Cognition and its Computation

Prof. Rajlakshmi Guha
Prof. Sharba Bandyopadhyay
Biotechnology and Bioengineering
Indian Institute of Technology, Kharagpur

Lecture - 43
Different Types of Plasticity

Welcome, we have been discussing learning in biological networks and examples thereof. And as we know that learning is based on plasticity as we have learned in the earlier part of the course and synaptic plasticity can be of really the on neuroplasticity in general can be of 2 different types; one is functional plasticity the other is structural plasticity.

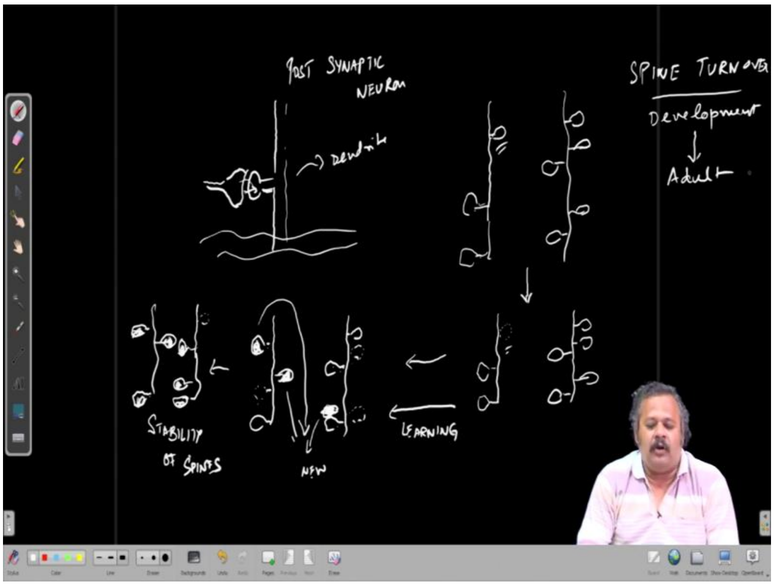
So, in terms of functional plasticity we have already discussed quite a few aspects and that is basically changing the strengths of the synapses. In the long term or in the short term either increases or decreases in synaptic strength, while the entire network remains the same, which is probably the most prevalent form of plasticity. However, the other form of plasticity is structural plasticity which was believed to be more in the stages of development when the entire brain is being is developing over the period of after birth.

And so later on in the 1960 and more afterwards people understood that there is a lot of structural changes even in the adult brain and not and the structural plasticity is not limited to the changes in the brain associated with development or around perinatal development or prenatal development when the brain circuits are forming.

The 2 of them important things is the presence of adult neurogenesis, the 2 of the important discoveries adult neurogenesis and observation or abilities to observe in vivo in an intact animal the dynamics of spines.

And so let us just discuss a little better rather revise a little bit of the functional plasticity that we had known and it is again the same kind of region where we will be talking, I mean region in the sense of the position in a neural circuit that we will be talking and the site of that is the synapse. And it is the spine for excitatory synapses forming on excitatory neurons.

(Refer Slide Time: 03:35)



So, if you recollect from our previous lectures the functional plasticity occurs basically at so if this side is the postsynaptic neuron and this is the dendrite of the postsynaptic neuron. We had said that there are these small protrusions called spines mushroom like structures on which the synaptic terminals are or the axon terminals make their contacts and produce a synapse. And it is the current injection at this synapse that determines how much current injection is going into that synapse is what determines the strength of the synapse.

And we say that the functional plasticity part of it is that we are or the system based on activity like we saw with the spike timing dependent plasticity, based on the input and output activity or their relative nature or relative timing of spikes in the postsynaptic side and presynaptic size. Determined how much stronger this synapse gets or how much weaker this snaps get over time and that is essential for any learning and that and it is easy to implement such ideas into computational models and understand many kinds of learning behavior or many kinds of plasticity in networks.

However more stronger form of plasticity actually these kind of this kind of plasticity lasts for probably shorter periods of time than more stronger effect that may be more or less permanent and that is the kind of plasticity seen with changes in structure. That is so initially let us say that this is one dendrite and this is another dendrite 2 neurons and so there is a spine that is here there is a spine that is here, there is a spine that is here. In the later case the spine or the rather in another case there is a spine that is here spine here a spine here a spine here a spine here.

