Computational Neuroscience
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Lecture – 39

Lecture 39: Single Cell Encoding - I: Operant Conditioning Task in Ferrets

Welcome. So we have discussed an application of the decoding or discrimination performance with an example of how we can use neuronal responses in order to understand whether the behavior can be explained based on the neuronal responses. And then we did not carefully or either we did not discuss in detail about the further step about establishing causation but we did mention about that by stimulating those same neurons we can actually bias the behavior of a subject. So now we will take a look at a particular application of the encoding side of it that is based on what we have learnt on spike triggered average where we know that we can model the receptive field of a neuron and based on that we can make predictions about responses. And we also mentioned that based on how the receptive field changes from one scenario to another based on that linear model we may be able to identify or I mean figure out mechanisms underlying certain phenomena that we want to observe. So we will take the example of the auditory system where let us say we are recording from a neuron in the auditory cortex and if you just recall that we have spike trains produced in response to stimuli and we use the we have a stimulus ongoing during that period and based on that location of the spikes or the spike times by taking the past some duration of the stimulus and averaging that we will get a measure of the receptive field or the impulse response first of all impulse response of the filter that the whole system up to that neuron may be representing the linear time invariant systems filter $h(t)$.

So if we remind ourselves further what we mean by that $h(t)$ we have this linear time invariant system at the first we have the stimulus $s(t)$ and then we have a static nonlinearity and then we have a point process driving function and then we have the spike trains here. And we had shown that if we do a cross correlation of the spike train and the stimulus then that is proportional to this $h(t)$. Definitely this kind of a linear description is not entirely correct and mostly as we go on in the let us say if we are talking about the auditory system as we go higher up in the auditory pathway these models fail as we go higher and higher up they fail more and more. However, even though they fail they have some description of the system they capture at least maybe 30, 40, 50 percent of the variance and explains at least 50 percent of the data and so under different two different circumstances if we can see what is the alteration in this $h(t)$ to say $h'(t)$ then that would help us understand underlying mechanisms.

With that thought we will extend the idea of this spike triggered average into using the spike triggered average to derive what we had discussed as what we had discussed as the STRF. So what we had discussed earlier is the STRF the spike I mean the spectro temporal receptive field. So how do we do that? We start off with the spectrogram of the sound. So this is an example spectrogram that we have where on the x axis we have time and it is in seconds like 400 milliseconds that is shown on the y axis side we have frequency in octaves and in the gray scale that is showing the colors here or rather the gray scale that is showing the intensity of the energy at different time points and different frequency in the sound signal. So by applying the same principles in as in spike triggered average we can derive what we call the spectro temporal receptive field in this manner that if let us say we have one spike, two spikes, three spikes for example.

So and the corresponding stimulus is a particular kind of sound called the moving ripple that is not important right now. It is just like a noise like stimulus and so if we take the spectrogram itself a segment of the spectrogram which is this particular part of the spectrogram and for this spike we take this particular part of the spectrogram and for the first spike we take this particular part of the spectrogram and as we average them or sum them together what we can find is what we call the spectro temporal receptive field. This is a description of the sensitivity of the particular neuron we are recording from in terms of which frequencies and also in time how it is weighing the past stimulus. So here when we say 0 that not the time is 0 to 100 but it is actually time before spike so it is in fact going into the past. So that means the neuron weighs this particular frequency with an excitation and in the past 30 up to 30 millisecond with a short latency between 0 to maybe 10 milliseconds and another frequency on the side this is of a color this is of a negative point that is in inhibition and so those frequencies energy in the stimulus at those frequencies and in the past are suppressing the response.

So this gives us basically a tuning sort of measure of the receptive field in the sense that now if we do average over time what we will see is something like if I were to plot it the excitation part with the inhibition so what we have here is this axis is what we are plotting so it is going to be something like this where this particular frequency is this particular frequency is represented here. So it is not going to go negative so this is sort of the representation of the neurons tuning and this axis is frequency here but again if we do an average across the frequencies then we get an idea of how the neuron modulates the energy in the stimulus in the past. So this is going to be 0 time up to let us say 100 milliseconds and this is the part where the neuron actually weighs the stimulus significantly. So with this as the point if we now consider the experiments that were done by Fritz et al published in 2003 in Nature Neuroscience what they did so we are now moving on to the application part what they did is basically they trained ferrets if we go here they trained they had ferrets as the subject animal and they were water deprived in the sense that they would be needing water when they would be put in the experimental setup and their objective would be to get as much water as possible because by then they have learned that this is the only place where they are going to get that water that they need. And so there is a water spout in front of them they are their head is fixed in that experimental chamber and essentially they would lick for the water coming out of this water spout and they have to do it in a particular manner.

