Computational Neuroscience Coursework 3

Integrate and Fire, STDP

COMSM2127

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PART A: Integrate-and-fire neurons

Question One

The rate of change in voltage for the "integrate and fire" neuron modelled in Figure 1 is given by the following equation:

$$\frac{dV}{dt} = \frac{Leak\ Potential - Voltage + MembraneResistance.Current_e}{\tau_m} \quad (1)$$

Where $\tau_m = \frac{Membrane\ Capacitance}{Membrane\ Conductance}$ and $Current_e$ refers to injected current from an electrode.

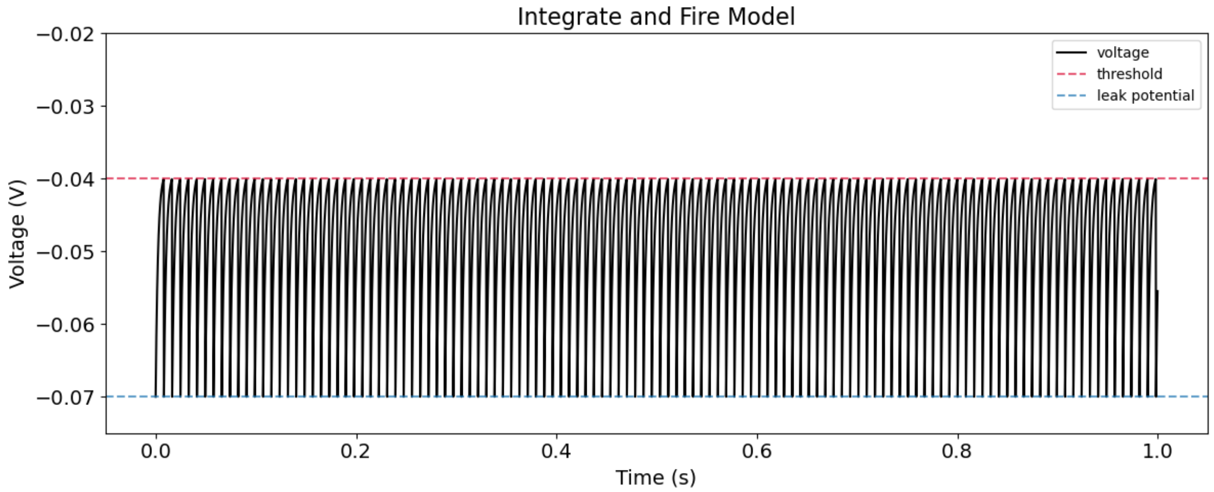

Figure 1

Question Two

The figures below show the relationship between two neurons with identical parameters. The neuron voltages for excitatory synapses are shown in Figure 2 and inhibitory synapses in Figure 3.

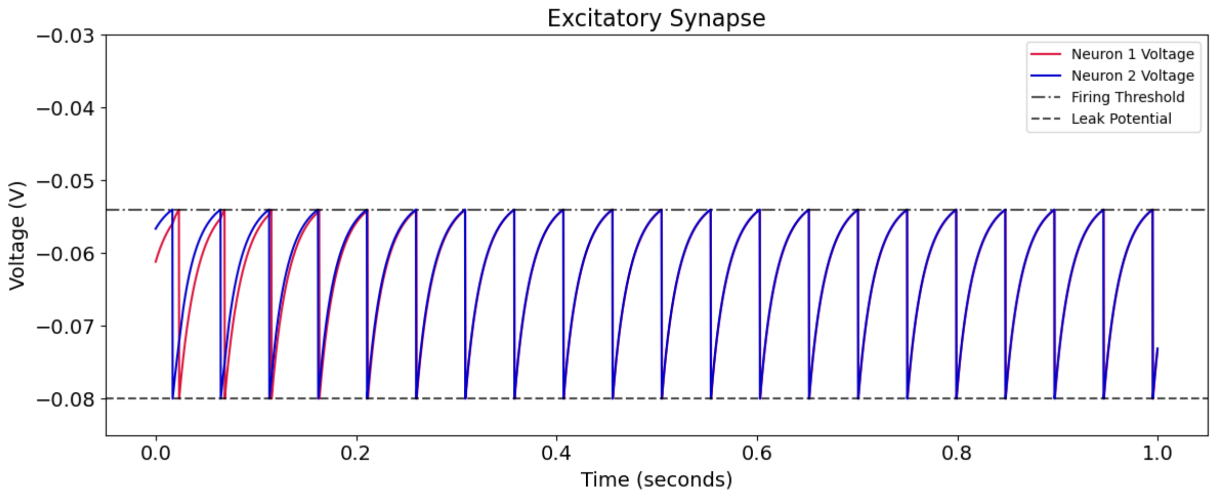

Figure 2

Looking closely at the figure above, it can be seen with the excitatory synapse that a spike in one neuron causes an increase in the rate of change of voltage in the other neuron. Also, the spike timings become synchronous over time.

