Coursework

This coursework relates to the properties of spike train. These questions are adapted from the exercises given in Part 1.1 of

`http://www.gatsby.ucl.ac.uk/~dayan/book/exercises.html`

in their original form they are exercises for the book Dayan and Abbott, a recommended text book for this course. In these question we are interested in the properties that spike trains have; this gives a more data-led perspective on spike trains than the one we have looked at before.

Poisson processes

The first question relates to Poisson processes, a Poisson process is a memoryless random process producing a time series of events; in the application to spike trains an event corresponds to a spike. By memoryless it is meant that the chance of an event depends only on a rate function $r(t)$ and not on the history of past events. The idea is that the probability of an event in a small interval δt wide is $r(t)\delta t$.

Imagine a person fishing in the sea, the chance of catching a fish might depend on the time of day but it doesn't depend on how many fishes the person has already caught, however, if they are fishing in a small pond the chance of catching a fish would diminish as they catch fish, so fishing in the sea is a Poisson process, but fishing in a pond is not. In the questions here the Poisson process is homogenous, that is, the rate is constant. Of course, if there is a refractory period, that is a time during which the neuron cannot spike, the spike train is not a Poisson process, but in this question a Poisson process is used to generate the spike train.

It can be proved, with a nice argument you are urged to look up, that the distribution of inter-event intervals t, here inter-spike intervals, is given by

$$p(t) = \frac{1}{r}e^{-rt} \tag{1}$$

A distinctive feature of a Poisson process is that its Fano factor and coefficient of variation. The aim here is to calculate these quantities for simulated and real spike trains.

The Fano factor is defined as

$$F = \frac{\sigma^2}{\mu} \tag{2}$$

where σ^2 is a variance and μ is an average. In the case of spike trains it is usually applied to the spike count; so to calculate it you divide the spike train into intervals and work out the spike count for each interval. The Fano factor is calculated using the average and variance for these counts. The coefficient of variation is

$$C_v = \frac{\sigma}{\mu} \tag{3}$$

where σ is a standard deviation and μ is an average. In the case of spike trains this is usually applied to the inter-spike interval, that is the time difference between successive spikes.

Question 1

Write code to generate spikes using a Poisson process. Calculate the Fano factor of the spike count and coefficient of variation of the inter-spike interval for 1000 seconds of spike train with a firing rate of 35 Hz, both with no refractory period and with a refractory period of 5 ms. In the case of the Fano factor the count should be performed over windows of width 10 ms, 50 ms and 100 ms. [10 marks]

Question 2

In the `spike_trains` folder you will find the data file `rho.dat`. This is contains data collected and provided by Rob de Ruyter van Steveninck from a fly H1 neuron responding to an approximate white-noise visual motion stimulus. Data were collected for 20 minutes at a sampling rate of 500 Hz. In the file, rho is a vector that gives the sequence of spiking events or non-events at the sampled time, that is, every 2 ms.

Calculate the Fano factor and coefficient of variation for this spike train as for the simulated spike trains above. [10 marks]

Question 3*

Consider an integrate and fire neuron, such as the one described in the formative coursework. With a constant input this neurons spikes periodically so that the variation in spike intervals is zero and if there is a variation in spike counts it is just the trivial consequence of a mismatch in the spike period and the interval overwhich counting is being performed. However, it is possible add noise to the input. One way to do this would be to include a synaptic input where pre-synaptic neurons are modelled by Poisson processes. Examine what happens in this case, try to keep the firing rate of the post-synaptic input constant but experiment with lots of weak Poisson input or a small amount of strong Poisson input. Consider having both inhibitory and excitatory input. Report on the Fano factor and coefficient of variation; for the highest marks consider plotting these against a parameter like the synapse strength or excitatory to inhibatory ratio. [15 marks]

The spike triggered average

The spike triggered average is used to identify what is causing the neuron to spike. Imagine the neuron spikes at times $\{t_1, t_2, \ldots, t_n\}$ and the stimulus is $\rho(t)$ then the spike triggered average is

$$s(\tau) = \frac{1}{n}\sum_{i=1}^{n}\rho(t_i - \tau) \tag{4}$$

In other words it is the average value of simulus a time τ before the neuron spikes.

Question 4

In the `spike_trains` folder you will find the data file `stim.dat`. This give the motion stimulus that evoked the spike train in `rho.dat`. Calculate and plot the spike triggered average over a 100 ms window. [10 marks]

Question 5

Calculate the stimulus triggered by pairs of spikes, that is for intervals of 2 ms, 10 ms, 20 ms and 50 ms calculate the average stimulus before a pair of spikes seperated by that interval; do this for both the case where the spikes are not neccesarily adjacent and the case where they are. [10 marks]

Question 6*

Again, compare your results to an integrate and fire neuron: the idea is that the integrate and fire would receive an input based on the stimulus file; to ensure the neuron fires you will need to also include the direct current, but this can be modified with the addition of the stimulus. What is the spike triggered average? You can experiment with changing the stength of the stimulus contribution and parameters like the membrane constant. [15 marks]

General instruction

There are 70 marks in total, this will be used to calculate a percentage. The two questions marked with an asterisk are harder and more open ended; do not spend too much time on these, the marking will give some credit for any attempt at the modelling they involve, but to get most or all of the 15 marks will require some experimentation.

Scientific communication of relies strongly on graphs and so you should take care in producing nice graphs; marks will be deducted for graphs where the text is tiny, or relevant units are missed. Do not include graphs that have been produced by screenshotting. Neuroscience as a subject favours long figure captions which provide detailed information about the graphs show, without giving interpetation, that is left to the main text. Try to follow this convention.

Please do not exceed six pages, however, you should not regard six pages as a target length, a much shorter submission could still earn all or most of the marks. The reason the length is not shorter is to make it easier to write without having to worry about being very precise, it is not to indicate that a long response is required. Do not use a font size less than 11pt and have normal looking margins. Submission is in pdf. You should include small code extracts where appropriate, any coding language can be used. You will also be required to upload your code. Submission is through blackboard upload.

This is a draft of the coursework offered in advance of the coursework period which starts on Monday 2023-11-20; between now and then I may make small adjusts to correct typos, to make more precise the submission instructions and to add some small clarifications. However the actual tasks will remain the same.