Assignment 1: Integrate-and-fire neurons

Neural Computation 2005-2006. Mark van Rossum

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Practical info

Report your findings. Plots should include axes labels and units (either on the plot, or mentioned in the text), see my web page link on reports! Particularly well-researched answers can receive additional points. There will a to be determined normalization factor between the number of points scored and the resulting percentage mark.

Copying results is not allowed. It's OK to ask for help from your friends. However, this help must not extend to copying code or written text that your friend has written, or that you and your friend have written together. I assess you on the basis of what you are able to do by yourself. It's OK to help a friend. However, this help must not extend to providing your friend with code or written text. If you are found to have done so, a penalty will be assessed against you as well.

Email me the Matlab script that you used for question 3, I will not assess the programming style, but I might check it if results are unexpected. I can also run plagiarism detectors on them. Email it to mvanross@inf.ed.ac.uk and the subject should contain 'nc1-2006' (all lowercase).

Deadline is Monday March 6 at noon (standard late policies apply). Hard-copies preferred, but if you are out of town an email to me is ok (pdf or postscript format). Hand in to Pat Ferguson, Rm. D10 in Forrest Hill.

Model

We study the effect of many inputs on a neuron's firing rate and its variability. The neuron is modelled as an integrate-and-fire neuron, supplemented with inputs, threshold detection and a reset. Parameters: $V_{rest} = -70$mV, $V_{thr} = -50mV$, $V_{reset} = -60$mV, $\tau_m = 20ms$, $C_m = 1nF$. No refractory time. Simulation parameters: time-step of 0.1 ms.

We are interest how synaptic input affects the firing of the cell. Hereto we provide both 100 excitatory and 100 inhibitory inputs to the cell. The time courses of the synaptic conductance changes are modelled as single exponentials. Parameters: reversal potentials $V_{rev}^{exc} = 0mV$, $V_{rev}^{inh} = -70mV$, time-constant of all synapses $5ms$. The inputs are activated with Poisson processes. For now, set the peak excitatory conductance to $1nS$, and the conductance of the inhibitory input to zero.

Smart coding will speed up your programme. For instance, it is not necessary to calculate the dynamics of each synapse individually (see lecture notes).

Question 1 (5 points) Assume that the excitatory inputs fire all at the same (Poisson) rate (called input rate), but are uncorrelated. Vary the input rate and plot the firing frequency of the neuron (range about 0..200Hz) as a function of the input rate.

Question 2 (10 points) Assume that the neuron is free of both input noise and intrinic noise. What is the theoretical f/I curve in this case? To get the current, measure the input current in your simulation and use this in the theoretical input/output relation. In the same plot as above, draw the theoretical f/I curve. Explain potential deviations between theory and simulation.

Question 3 (5 points) The Coefficient of Variation (CoV) of a quantity x is defined as $sd(x)/mean(x)$. Plot the CoV of the interspike intervals as a function of the input rate. Explain the behaviour.

We would like to compare the simulation results on the CoV with section 6.4 from the lecture notes. This means we need mean and variance of the input current. The mean and variance of the input current can be calculated from Campell's equations: When a quantity x consists of the sum of many Poisson events with rate ν where each individual event leads to an response $g(t)$, the mean and variance of x are,

$$\begin{aligned} \langle x \rangle &= \nu \int_{-\infty}^{\infty} g(t) \\ \langle \delta x^2 \rangle &= \nu \int_{-\infty}^{\infty} g^2(t) \end{aligned}$$

Question 4 (5 points) Go to section 6.4 of the lecture notes. In order to use the equation for $\langle \delta t^2 \rangle$ on p. 49, it has to be scaled with the synaptic timeconstant. Give the intuition behind the need for this correction.
Next, show that the CoV of the ISI is independent of the input rate.

Question 5 (10 points) Compare the CoV in the simulation to the expressions obtained in the lecture notes. Which assumptions do not hold in the simulation? Explain possible deviations between theory and simulations and proof your claims by changing the simulation.

We are interested in how correlations in the input affect the firing rate. A commonly used method to introduce correlations is to generate m Poisson trains and distribute them randomly over the n synapses. Each time-step a new distribution is drawn. Hereto use code like the following (within the time loop):

```
intrains = rand(m,1) < rate*dt; % m Poisson input trains with rate 'rate'
index = floor(m*rand(n,1)+1); % distribution of the Poisson trains over n synapses
g = g + g0 *sum(intrains(index)); % total conductance change
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Question 6 (5 points) Choose m such that on average the probability for sharing an event between any pair of synapses is 20% (state the value of m you used). Simulate and plot again the relation between input and output frequency and CoV. Explain possible differences with the uncorrelated case.

Now turn on inhibition. In order to compensate for the inhibition, increase the excitatory conductance to 8 nS, and set the inhibitory conductance 7 times that. The inhibitory inputs have a Poisson rate equal to the excitatory inputs. The inhibitory inputs are assumed to be uncorrelated to each other and to the excitatory inputs.

Question 7 (10 points) Again plot the input output relation and the CoV for uncorrelated and correlated excitation. How does correlation in the excitation affect the firing rate? Explain the result.

Question 8 (5 points) Which biological experiments could be used to determine the amount of excitation and inhibition, and their correlation in real neurons.