CS 443 / 525 Homework 1

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1 Questions

1.1 Very Low Input Current: IF, LIF

Capacitance is a constant for an IF neuron, so then if its input current is positive, its dV/dt will be positive. This means the neuron will accumulate voltage over time and generate a spike when the voltage passes an upper threshold before falling back to a lower voltage threshold. Spikes will be far between but come consistently.

Voltage leaks over time for an LIF neuron, so it'll take a stronger consistent input current to generate the same spike train as that which would be generated by an IF neuron. If the input current is not greater than the upper voltage threshold (required for spiking) divided by its resistance parameter, the LIF neuron will never spike because it will be losing voltage too quickly for the input current to counter.

1.2 Larger Input Current: IF, LIF

If an IF neuron is constantly fed a large input current, then it will spike frequently and evenly because its voltage will quickly reach the upper threshold for spiking, the neuron will spike, the voltage will fall back down, and repeat. If an LIF neuron is constantly fed a large input current, then as long as it has a sufficient resistance parameter, it will also spike frequently and evenly, but less frequently than a corresponding IF neuron.

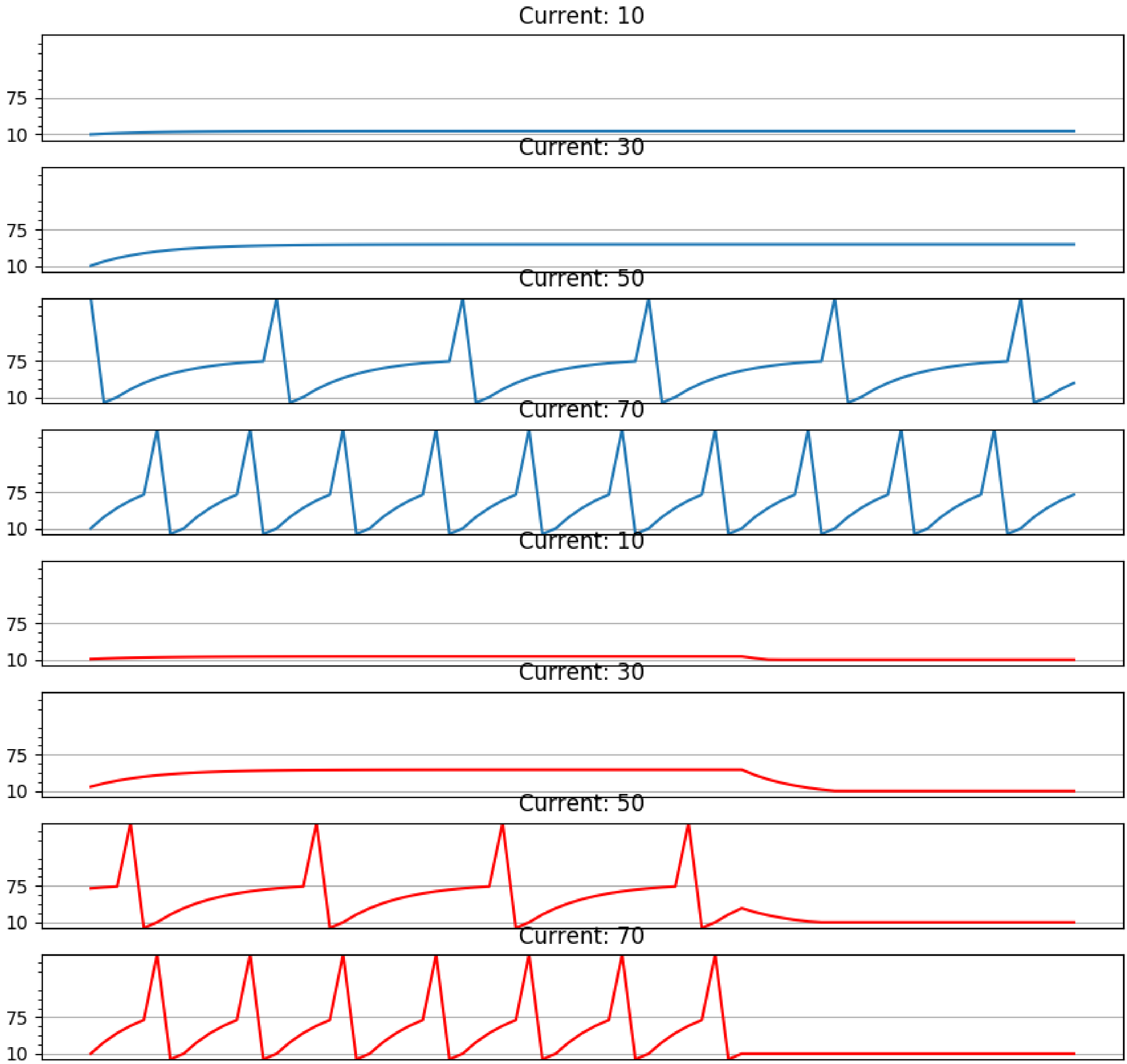
1.3 Limitations: LIF

One particularly significant limitation of the LIF model of a neuron is that it integrates input current linearly regardless of the state of the post-synaptic neuron. No memory of previous spikes is kept because the voltage falls back to the minimum voltage threshold after every spike. In theory, a massive input current would then cause an extremely frequent spike train for the LIF neuron, despite the fact that we observe refractory periods in real neurons after spikes during which it is impossible or difficult for the neuron to spike (even if a neuron receives a pre-synaptic spike, its ion channels may still be open and unable to yet propagate a spike). The LIF model does not capture adaptation of faster spiking over time, or burst-like or stutter-like spiking behavior either.

2 Programming

2.1 Simulate LIF

In these plots, I have simulated input currents to an LIF neuron. The blue plots correspond to constant input currents - spiking behavior is observed. The red plots correspond to input currents that are constant for the first half of the time period analyzed and zero for the second half - membrane potential decays over time.


