Methods in Computational Neuroscience
The neural code: spike train statistics

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Our journey through the brain continues with spike train statistics, fundamental patterns that neurons use to encode and transmit information across neural circuits. We closely examine these essential signaling elements and build analytical tools to decode them. While the Integrate-and-Fire and Hodgkin-Huxley models revealed how individual neurons produce action potentials, the neural code of the brain is more complex, and emerges not from isolated firing patterns, but from intricate, variable sequences of spikes distributed across neurons.

1. Spike train statistics

1.1 Create a spike train. Let's create a spike train with a length of 1 second and an average rate of 250 spikes per second. Each time bin will be 1 millisecond (Δ_t = 1 msec), resulting in 1000 time bins total. Represent the spike train as a vector of 0s and 1s, where 1 indicates a spike and 0 indicate no spike.
[On average, 250 of these 1000 elements should be 1 (spikes). Plot the vector, by using one dot for each spike, for example, or by using the matplotlib function 'eventplot'.]

1.2 Create a raster plot and compute the spike counts Generate N = 300 spike trains with firing rate 80 Hz and count the total number of spikes in each of them. Plot 40 of these trials as a rasterplot. Plot a histogram of the spike counts for the 300 trials. [The firing rate is a frequency, then it is measured in Hz=spikes/sec. In the previous exercise, 250 spikes per second = 250 Hz.]

1.3 Inter-spike interval distribution Compute the histogram of interspike intervals for the above spike trains and compute the Coefficient of Variation (CV), explaining the meaning of the value you obtain.

2. Analysis of spike trains

In the next exercise, we want to do some simple analysis of real spike trains. First, download the data-file provided on moodle. The data file contains the recordings of a single neuron in the primary somatosensory cortex of a monkey that was experiencing a vibratory stimulus on the fingertip.

To load a mat file in python we have to import the loadmat function from the scipy.io package as follows: from scipy.io import loadmat, and then load the file with data = loadmat('simadata.mat')
There are three variables of relevance in the file: 'f1', 'spt', and 't'. The variable 'f1' is a vector that contains the different vibration frequencies experienced by the monkey. The variable 'spt' contains the recorder spike trains. Note that this variable is a cell array — to retrieve the spike trains recorded for the i-th stimulus, you need to type 'rasterf1=data['spt'][0][i]'. Afterwards, rasterf1 is a matrix of 0s and 1s as above. The variable 't' contains the respective time points (check Δ_t!).

2.1 Raster plot Plot the raster plot for the first stimulus (f1=8.4 Hz). What do you observe? In the same rasterplot highlight the stimulation period (200...700 msec), by either adding vertical lines or shading the region between them on the raster plot.

2.2 Spikes count: mean and variance Count and collect the number of spikes **in each spike train**, only in the stimulation period. Compute the mean and variance (they are estimated by averaging over trials). Calculate the mean firing rate = [spikes/sec]

2.3 Spike density Count the number of spikes that occur in each Δ_t, only in the stimulation period, and plot the **spike density** in a barplot. [barplot $\neq$ histogram]
[This is different from the spikes count of the previous point. Here, you have to compute how many spikes occur in a given time window, averaging over trials, and diving by Δ_t.]

2.4 All rasterplots together. Now we want to plot a raster plot for each of the 8 stimuli and put them together. Plot all raster plots into the same graph. You can use alternating white and grey colors in the background to indicate the different stimuli, or different colors. [You may check the function plt.axhspan()]
In a different graph, plot the bar plots for the spike density in the simulation period (as done in 2.3), for each of the rasterplot. What do you see?

2.5 Mean and variance of spikes count For each raster plot, compute the spikes count, its mean and variance (as in 2.2). Compute the mean firing rates (as in 2.2). What is the relationship between the mean firing rates and the stimulation frequency? To see it, plot the tuning curve of the neuron, i.e., its average firing rate (=spike count / sec) against the stimulus frequency.