What is that particular manner that there would be sounds coming on which is there would be sounds that are references and the sounds that are targets. So what we mean by references these are actually noise like sounds which allow calculation of the spectro temporal receptive field. So from these the STRFs can be calculated of a neuron that is responding to those references while the animal is a head fixed and in front of a water spout doing this whole task and when the target comes on the animal has to so the target is a tone and the animal has to stop their licking. So this is what is generally I mean this is what is called operant conditioning and avoidance behavior so basically the animal is getting the water reward when the references are being played which are noise like sounds and randomly sometimes the target sound or a tone would come on and the animal or the ferret has to stop licking and so this is essentially a tone detection task and they learn this task pretty fast by means of a tiny shock on their tongue and so they learn to avoid the tone. So the tone gets associated with the shock and so they know that they cannot lick the spout at that point and the rest of the time they can.

So this can be done in parallel with simple presentation of the same sounds when the ferret is not performing that task. So from the from the same ferret we can I mean what they did they performed the experiments where the ferret was actually simply listening to the sounds passively without paying attention to what is coming on whether it is reference or target as it is skewed to not do the water licking task and so the animal so during that time also there are recordings being done from the auditory cortex from single units in the auditory cortex and again we they can be measuring the spectro-temporal receptive fields based on the spike trends produced by the reference noises. So if we go back so the experimental setup I mean the process is somewhat like this that there are what we call torque like sounds that is these are what we mean by torque is a temporally orthogonal ripple combination the name is for the purposes of this course is not important what we want to know that these are special kinds of broadband noise that is of a large range of frequencies with certain properties imposed on them but our calculation of the spike triggered average and hence the STRF that remains the same. So based on these sounds there because of certain properties they are more useful than simply using white noise in order to determine the STRF. So let us say that the animal is presented with this reference then reference then reference and then a target tone and this is the spectrogram of the references and here the spectrogram of the tone.

So this particular frequency tone is to be detected. So in that spectrogram there is no energy outside that frequency and there is a large amount of energy in that particular frequency or the target frequency here. So this is a target frequency. So as represented here the responses to the different reference sounds produce these kind of post stimulus time histograms or essentially a number of spike trends on different repetitions and so these are examples of such spike trends and this is corrected so that there is I mean for zero mean responses and so by averaging the previous spectrograms just as we talked about earlier a neuron's STRF is obtained. So that is shown on the right bottom side here.

This is the spectro temporal receptive field for example of one neuron in the auditory cortex of the behaving ferret in the sense that it is performing the task that we have just described. So now if we look at the passive STRF so what we had was I mean there are two conditions that we can have a passive STRF that is when the animal is not performing the task and the behavior STRF when the animal is performing the task and there are differences in these two situations. So let us this example here there is an excitation region near 8 kilohertz which is the best frequency or the tuning frequency of the neuron that is being recorded from and so this STRF weighs energy in the sound in the past 40 milliseconds as described here and has a tuning around the 8 kilohertz region. However, when the same when the recordings from the same neuron are done with the same reference stimuli and the tone target stimulus the receptive field can again be calculated and this STRF is shown here and there is a change in the STRF that is if this is the frequency that was to be detected by the animal then there is a larger I mean there is an enhancement in that particular frequency region in terms of the neuron sensitivity to that particular frequency. So now if one looks at the difference between these two STRF that is the behavior STRF minus the passive STRF.

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STRF. What you see is there is a clear enhancement of the frequency that was supposed to be detected. Now in different experiments the animal was supposed to detect different frequencies these are simply three different examples that are shown here. So it is not that it is always exactly the same kind of result. There can be sometimes a suppression in the detected frequency also but or enhancement nearby so basically now we have to look at the overall average effect of this change.

So that is we look at the behavior STRF minus the passive STRF. So in that case if we take the average of all the neurons that they have recorded from and if you align each of the STRF based on the target frequency which is then given by which is aligned in the sense that all the target frequencies are set to 0 and the STRF is now averaged the difference in the STRF is now averaged across the units setting the target frequency at 0 or the reference frequency. So as you can see this global average here is showing a huge enhancement in that particular frequency that or in the frequency that has to be detected or the target frequency. So this particular frequency is what is to be detected or it is the target frequency in the experiment. So this is varying from case to case.

Now when what they looked at is that the overall change in the region this is quantified by ΔA_{local} by averaging the energy in that region and if what is shown on the right hand side is a histogram of the amount of change in the local region of the target frequency. So there are many neurons that do not change at all in terms of that ΔA_{local}. However there is a significantly higher number of neurons that show a very large change that is the same as the overall average and hence that means that overall there is a tendency of the neurons to actually selectively amplify the target frequency. So as we said in this case with the approach of spectro-temporal receptive fields although they are not extremely good at characterizing responses that is predicting responses to unknown stimuli they can actually show us the way the neurons are changing based on the requirement in a particular task. And in this particular scenario later on there was a separate experiment done and we will be discussing that in the next lecture. Thank you.