Computational Neuroscience - Project 5
Neural Data Analysis I: Encoding

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Introduction

The main purpose of this project is to get familiar with analysis of spike trains of single neurons.

Some main tools (or figures) that we use in this project are *raster plot*, *perievent time histogram* and *tuning curve*. Raster plot is a trial-by-trial method of examining neuron responses through time. By using the same data, but averaging over all responses, a perievent time histogram can be created and finally, to visualize variety in the average response of the neuron with sensory feature, we use a tuning curve which basically maps the feature value onto the average response of the neuron.

$\rightarrow$ Information about trial and dataset

The data that is analysed in this project is collected from the primary motor cortex (abbreviated as MI) of a macaque monkey. MI region is related to voluntary movement but does not mean that it certainly controls movement. This region still contains information about motor movement and the information usually happens few hundred milliseconds before the motor movement, that is thought to be because this area is also involved in planning of the movement.

In this trial, animal first holds the cursor over the center target for 500 ms. Then a peripheral target appears at one of eight locations arranged in circle around the center target. In this task there is an instructed delay, which means that after the peripheral target appears, the animal must wait 1000-1500 ms for a go cue. After the go cue, the animal moves to and holds on the peripheral target for 500 ms, and the trial is completed.

Using the *spike* dataset, we can directly create a raster plot.

Dataset *spike* contains information about one neuron's firings with respect to time for 47 trials. Since information of action potentials is not carried by the amplitude, but the frequency, we disregard the amplitude information of the neuron and just record the times when the raw voltage trace crosses some threshold. This information is directly used when plotting a raster plot.

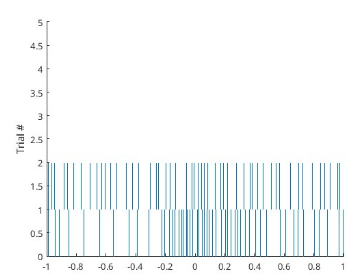


Figure 1: An example raster plot showing events with respect to time for 2 trials

In the data, other datasets are *direction* and *go*, where direction contains information about in which direction the trial happened and go contains the respond time of the animal happening with go cue.

Analysis

Raster Plots and Perievent Time Histograms

Let's start by plotting the raster plot for the spike data. We see in figure 2, 47 trials row by row for times taken in 5 millisecond intervals.

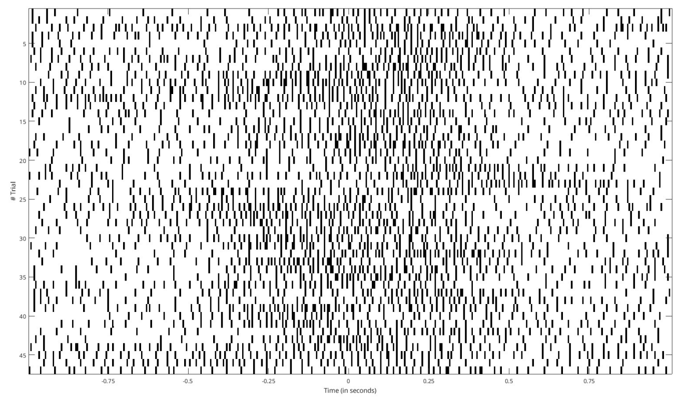


Figure 2: Raster plot of spike dataset

From figure 2 we can already tell that around the time of event (time point 0, since the data is centered), there are more action potentials happening, which is expected.

This raster plot shows how most action potentials occur with the event. The x-axis in this plot is the time and it goes from -1 to 1 in seconds. Since this dataset is centered, time point 0 is the event time, and that is where we expect most responses from neurons (given that this is a motor cortex data and the task is movement related).

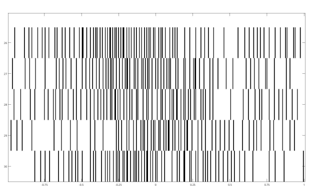


Figure 3: Raster plot of 26th to 30th trials.

Figure 3 shows trial numbers 26 to 30, which seem to contain lots of activation.

