Signal and Data Analysis in Neuroscience
Bar-Ilan, spring 2022

Due date: 24/04/22, 08:00

Assignment 4

General Instructions:

1. Please add comments to your code and submit only the codes specified in the grating grade.
2. We encourage you to write your solution in English. (5 points bonus)
3. Individual work - No code sharing.

1) Encoding: from stimulus to neuronal activity (PSTH) (40)

Important note: attach your code for all your answers in this question

Prof. E. E. Poe have modeled the neuronal activity in the Annabel-lee nuclei to study electrical possible stimulation treatments for depression. Prof. Poe would like to understand how an excitation relation between two neurons effects their response to an intracranial electrical stimulation (link for example of stimulation in the face area (FFA)).

In his 500 trials simulation, in each trial 2 Poisson neurons are simulated for 100 seconds using a sampling rate of 1000 Hz. In each trial the stimulus onsets are given from a uniformly random distribution between 100 ms and 90 seconds. Neuron A is defined to excite neuron B within various excitation durations, but both neurons also respond to the stimulation.

Help prof. Poe to evaluate how effective is the intracranial electrical stimulation with the following example simulation (excitation duration of 25 ms). The example simulation is of the 3 CSV files under the folder 'PSTH', and the generator of the simulation is attached.

A. For each neuron create a PSTH and raster plot. Decide what is the relevant duration to present and what normalization you use. Explain what parameters of the neurons can be studied from this figure.
B. Create three matrix JPSTH:
    a. One without any reduction
    b. One with reduction of shift predictor
    c. One with reduction of stimulus onset shuffle

    Decide what is the relevant duration to present and what normalization you use.

    Explain The differences between the three matrices. Address differences in clusters you notice in each one, and differences in the diagonal values.
C. Define a qualitative measurement for the effectiveness of the stimulation on the neurons activity. Using the code 'spike generator for PSTH' offer a method to evaluate the relation between excitation duration and the effectiveness of the stimulation:
    - Give an example for a figure which corresponds to the method you offered.
    - If you change in the code:
        - Only definitions- write the changes in your explanation. If this is the only changes you've done in the code, you don't have to attach it.
        - Any other changes in the code- save the code with a different name and attach it to the assignment. Add a note which describes the changes you've made, and start the note with your name. For example: #Yarden: I added this line
        - If you write a new code, attach it.

          Note to write the code in a high standard (using notes, function and clear parts). No point reducing for efficiency.

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Grading Table

Grade component	**Requirements**	**Points**
Creativity (only for section C)	Creative Ideas and answers which are well explained. New codes or commands are noted and working. No point reducing if you didn't change anything in the code or write a new one.	15
Accuracy and code writing (grading instructions only for section A,B)	Accurate calculations and clear code writing (code is working, notes). 2 points for each calculation and code writing: raster plot, PSTH, JPSTH, shift predictor, stim onset shuffle No point reducing for efficiency.	10
Explanations	Clear and concise explanations, describing in full details your figures and the conclusions from them. No point reducing for grammar and spelling mistakes.	10
Figures	Correspondence to instructions, no missing components, clear visibility.	5

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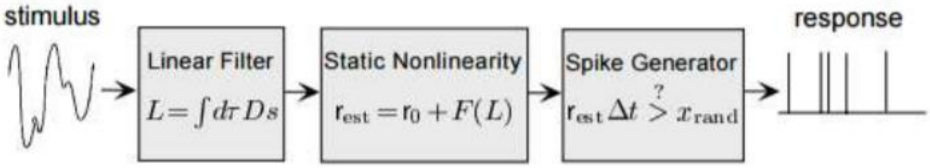
2) Encoding: GLM: optimal kernel and STA (45)

Dr. B. Brecht is studying the sensory neurons in the Magical Toad. He would like to generate a basic GLM model based on linear kernels. Dr. Brecht recorded two sets of experiment which are saved in mat formats (matlab):

1. Main experiment:
   The file 'STA.mat' contains a stimulation signal presented to a neuron and its corresponding resulted spike train. The signal is sampled at 2000 Hz.
2. Complementary experiment (white noise):
   The file 'k*ernel.mat*' which contains two variables: stim – a vector (1*60000) of the white noise magical stimulus played to the toad (measured in MU) and resp – a matrix (100*60000) of the spiking activity of a neuron during 100 exposures to the stimulus. The variables are 60 seconds long and recorded at 1000 Hz.

