hw01

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1 Homework #1- Single LIF Neuron

Taylor Salo

Instructions

```
In [1]: %matplotlib inline
        from __future__ import division
        import numpy as np
        import brian2 as br
        import pylab as plt
        import seaborn as sns

        sns.set_style("darkgrid")
        sns.set_palette(sns.color_palette("bright", 10))
```

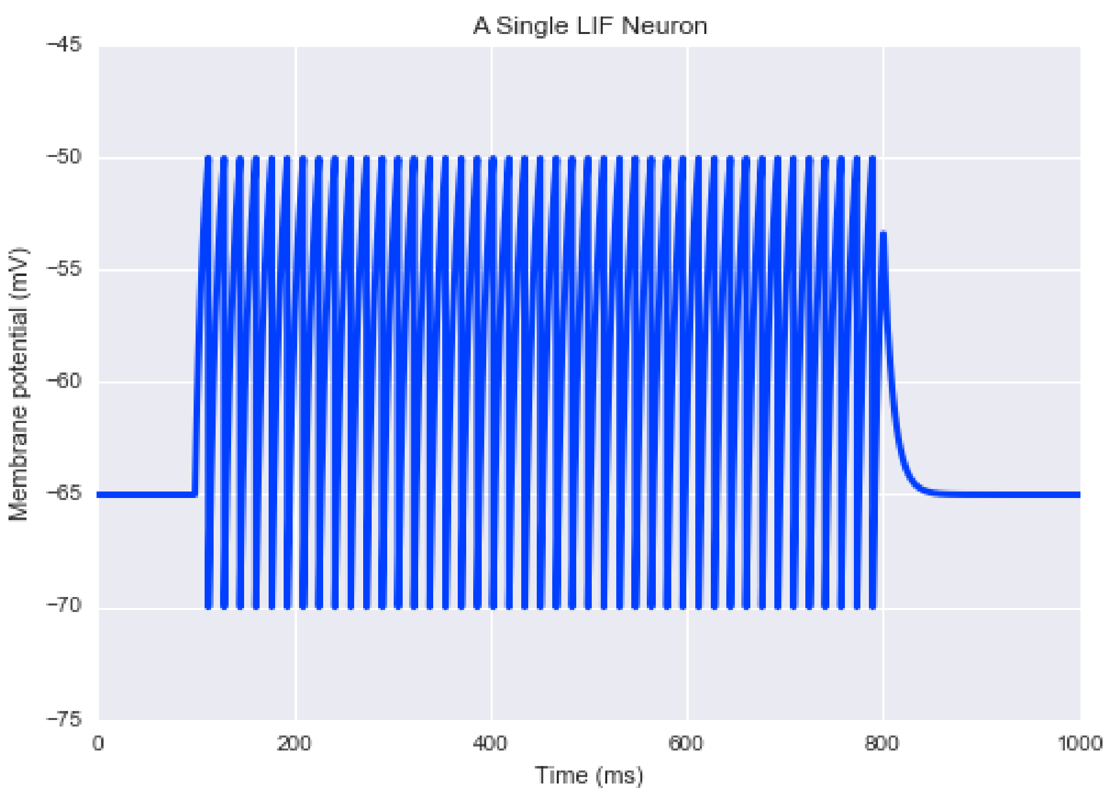
1.1 Q1 A Single LIF Neuron

```
In [2]: # Start scope for brian2 simulation
        br.start_scope()

        # Define parameters of the LIF model
        R = 100 * br.Mohm  # membrane resistance
        tau = 10 * br.ms  # membrane time constant
        thr = -50 * br.mV  # spike threshold
        u_rest = -65 * br.mV  # resting potential
        u_r = -70 * br.mV  # reset potential

        # Define equation for the LIF model
        eqs = '''
        du/dt = ( -(u - u_rest) + R*I ) / tau : volt
        I = input_current(t) : amp
        '''

        # Create stimulation timeseries
        # I = 200pA, between 100 ms and 800 ms
        tmp = np.zeros((1000,))
        tmp[99:800] = 200
```

```
        input_current = br.TimedArray(tmp*br.pamp, dt=1*br.ms)

        LIF = br.NeuronGroup(N=1, model=eqs, method="linear",
                             threshold='u>thr', reset='u=u_r')
        LIF.u = u_rest
        rec = br.StateMonitor(LIF, 'u', record=True)
        rec2 = br.SpikeMonitor(LIF, 'u', record=True)
        br.run(1*br.second)

        n_spikes = rec2.count[0]
        n_secs = len(range(99, 800)) / 1000
        spike_rate = n_spikes / n_secs
        print spike_rate
```

```
61.3409415121
```

```
In [3]: # Plot membrane potential against time for LIF neuron.
        fig, ax = plt.subplots()
        ax.plot(rec.t/br.ms, rec.u[0]*1000, label="State", lw=3.)
        ax.set_ylim((-75, -45))
        ax.set_title("A Single LIF Neuron")
        ax.set_xlabel('Time (ms)')
        ax.set_ylabel('Membrane potential (mV)')
        plt.show(fig)
```