Using the raster plot, we easily see trial to trial variability, but we do not answer how an average trial might look like. For that, we use *perievent time histogram*, where peri-event means that all the trials are centered relative to some event (start of movement in our case). We divide the time period into a series of bins and count how many spikes fall into each bin. So basically, we plot the count distribution of the spikes with respect to time points.

From figure 4, we can see that there are activations whether the event is present or not (meaning even 1 second before the event, there are spikes occurring). This might be due to noise or MI responding to other non-event-related movements, or combination of both. But what we can conclude is that with an incoming event, neurons start to fire more action potentials starting from before the event, and continue an increased firing rate to some time after the event happens. Firings following the event seem to decay faster than the increase of the firings before the event, and that is most probably related to the planning

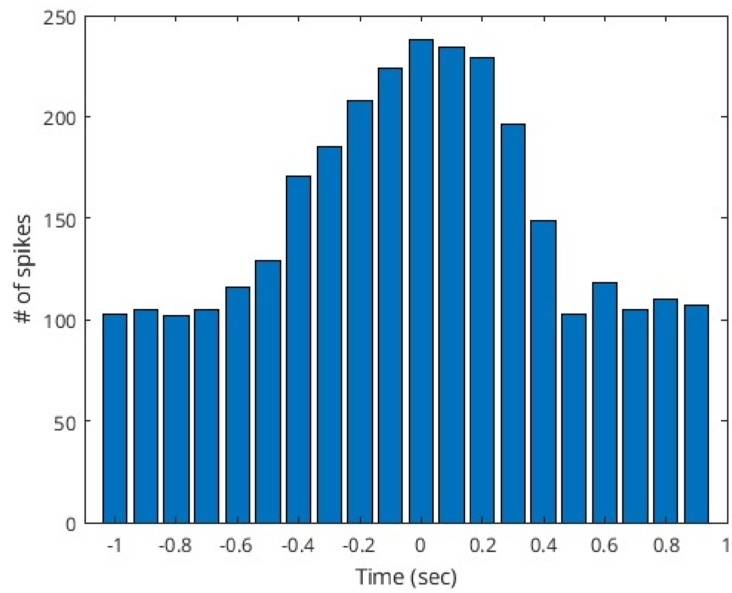


Figure 4: PETH for all spike data. We can see that an average trial would have increased responses starting from around 300 milliseconds before the event and continuing till about 200 milliseconds after.

stage of the event - MI first starts to plan the movement, than acts on it.

I believe PETHs present a good summary of the raster plots since in a raster plot, it is not definite in which time point spikes occur, but with a PETH, we can numerically see when they do. It also more visually presents an average trial's result then a raster plot.