Current: 10
75
10
Current: 30
75
10
Current: 50
75
10
Current: 70
75
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Current: 10
75
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Current: 30
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Current: 50
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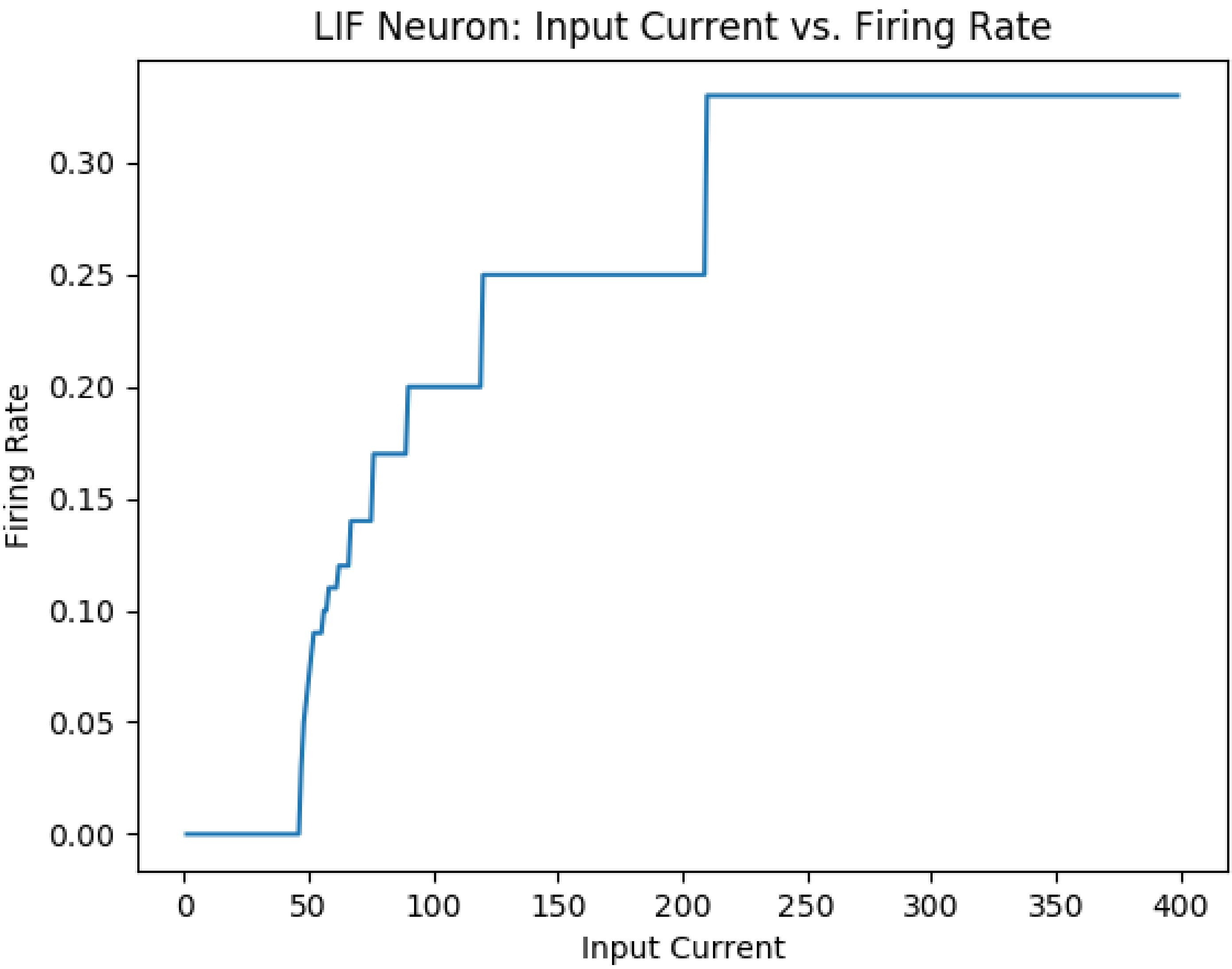
Current: 70
75
10

