Signal and Data Analysis in Neuroscience
Bar-Ilan, spring 2023

Due date: 16/04/23, 08:00

Project 02

General Instructions:

1. Remember legends, axis labels (for all axes) and units for all graphs/plots.
2. Please add comments to your code and submit only the codes specified in the grading table.
3. Write codes in python.
4. We encourage you to write your solution in English. (5 points bonus)
5. Submit a softcopy (including source code) to biu.sigproc@gmail.com.
6. Note the due date and time.
7. Individual work - No code sharing.

1) Paper assignment: Cross correlation for evaluating spatial propagation (40 points)

Dr. Borges studies spontaneous activity (activity which is not driven by any external stimuli directly) during resting state and free motion. Dr. Borges studies the somatosensory area mice neocortex using LFP recordings from layer 5. His electrode arrays are organized in a grid of 10X10, where each electrode's sampling rate is 1 ms and 0.1 mm between each two adjacent electrodes (assuming this is the distance between two adjacent barrels, link for image).

Dr. Borges has been studying lately the propagating signals between barrels in the cortex and wants to use a general algorithm for detecting propagation patterns in the somatosensory area. He addressed you for implementing one based on the paper of Takagaki et al. 2011 (link).

A. Create a simulated data with the same properties of sampling rate and spatial organization as the real data. Assume the baseline activity of this data is zero. In this simulated data generate a full radial propagation from the most middle electrode towards the neighbours. This signal propagates within 20 ms between adjacent electrodes and transitions between high positive and high negative activity every 50 ms. Add a noise to the activity of each electrode within each sample. Use a gaussian noise which its effect on the activity is lower than the propagation activity.

   Describe the simulated data you generated, the values you assigned and demonstrate the spatial propagation using a movie or sequences of frames of a movie.
   10 points

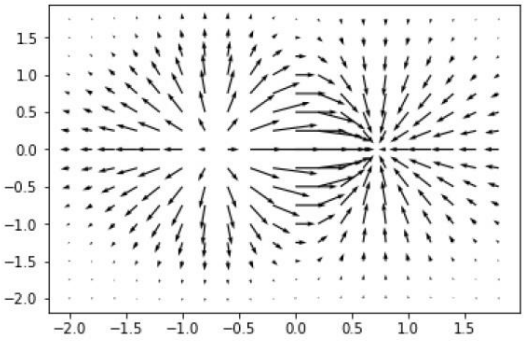
B. Explain the use of cross-correlation in the algorithm of Takagaki et al. For implementing this algorithm and test it with your simulated dataset, specify at least 3 editable parameters of the algorithm you want to test.
   Relevant paragraphs in the text:
   - Abstract
   - 2.2. Evaluation of pairwise flow (no need to explain the next steps of the algorithm)
   - Figure 1

   5 points

C. Create a function which implements the evaluation of pairwise flow of Takagaki et al. algorithm for a given LFP dataset.
   The function must include the following definitions:

input: dataset matrix (2D array of electrodesXsamples)
editable parameters

output: flow matrix: 3D array of electrodesXflowVectorXtime
This matrix will be used for drawing the flow of each electrode calculated between two following samples. Here is an example of a python illustration of one time sample of the 2D array of electrodesXflowVector.



10 points

D. Run your function on the simulated data you've generated using different editable parameters. Evaluate the differences between the results and use figures or movies to demonstrate your claims (for example pyplot.quiver to illustrate the vector flows). For example, you can demonstrate that one of the parameters should be assigned 1 for good SNR dataset.
Write Dr. Borges a summary review about the function you wrote: Explain how it computed the flow vector field, what the editable parameters represent and recommendations how to use it.
15 points

Grading Table

Grade component	**Requirements**	**Points**
Figures	Relevant graphs, correspondence to instructions, no missing components, clear visibility	5
Simulated Data (Submit the simulated data you generated for section A)	Data is organized clearly, correspondence to instructions.	5
Code writing (Submit code only for section D)	Accurate calculations, comments to explain your code, code is running (no bugs). No point reducing for code efficiency.	10
Argumentation	Presenting persuasive and strong arguments for your claims. Accuracy in the details provided.	5

Explanations (Sections A,B,D)	150-500 words sections A and B, 1-1.5 page for section D. Use clear and concise explanations, describing in full details your figures and the conclusions from them. No point reducing for grammar and spelling mistakes. Points will be reduced for overly long, vague explanations.	15

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2) Properties of a single Poisson process with refractory period (30 points)

Prof. V. Woolf is writing a paper about the properties of neurons with refractory period. A part of her paper is a model of Poisson neuron with refractory period. Help her with the following tasks:

A. Write a code which generates a simulation of a spike train for 90 seconds using a Poisson process with a refractory period, in 1 millisecond bins with the following parameters:
   - The baseline firing rate rate (r_0) is 55 spikes/second.
   - The refractory period as followed:
     - Absolute refractory period: After each spike, 5 ms with no spikes at all (i.e. r(t+1)= r(t+2)= r(t+3)= r(t+4)=(t+5)=0, where t (in ms) is the time of the spike)
     - Recovery period: a period of 6 ms, in which the firing rate of the Poisson process (r_{ref}) increases linearly from 0 back to r_0 (i.e. r(t+6)=(r_0*1/6) , r(t+7)=(r_0*2/6), r(t+8)=(r_0*3/6), etc.)

