5.2 Short-term depression (STD)

(Video 5.2) Now let us move to STD, which results from temporary depletion of neurotransmitter. The STD is captured by the variable x [1]:

$$\frac{dx}{dt} = \frac{1-x}{\tau_d} - (u^+x^-)\delta(t - t_{\rm sp}) \tag{1}$$

where x is analogous to the available stock of neurotransmitter. When spiking ceases, x relaxes back to the value of 1, with time constant τ_d. Here, x^- is the value of x just before the spike. If we consider again $w_{\rm fixed}$ to be the maximum efficacy of the synapse, then in a synapse containign both STF and STD, at any moment the synaptic efficacy is the product of u and x:

$$w_{\rm e} = w_{\rm fixed}u^+x^- \tag{2}$$

Notice that the product of u and x is bounded by the interval [0,1]. Switch all other types of plasticity off and implement the STF and STD together, with a single excitatory input synapse, connected to a regular (periodic) spike train. Periodic spikes will allow one to see the difference in effect more easily. When both STF and STD are in place, the neuron responds in an input frequency-dependent manner. Which frequency the neuron prefers depends on the ratio between τ_f and τ_d. First set $U = 0.45$, τ_f = 50 ms and τ_d = 750 ms. Use $w_{\rm fixed} = 2.5$. You now have a synapse that contains both STF and STD, but is mostly dominated by STD. Set the firing rate of the input spike train to 2 Hz to the neuron, and track the variables x, u, $w_{\rm e}$ and the number of output spikes relative to the number of input spikes (ratio of transmitted spikes). Set this ratio in the figure title. Now increase the frequency of the inputs to 20 Hz. How does the neuron respond to low and high frequencies in its inputs? Now switch the values, set τ_f = 750 ms and τ_d = 50 ms, and change U to 0.15. This is now a STF-dominated synapse. Try again the inputs with firing rates 2 Hz and 20 Hz. Does the neuron still prefer lower input firing rates? The key insight here is that the type of STP in the synapse can act as a frequency filter, making the neuron more or less responsive to different input firing rates.