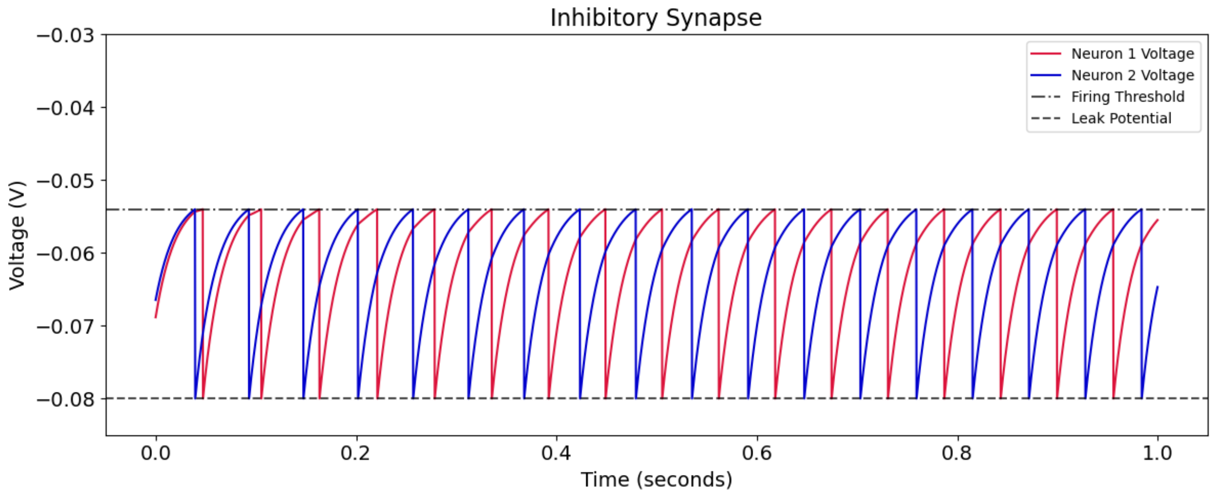

Figure 3

Looking closely at the figure above, it can be seen with the inhibitory synapse that a spike in one neuron causes a decrease in the rate of change of voltage in the other neuron. Also, the spike timings become fully asynchronous over time, with uniform timings between alternate spikes.

Question Three

1. The minimum current required to for the neuron with the above parameters to produce an action potential can be found using the equation below:
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$$R_m \cdot I_e > V_T - E_L \iff I_e > \frac{V_T - E_L}{R_m} \iff I_{e-min} = \frac{V_T - E_L}{R_m} \qquad (2)$$

The computed minimum required current is 3 [nA].

2. The figure below shows an Integrate and Fire model with an input current with amplitude *Ie* which is 0.1 [nA] lower than the minimum current. The graph shows no spiking for *Ie* < 3 [nA].