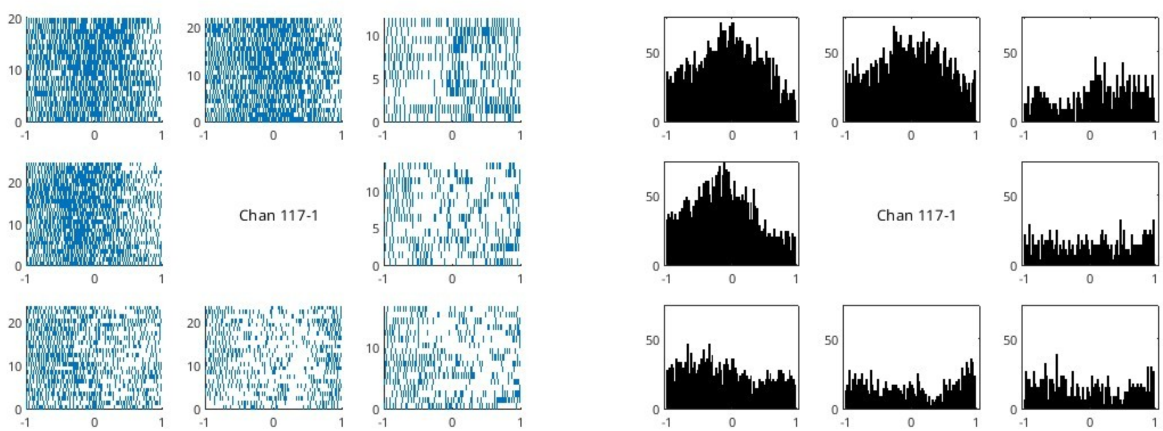


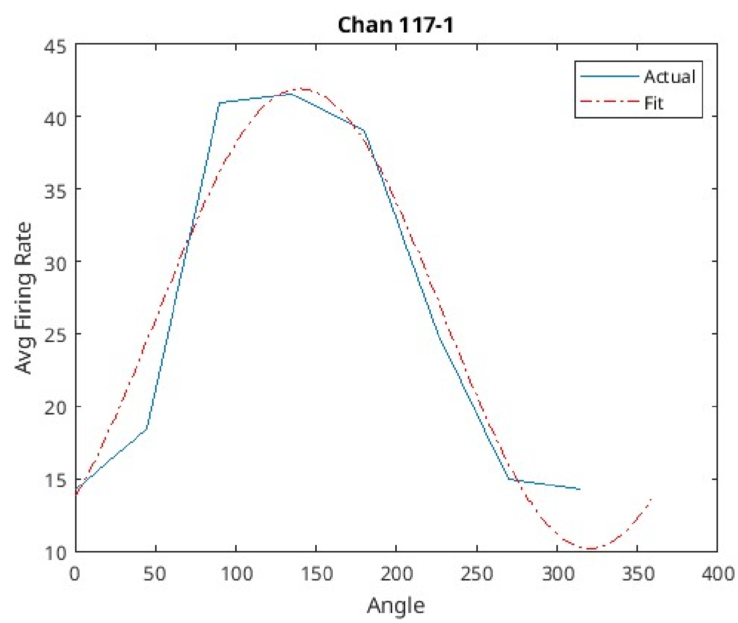
Figure 5: Raster plots and PETHs where grid location of plots represent direction. We see denser raster plots on left, top-left and top hinting more activation towards top-left direction.

Many neurons can preferentially respond to particular values of stimulus, i.e. direction or orientation of the stimulus. Using direction data, we can create raster plots and PETHs to distinguish in which direction the neuron fires more. This direction represents the appearance of the location of the target in the experiment. Figure 5 shows raster plots and PETHs combined in subplots, where grid location of the plot represents the direction. Clearly, selected neuron prefers top-left direction more than top-right. PETHs also indicate that on an average trial, we are more likely to see an increase in activation if the target appears on top-left side. Conversely, from figure 5, we also see that bottom-right direction has the least amount of responses. This result is shown more precisely by a tuning curve as can be seen in figure 6.

Tuning Curves and Curve Fitting

We can also determine the preferred stimulus of a neuron by plotting the stimulus dimension on the x-axis and the neural activity on the y-axis. So in figure 6, we plot angle versus firing rate - using MI region, and the same neuron - which shows that the chosen neuron does indeed prefer upward stimulus more to respond (from around 70 degrees to 200 degrees).

Figure 6: Tuning curve with cosine fit. Visualizes that the chosen neuron prefers upward stimulus to respond.



Preferred direction is found to be 141 degrees.

It is typical to fit Gaussian curve or a cosine function to tuning curves to present a smoother change the data may be representing, disregarding the errors. This curve actually is the model in which we assume the underlying physical relation lies beneath the observation. So if the data closely resembles the fit, we conclude that the model is a good one.

The cosine fit has a peak in about 150 degrees, which indicates the firing rate is at its maximum value (on average) when 150 degrees stimulus is presented. Numerically the preferred direction is found as 141 degrees by taking the maximum value of fit curve in MATLAB.

The Most Responsive Neuron

From the tuning curve, when we take maximum y value, we get the maximum firing rate for a given direction for the neuron. Over all neurons, using MATLAB, I have found that the neuron indexed 132 is the most active neuron in this experiment. This neuron is also from MI (not surprisingly, since this is a motor task) and figure 7 are its figures.

