Computational Neuroscience
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Week – 12
Lecture – 60

Lecture 60 : Important Problems in Neuroscience

Welcome to our last lecture of Computational Neuroscience. I hope you have enjoyed your time so far and today we will be discussing brief overview of what we have covered and basically take you through briefly some of the current research topics in computational neuroscience from a very biological angle. There are many other topics that we can discuss which has to do with AI and machine learning related fields. Here we will talk more about be grounded more in terms of biological neurons and biologically possible computation and so on. Ah so overall in this course in the first part we have discussed about action potentials and we have done modeling of neurons. And so when we talk of models of neurons we have done it at multiple levels that is either as a system, that is either as a system or as a spiking biophysical model.

What I mean by system is let us say the like a linear time invariant system plus non-linearity and so on. And then the simpler spiking models that is like the leaky integrate and fire kind of neuron, these ones have elaborate ion channels in them to model specific spike timing and also incorporate specific spike specific types of channels if required and how they affect spike timing and so on. So, along with the systems model we have connected to the second part where we have looked at receptive fields of neurons that is on the encoding aspects. Ah so here we have looked at how we can use a linear time invariant model to represent stimuli and represent the receptive field of the neuron and also represent the neuron in indirectly.

So, from the linear model we know that we cannot go on further beyond the second order maybe because of the huge amount of data that is required we discussed the introduction of information theory in the receptive field world and we looked at information maximally informative dimensions, maximally informative dimensions. And these this method provided us with another approach to looking at what aspects of the stimulus space a neuron is encoding. Similarly, we have looked at decoding by neurons that is going from the spike train to the stimulus and we have approached this from the perspective of discrimination from either through statistical approaches or we have also looked at some biologically possible methods of discrimination based on spike distance matrix that like the Van Rossum distance. So, all this so the things that we have talked about so far are all sort of ideas in isolation that is either it is one stimulus its representation in the spike train or from the spike train to getting back the stimulus, reconstructing the stimulus or saying which stimulus of the two might be present and so on. It is devoid of an overall overall what should overall behavior incorporated in this whole scheme of things.

So, these receptive fields or decoding based on spike trains can be combined with behavior where let us say we have online learning and so plasticity can be included in there and that is we have looked at the principles by which plasticity occurs short term plasticity, long term plasticity and how they are implemented in neural models and synaptic models and then we looked at examples of these implementations. So, again even in this case when we looked at plasticity and examples we have looked at one aspect in isolation only that is ok this synapse is synapse is plastic it has this input and this particular output how does it change not at an overall overall level overall systems kind of level like overall organism level. So, now in the more recent past people have been looking at more simpler organisms which is like the zebra fish or sea elegance worm and people are trying to understand or quantify behavior as a whole from the entire set of sensory inputs and the entire set of motor outputs in an environment. So, the the the easy or rather what allows one to quantify the overall behavior of the entire organism is the simplicity of these organisms. However, these approaches are extremely instructive to to uncover underlying principles.

So, in in general as you have probably gotten an idea so far that it is if we talk of some particular sensory input the up to an output it is ah essentially a process of sensory motor ah transformation. So, that is we have some sensory input that is getting gradually represented at higher and higher levels in the sensory system finally, there is some other requirement of the system based on the sensory input ah and ah based on that the there is some decision making and based on that there is a set of motor plan that is executed which is implemented by the motor circuitry. So, this whole process as a whole ah can be studied not in higher organisms currently because we do not have access to all the data simultaneously. However, we do have access to all the data ah in ah for example drosophila or sea elegance or zebra fish and ah. So, here computational neuroscience has a huge role to play in terms of ah covering this entire process as a whole and understanding the system as a whole not ah things in ah isolation.

And ah this this also will ah allows us to again ah apply theoretical principles in this transformation as we have discussed in our ah encoding ah decoding aspect where we have looked at the emergence of receptive fields, we have looked at emergence of learning rules ah and so on. Here also the overall behavior we can probably ah have through those principles have an overall behavioral strategy emerging or the overall how this system should be designed ah that kind of ah strategy can emerge based on ah these studies. So, again as ah as mentioned here that the concept of optimality in some sense remains one of the leading postulated design principles underlying behavioral strategies as well as information processing in general. So, this part ah we had ah covered in our previous lectures and so now it is about ah in and about using similar principles ah to look at behavioral strategies that is starting from the information processing that is the sensory input right up to the motor output that is the entire sensory motor transformation. So, this is ah this was mentioned as one of the important ah current topics in computational neuroscience by Adrian Fairhall and Christian Mackenzie in in a recent ah commentary paper or ah in ah in nature communications.

