Learning objectives

- Cultivate and demonstrate a deep understanding of how to build biologically plausible models of brain networks using Izhikevich neurons.
- Learn how to imbue these networks with synaptic plasticity.

General instructions

- When I say 'show that blah blah blah' in the problems below, I mean replicate the plots. Or get close enough to replication that I can see that you understand how to program the basal ganglia and also that you understand the qualitative patterns that I'm trying to highlight.

Key features of the basal ganglia from the previous homework

- The **direct pathway** of the basal ganglia is: Cerebral cortex (ctx) $\rightarrow$ striatum (str) $\rightarrow$ internal segment of the globus pallidus (gpi) $\rightarrow$ thalamus (thl) $\rightarrow$ cerebral cortex (ctx). The striatal cells on this pathway contain D1 dopamine receptors so we may abbreviate them d1 instead of str.
- The **indirect pathway** of the basal ganglia is: Cerebral cortex (ctx) $\rightarrow$ striatum (str) $\rightarrow$ internal segment of the globus pallidus (gpi) $\rightarrow$ external segment of the globus pallidus (gpie $\rightarrow$ thalamus (thl) $\rightarrow$ cerebral cortex (ctx**. The striatal cells on this pathway contain d2 dopamine receptors so we may abbreviate them d2 instead of str.
- The **hyperdirect pathway** of the basal ganglia is: Cerebral cortex (ctx) $\rightarrow$ subthalamic nucleus $\rightarrow$ internal segment of the globus pallidus (gpi) $\rightarrow$ thalamus (thl) $\rightarrow$ cerebral cortex (ctx**.
- Both segments of the globus pallidus have high baseline firing rates (they fire a high frequency train of action potentials even in the absence of excitatory inputs).
- Striatal cells (d1 and d2 cells) have interesting elecrophysiological properties, so they are deserving of a special set of izhikevich model parameters. Every other cells in the network can be modeled with a regular spiking neuron. Please use the following parameters for these two neuron types:

```
# # striatal projection neuron
# C = 50; vr = -80; vt = -25; vpeak
= 40;
# a = 0.01; b = -20; c = -55; d = 1
50; k = 1;

# # regular spiking neuron
# C = 100; vr = -60; vt = -40; vpea
k = 35;
# a = 0.03; b = -2; c = -50; d = 10
0; k = 0.7;
```

New key features of the basal ganglia

- Dopamine (DA) neurons in the substantia nigra pars compacta(SNpc) encode reward prediction error. This means that they fire above baseline when something better than expected happens (positive prediction error) and the fire below baseline when something worse than expected happens (negative prediction error).
- SNpc neurons project to both D1 and D2 strial projection neurons.
- The effect of elevated DA – relative to baseline – on D1 projection neurons is to strengthen all active synapses.
- The effect of depressed DA – relative to baseline – on D1 projection neurons is to weaken all active synapses (on the D1 containing neuron).
- The effect of DA on D2 projection neurons is exactly the opposite. That is, elevated DA leads to synaptic weakening and depressed DA leads to strengthening.

1.

- Implement reinforcement learning between ctx-d1 synapses and use thalamus output to threshold motor responses.
- Implement a threshold Θ such that the model "repsonds* whenever activity in the motor unit exceeds Θ.
- Implement baseline responding such that the model selects a random percentage of trials to respond on. This should operate in addition to the weight-based responding from the first bullet in this question.
- Show that this model can learn to respond to a sensory cue that predicts reward.
- Show that this model can learn to extinguish a response when the reward is no longer available.
- Show that this model can reacquire its response to a sensory cue but that the rate of reacquisition is not reliably faster than the rate of initial acquisition. That is, show that extinction causes true unlearning / erasing of the initial learning.

2.

- Extend the network you built in problem 1 by implementing reinforcement learning between ctx-d2 synapses. Note that the LTP and LTD conditions are exactly reversed for ctx-d2 synapses relative to ctx-d1 synapses.
- Implement inhibitory connections between d1 and d2 projection neurons. Show that this network can show faster reacquisition than initial acquisition.