Neural Information Processing: 2017/18 Assignment 1

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Practical information

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LNP models with refractoriness

In this assignment we analyse LNP models of neurons. Instead of using real data, the neuron that we try to model is an integrate-and-fire model, the code of which is on the website. The input of the neuron is a one dimensional temporal stimulus. The output is the spike train.

In LNP models the probability of a spike in a time interval between t and $t + \Delta t$ is given by $p_{spike}(t) = f(K \star s)$, where $K \star s$ is the convolution of the stimulus with a to be fitted kernel, and $f()$ is a non-linearity. We a use rectifying non-linearity with adjustable threshold $f(x) = x - \theta$ for $x > \theta$ and $f(x) = 0$ otherwise. In theory the time bin $\Delta t \to 0$, but in practice we uses a finite value (1ms) as otherwise the problem is ill-posed.

In the lectures we used the cross-correlation between a white Gaussian stimulus and the response to determine the kernel. Here we use that for certain classes of the non-linearity, the optimal kernel can be found by maximising the log-likelihood. This is worked out in [Paninski, 2004] (paper on course website). Study section 1,2 and 6 of this paper.

Given a small enough time bin, the probability for a spike is $p_{spike}(t) = f(K \star s)$, and thus the probability $p_{no\,spike}(t) = 1 - f(K \star s)$. This leads to the log-likelihood given by the last equation on p. 245.

Question 1: Generate data using the integrate-and-fire code. Numerically find the optimal kernel that maximises the log-likelihood (last equation on p. 245) by varying the kernel elements. Use a time bin of 1ms and kernel length of about 10 time bins. Include one additional variable to be optimised that sets the threshold.
Plot the kernel found and comment on its shape.
Note: 1) You can use the Octave/Matlab function 'fminunc' for optimisation. Scipy also has appropriate functions for multidimensional optimisation. Take a reasonable initial condition for K. 2) You will not only need to restrict f to be between 0 and 1, but because of the logs the values 0 and 1 are also problematic. Rectify f such that it cannot reach those values.

Next, we include a refractory effect in the model. See section 6 of the paper.

Question 2: Derive the one before last equation on page 253, in a discrete time formulation (note, there is a typo in this equation...) assuming very small time bins such that $\log(1 - f) \approx -f$.

Also derive an equation for r in the discrete time formulation without making this approximation.

Question 3: Use the one before last equation on p.253 to find the (time-discretized) refractory function r. Use about 20 1ms time bins.
Plot it and comment on its shape. How is it possible to see a refractory effect, while the integrate-and-fire neuron does not have a refractory period built in?
Note, the integrate-and-fire simulation script creates an array with Interspike Intervals, and an array with the time since the last spike. These can be helpful.

Question 4: Improve the model parameters by alternating finding the kernel K and determining r a few times (see bottom of p.254). Report the final values found for K and r.

Question 5: Plot the output of the LNP model averaged across a number of trials. Compare the result of the predicted firing rate with and without refractoriness to the actual spike train.

References

[Paninski, 2004] Paninski, L. (2004). Maximum likelihood estimation of cascade point-process neural encoding models. *Network: Computation in Neural Systems*, 15(4):243–262.