Lab 8

March 3, 2007

Enhancing Synchrony with Plasticity

In the previous lab, we explored spike timing-dependent plasticity (STDP). 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_{T}) depends on intrinsic variations (σ_{I}) among neurons and extrinsic variations (σ_{E}) in neurons' inputs. Intrinsic variation distributes neurons' spike timings within a theta cycle despite identical input. Extrinsic variation disperses each neuron's spikes in each theta cycle (independent from other neurons). Explain why the total spike timing standard deviation is the sum of the intrinsic and extrinsic components:

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

   (Hint: the variances of independent variable are additive.)

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 one; 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 how increasing σ_{E} reduces the number of synapses that STDP potentiates.

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. **experiment.exe** drives a patch of neurons and records their spikes, **synapse.exe** records the states of synapses (potentiated or depressed), generating a plot of

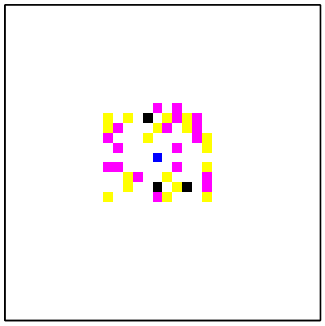

Figure 8.1: Each pyramidal neuron (blue) sends (magenta) and receives (yellow) randomly chosen STDP synapses to and from neurons up to 5 nodes away (black indicates both). Neurons near chip boundaries may send some connections farther away when all local synapses are occupied.

each neuron's synaptic weights, and **ltd.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. Also, the M-current strength and decay-constant are set 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 an 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 ($CV_I = 0$).

Initialize the synapses to the depressed state by running **ltd.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. Calculate spike timing standard deviation in each of the last twenty theta cycles before and after STDP and take the means. These two means are the intrinsic components of variation (σ_I) before and after STDP, respectively. How much improvement does STDP make? Record the states of the synapses with **synapse.exe**. Notice that neurons do not receive the same number of potentiated synapses. Explain why the number of potentiated synapses neurons receive varies.

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 points). Again, calculate spike timing standard deviation in each of the last twenty theta cycles before and after STDP and take the means. These two means are the total spike timing variation (σ_T); use the values of σ_I from Experiment 1 and the expression from Prelab Question 1 to find the extrinsic components of spike timing variation (σ_E) before and after STDP. Plot both results, σ_E versus CV_I; fit each data set with a line. Add lines showing σ_I values. On the same graph, plot σ_T versus CV_I; use the measured values of σ_I and the fits of σ_E to fit these data. Plot the average number of synapses potentiated per neuron versus σ_E (before STDP).

8.4 Postlab

In Experiments 1 and 2, we observed that STDP potentiates synapses from excitable neurons to lethargic ones, providing the lethargic neurons with additional input. The additional input advances the lethargic neurons' spike phases closer to the excitable neurons, improving timing precision.

In our model, STDP results in depression and potentiation for spike timing differences ($t_{pre} - t_{post}$) less and greater than zero, respectively. It is most effective for spike timing differences near this transition at zero. In neurobiology, different forms of STDP have been found where the transition from depression to potentiation occurs at spike timing differences several milliseconds past zero with weak efficacy near this transition. In locusts, STDP from Keynon cell afferents transitions from depression to potentiation as spike timing difference increases above 5ms (Figure 8.2).

A possible reason for the transition to occur at spike timing differences above zero is that it prevents ineffective synapses from potentiating. Synaptic spikes that arrive immediately before a neuron spikes do not contribute to the spike because the synapse takes time to

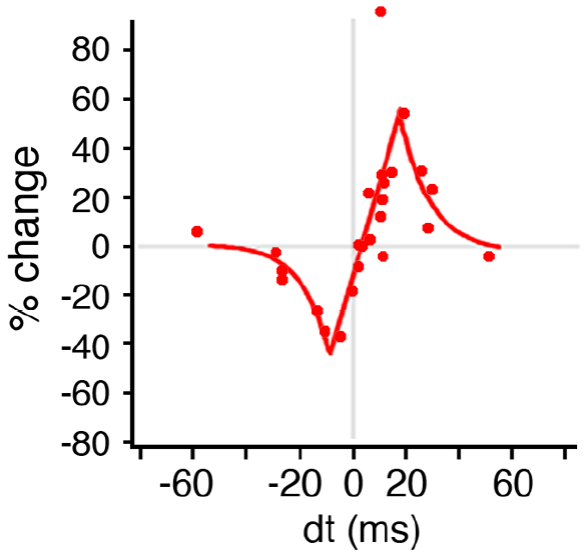

Figure 8.2: STDP in Locusts: the Kenyon cell afferents onto beta-lobe neurons potentiate when presynaptic spikes precede postsynaptic spikes by more than 5ms and depress most when they precede by less than 5ms or follow.[Laurent 2007].

rise and the generation of a spike takes time after the decision to spike is made (e.g., when the membrane potential increases above its unstable equilibrium). In our model, are some potentiated synapses ineffective since the neuron has already decided to spike when they arrive? Consider both noiseless and noisy cases.