Lab 8

February 23, 2010

Enhancing Synchrony with Plasticity

In the previous lab, we explored spike timing-dependent plasticity (STDP) as well as its role in achieving precise timing in a feedforward network. In this lab, we study how STDP compensates for neuronal variations and input noise in a network of recurrently connected neurons.

8.1 Prelab

In this prelab, we consider how a recurrent network with STDP synapses and (sinusoidal) global theta inhibition (8.75Hz) responds to both constant and noisy input.

1. Spike-Timing Variation

   Spike-timing variation (σ_{N}) depends on intrinsic variations (σ_{I}) among neurons and extrinsic variations (σ_{E}) in neurons' inputs. Intrinsic variation disperses neurons' spikes within a theta cycle despite identical input. Extrinsic variation disperses each neuron's spikes from cycle to cycle (independent from other neurons). The total variance is the sum of the intrinsic and extrinsic components:

   $$\sigma_{\mathrm{N}}^2 = \sigma_{\mathrm{I}}^2 + \sigma_{\mathrm{E}}^2 \tag{8.1}$$

   This implies that the actual spike times are the sum of two independent random variables. What are these two independent variables?

2. Extrinsic Variation

   STDP potentiates synapses from excitable neurons to lethargic ones, because these synapses satisfy the pre-before-post criteria. The additional drive from potentiated synapses motivates lethargic neurons to spike earlier, closer to the excitable ones; hence, timing precision improves.

   Adding (extrinsic) noise to neurons' input currents challenges STDP. Excitable neurons spike before lethargic ones on average; however, noise can reorder the spikes, causing lethargic neurons to spike before excitable ones, occasionally. Explain why the number of potentiated synapses drops when $\sigma_{\mathrm{E}} > \sigma_{\mathrm{I}}$.

8.2 Setup

As in previous labs, there will be a folder on the Desktop; this one is named **Plasticity and Synchrony Lab**. This folder contains the three instrument-control programs to acquire and view the neuron spikes and membrane potential in real-time as well as record and clear the synaptic states. **writeSRAM.exe** sets the connectivity of neurons. **experiment.exe**

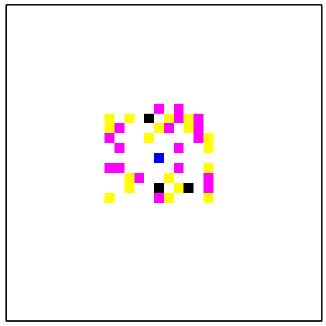

Figure 8.1: Each pyramidal neuron (blue) sends (magenta) and receives (yellow) randomly chosen STDP synapses to and from neurons up to 5 nodes away (black indicates both). Neurons near chip boundaries may send some connections farther away when all local synapses are occupied.

drives a patch of neurons and records their spikes, **read_syn.exe** records the states of synapses (potentiated or depressed), generating a plot of each neuron's synaptic weights, and **clear_syn.exe** initializes all synapses to the depressed state. The TA will instruct you on the use of the software.

Before each test, edit the contents of *parameters.txt*. In this lab, the parameters of interest are:

- Input current coefficient of variation ($\mathrm{CV_I}$)
- STDP active (1) or inactive (0) (W_{stdp})

Note that the mean input current (I_μ) is set such that neurons spike near the center of the decreasing phase of the theta inhibition. The $\mathrm{CV_I}$ value sets the standard deviation of the neurons' input current over time (normalized by the mean current). Also, the M-current strength and decay-constant are set to allow each neuron to spike once per theta cycle.

8.3 Experiments

In the first experiment, we will drive and observe a patch of recurrently connected neurons with constant input current, observing STDP improve timing precision by compensating for neuronal variability. In the second experiment, we will drive and observe the patch with noisy input current, observing STDP compensate for input variability as well. Each neuron sends and receives STDP connections randomly within a local area, up to 5 nodes away (Figure 8.1).

Experiment 1: Compensating for Heterogeneity

In this experiment, we will

- Study how STDP can compensate for heterogeneity (intrinsic variability) among recurrently connected neurons

We will drive a 10 by 10 patch of neurons with constant current as well as an 8.75Hz inhibitory theta rhythm. Obtain constant current by setting the input noise to zero ($CV_I = 0$).

Connect the neurons by running **writeSRAM.exe**. Initialize the synapses to the depressed state by running **clear_syn.exe**. Then, run the data acquisition program **experiment.exe** for two cases: STDP inactive ($W_{stdp} = 0$) and active ($W_{stdp} = 1$). The program returns 20 seconds of neurons' spike times. For both cases, find the standard deviation of spike times for each of the last twenty theta cycles. The means of these values are the intrinsic components of variation (σ_I) before and after STDP. How much improvement does STDP make? Record the states of the synapses with **read_syn.exe**. Notice that neurons do not receive the same number of potentiated synapses. What is the average number of potentiated synapses?

Experiment 2: Compensating for Noise

In this experiment, we will

- Study how STDP can compensate for input noise (extrinsic variability) among recurrently connected neurons

Repeat the process described in Experiment 1 (remember to initialize the synapses), varying CV_I between 0 and 10 (about 10 values). The means now give the total spike-timing variation (σ_N); use the values of σ_I from Experiment 1 and the expression from Prelab Question 1 to find the extrinsic component of spike-timing variation (σ_E) before and after STDP. Plot σ_E versus CV_I for both cases and fit each data set with a line. Add lines showing σ_I values. On the same graph, plot σ_N versus CV_I; use the measured values of σ_I and the fits of σ_E to fit these data. On another graph, plot the average number of synapses potentiated per neuron versus σ_E (after STDP).

8.4 Postlab

In Experiment 1, we observed that recurrent STDP potentiates synapses from excitable neurons to lethargic ones, providing the lethargic neurons with additional input. The additional input advances lethargic neurons' spike phases closer to the excitable neurons' phases, improving timing precision. In Experiment 2, we observed that STDP also reduces the extrinsic component of variation. Explain how STDP reduces σ_E when input noise is below a critical level and why it is unable to compensate above that level. Is STDP more effective in reducing the lethargic or excitable neurons' sensitivity to input noise?