Neurodynamics Homework 4

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1 Uncoupled Neurons

We simulated two independent uncoupled neurons with $I_{ext} = (10, 20)\mu A$ respectively. We visualized their spiking patterns and spike rates over time (Figures 1,2) and found that the cell with $I_{ext} = 10\mu A$ had an ISI of 14.6 ± 0.08 while the neuron with $I_{ext} = 20\mu A$ had an ISI of 11.6 ± 0.09. This fits with what we would expect where lower input currents result in lower spike rates.

2 Inhibitory (GABA) Coupled Neurons

Next, we simulated two neurons with an inhibitory coupling. We modified the rate of coupling by changing the conductance g of $GABA_A$. We found at various values ot g_{GABA} that while the spike rates matched up, the timing did not synchronize (Figures 3,4,5). The two neurons were effectively coupled at $g_{GABA} = 0.4$ and remained coupled trough $g_{GABA} = 1.0$ (Figures 6,7).

3 In-Phase Oscillations

Here, we set the external current to our two neurons be very close but distinct, $I_{ext} = (10.0, 10.1)\ \mu A$. We held our inhibitory conductance g_{GABA} constant while varying out gate closing probability in our Markov process for $GABA_A$ channels. We found that when the gates had a low probability of closing ($GABA_A \leq 0.1$), they were much more likely to become synchronized, while at higher closing rates($GABA_A > 0.1$) they became anti-synchronized (Figures 8,9,10,11).

4 Excitatory Synapse Model

Next, we introduced excitatory (glutamate) synapses with neuron 1 receiving an $I_{ext} = 10.0\mu A$ with an excitatory glutamate synapse to neuron 2 which receives no external current. We experimented with several conductance values between $g_{Glu} = 0.0\ to\ 0.5$ and found that neuron 2 does not fire at all below

$g_{Glu} = 0.25$ and steadily increases its firing rate until $g_{Glu} = 0.5$ where it has the same firing rate as neuron 1 of 70 Hz (Figures 12,13,14,15,16).

5 Feedforward Inhibition

We simulated a feedforward inhibition circuit with three neurons where neuron 1 received an external current and had excitatory connections to neurons 2 and 3 while neuron 2 had an inhibitory connection to neuron 3. With this circuit, we first experimented varying the excitatory current g_{Glu} while keeping the inhibitory conductance constant $g_{GABA} = 0.5$. As was expected from what we found with our excitatory synapse model, both neurons 2 and 3 increased there firing rates once above threshold of $g_{Glu} = 0.3$ until they matched the firing rate of neuron 1 (Figure 17). Neuron 3's firing rate was always below Neuron 2's until it reached maximum due to the proportional inhibition it was receiving from 2.

Next, we varied g_{GABA} while keeping g_{Glu} constant at 0.4 (Figure 18). Here we found that, as expected, neurons 1 and 2 were unaffected while neuron 3's firing rate robustly decreased as a function of g_{GABA}. Interestingly, neuron 3's firing rate seemed to behave in a quantal manner, it plateaued at a few specific firing rates across many values of g_{GABA}, specifically 45 and 35 Hz. Finally, we took intermediate values of g_{GABA} and g_{Glu}, (0.4, 0.4), and stimulated with varying external currents to visualize how it might affect phase locking. At any external current above $10\mu A$, neurons 2 and 3 were strongly phase locked indicating they were both being strongly driven by neuron 1 (Figures 19,20,21).

6 Feedback Inhibition

Feedback inhibition consists of one neuron inhibiting the neuron that provides it an excitatory input. In our construction, this is a circuit where 1 excites 3, 3 excites 2, and 2 inhibits 3. While increasing I_{ext}, we find that Neuron 1 continually increases its firing rate while Neurons 2 and 3 decrease between 10 and 15 μA before increasing steadily through 30 μA (Figure 22). Strikingly, Neurons 2 and 3 have identical spike rates across all current injections, a characteristic of Feedback inhibition. Looking at the voltage traces themselves, we see that no spiking occurs at all below 10 μA, and that while Neurons 2 and 3 have a similar spike rate, they are anti-phaselocked (Figure 23,24,25).

7 Function of Mini-Networks

Feedforward networks lead to very high synchrony between neurons with the down-stream neuron occasionally missing a beat (Figures 17,19). Feedback networks on the other hand, lead to very high frequency locking between neurons but with no synchrony and possibly anti-phase locking (Figures 22,25).

