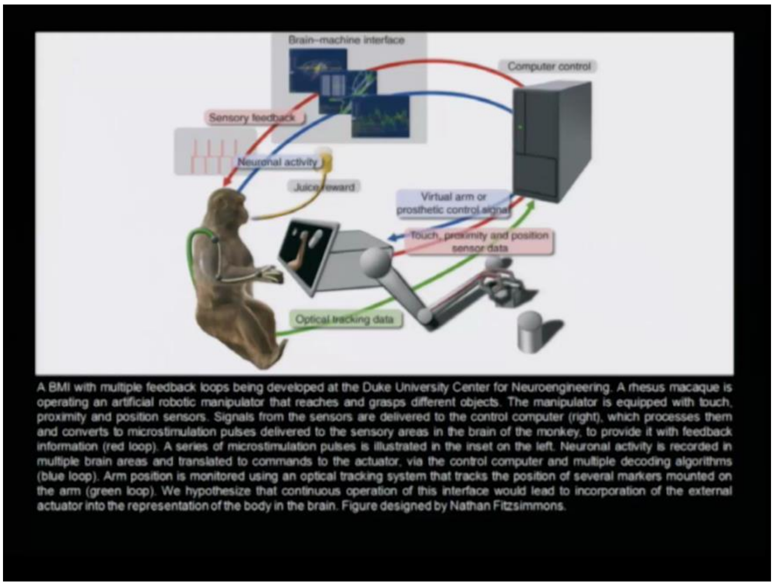

So, this is what if you have to really open up this problem . So, b m I stands for the brain machine interface. So, b m I multiple feedback loops being developed at the duke's university center of neural engineering rhesus macaque is operating an artificial robotic manipulator that reaches, and grasps certain objects the manipulators equipped with touch proximity, and position sensors the signals from the sensors are delivered to the control computer which processes them, and converts to micro stimulation pluses delivered to the sensory areas of the brain of the monkey which I have already shown you to provide it with a feedback information which is the red loop you could see a series of micro stimulation pulses is illustrated in the in set on the left.

So, this is those micro stimulation pulses what you see on the left the neural activities recorded in the multiple brain areas, and translated to command to the actuators by the control computer, and multiple decoding algorithms in the blue loop this is the blue loop which is involved in it arm position is monitored using an optical tracking system that tracks the position of several markers mounted on the arm green green loop. So, we hypothesis this is the hypothesis is that continuous operation of this of this interface would lead to the incorporation of the external actualator into the representation of the body in the brain.

So, basically you're decoding the neural code for that action, and if you know that neural code you can actually use that neuro code to do some actuation using a robot. So, there is almost a imaging of a neural code which they are trying to do at this point. So, from here I will move on to the (( )) side of it, now this of the game all the different kinds of electrodes which are involved in it this is very essential for you to understand those electrodes.

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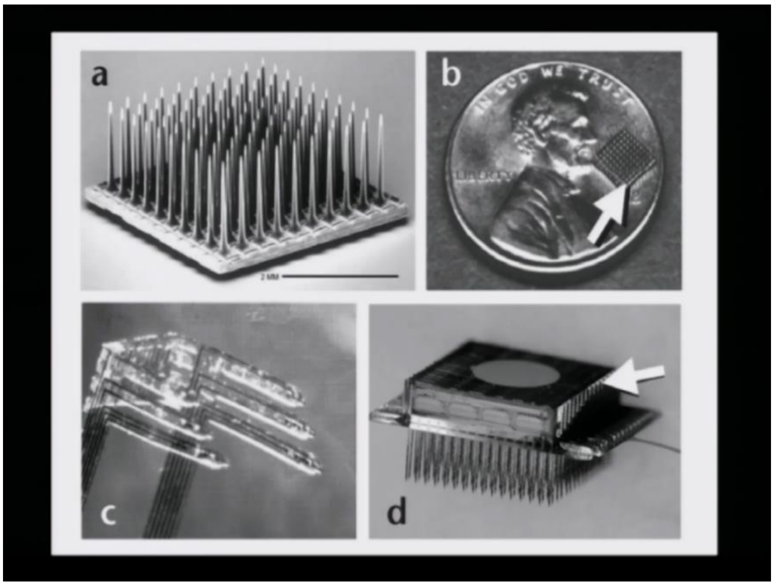

Now this is how the electrodes look like, and please make a note of the scale this is very important make a note of the scale these are the different configurations of the electrode they are very sharp electrodes, which gets into the brain, and implanted into brain as of now I have always talked about electrode I have drawn, but this is the physically how most of these electrodes look like.