2.2 Firing Rate vs. Input Current

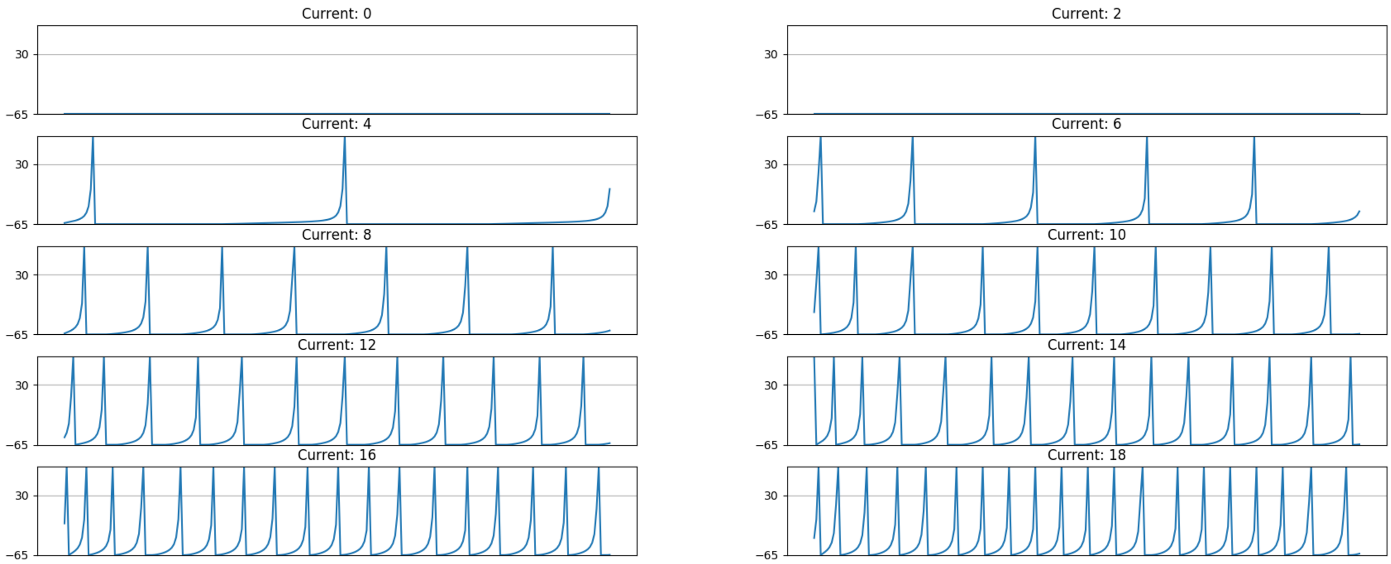


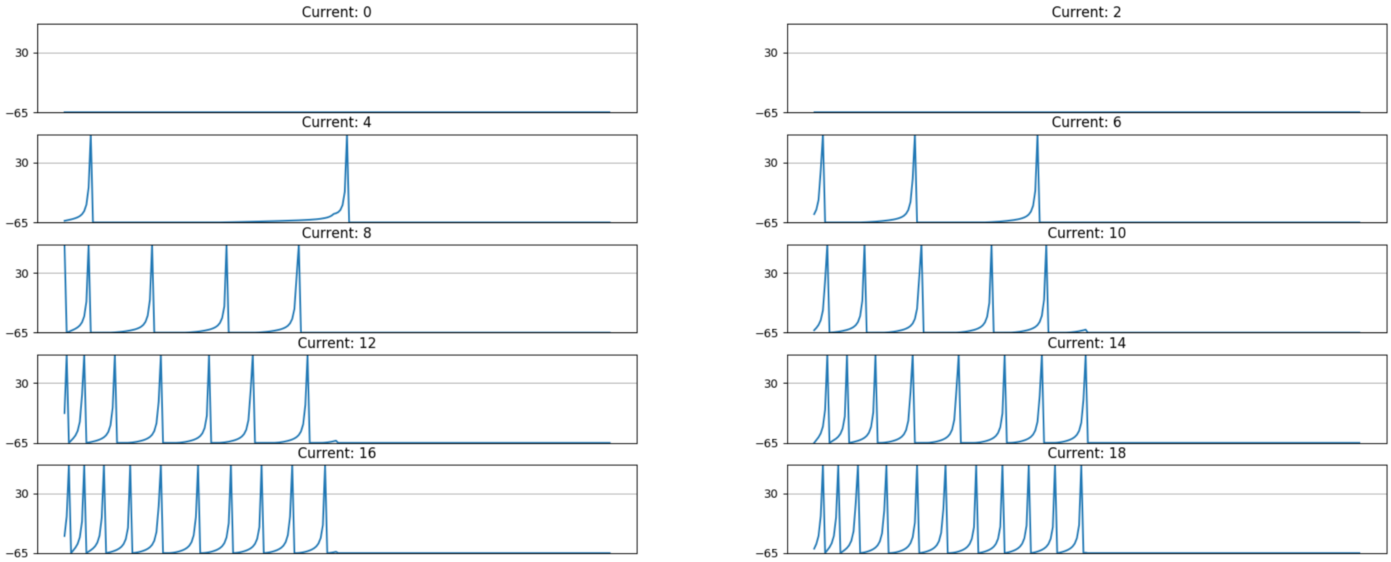
2.3 Continuing to Increase Input Current

As you increase the input current, the LIF neuron's firing rate increases in steps after a certain threshold. In this plot, the threshold was near an input current value of 50, which means that that was the minimum current required for any spiking to occur. Past this minimum current, the steps are steep at first and then level off at higher input currents. So as input current gets higher, it takes more and more current to increase the neuron's spiking rate to the next frequency level until it reaches a maximum spiking rate (I increased input current to 100,000 and firing rate leveled off indefinitely).