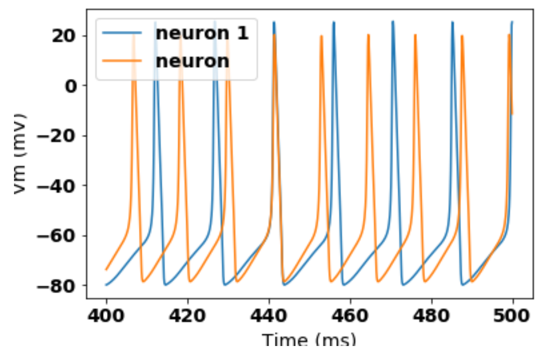

Figure 1: Spiking Uncoupled Neurons

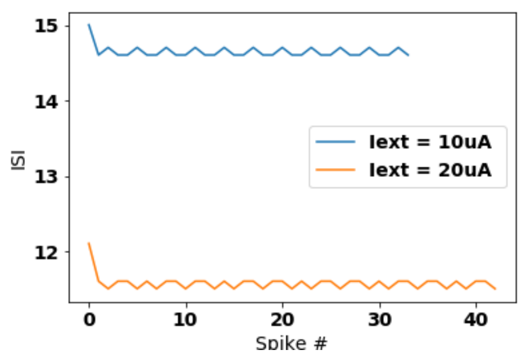

Figure 2: ISI Uncoupled Neurons

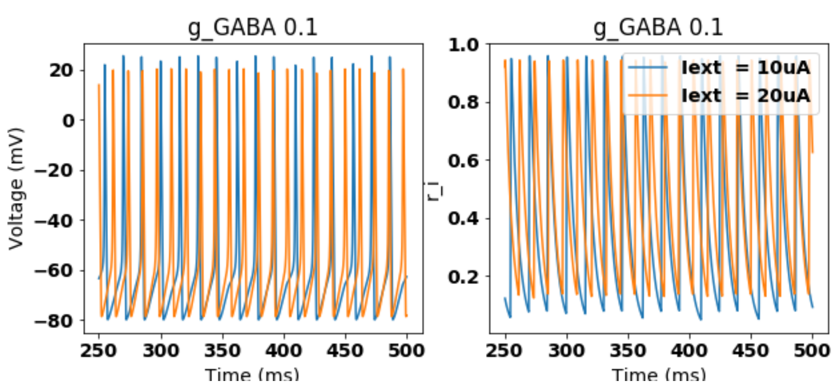

Figure 3: $g_{GABA} = 0.1$

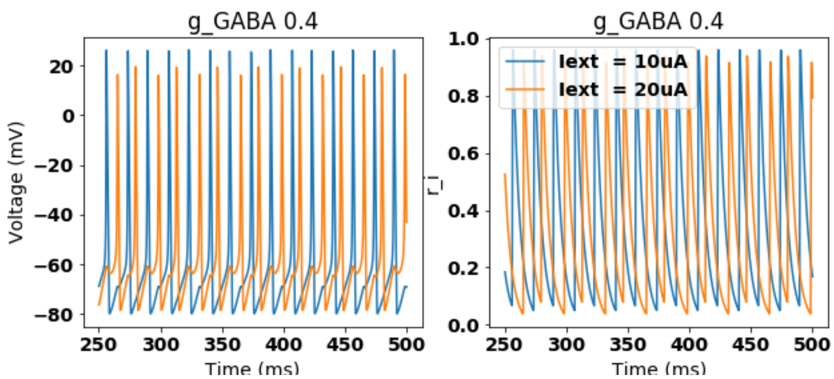

Figure 4: $g_{GABA} = 0.4$