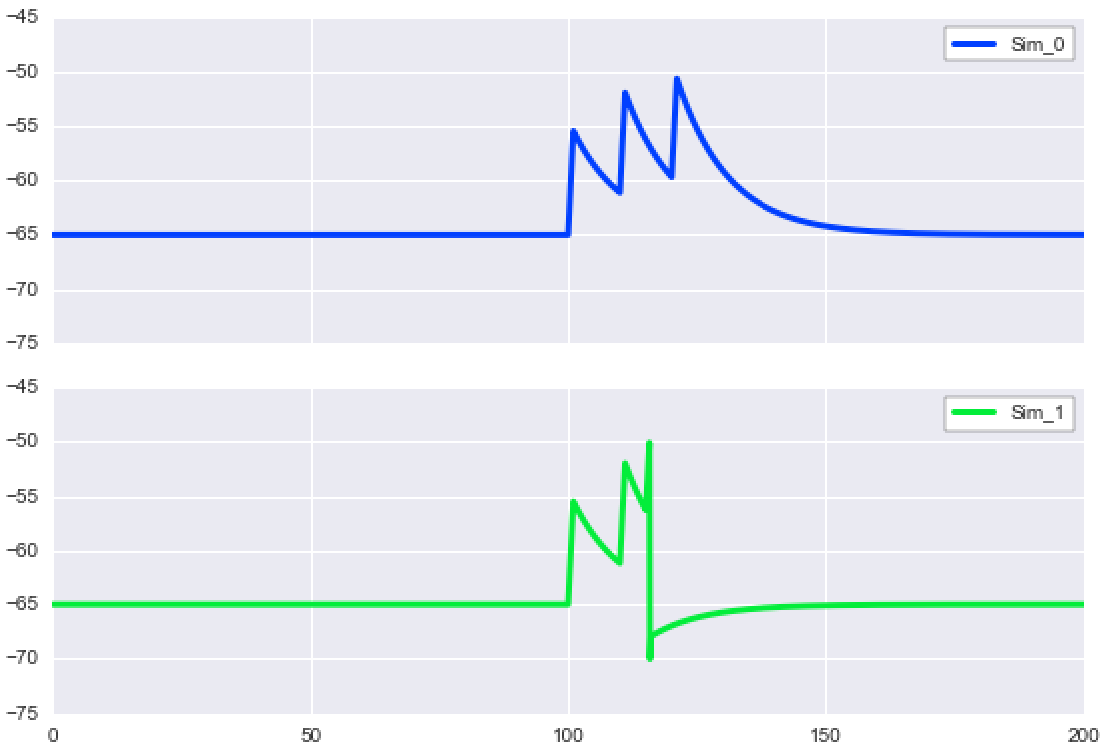
A constant input current of 200 pA causes a spike train of 61.3 spikes per second. After the first spike, a spike train occurs until the input current stops, at which point the LIF stops firing.

1.2 Q2 Effect of Current Timing on LIF Spiking

In [4]:
```
# Set basic parameters.
R = 100 * br.Mohm  # membrane resistance
tau = 10 * br.ms  # membrane time constant
thr = -50 * br.mV  # spike threshold
u_rest = -65 * br.mV  # resting potential
u_r = -70 * br.mV  # reset potential

# Define equation for the LIF model
eqs = '''
du/dt = ( -(u - u_rest) + R*I ) / tau : volt
I = input_current(t) : amp
'''
```