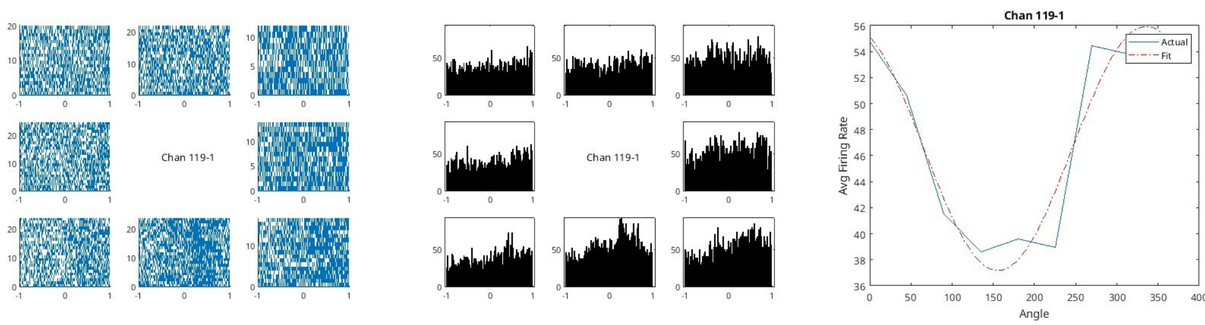


Figure 7: All plots of most active neuron in this dataset, which is unsurprisingly in MI region.

Magnitude of maximum firing is 55.9 for this neuron. From raster plot, this neuron does not seem to care about any direction and seems like just fires for all stimuli in all directions. Its fit is different from neuron indexed 129 (the one mentioned above) though, and only when I saw the tuning curve, was I able to understand that it does choose a direction. Preferred direction seems to be around 0 degrees and the reason direction was not clear from raster plots is that this neuron also shows increased activity for other directions.

Figure 7 shows from left to right, how it is easier to see a neuron's preferred stimulus value using these plots; raster plots are somewhat similar and harder to see the direction, PETHs do a better job as the right PETH plots do show increased magnitudes of firing rate, but the best plot to tell the direction is the tuning curve in this experiment, since it indicates the preferred direction clearly.

Appendix

We can also check other neurons in the dataset and create plots for those neurons. For example, figure 8 shows 2 neurons from MI regions which respond to the same stimuli very differently.

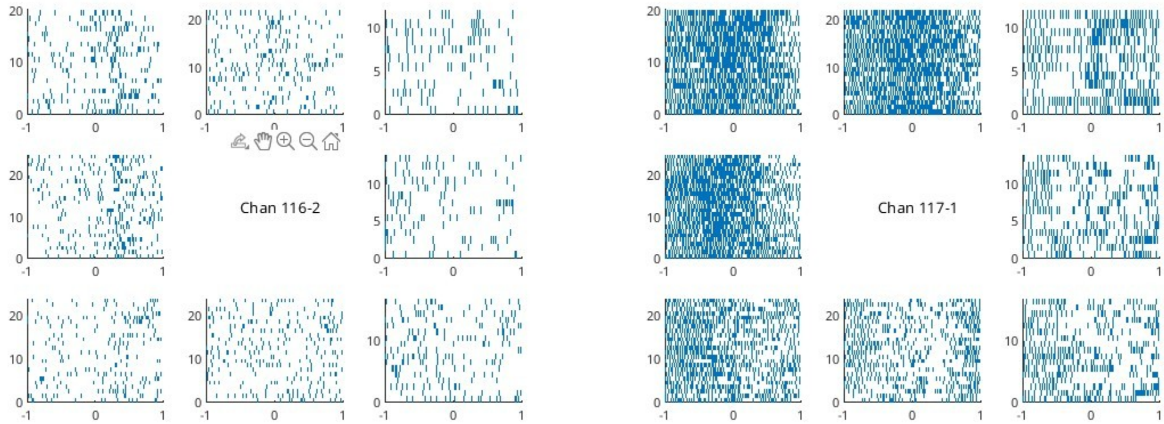


Figure 8: Raster plots for neurons with index 128 (left) and 129 (right). Both neurons are in MI region.

On neuron indexed 128, we see much less activation in about all directions than neuron indexed 129, even though they both are in MI region. Figure 9 also shows the average responses of these 2 neurons (with direction included).