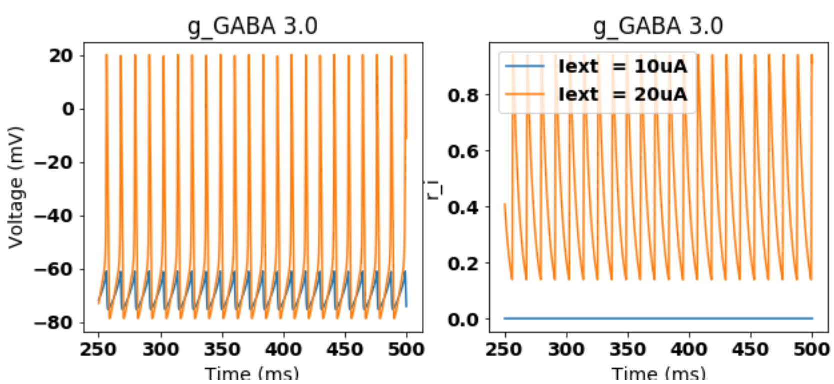

Figure 5: $g_{GABA} = 3.0$

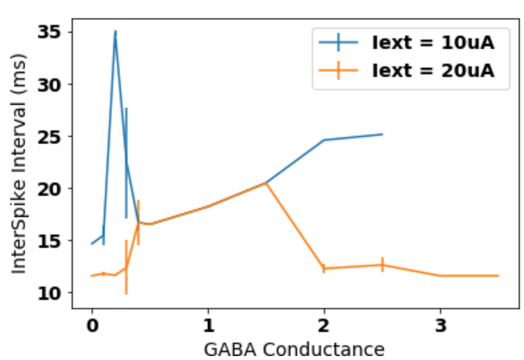

Figure 6: ISI Inhibitory (GABA) Coupled Neurons

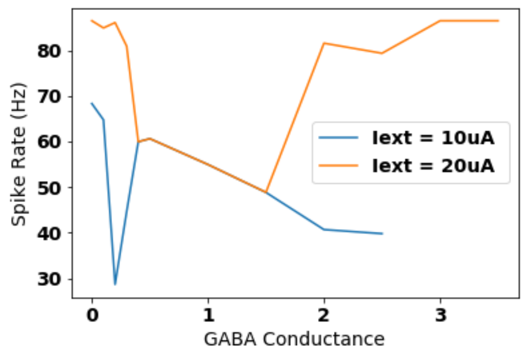

Figure 7: Spike Rate Inhibitory (GABA) Coupled Neurons

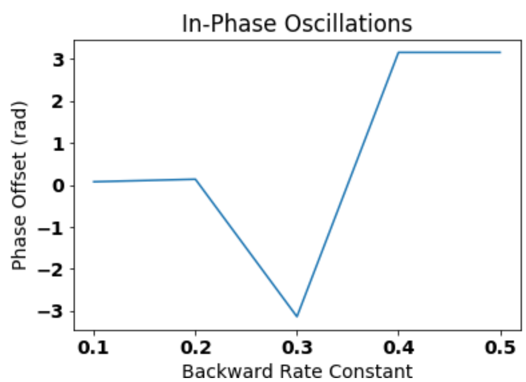

Figure 8: Phase Offset f(r)