In [5]:
```
# Plot results of two simulations with different input timing parameters.
fig, axes = plt.subplots(2, sharex=True, sharey=True)
sim_times = np.array([[100, 110, 120],
                      [100, 110, 115]])

for i in range(sim_times.shape[0]):
    br.start_scope()
    tmp = np.zeros((1000,))
    tmp[sim_times[i, :]] = 1000

    input_current = br.TimedArray(tmp*br.pamp, dt=1*br.ms)

    LIF = br.NeuronGroup(N=1, model=eqs, method="linear",
                         threshold='u>thr', reset='u=u_r')
    LIF.u = u_rest
    rec = br.StateMonitor(LIF, 'u', record=True)
    br.run(1*br.second)

    axes[i].plot(rec.t/br.ms, rec.u[0]*1000,
                 color=sns.color_palette("bright", 10)[i],
                 label="Sim_{0}".format(i),
                 lw=3.)
    legend = axes[i].legend(frameon=True)
    frame = legend.get_frame()
    frame.set_facecolor("white")
    frame.set_edgecolor("black")

axes[0].set_ylim((-75, -45))
```

```
axes[0].set_xlim((0, 200))
fig.title = "Effect of Stimulus Timing on LIF Spiking"
fig.tight_layout()
plt.show(fig)
```



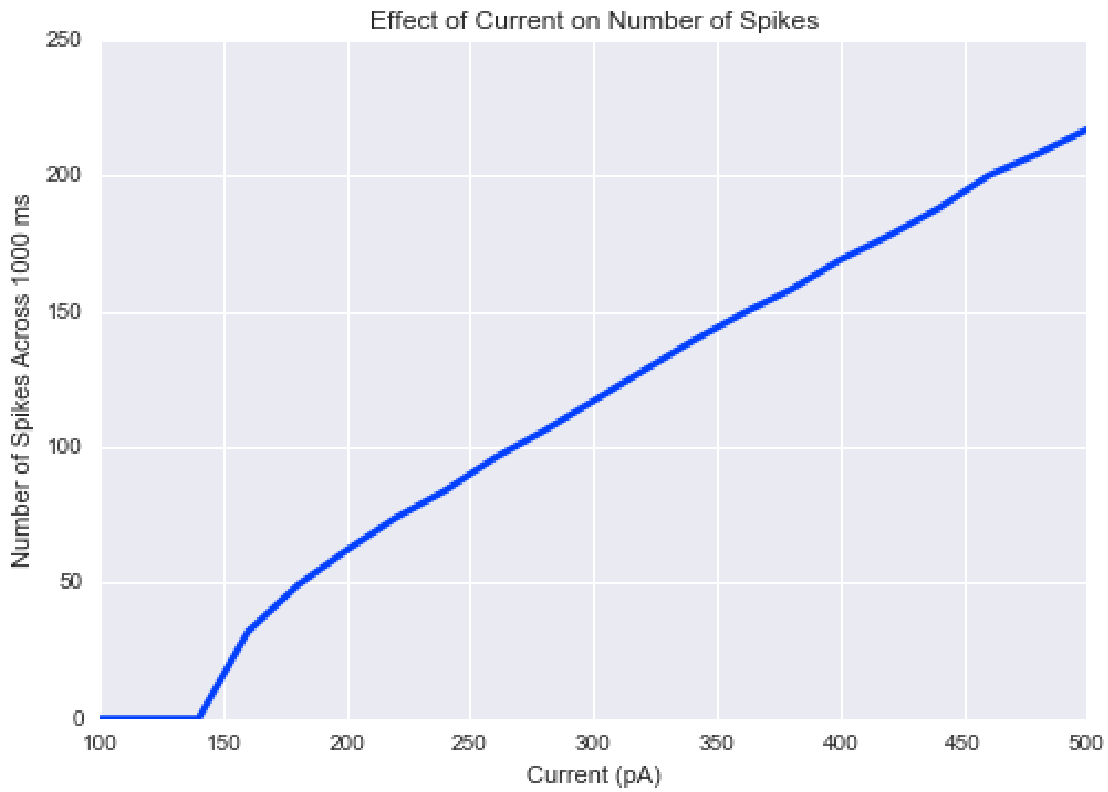
In the first simulation, the input currents occur rapidly enough to increase the membrane potential, but not enough to cause a spike. In the second simulation, a spike occurs as a result of the last input. This is because the last input occurs soon enough after the second input to raise the membrane potential above -50 mV, the firing threshold, before the leak can lower the membrane potential too low.