2.4 Izhikevich Model

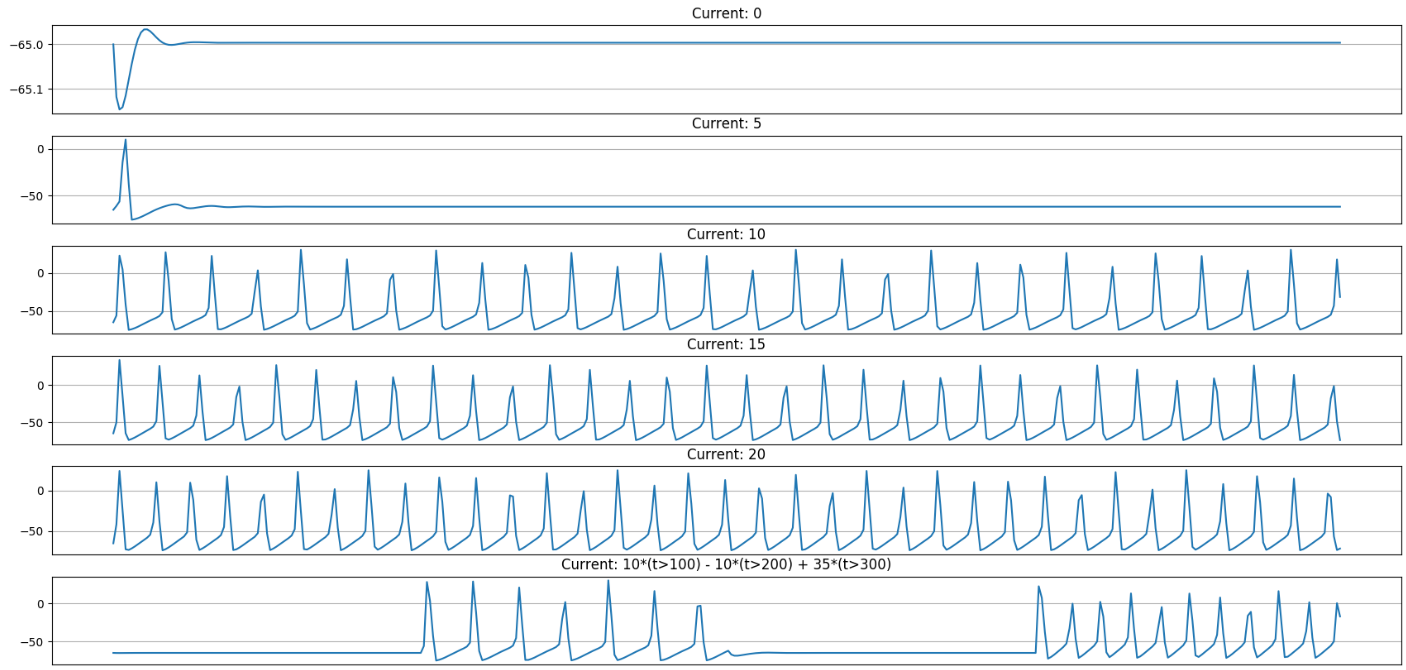
In these plots, I have simulated input currents to an Izhikevich neuron. Spiking behavior is observed, and membrane potential decays are observed when the input current goes to zero. Initial conditions for the parameters were taken from the paper in class (a=0.02, b=0.2, c=-65, d=2, u=-65*0.2).