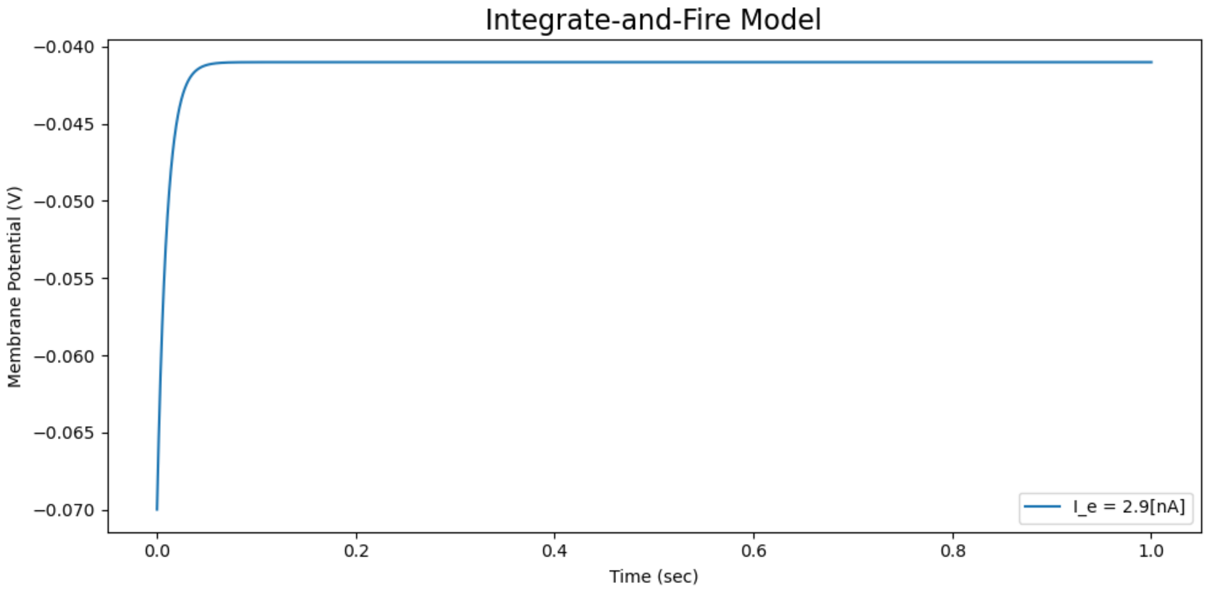


Figure 4

3. The figure below shows firing rate as the function of the input current for a neuron simulated for currents ranging from 2 [nA] to 5 [nA] in steps of 0.1 [nA]. The graph shows no spiking till *Ie* is bigger than 3 [nA] and the number of spikes increasing as the input current increases thereafter.

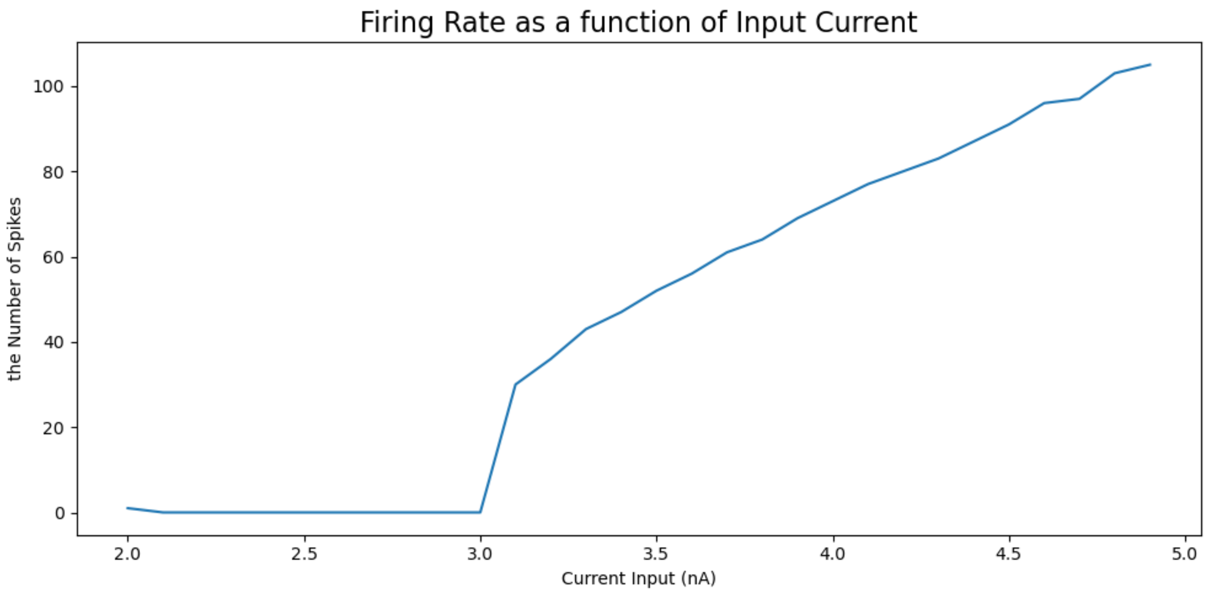


Figure 5

PART B: STDP

Question One

The figure below shows 40 incoming synapses simulated at the same length. It can be observed that the neurons fire irregularly at a rate of roughly 20 Hz for 1 second of simulation time.

