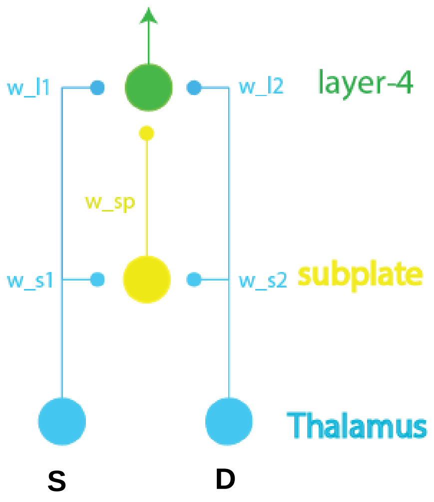
Computational Neuroscience (Autumn 2019)

Project IV

Submission: Due Date 3rd December 5 pm by email (sharba@ece.iitkgp.ernet.in). It must be only 1 *pdf* file and only 1 *m-file* (no zip files please) per group with the following:
a) Clearly state contributions by each group member
b) A cogent write up with figures appended at the end, as asked below; the writing should not exceed 2 pages – refer to figures by figure numbers.
c) A single MATLAB m-file code that should generate all the figures
For any assistance, contact Adarsh Mukesh (a.mukesh1055@gmail.com) and cc me.



Network structure:
As discussed in class, you will be simulating an adaptive network as shown to the left. There are 2 input neurons S and D (standard and deviant; at the level of the hypothetical thalamus). You will not need to simulate the neuron model for the thalamic neurons. You will only need to simulate spike trains as mentioned below, which will depict the output of these neurons. S and D make projections to the single subplate neuron (SP, yellow) and single Layer 4 neuron (L4, green) in the network. The SP projects to L4. There are a total of 5 synapses: Th(S)->SP, Th(D)->SP, Th(S)->L4, Th(D)->L4 and SP->L4. All 5 synapses are excitatory and follow short term plasticity modelled by the recovered-effective-inactive model of neurotransmitter recycling. Thus all synapses are depressing in nature. On top of the synaptic depression, the 3 synapses on L4 are plastic following STDP. The 2 neurons SP and L4 are to be simulated with a leaky integrate and fire model with absolute and relative refractory modelled with a large drop in membrane potential after a spike (threshold crossing) in the neuron, followed by an exponential recovery (as discussed in class).

Model parameters:
The initial thalamic weights:
Th(S/D)->SP = 0.2 each (to be kept constant throughout the simulation)
Sp->L4 = 0.11
Th(S/D)->L4 = 0.02 each

Hebbian learning rule for the synapses on L4:
$\Delta w/w = a_{LTP} * exp(-\Delta t/\tau_{LTP})$ for strengthening (LTP); $\Delta t > 0$
$\Delta w/w = -a_{LTD} * exp(\Delta t/\tau_{LTD})$ for weakening (LTD); $\Delta t < 0$
where Δt is the post-pre spike time; a_{LTP}=0.015, τ_{LTP}=13 ms, a_{LTD}0.021 and τ_{LTD}=20 ms.
Range of values of the Th(S/D)->L4: 0.0001 – 0.4 and SP->L4 0.0001 – 0.11. Please note that once a synapse reaches the upper or lower limit of its value it cannot cross the limit, but it can reduce (on reaching its upper limit) or increase (on reaching its lower limit).
All the synapses follow the depressing synapse dynamics (as done in class):
For the thalamic projection synapses: $\tau_{re} = 0.9, \tau_{ei} = 10, \tau_{re} = 5000;$

For the SP projection synapse: $\tau_{re} = 0.9, \tau_{ei} = 27, \tau_{re} = 5000;$
(all time constants above are in ms)
The SP and L4 neurons are to be modelled with integrate and fire dynamics with the refractory phase following an exponential rise with threshold of both neurons being 0.05.
v_l4(t) = g_S(t-1)*w_S(t-1)*x_S(t-1) + g_D(t-1)*w_D(t-1)*x_D(t-1) + g_{sp}(t-1)*w_{sp}(t-1)*x_{sp}(t-1)
v_sp(t)=g_S(t-1)*w_S(t-1)*x_S(t-1) + g_D(t-1)*w_D(t-1)*x_D(t-1)

g(t) for any neuron is the convolution of the spike train of that neuron with an exponential kernel $k(t) = \exp(^{-(t - t_{spike})}/_{\tau_{syn}}); \tau_{syn} = 10\, ms;$ ie $k(t)$ is the EPSP produced by each spike.