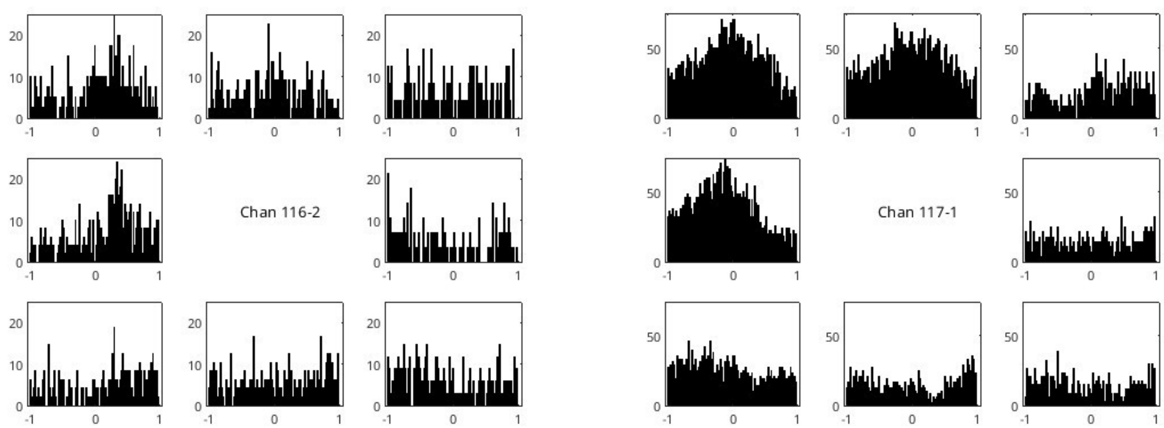
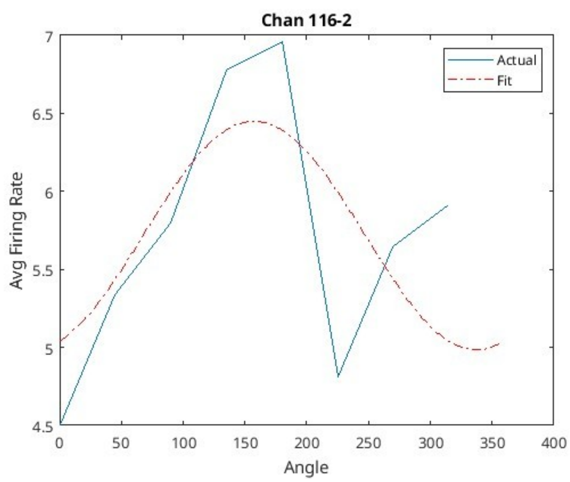


Figure 9: PETHs for neurons with index 128 (left) and 129 (right). Both neurons are in MI region.

Lastly, for these 2 neurons, we can plot tuning curves which is shown in figure 10 and while the data represents the fit worse, note that the magnitude of average firing rate also is lower.



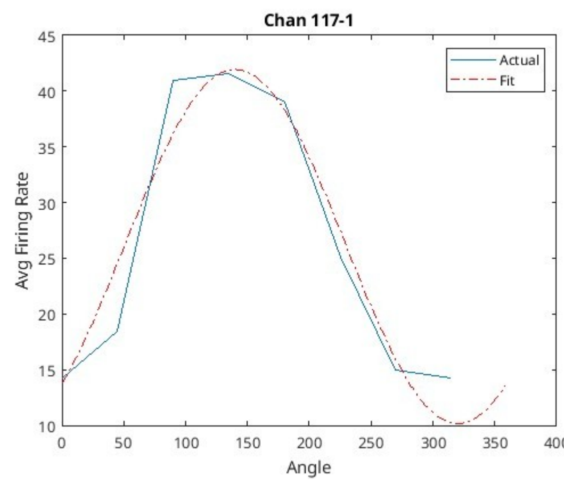


Figure 10: Tuning curves with cosine fits for neurons with index 128 (left) and 129 (right). Both neurons are in MI region.