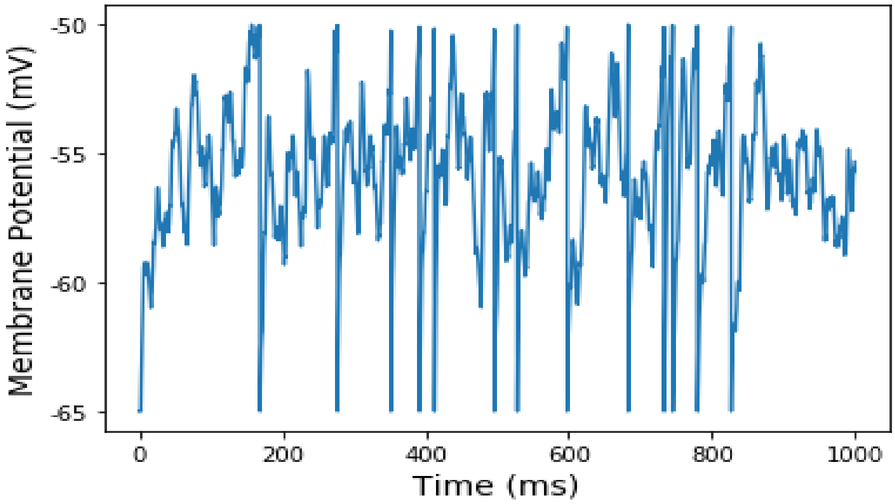
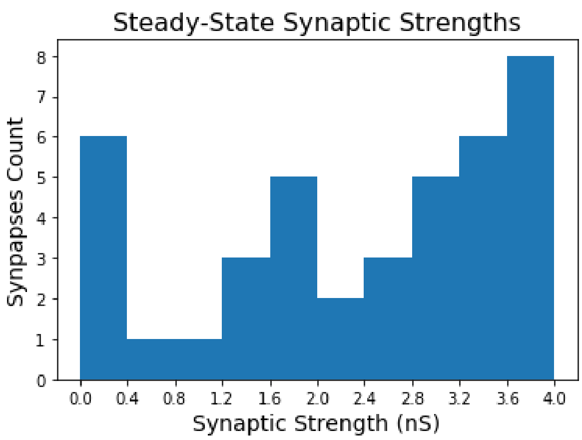


Figure 6: 40 incoming synapses observed in 1 second

Question Two

After adding Spike-time-dependent plasticity (STDP) to the single leaky integrate and fire neuron, the steady state synaptic strength and post-synaptic firing rates were observed.



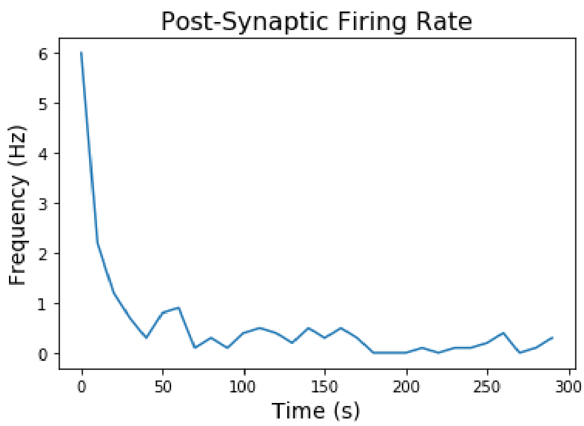
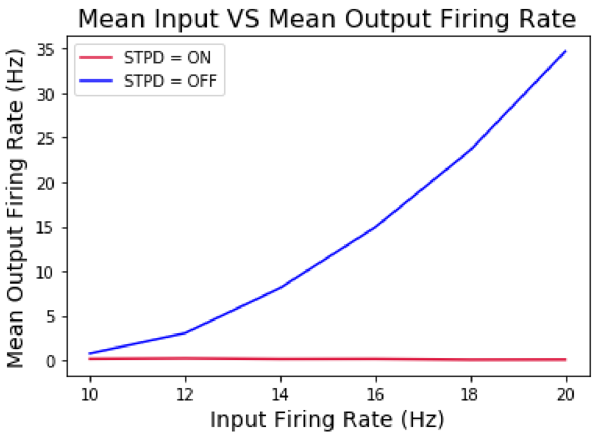


Figure 7,8

When STDP is switched 'on' a wider distribution of synaptic strength can be observed. This can also be assumed looking at figure 8, as time increases the frequency of post-synaptic firing rate decreases. Comparatively, when STDP is 'off' a lower number of spikes are seen with high firing rates.