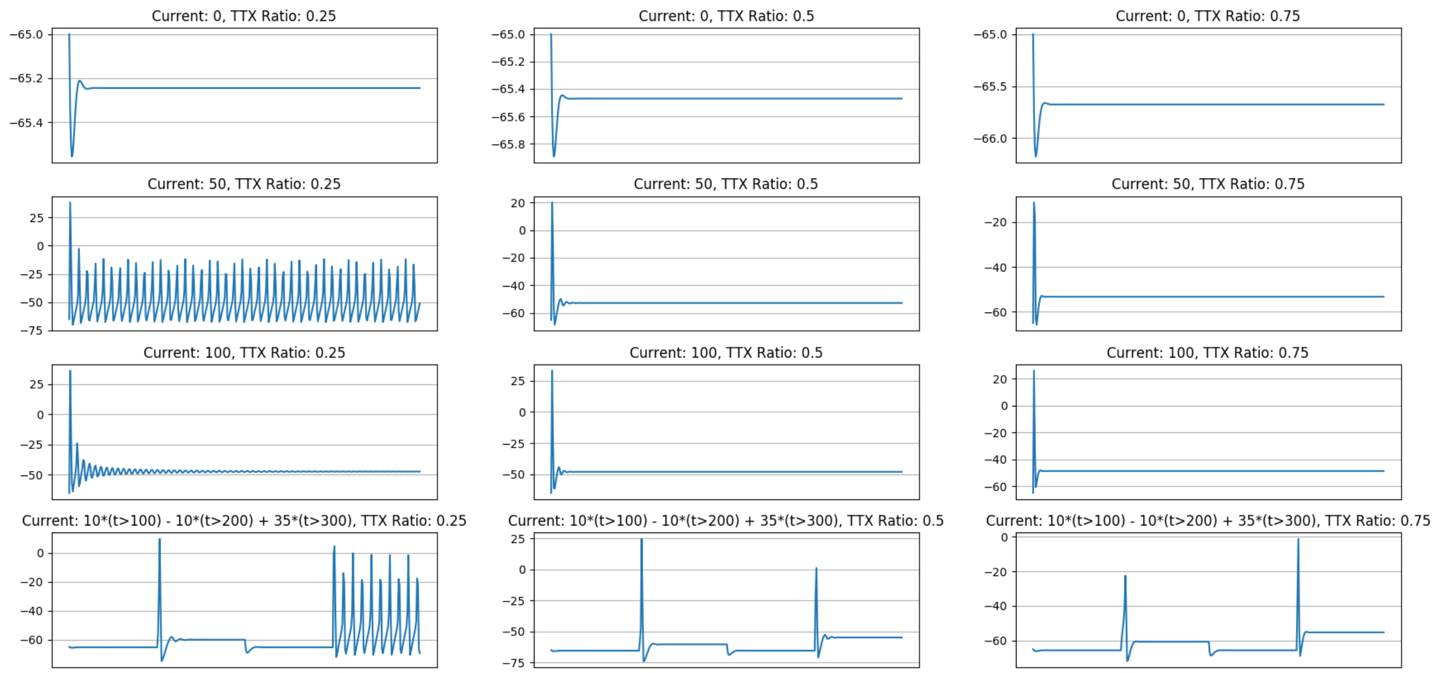
2.5 Hodgkin-Huxley Model

In these plots, I have simulated input currents to a Hodgkin-Huxley neuron. Spiking behavior is observed, and membrane potential decays are observed when the input current goes to zero. Initial conditions and differential equations were taken from the paper and the Internet (see the code for these).