B. Based on your simulation, calculate and plot the following:
   a. TIH and TIH in logarithmic scale; b. Survivor Function; c. Hazard Function; d. Autocorrelation (maximal time-lag 100 ms) normalized as rate. Assign 0 for zero time-lag.

C. The paper is comparing the differences of neurons with and without refractory periods. For each graph, write a comparison between your results and a simple Poisson neuron (without refractory period). Illustrate the differences by adding at least one plot for the simple Poisson neuron.

D. Write a possible result section for Prof. Woolf paper with your results. Organize all your plots in one figure (you can use PowerPoint for that) and add a figure legend: a short explanation with the title of the figure and an explanation for each plot. Write 2-3 paragraphs explaining the results presented in the figure.

Grading Table

Grade component	**Requirements**	**Points**
Code writing (Submit code only for section A)	Relevant method for simulation, comments to explain your code, code is running (no bugs). No point reducing for code efficiency.	10
Explanations	250-500 words for section B and C together. Use 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, short and precise explanations in the figure legend.	10

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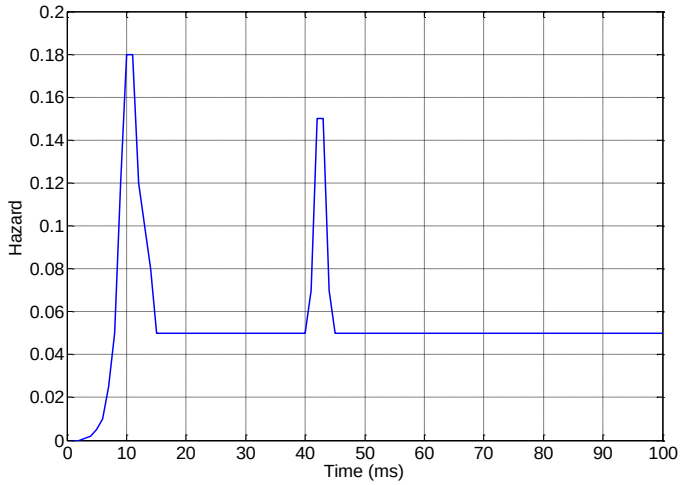
3) Extracting the autocorrelation from the Hazard function (10 points)

Given the following hazard function:



A. Sketch the autocorrelation function ±1 second and explain your computations.
B. Is the neuron Poisson, Regular, Bursty? Explain your answer.

Important note: "Sketch" means draw by hand a coarse solution where you write values for points of special interest (for example min/max). Values should be accurate calculation if results are easy to extract; Otherwise, provide a rough estimation.

Grading Table

Grade component	**Requirements**	**Points**
Calculations and sketches	Accuracy, no missing components	6
Explanations	250-500 words for the whole question. No point reducing for grammar and spelling mistakes.	4

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4) Cross-correlation (20)

In this question you need to calculate the autocorrelation and cross-correlation of three neurons:

1. Neuron A is a regular neuron, alternating between ISIs of 100 and 200ms (e.g. spike at 100, 300, 400, 600, 700, 900, etc.).
2. Neuron B is a Poisson neuron excited by neuron A. Every spike of neuron A leads to an increase in neuron B firing rate from a baseline of 10 spikes/sec to 20 spikes/sec, for a period of 20 ms, following a delay of 4 ms.

Recordings from these neurons were conducted 5 times, for 3 minutes each with a sampling rate of 30000 Hz.

Draw by hand a solution and indicate exact values for points of special interest (critical points in X and Y axes):

A. Sketch the autocorrelation functions of A & B in the range of ±500ms, normalize to rate.
   10 points
B. Sketch the cross-correlation of (A,B) in the range of ±500ms, normalize to rate.
   10 points

For each section add a one-two paragraph explanation about the method of calculating the autocorrelation.

Grading Table

Grade component	**Requirements**	**Points**
Calculations and sketches	Accuracy, no missing components	10 (5 for each section)
Explanations	250-500 words for the whole question. No point reducing for grammar and spelling mistakes.	10 (5 for each section)

Good luck!
SDA team.