A 1 ms synaptic delay is to be given to the kernel before convolution. The time steps are to be 1 ms.
If v_sp or v_l4 crosses 0.05, a spike happens and the voltage drops by $v_\Delta(t)$ starting from the point of spike where, $v_\Delta(t) = \beta \exp(^{-(t - t_{spike})}/_{\tau_{ref}});\ \tau_{ref} = 2\, ms; \beta = 5$. This subtraction is done for a period of 20 ms following each spike. The voltage is also decreased by an additional 10% of the last voltage value as leak at every time step.

Input Activity:
The model develops based on input activity from the thalamic neurons. This activity will be simulated as spike trains (ie essentially spike times in the two thalamic axons).
1) First write a code to generate inhomogeneous Poisson spike trains with an average rate function $\lambda(t)$; where t has a resolution of 1 ms. Generate a random $\lambda(t)$ (>0 for all *t* and approximately around 40-50 spikes per second) over a period of 1 sec.
Use your code to generate spike times based on your $\lambda(t)$. Generate multiple replicates (*n*=320) and construct a PSTH (in units of spikes/sec with 1 ms bin size) of the generated spike train from the 100 repetitions. Check that your PSTH approximates $\lambda(t)$. Show that the root mean square error (rmse) using 10, 20, 40, 80, 160 and 320 (or more) repetitions finally asymptotes. Plot the rmse as a function of number of repetitions.
Once your inhomogeneous Poisson simulation works, it will be used to generate spike times of the S and D thalamic neurons that are the presynaptic activity for the SP and L4 neurons' inputs from the thalamus. There are essentially 2 stimuli to which the S and D neurons respond and they are stimulus S and D. Neuron S is selective to stimulus S and neuron D is selective to stimulus D. When stimulus S occurs, neuron S responds with 10 sp/s and neuron D responds with 2.5 sp/s. When stimulus D occurs, neurons S responds with 2.5 sp/s and neuron D responds with 10 sp/s; S and D never occur together. These rates are constant over the stimulus duration. When there is no stimulus there is a 0.5 sp/s spontaneous activity in the S and D neurons.
First have a version of your network (say verNOp) where LTP and LTD are off (ie there is no long term plasticity). This will be used to study responses of the network (SP and L4) to stimuli at a single point of time, in order to see changes that have occurred at different stages.
Use verNOp to get responses of SP and L4 with the initial synaptic weights (as given above) to the following stimulus protocol (ODDBALL):
A stream of 15 stimuli – S-S-S … S-D-S-S … S-S. Each stimulus is 50 ms long, the gap between stimuli are 250 ms and all 15 stimuli are S except the 8th stimulus, which is D.

2) Repeat this stimulus 50 times and obtain spike times of L4 and SP to get their PSTHs. Plot their PSTHs with a 10 ms bin size in units of sp/s. Comment on your observation.

3) Change τ_{re} for both the S&D and SP neurons to a) 1000 ms; b) 3000 ms and c) 10000 ms. What is the effect on PSTHs of L4 and SP and response to D for the variation of τ_{re}. Compare with your results in Q2.

4) Now use the regular version of the model with plasticity (LTP and LTD in the synapse on L4 neurons). Generate stimulus sequence something like: S-S-D-S-S-S-S-S-S-D-S-D-S-S-S-S-S … that lasts for more than 90 mins - each stimulus is 50 ms long, gap of 250 ms (ie stimulus start to next stimulus start is 300 ms, thus in 60 mins there will be 90*60/0.3 = 1800 stimuli). S and D occur randomly with probabilities of 0.9 and 0.1 respectively. If you run into memory problems (you should not) you would need to run it in chunks. Remember to save all model variables at the end of each chunk and start the simulation with those values in the next chunk. Please save all results. Make a plot of what happens to the 2 thalamic synapse strengths on L4 and SP synapse strength on L4. From the plot mark out time points at which, main changes occur. Use your verNOp model at those points to get responses to the ODDBALL stimulus protocol. Compare to what the ODDBALL stimulus protocol responses (of L4 and SP) that you did initially. Comment on the changes.