HUMBOLDT-UNIVERSITÄT ZU BERLIN
BERNSTEIN CENTER FOR
COMPUTATIONAL NEUROSCIENCE

Humboldt-Universität zu Berlin
Philippstr. 13 House 6

Phone: 030/2093-9110
Fax: 030/2093-6771
webpage: http://www.bccn-berlin.de/

Models of Neural Systems, WS 2009/10
Project 3: Spike-timing-dependent plasticity

Project presentation and report submission: February, 8th, 2010

Background

The normal function of neural systems relies on the synapses being able to adjust their weights to different input and output distributions. However, the mechanisms underlying this synaptic plasticity still remain unclear. Hebb postulated that the increase in synaptic weights requires coherent pre- and post-synaptic activity, but he did not provide much details on how these activities could be defined. Here, you will study a plasticity rule based on the relative timing of spikes in pre- and post-synaptic terminals. You will test if such a rule will lead to stable distribution of synaptic weights and generation of output spike times with realistic statistics.

Problems

1. *Literature review.* Study the paper of Song, Miller, Abbott, Nature Neuroscience 2000. Focus on the figures and the method section. What is the hypothesis? What are the main results and conclusions? What are the main assumptions of the model? What are the strengths and weaknesses of the paper?

2. Implement the leaky integrate-and-fire model with inhibitory and excitatory inputs described in the paper (see Methods section):

$$\tau_m \frac{\mathrm{d}V}{\mathrm{d}t} = V_{\mathrm{rest}} - V + g_{\mathrm{exc}}(t)(E_{exc} - V) + g_{\mathrm{inh}}(t)(E_{\mathrm{inh}} - V) \tag{1}$$

3. Assume that each spike results in a sudden increase of post-synaptic conductance, which then decays exponentially until the next input arrives:

$$g_{\mathrm{syn}} \longrightarrow g_{\mathrm{syn}} + \bar{g}_{\mathrm{syn}}, \text{ if } t = t_{\mathrm{pre}} \tag{2}$$

$$\tau_{\mathrm{syn}} \frac{\mathrm{d}g_{\mathrm{syn}}}{\mathrm{d}t} = -g_{\mathrm{syn}}, \tag{3}$$

where $\mathrm{syn} \in \{\mathrm{exc}, \mathrm{inh}\}$, t_{pre} is the time of a pre-synaptic time.

4. Spike-timing-dependent synaptic plasticity is implemented in the model by means of modification of the peak conductances of excitatory synapses $\overline{g}_{\text{exc}}$ (inhibitory synapses are not changed) according to the rule:

$$\overline{g}_{\text{exc}} \to \overline{g}_{\text{exc}} + M(t)\overline{g}_{\text{max}}, \text{ if } t = t_{\text{pre}} \tag{4}$$

$$\overline{g}_{\text{exc}} \to \overline{g}_{\text{exc}} + P(t)\overline{g}_{\text{max}}, \text{ if } t = t_{\text{post}} \tag{5}$$

Every time the post-synaptic neuron fires an action potential, $M(t)$ is decremented by an amount A_-, and every time a synapse receives an action potential from the pre-synaptic neuron, $P(t)$ is incremented by an amount A_+. If $g_{\text{exc}} < 0$ the peak conductance is reset to zero and if $g_{\text{exc}} > \overline{g}_{\text{max}}$ it is reset to $\overline{g}_{\text{max}}$. If there is no pre- or post-synaptic spikes $M(t)$ and $P(t)$ decay exponentially such that:

$$\tau_- \frac{\mathrm{d}M}{\mathrm{d}t} = -M \text{ and } \tau_+ \frac{\mathrm{d}P}{\mathrm{d}t} = -P. \tag{6}$$

5. For the initial excitatory peak conductances take $\overline{g}_{\text{exc}} = g_{\text{max}}$. Simulate the model with $N = 1000$ excitatory and $M = 200$ inhibitory synapses both of which receive independent Poisson spike trains (10 Hz for inhibitory, $10 - 40$ Hz for excitatory). Plot the final weight distribution for different excitatory firing rates. Plot the output firing rate and coefficient of variation as a function of the input firing rate.

6. Simulate the model with inputs consisting of bursts of action potentials. To this end, take that the inputs are silent except for isolated events represented by bursts of spikes with a Poisson distribution at 100 Hz for 20 ms. The inputs arrive at each synapse with random latencies drawn from Gaussian distribution (mean 0, standard deviation 15 ms). Plot a response to the same of burst of spikes at the beginning and at the end of the simulation. Plot the weights of synapses as a function of the relative latencies of incoming spike bursts (Song et al., 2000, Figure 4).

Richard Kempter	Phone: 2093-8925	Email: r.kempter(at)biologie.hu-berlin.de
Robert Schmidt	Phone: 2093-8926	Email: r.schmidt@biologie.hu-berlin.de
Bartosz Telenczuk	Phone: 2093-8838	Email: b.telenczuk@biologie.hu-berlin.de