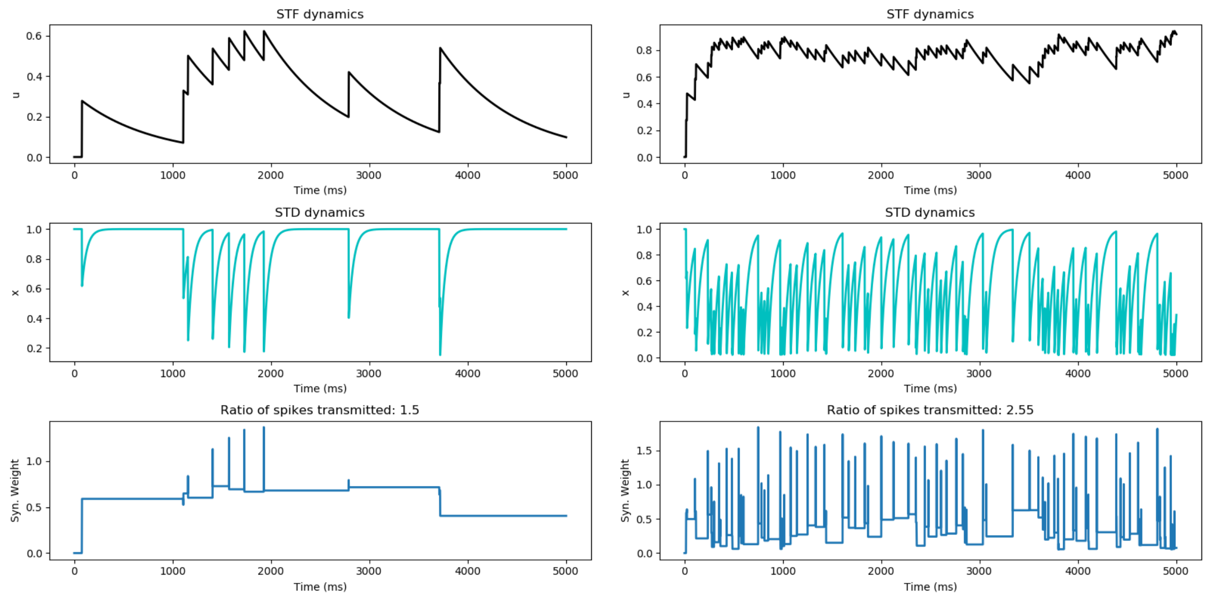

Figure 1: A LIF neuron with excitatory inputs and short-term facilitation in the input synapses. The time constants are $\tau_f = 750$ ms and $\tau_d = 50$ ms, and $U = 0.15$, resulting in facilitation-dominated synapses. The left three figures are for input firing rate 2 Hz, the right three figures are for input firing rate 20 Hz. Here, the ratio of transmitted spikes is higher for the high frequency input. Top: The fraction of facilitated neurotransmitter in the presynaptic terminal. Middle: The fraction of depleted neurotransmitter in the presynaptic terminal. Bottom: The change in the effective synaptic weight.

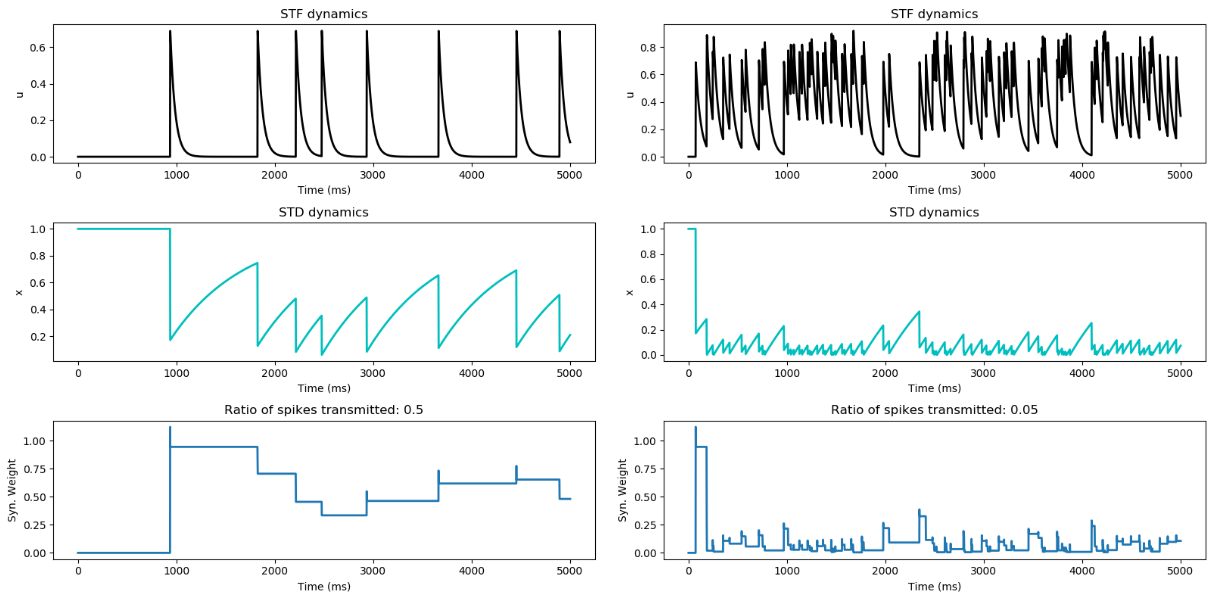

Figure 2: A LIF neuron with excitatory inputs and short-term facilitation in the input synapses. The time constants are $\tau_f = 50$ ms and $\tau_d = 750$ ms, and $U = 0.45$, resulting in depression-dominated synapses. The left three figures are for input firing rate 2 Hz, the right three figures are for input firing rate 20 Hz. Here, the ratio of transmitted spikes is higher for the low frequency input. Top: The fraction of facilitated neurotransmitter in the presynaptic terminal. Middle: The fraction of depleted neurotransmitter in the presynaptic terminal. Bottom: The change in the effective synaptic weight.

References

1. M. Tsodyks and H. Markram, "Neural Networks with Dynamic Synapses," *Neural computation*, vol. 10, pp. 821–835, 1998.