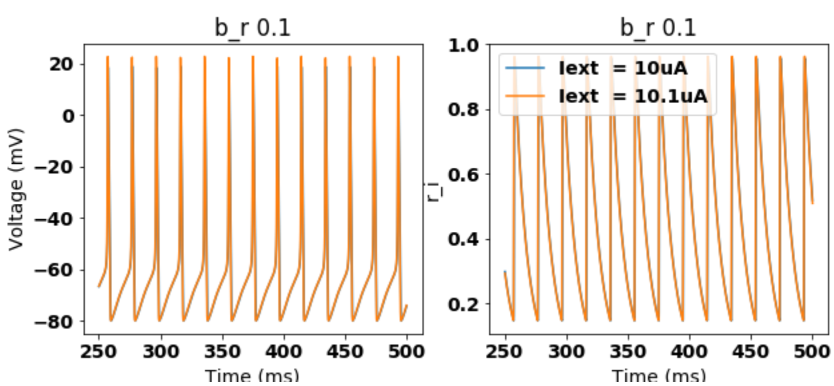

Figure 9: $\beta_r = 0.1$

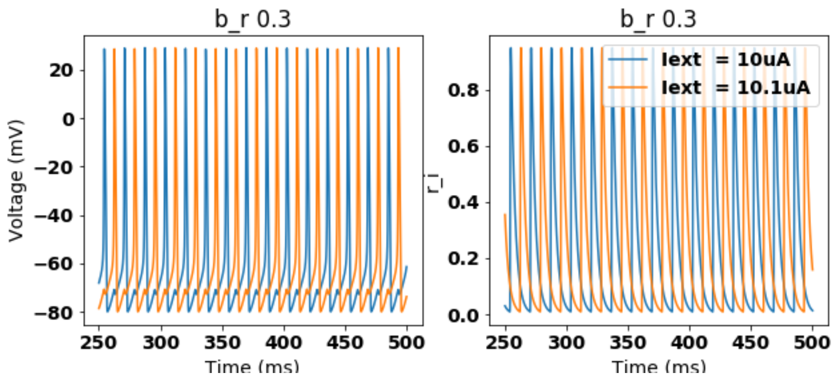

Figure 10: $\beta_r = 0.3$

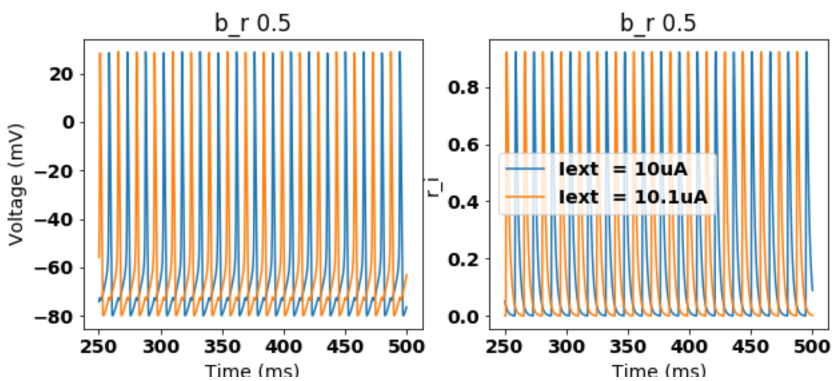

Figure 11: $\beta_r = 0.5$

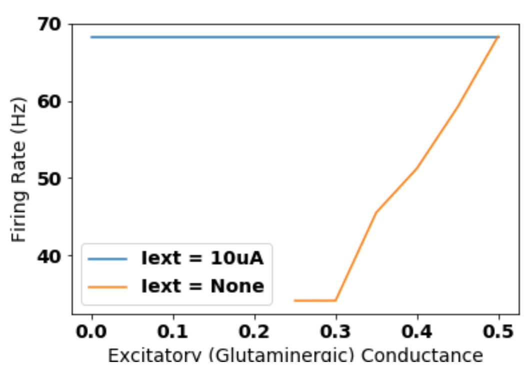

Figure 12: Spike Rate vs. G_{Glu}

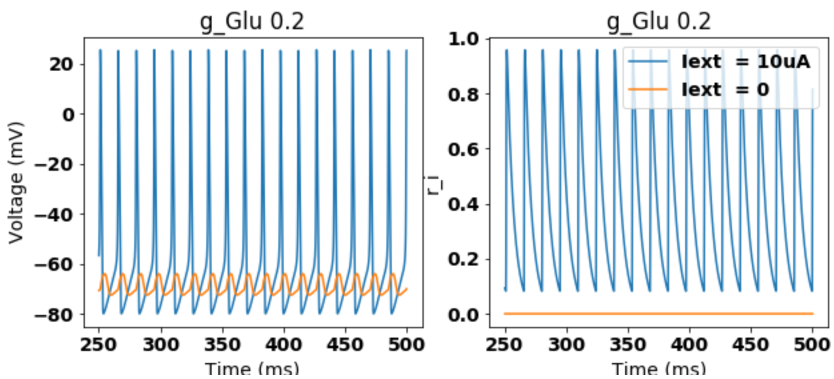

Figure 13: $G_{Glu} = 0.2$