So, the other ah points that were mentioned are ah the the ideas of feed forward versus recurrent network model. So, ah often ah in even in our case most of the examples of networks that we looked at we have looked at it ah as feed forward networks because ah based on feed forward networks ah for example in the visual system a large amount of ah understanding of the brain and parallels parallel ah visual computer vision systems have developed. So, ah a lot of the visual system can be explained with ah feed forward processing. However, ah the brain as we know with more and more experiments we clearly know that it is largely recurrent in nature that there is tremendous amount of ah recurrence within each layer ah of representation. And the why they are there and how they are ah implementing ah the stimulus independent internal dynamics or how they ah allow systems of neural systems to adapt ah these are ah much ah open these are some of the open questions ah in computational neuroscience and the theoretical principles ah that can be applied in terms of what processing such recurrent networks can achieve ah that also needs ah attention.

So, these are ah some of the ideas that one can look into ah in terms of ah comparing feed forward and recurrent networks and ultimately it will be about combining the two together ah because ultimately the brain is also feed forward in nature while ah being recurrent within each layer extreme with extreme recurrence within each layer. So, further there are ah more important points ah two of them are ah obviously we have been dealing with them continuously that is ah dealing with high dimensional data ah there is ah not much to explain to you in terms of ah the importance or the of this topic that is with more and more time we are getting more and more advanced technologies to ah access activity of neurons or even at the synaptic level or spine level at a huge ah at a very very good ah spatial resolution and temporal resolution and so these are providing huge amount of data simultaneously at multiple levels and it is not even ah just about ah fine time scale and fine spatial scale. It is also in the coarser spatial scale also we are getting huge amount of high dimensional data in let us say fMRI or even EEG. So, a multi level multimodal high dimensional data is now emerging from all the work that is going on with experimental neurosciences especially in animal work and some in humans. And so we need newer and newer computational tools to handle these kind of high dimensional data and treating treating them in order to extract hidden features from these kind of high dimensional data and what should be the principles that we apply or how can we derive what principles are governing the dynamics of such high dimensional data systems.

Of course, learning and plasticity are always going to be the probably the most important part of neuroscience because that is what makes the brain unique the way it adapts the the extreme adaptability that the brain has the neural systems have and we are only scratching the surface in terms of biological computation and biological learning and plasticity. And so far in this course and usually in any theoretical neuroscience course we talk of learning and plasticity based on only activity input output activity. And while it is true it is all based on input output activity we are looking at the plasticity rules based on directly the input output activity, but we do we bypass a number of processes that are happening inside the neuron in terms of behind learning and plasticity based on those input output activities. For example, there are multiple genes multiple proteins that are synthesized and play a role in all of these plasticity kind of questions that we have addressed. However, the computational models of them or the biochemistry is not incorporated in these plasticity rules which there are some work there is some work along those lines, but mostly they are devoid of that particular aspect.

And there are many questions that can be framed by incorporating let us say the effect of calcium in long term plasticity by including the different transcription factors the downstream events that happen from the concentration of calcium and leading to finally, transcription and translation and basically synthesis of plasticity related proteins in the system. So, those the the modeling the computational modeling of those aspects are largely missing and so those can be taken up as future areas of work. Ah Finally, we come to another important factor that so far in our discussions we have rarely talked about state dependence and state dependence is a more general term it actually can can be used for many other factors let us say age sex and and of course, the other kind of situations state state dependence of all the processing. And so, these aspects we have are are missing and often in computational models we are not taking into account the different states of the animal if it is awake and behaving what what what other situations can be at play like many cognitive factors may be at play maybe hunger on a particular day or maybe an interaction that it has had in that particular day the animal that we are talking about on which we are conducting awake behaving experiments it it is not the same person just as we are not the same person every day. Ah So, these kind of factors are not at all incorporated in any of our work that we have discussed and it is indeed difficult, but that neuronal coding is in actually dynamic process and it is heavily influenced by exactly what we are doing and exactly what our history has been and so on and these can become an important study because these become important when we talk of brain computer interfaces and so on so on.

Because if the coding is dynamic based on the state which we are unaware of then to have a brain computer interface to perform correctly and perfectly we need to incorporate such state dependence into those models into those decoding algorithms and so on. So, with this these few topics I will leave you to ponder upon further ideas further ways in which you can tackle problems in computational neuroscience you yourself may have some particular desire to work on a particular problem and we will be happy to discuss with you if you have such ideas in mind and I hope you have overall enjoyed our computational neuroscience course and have taken most of the material to heart and will be going forward with research in these directions and go on to be computational neuroscientists. Thank you.