So, looking at the slides. So, look at it I mean there’s almost an array of one two three four five six seven eight nine ten almost I think ten by ten array which is of electrodes sitting out there. So, then you have all the connectors showed by the arrow out here.

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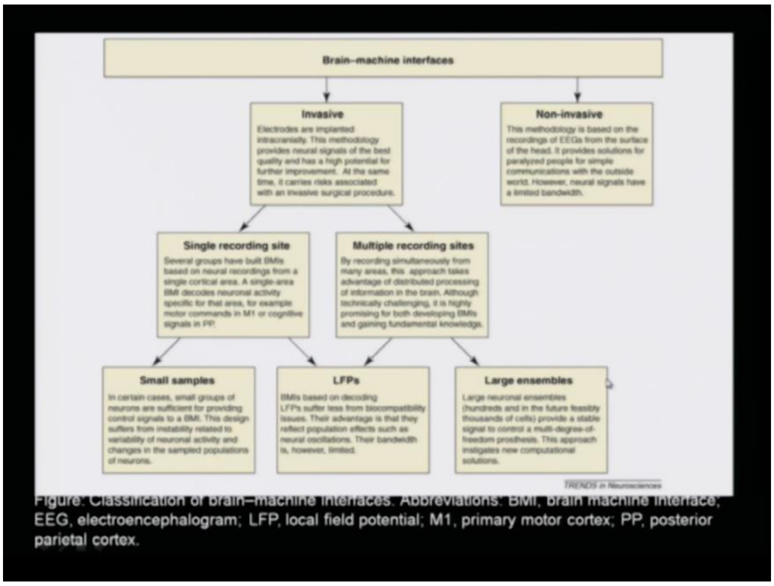

So, these are this is your summary of a the brain machine interface, if you look at it. So, there is in this you could have invasive technique or a non invasive techniques either invasive technique of the electrodes implanted (( )).

So, basically you are pushing the electrodes through the brain using surgical techniques you could have single recording side or you could have multiple recording sides depending on how may electrodes. If you really can push into the brain, then you have in the single electrode a single recording side you have a small samples where as you have the local field potential out of the l f p’s, you could see the you could follow the code underneath the abbreviation the b m I the brain machine interface e e g is electroencephalogram l f p is the local field potential m one is the primary motor cortex p p is the posterior parietal cortex.

So, you have these l f p’s where the brain machine reveals based on the decoding the l f p’s suffer. So, there’s a always there is another problem I will come to that, then you have the large ensembles, then you have the complete non invasive process of e e g electroencephalograms about which we have talked about different kind of waves which are involved in it alpha waves gamma waves that is where we decoding those information’s from the brain using the surface electrode of the electroencephalograms what I wanted to highlight here is this.

So, from the beginning of this course I am repeatedly highlighting this part see this is a big the biggest central problem apart from any other problem is this cell electrode interface, and if you read through this line very carefully b m i's based on decoding left piece suffer less from biocompatibility issues. So, there is always a biocompatibility issues with the electrodes involved, and this is very very important. So, the large ensembles large ensembles hundred, and in future feasibly thousands of cells provide stable signal to control multi degree freedom prosthesis this approach instigates new computational solutions.

So, if you look at this whole thing this whole brain machine interface this revolves around revolves around the fact that how good you are in terms of the electrodes as well as how good you are in terms of you know getting the electrode material which you'll which will ensure that there is maximum biocompatibility, and long term signal harnessing ability these electrodes should have…

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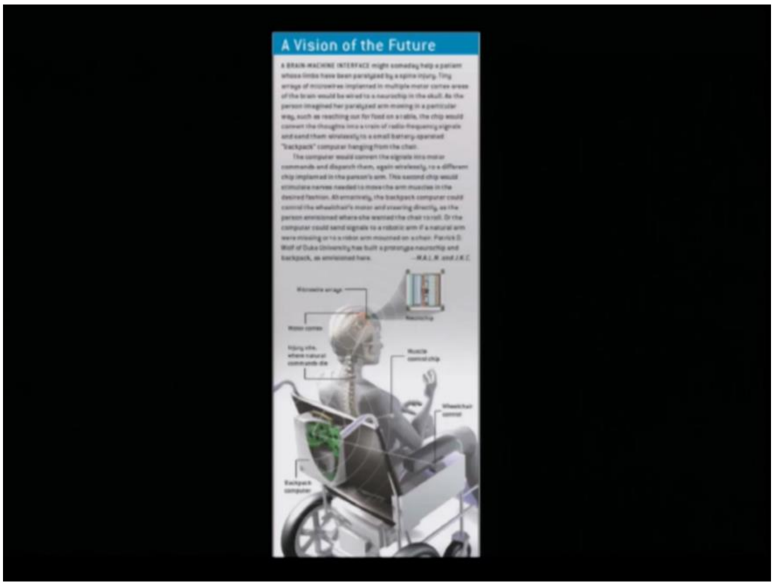

So, coming to some of the vision of the future. So, these are some of the vision of the future the man machine interface a brain machine interface might someday help the patient whose limbs have been paralyzed by a spine injury tiny array of micro wares implanted in the multiple motor cortex of the brain would be wearied to a neural chip in the skull as the person imagined how paralyzed arms are moving in a particular way such a reaching out food on a table a chip would convert the taught's into train of radio frequencies. So, this is very important.