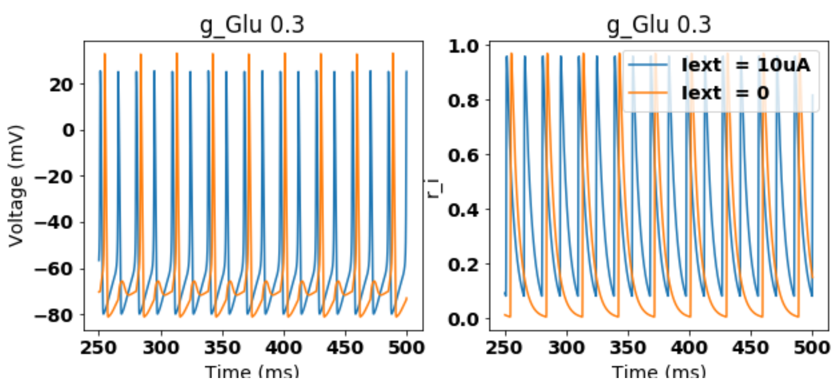

Figure 14: $G_{Glu} = 0.3$

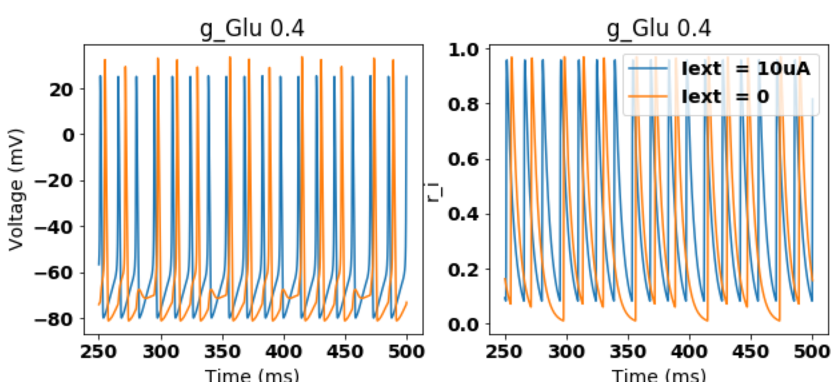

Figure 15: $G_{Glu} = 0.4$

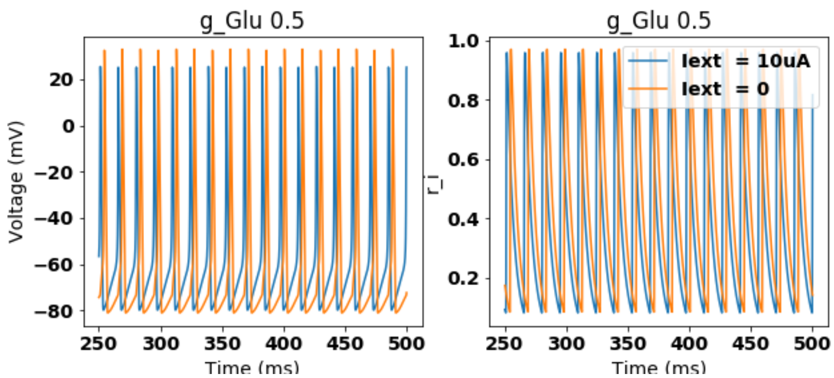

Figure 16: $G_{Glu} = 0.5$

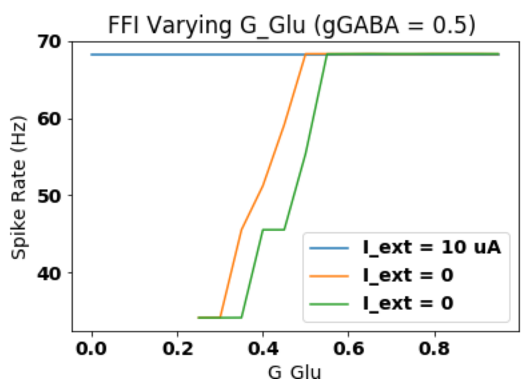

Figure 17: SR(G_{Glu})

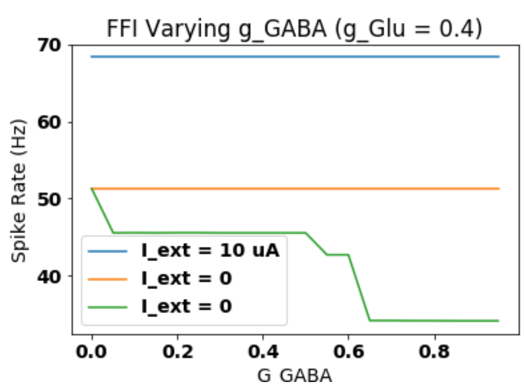

Figure 18: SR(G_{GABA})