So, these are 2 dendrites and over some learning period or over some manipulation, there is what is what we call is spine turnover. Spine turnover is happening all the time that is but in a very small scale. For example, over this kind of 2 dendrites may be let us say one of these spines disappeared got eliminated and the other 2 spines remain intact and in this case may be all the spines remain intact.

So, as you can see this is sort of what we call a spine turnover just this one particular spine disappeared or got eliminated and with learning or with plasticity and specifically what we call structural plasticity. What happens is this is happening at a much more active scale much faster scale and that is more of these spines are forming and disappearing. So, let us say this one also disappeared a new spine formed here this spine remained intact another new spine formed here in this case.

And let us say in this case these 2 spine stayed this spine disappeared this spine remained this spine remained and let us say this spine disappeared and the new spine formed here. So, essentially what we are showing is that ok, now we are for we have more spines forming this is a new spine similarly this is a new spine this is a new spine.

So, these are new spines that have formed and there are 3 spines that have disappeared also. So, all this is so this kind of increase in synaptic spine turnover happens during learning phases this kind of structural plasticity.

So, intense learning phases and it we do have evidence that shows that in mice actually in behaving mice that depending on the with a strong dexterity involved motor task, the mice that acquired those tasks the spine turnover increases tremendously in their motor cortex, when they are when they are learning the task.

And actually it is also related that it is a related information is that the degree of spine turnover actually determined how well the mice performed those tasks and so there is a direct correlation with the spine turnover rate and how well the mice performed a particular task.

And so this directly shows us that or rather at least correlationally shows us that is spine turnover has an important role to play in terms of learning and also as you know in as we have discussed in also in memory in the sense that memory involves the 2 steps. Where we actually learn something and acquire something or know about something and then retain that information and that retention is based on the stability of spines.

Stability of spines in the sense that let us say here these spines over longer period of time, those new spines that came up. They actually remain stable and maybe this particular spine also remains stable and on the other side let us say this particular spine this particular spine and this particular spine or maybe just for to clarify things that this may have disappeared.

So, and these are the stable spines that are retained and probably form the basis of memory and so the spine turnover and their stability actually provide the dynamic nature provide the dynamicity in the structure of the network or make the neural networks dynamic over time. And that is something that is, was overlooked for a long period of time and it is also true that we may not it is difficult to actually bring this down to computational models.

Because I mean the way activity directly determines these processes that is how synapses are formed, how synapses or new spines are formed and new spines are eliminated or old spines are eliminated or and how spines stay stable based on activity these are still open areas of research. And so bringing these ideas into network computations become difficult, it is not as easy as the way the functional plasticity that we talk about talked about earlier.

And it is implementation using spike timing dependent plasticity window it is not that straightforward in this case. Although we know that all these spine dynamics are related to activity or synaptic activity or spiking activity in the network, the direct relation is still is elusive.

And the these discoveries were made only in the last 2 decades or a little more than that, when people could actually see spines in vivo in an intact animal, which is actually performing a task and where we dynamically see the neural actually the network changing or spines forming or disappearing and connecting it to the behavior of the animal.

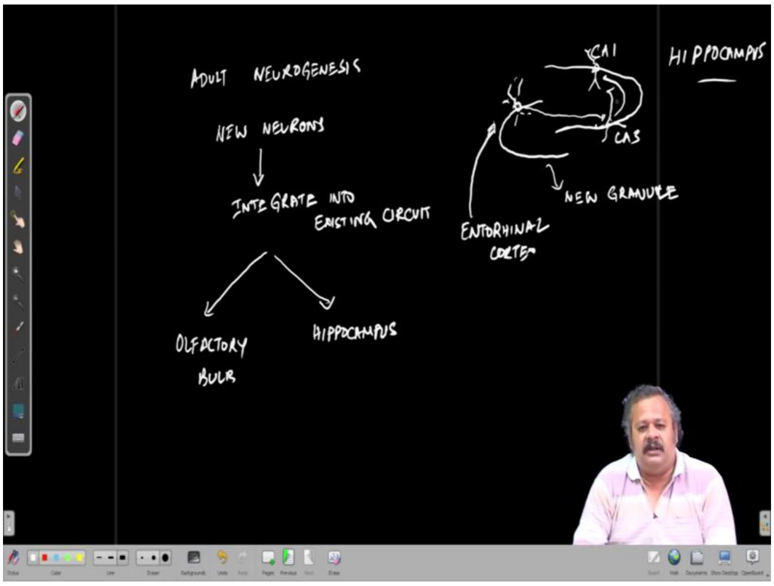
So, these are very difficult experiments and the complete understanding as I said will require many more experimental evidences and also many more experiments, where we can actually manipulate the formation of spines in an intact animal and actually show interfere with the process and show that we can actually interfere with learning.