The chip would convert the taught. So, I am just thinking that I want to have a food into a train of radio frequency signals, and send them wirelessly to a small battery operated backpack computer hanging from the chair. So, this is where the backpack is hanging. So, this is the neuronal chip the computer would convert the signals into motor commands, and dispatch them again wirelessly to a different chip implanted in the persons arms.

So, this chip is implanted out here. So, basically what is happening in this situation the signal from here cannot travel, because of a injury in the spinal cord injury side of the neural command die. So, in this situation this person is thinking this thinking process from here through this is transferred to the to the arm now the second chip would stimulate the nerves needed to move the arm muscle in the desired fashion alternatively the backpack computer could control the wheel chair motor, and steering directly the person in vision where he or she wanted the chair to roll or the computer could send signal to the robotic arms, if a natural arms are missing or to a robot arm mounted on a chair .

So, this is, then by patrick wolf in duke university has built a prototype neuronal chip, and a backpack as in vision here. So, this is basically those kind of chips what we're talking about this is some of the futuristic ideas.

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This is another futuristic idea where fully implantable multichannel recording devices are being put, and there are touch, and position sensors sitting there mechanical actuator. So, both power, and accuracy, and wireless link by which a person can really do certain things which he or she cannot do, because of certain injury.

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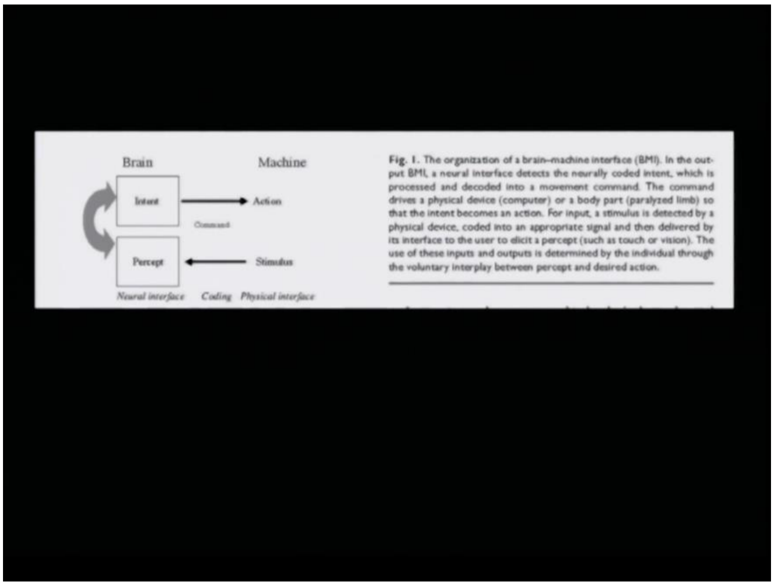

So, coming back, and summarizing this whole process. So, here you have the machine, and here you have the brain, and the percept, and the indent, and the command the actions, and the stimulus. So, this is the physical interface, and this is the coding interface, and this is the neuronal interface, and in the organization of the brain machine interface in the output b m I a neural interface detects the neutrally coded intent which is processed, and decoded into the moment command the command drives a physical device a computer or a body part of paralyzed limb. So, that the intent becomes an action for input a stimulus is detected by a physical device coded into the appropriate signal, and then delivered by its interface to the user to illicit upper set such as touch or vision.

The use of these inputs, and outputs is determined by the individual through the voluntary interplay between the percept, and the desired action. So, essentially what this means is you’re thinking something, and those signals are being picked up, and put those signals to a robot, and the robot executes the task. So, this is essentially all about the brain machine interface, and I have given you sufficient number of references please go through them, and this is where we will close on human or the animal bioelectricity.

It is a long journey of mankind in future those of who get inspired please pursue these kind of fields, because these are something amazing areas, where there are lot lot lot more to be done. We are nowhere even close to anything discrete one or two examples here, and there, but will be a reality someday the future or the success everything lies on the young brains who will take up these kind of challenging problems, and will make a difference for the society.

Thank you.