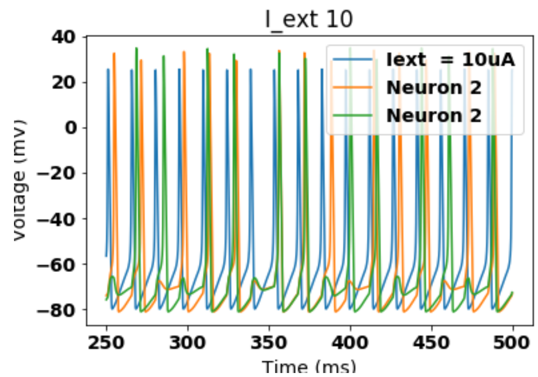

Figure 19: $I_{ext} = 10\mu A$

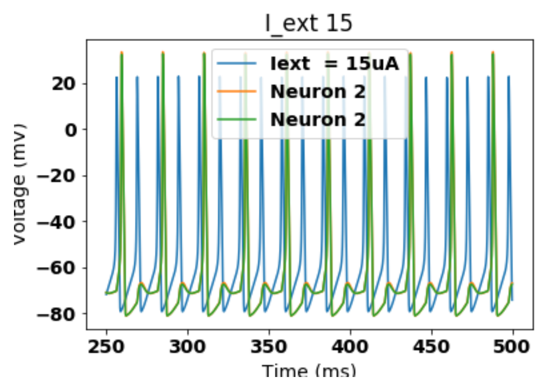

Figure 20: $I_{ext} = 15\mu A$

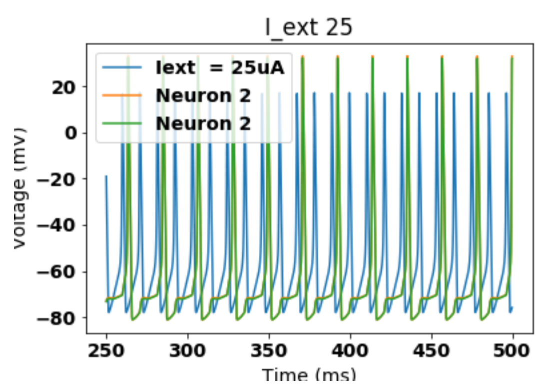

Figure 21: $I_{ext} = 25\mu A$

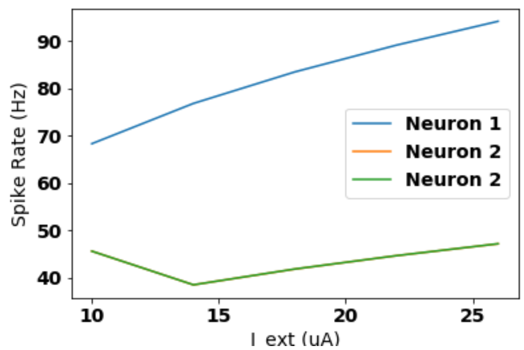

Figure 22: (SR(I_{ext})

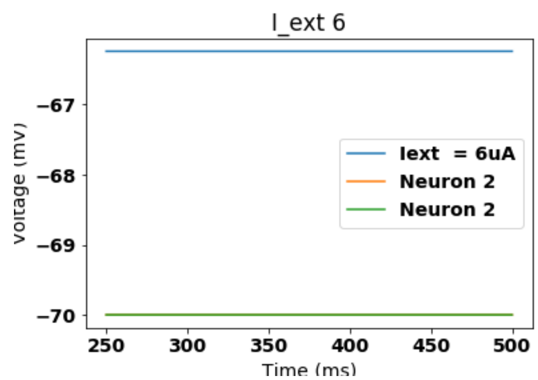

Figure 23: $I_{ext} = 6\mu A$

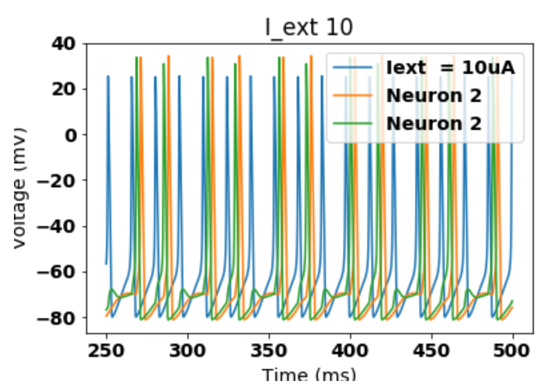

Figure 24: $I_{ext} = 10\mu A$

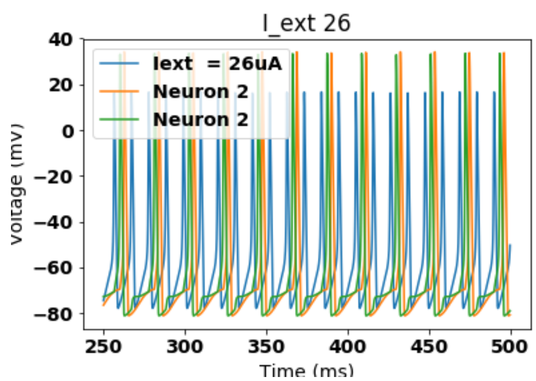

Figure 25: $I_{ext} = 26\mu A$