Lecture Series in Physics for Data Scientists

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Problem Set - Neuroscience and Data Science

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Assignment, due Friday, 28th June 2023

Problem 1 *Homework*

In an experiment, visual stimuli in form of moving light bars are presented on a 64x64 pixel screen with the origin at the center. They move perpendicular to their orientation ϕ, which cycles through the sequence [0; 22.5; 45; 67.5; 90; 112.5; 135; 157.5]. Each moving bar is shown for 500 ms until the stimulation switches to the next orientation. During that time, the center of the bar always moves $64\sqrt{2}$ pixels (whole length of the diagonal) with the origin always being passed after 250 ms. Thus, at time t (in ms) the distance from the origin is given by

$$d(t) = 64\sqrt{2} \cdot \left(\frac{t \mod 500}{500} - \frac{1}{2} \right).$$

With the light bars having a width of 10 pixels, the set of illuminated pixels is:

$$\{(x, y)||cos(\phi)x + sin(\phi)y - d(t)| < 10/2\}$$

wheras the rest of the pixels remained dark

(a) Input generator Implement a function that returns the stimulus (matrix) for any given time. Plot the visual stimulus at 22.2 s and 33.3 s after the experiment has started.
Tip: Python sine and cosine functions do not operate in degrees but radians.

(b) Data inspection: Download the data files ("Cell0.txt" ... "Cell7.txt" in Data.zip) from StudIP. Each file contains the spike times (in milliseconds) of one neuron during the same experiment following the above description.
For cell 0, make a raster-plot, where the x-axis marks the time since the bar with the current orientation is shown (time during trial). In the y-axis, all trials with the same orientation should be adjacent and these groups should be ordered according to the bar orientation.

(c) Receptive fields: Use the spike-triggered average to calculate the receptive fields for all cells:

$$STA(x, y) = \frac{1}{\#\ of\ spikes} \sum_t I(x, y, t)s(t)$$

where $I(x, y, t)$ is the stimulus image and $s(t)$ a binary variable that indicates whether the neuron has spiked at time t. Plot the receptive fields (Use color coded 2D plots e.g., pcolor/imshow in python).
Tip: The results become more interpretable if the input stimuli have zero mean. Hence, it may help to subtract the mean stimulation from your STA.

(d) Conditional firing rates: For each cell, evaluate and plot the time-dependent average firing rate for each stimulus (using 25 ms bins).

(e) Tuning curves: For each cell, plot a tuning curve that shows how the firing rate changes with the presented stimulus. For each stimulus, use the maximal average firing rate of all 25 ms bins. Plot the tuning curve. Report the orientation ϕ to which the cells are tuned.

(f) Population vector decoding Decode the angle of the currently shown stimulus using the population vector method. Note, this method can only applied if the vectors point into all different directions in 2D space. Therefore, to also incorporate the periodicity of the tuning-curves, instead of using cell i's the preferred orientation $\phi_i \in [0, 180]$, use $2\phi_i \in [0, 360]$. Every spike cell i fires while a stimulus is presented should increase the population vector by

$$\overrightarrow{e}_i = (\cos(2\phi_i), \sin(2\phi_i))^T$$

After summing the contributions of all spikes and neurons up, use the (two-argument) arctan-function, divide by 2 to get back to our original preferred orientations and bring the result to the desired range of [-10,170] degree. Report the output of the first 10 stimuli.

Submit your results (plots with labeled axes in a pdf) and code before the tutorial on 08.07.2022 to mfauth[at]gwdg.de.