Assignment 2: Synapric plasticity models

Neural Computation 2014-2015. Mark van Rossum

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Practical info

Organize your answers according to the questions; don't merge them. Plots should include axis labels and units (either on the plot, or mentioned in the text), see link on the course website.

There will be a to-be-determined normalization factor between the number of points scored and the resulting percentage mark.

You will find that some questions are quite open-ended. In order to receive full marks for those questions, your answers need to go beyond running a simulation and making a plot. Instead, you should substantiate your explanations and claims, for instance by doing additional simulations or mathematical analysis. In particular for discussion questions core-dumping (just writing down all you can think of) is discouraged, and incorrect claims can reduce marks. It should not be necessary to consult scientific literature, but if you do use additional literature, cite it.

Copying results is absolutely not allowed and can lead to severe punishment. It's OK to ask for help from your friends. However, this help must not extend to copying code, results, 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. Similarly, 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.

Deadline will be announced via email and the website. Hand in a paper copy to ITO (if you are out of town an email with a PDF to me is fine, and I will confirm receipts). Late policies are strict and are stated at `www.inf.ed.ac.uk/student-services/teaching-organisation/for-taught-students/coursework-and-projects`.

Assignment

In this assignment we look at various aspects of plasticity without however implementing a full plasticity model. The two parts can be answered independently.

Part 1: STDP

Spike timing synaptic plasticity (STDP) models can be written using so called traces. The pre-synaptic trace $x(t)$ is set to one with every pre-synaptic spike, and between pre-synaptic spikes the trace decays as $\tau_x dx(t)/dt = -x(t)$. [1]

[1] A variant would be to increase $x(t)$ with a fixed value with every spike $\tau_x dx(t)/dt = -x(t) + \tau_x X(t)$, where the pre-synaptic spike train written as a sum of delta-functions $X(t) = \sum_i \delta(t - t_i)$, and t_i are the times of the spikes. We do not consider that here.

Similarly we define the post-synaptic trace that is set to one with every post-synaptic spike and decays as $\tau_y dy(t)/dt = -y(t)$.

STDP potentiation can be reasonably modelled $\Delta w_+ = c_+ x(t-\epsilon)y(t-\epsilon)Y(t)$, describing LTP, and$\Delta w_- = c_- X(t)y(t-\epsilon)$, describing LTD. The pre-synaptic spike train is given as $X(t)$ which is one when there is a spike in that time-bin and zero otherwise, while $Y(t)$ represents the post-synaptic spikes in the same fashion. Furthermore, ϵ is a small number (one time-step in simulations), so that the values for the traces are taken right *before* they get updated (in particular this is important for the LTP term as otherwise $y(t)Y(t) = Y(t)$). Use for the constants $c_+ = 5$, $c_- = -1$, $\tau_x = 10ms$, $\tau_y = 50ms$.

First, we assume that both pre and post-synaptic trains are periodic with a frequency f_{pair}. The post-synaptic neuron fires a delay Δt after the pre-synaptic neuron (Δt can be negative, which means that the post-synaptic neuron spikes first).

Question 1 (5 points) Numerically calculate and plot the total weight change $\Delta w = \Delta w_+ + \Delta w_-$ as a function of Δt ($=-20\ldots+20$ms) for a couple of pairing frequencies f_{pair} in the range $1\ldots100$Hz. Take 20 pre-post spike pairs. Comment on your findings and the various contributions to Δw. Note, that this calculation does not require any neural model, but just the implementation of the spike trains, the traces, and the weight change.

Question 2 (5 points) Calculate analytically the general expression for the weight change per pre-synaptic spike for the setup of the previous question. Ignore the first pre-post pair, as for that one $y(t) = 0$. Compare your results to Question 1.

Question 3 (5 points) Repeat Question 1 for the case that both spike trains are Poisson trains with rates ρ_x and ρ_y respectively. Plot the change over a one second interval for a couple of settings of ρ_x and ρ_y. Comment on your findings.

Question 4 (5 points) Calculate the average weight change per pre-synaptic spike in case both spike trains are Poisson trains.

Part 2: Post vs pre expression of plasticity

There is some evidence that plasticity of the connection changes the release probability of pre-synaptic terminals, while other evidence points towards post-synaptic expression. Here we examine the consequences of either variant.

To model the synapse, we define the normalized number of available vesicle as $r(t)$ and U is the release probability. The number of available vesicles is a dynamic variable and obeys

$\tau_D dr(t)/dt = 1 - r(t) - Ur(t)X(t)$

That is, between spikes $r(t)$ recovers to one, while with every pre-synaptic spike it decreases an amount $r(t)U$ (that is, the average amount of vesicles released).

The average synaptic strength is the product $w = r(t)UA$, where A is the post-synaptic strength and $r(t)U$ is the pre-synaptic component. Both $r(t)$ and U are between 0 and 1.

We do not implement various plasticity rules here, but instead simply compare the effect of changes in U to changes in A.

Question 5 (5 points) Create an integrate and fire neuron that receives a 1 second long periodic train of pulses at 50Hz through a synapse with release modelled as above. The synaptic input is modelled as a current, decaying with a time-constant τ_{syn} between inputs and increasing an amount $r(t)UA$ for every input pulse. Parameters are as in the practical, further use a 5ms synaptic time-constant and $\tau_D = 200$ms. Take A about 5000, so that the neuron has a decent response. Compare the effect on the firing rate of the neuron when A is doubled vs a doubling of U. Make sure to study the onset transient in the response as well.

Question 6 (5 points) Assume a very long train of pre-synaptic spikes. What is the steady state synaptic strength during this prolonged stimulation? Does this explain the result from Question 5?