Dr. Brecht wishes to create a GLM based on the following diagram (studied in recitation 5):



To create a basic GLM for Dr. Brecht, Perform the following steps:

A. Using the main experiment data, calculate the spike triggered average of this signal-spike train pair using a +/-500 ms window.
   a. Present your results with a figure. The signal amplitude can be represented in arbitrary units ("au").
   b. What would be the optimal sine frequency to activate this neuron?
B. Using the complementary experiment results:
   a. Calculate and plot the rate function of the neuron. Use a method for firing rate calculation which can be later for a linear kernel model.
      Try different window sizes in the range 100-1300ms and choose the best to present.
   b. Calculate and plot the optimal kernel of the neuron assuming linearity.
      Explain the kernel you found and when using a linearity assumption, what computation is performed by the neuron.

For the next section use the equation: $r_{model} = r_0 + D(t) * s(t)$

C. Write a code to simulate a model of the neuron. Optimize the size of the convolution window using the results of the main experiment and a RMSE error. Regarding the level of optimization:
   - You can use any method for optimization, including a simple brute-force (systematically calculating all options from the a given range of window sizes).
   - If you wish to use static non-linearity, use a simple rectifier.
   - You don't have to optimize the model to its best, use only a basic optimization.

   Summarize the steps you've done for optimization and add figures (1-3 figures) to demonstrate your model.

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Grading Table

Grade component	**Requirements**	**Points**
Code writing (Only for section C)	Relevant method for GLM, comments to explain your code, code is running (no bugs). No point reducing for code efficiency.	15
Accuracy (Only for section A,B)	Accurate calculations. 4 points for each calculation: STA, firing rate, kernel	12
Explanations	Clear and concise explanations, describing in full details your figures and the conclusions from them. No point reducing for grammar and spelling mistakes.	10
Figures	Correspondence to instructions, no missing components, clear visibility.	8

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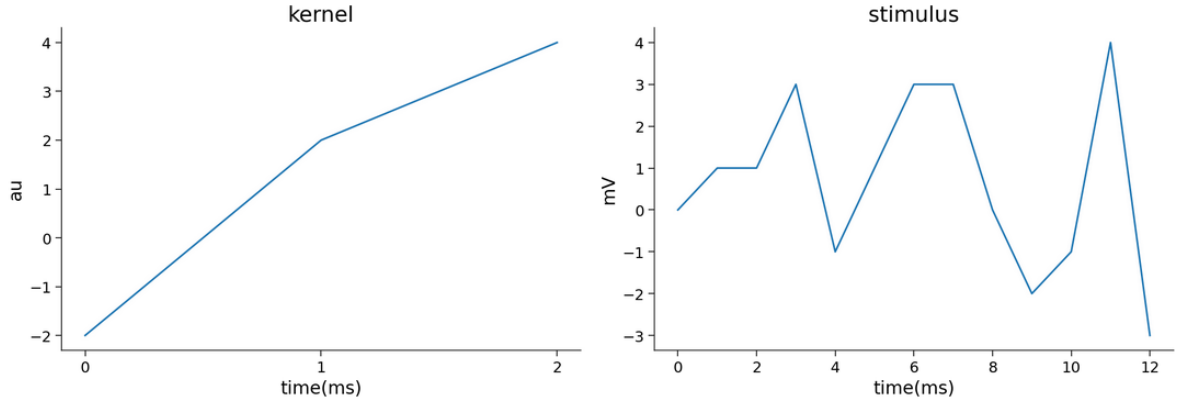
3) Analytical computations for optimal kernal (15)

Important note: Solve this question analytically, without using any code. You can use excel or wolfram alpha.

Given the following kernel and stilmulus:



A. Draw a linear estimation of the rate function for this neuron.
   Choose any baseline firing rate you wish.
   Explain your solution in detail and include example for calculations in your answer.

B. Translate the neuron's response to a fight/flight decision by Implementing a **sigmoid** non-linearity (a soft threshold – see equation below), that converts the neuron's rate function (that you found in A) to vary between 2 possible values.
   Draw the new estimation and explain the parameters you chose for the sigmoid ($r_{1/2}$, β) and for the rate clipping (the 2 values of rate).

$$Sigmoid = \frac{1}{1 + e^{\beta(r_{\frac{1}{2}} - r)}}$$

Grading Table

Grade component	**Requirements**	**Points**
Accuracy (Only section A)	Accurate calculations with clear and concise explanations and examples.	5
Mathematical understanding (Only for section B)	Explanations which show understanding of the function and its parameters.	5
Figures	Correspondence to instructions, no missing components, clear visibility.	5

Good luck!
SDA team.