## BCS304 Theoretical Neuroscience Spring 2025

## Midterm Exam: Due 4/21(Mon), 6:00 PM

Please prepare your report as outlined below and send it to: **bcs304ta@gmail.com**

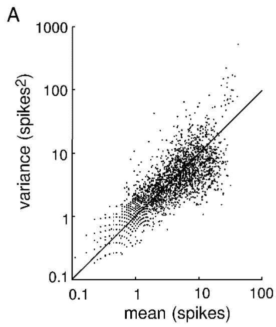
- Summarize your results, including discussions and comments for each question, in a PDF file. Name the file as: **"Midterm_answer.pdf"**.
- Zip all the MATLAB® codes and text files into one compressed folder, named as: **"Midterm _YourSID_YourName.zip"**.
- For each problem, clearly indicate which file to run by naming them as: **"Prob1a.m"**, **"Prob1b.m"**, etc. You may also include as many sub-function files as necessary.
- Failure to follow these instructions may result in a penalty.

### Problem 1 [40 pts]

Build a Poisson spike generator, using the Poisson point process model (Δt=1ms).

**a.** Generate a spike train with a constant firing rate r = 5Hz for T = 0.1s and N = 10 trials. Calculate the average firing rate (μ) and the standard deviation (σ) in Hz.

**b.** Repeat the same estimation while increasing the firing rate for r = [5, 10, 15, … , 50] Hz (repeat the process for N = 10 and T = 0.1s for each r). Make a scatter plot of the mean firing rate (x-axis) vs. the variance (y-axis) on a log-log scale. Perform a linear fit to this dataset to estimate the Fano factor.




O'Keefe et al. 1997

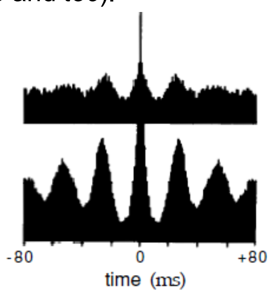
**c.** Repeat the process in part **b** for T = 10s. Discuss the differences, particularly in terms of the reliable estimation of the Fano factor.

**d.** Suppose you need to estimate the statistics of spike trains achieved from an animal experiment. Discuss your strategy for measuring the spike statistics accurately and efficiently, focusing on the minimum length of the spike measurement for different average firing rates.

Now build a different type of Poisson spike generator based on the statistics of inter-spike interval.

**e.** Repeat the process from part **a**, and compare the results. Compare the computation time for achieving the results in part **a** and **e** (You can use Matlab functions *tic* and *toc*).

**f.** Generate a spike train of a constant firing rate r = 50Hz (You can generate an arbitrary length of spike train as needed). Calculate and display the autocorrelation of spikes as shown. Does the profile of the autocorrelogram look as expected? If not, what conditions can you adjust?

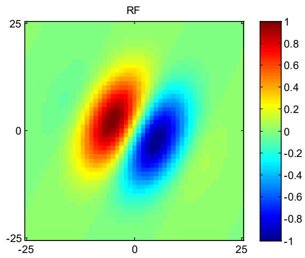


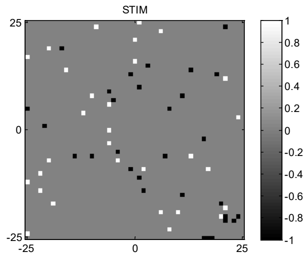

Dayan and Abbott 2001

**g.** Perform the same process as in part **f** for a time varying firing rate r(t), modeled as a cosine function with a period of 0.1s, an average firing rate of 50Hz, and a peak firing rate of 100Hz. Discuss the different patterns of spikes synchrony observed in the autocorrelograms from part **f** and **g**.

## Problem 2 [30 pts]

Implement a model simulation of reverse-correlation analysis to measure the spatial receptive field (RF) of a neuron as follows.




**a.** Prepare a simplified model RF of a simple cell in V1 as shown in the figure: (i) Use a Gabor function (ii) The ON/OFF boundary axis should be tilted by a non-zero arbitrary angle from the vertical line (iii) Define the matrix space x = y = [-25:25]. Plot the RF with a colorbar, using appropriately chosen boundary values for amplitude.

**b.** Implement a random-noise visual stimulus (STIM) similar to the sample figure shown. (i) White (+1) and black (-1) dots (N=30 each) are distributed randomly (ii) Ensure that the white and black dots do not overlap (iii) Set the background value to 0. Plot five sample STIMs that you generate.

**c.** Calculate the linear response L, i.e. the sum of the pixel-by-pixel multiplication of the RF and each STIM image, for 200 trials. Plot a histogram of the 200 values of L.

**d.** You can reconstruct the RF profile using a reverse-correlation method: Using the result from part **c**, select the STIMs that generate relatively higher values of L (e.g. the top 20%) and average them together. Can you observe a profile of the RF similar to the one you initially used? If not, try changing (i) the number of white and black dots in each STIM (ii) the number of STIMs used and (iii) the criteria for selecting STIMs with higher L values, to achieve a satisfactory result.

**e.** Now, devise your own method for improving the results, specifically by adjusting one factor of the STIM design (e.g. changing dot size or shape). Explain your approach and plot five sample STIMs generated using this way. Repeat the process from part **d** using your new STIMs. Discuss the advantages of your new method.

## Problem 3 [20 pts]

**a.** A time-varying neural firing rate is modeled as

$$\mathrm{r(t)} = C_1 \sin(C_2 t - C_3) + C_4$$

Determine the values of constant $C_1$~$C_4$ so that r(t) satisfies these conditions: the period T = 0.5 sec, r(0) = 10Hz, $r_{max}$ = 50Hz, $r_{min}$ = 10Hz. Plot $\mathrm{r(t)}$ for t=[0, 1]s.

**b.** Using the $\mathrm{r(t)}$ from part **a**, generate a model spike train for t=[0, 1]s using a model Poisson spike generator with no refractory period (use 1ms resolution). Plot r(t) for t=[0, 1]s and the corresponding spike train for 5 repeated trials.

**c.** Now implement a new firing rate $\mathrm{R(t)}$ with a time-varying refractory period as

$$\mathrm{R(t)} = \mathrm{r(t)}\left[1 - \exp\left(-\frac{\Delta t}{\tau_r}\right)\right]$$

where $\Delta t$ is the time since the previous spike — i.e. $\mathrm{R(t)}$ is set to 0 after each spike and recovers exponentially. Plot $\mathrm{r(t)}$, $\mathrm{R_1(t)}$ for $\tau_r$=1ms, and $\mathrm{R_{10}(t)}$ for $\tau_r$=10ms for one sample trial. Discuss the effective contribution of the refractory period for different values of firing rate.

**d.** Plot the histogram of inter-spike intervals (ISI) using the spike trains from $\mathrm{R_{10}(t)}$ in part **c**, to validate the design of the refractory period.

## Problem 4 (Questions for questions) [10+α pts]

Design a sub-question that can be added to Problem 1, 2, or 3, and specify where it should be placed. Provide a sample answer to the question and explain the important issue that can be discussed through it.