Then we will have more causal relations established for spine turnover with learning and plasticity and memory. So, this kind of changes of spines formation elimination and also changes in shape of spines and that is what we call Filopodia, which are more narrow protrusions which are present more in development.

It becomes the problem becomes even more complex in terms of abstracting such changes into computational models to better understand learning and behavior in the brain. And the other important thing is even though we are saying this kind of structural plasticity is present in adulthood, it is true that such spine turnover is more abundant I mean it is immense during development and actually it with time it goes down into adulthood but even in the adult it stays.

Not to the degree it is observed in the developing animals. So, this is one form of the structural plasticity that is different from the functional plasticity that we talked about. More sort of vigorous form of structural plasticity actually involves new neuron formation that is and hence a new synapse formation and new axon new dendrites and so on.

(Refer Slide Time: 17:09)



So, neurogenesis in the adult neurogenesis came into I mean it was discovered first in 1960 and was actually not believed so much or did not get the traction it should have gotten. But a few decades later in the 1980, 90 people with more and more experiments and more evidence were convinced of adult neurogenesis occurring that is new neurons forming in the brain and these new neurons actually integrate into the existing circuitry.

So, we must go forward with a little caution here, in the sense that such formation of new neurons or adult neurogenesis is mainly in 2 regions of the brain that is the olfactory bulb and in the hippocampus of which I mean both are extensively studied in terms of what kind of neurons are formed how they integrate into the existing circuitry and so on.

So, if we take the case of the hippocampus particularly if we look at the granule cell layer in the dented gyrus and the CA3 CA1 regions CA3 CA1 regions in the hippocampus. So, from the memory lectures and hippocampus you should be familiar with this structure.

And so the granule cells here actually receive input from the entorhinal cortex the which is the gateway into the hippocampus and the granule cells have extensive dendritic arbors, which get projections from the entorhinal cortex, they then project on to pyramidal neurons in the CA3 region and these then project onto pyramidal neurons in the CA1 region. So, it is in this granule cell layer that new granule cells form, new granule cells are integrated into the structure and there are axons again go forward into the CA3.

And make connections and thus the new granule cells actually gets inputs from the entorhinal cortex and so those synapses are first made such that these new granule cells get the required inputs and they then project onto the CA3, which themselves can change their dendritic structures. The granule cells existing granule cells or the old granule cells they also undergo changes in their dendritic arbors, that is they can contract or even increase the number of neurites that they have, the similar changes can also happen in the CA3 and CA1.

And all this on top of this the new granule cells that are getting integrated into the circuit actually show that with these kind of changes possible in the hippocampus, many parts of the network become totally different totally new for probably for some new function or a new kind of learning or memory that all the always require the such kind of plasticity.

So, with neurogenesis the malleability of the circuits the possibilities become huge and the again as like spine turnover.

Here also we are not completely sure about the exact kind of activity that drives the specifics of the structural plasticity that we are talking about in this case with new neurons being integrated into circuits. So, as we see the similar kind of effects are also there in olfactory bulb and in both cases such neurogenesis is tied to new learning, new phases or immense amount of sensory inputs that actually drive these neurogenesis.

And it is again basically activity dependent changes in the network structure itself. So, when we talked of functional plasticity we talked of the existing structure the existing scaffold to be there and then the connections in the scaffold where, either weakened or strengthened and sometimes can go towards 0 that is getting removed that is more like fine tuning required for learning.

But for totally new kind of tasks or that required that we can need to acquire, probably more this structural plasticity gets involved. Where we are completely changing the circuit itself or within the circuit we are changing many connections between the different elements.

So, as we said that these kind of this kind of plasticity was believed to be more a part of development and not more not so involved in adult it is true, that it is far reduced than in development. So, the next thing that we will consider is actually developmental plasticity and the form of structural and functional plasticity that is present during development.

Thank you.