Question Three

Varying the input firing rates from 10 Hz to 20 Hz with both STDP on and off resulted in the plots shown below.



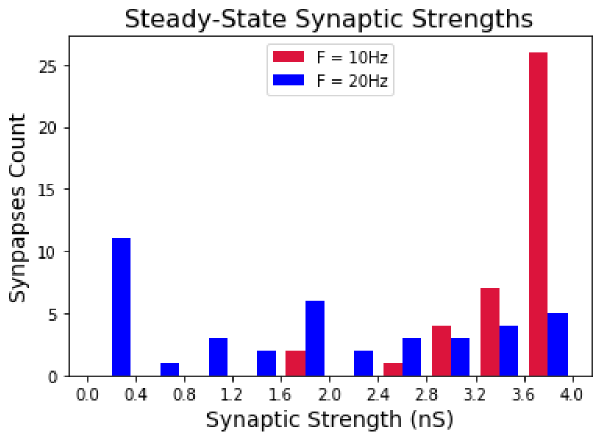
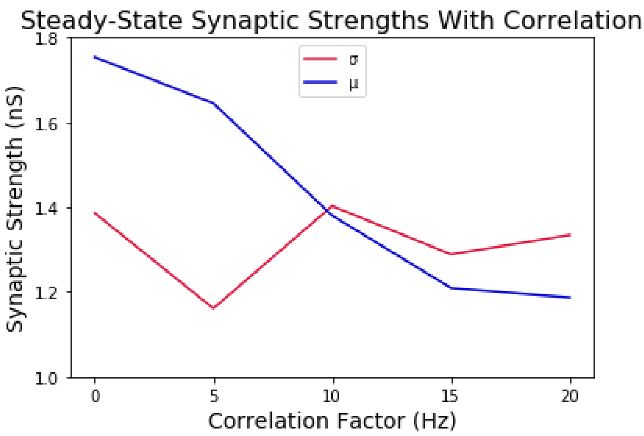


Figure 9,10

As shown in Figure 9, the left plot illustrates an upward trend in the mean output firing rate with the increasing input firing frequency in STDP 'off' situation, because the higher input frequency is result in the increasing *S* directly but the synaptic strengths (g_{syn}) are invariable, which can make the postsynaptic neuron fire more. However, although the trend of output firing rate in STDP 'on' simulation is not clear, it generally declines slightly with the increasing input frequency.

In the case of the synaptic strength, a lower input firing rate resulted in a higher number of synapses with higher synaptic strength while a higher input firing rate produced low number of synapses with varying synaptic strength. Showing that STDP greatly influences synaptic strength.

Question Four



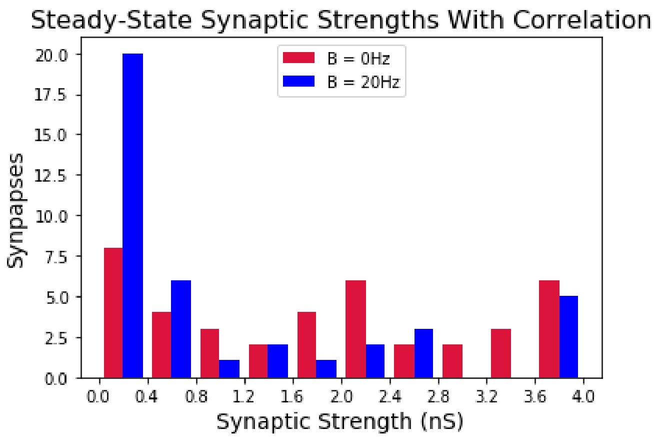


Figure 11,12

The two graphs in Figure 11,12 show that there has been a marked decline in the mean (μ) of synaptic weights as B rises. And the synaptic weights are not intensive due to the fluctuation of standard deviation (σ) plot.

This can also be observed through the histogram illustrating how when (*B = 0*), a range of synapses are produced with synaptic strength ranging from 0.3 – 4.9 nS. While, a value of *B > 0* results in majority of synapses fired to have a synaptic strength of less than 1 nS.