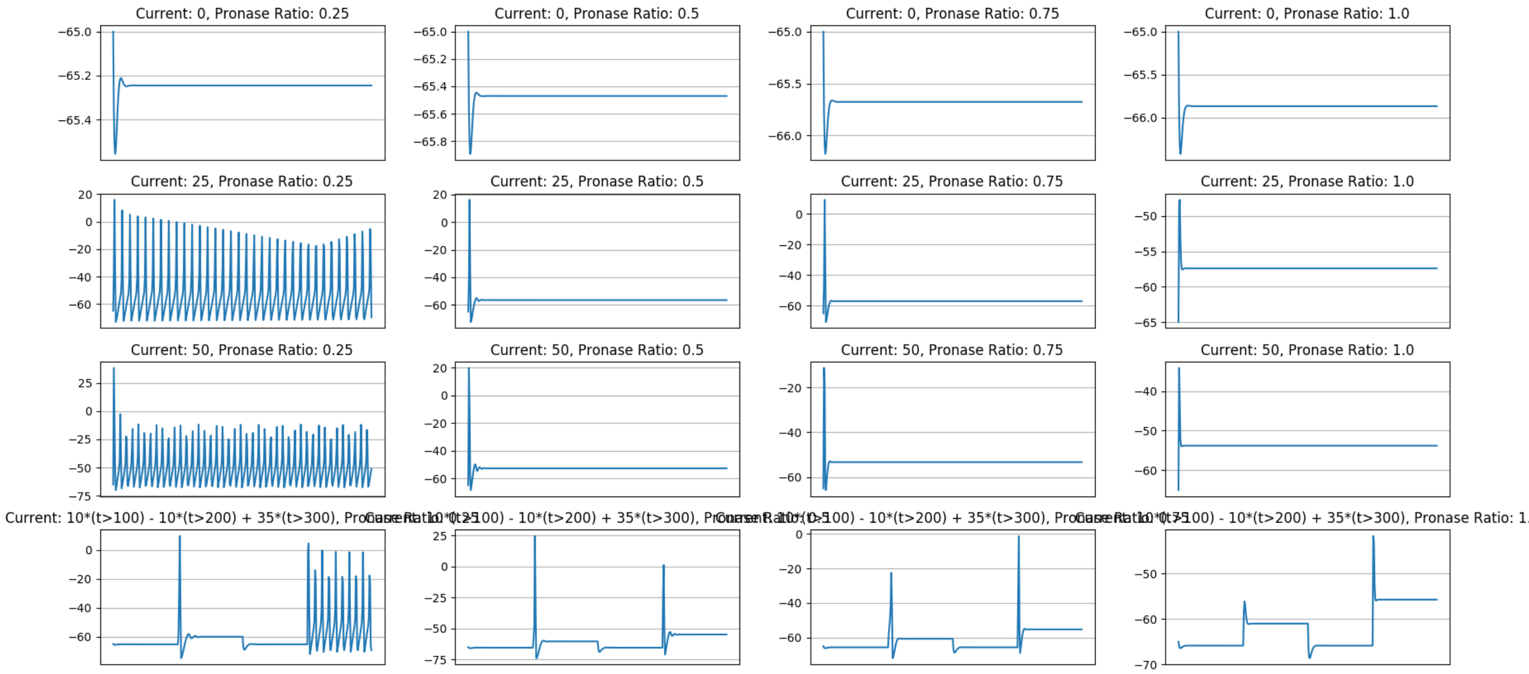


2.6 Bonus

I varied a value I called "TTX Ratio" which inhibited the sodium current to varying degrees. The resulting plots show that administration of TTX does indeed cause less frequent spikes.



I also varied a value I called "Pronase Ratio" which eliminates the sodium inactivation to varying degrees. Since the variable h represents a dimensionless sodium inactivation ratio, I simply mitigated this at different levels. The resulting plots show that eliminating sodium inactivation generally mitigates the amplitude of spikes and lengthen the refractory period.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Current: 0, Pronase Ratio: 0.5
Current: 0, Pronase Ratio: 0.75
Current: 0, Pronase Ratio: 1.0
Current: 25, Pronase Ratio: 0.25
Current: 25, Pronase Ratio: 0.5
Current: 25, Pronase Ratio: 0.75
Current: 25, Pronase Ratio: 1.0
Current: 50, Pronase Ratio: 0.25
Current: 50, Pronase Ratio: 0.5
Current: 50, Pronase Ratio: 0.75
Current: 50, Pronase Ratio: 1.0