1.3 Q3 Effect of Current on Number of Spikes

```
In [6]: # Define parameters of the LIF model
        R = 100 * br.Mohm  # membrane resistance
        tau = 10 * br.ms  # membrane time constant
        thr = -50 * br.mV  # spike threshold
        u_rest = -65 * br.mV  # resting potential
        u_r = -70 * br.mV  # reset potential

        # Define equation for the LIF model
        eqs = '''
        du/dt = ( -(u - u_rest) + R*I ) / tau : volt
        I = input_current(t) : amp
```

```
'''

n_spikes = []
current_range = np.arange(100, 501, 20)
for current in current_range:
    br.start_scope()
    tmp = np.ones((1000,))
    tmp *= current

    input_current = br.TimedArray(tmp*br.pamp, dt=1*br.ms)

    LIF = br.NeuronGroup(N=1, model=eqs, method="linear",
                         threshold='u>thr', reset='u=u_r')
    LIF.u = u_rest
    rec = br.SpikeMonitor(LIF, 'u', record=True)
    br.run(1*br.second)
    n_spikes.append(rec.count[0])

n_spikes = np.array(n_spikes)
```

In [7]:
```
# Plot number of spikes against current value.
fig, ax = plt.subplots()
ax.plot(current_range, n_spikes, lw=3.)
ax.set_xlabel('Current (pA)')
ax.set_ylabel('Number of Spikes Across 1000 ms')
ax.set_title("Effect of Current on Number of Spikes")
plt.show(fig)
```



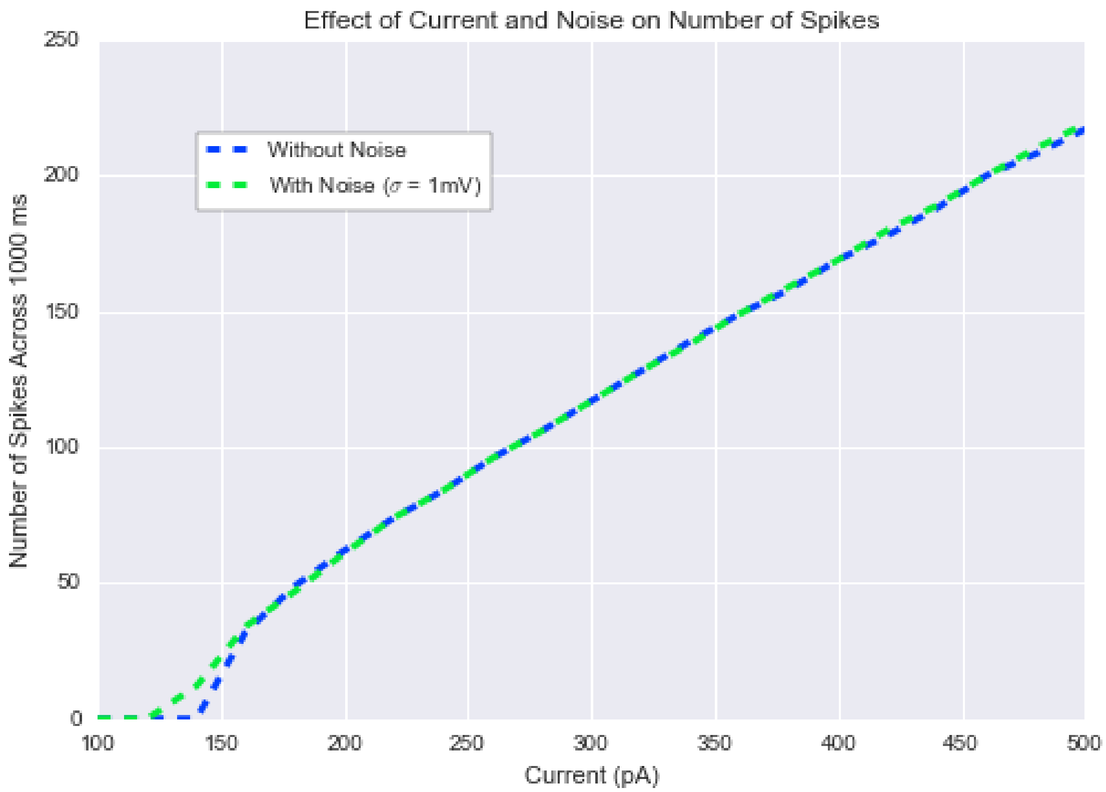
Up to a point, a constant input current will not cause any firing in an LIF neuron. This explains the horizontal portion of the line plot where the spike rate is zero (100pA < I < 140pA). After reaching a current value where spikes will occur, the spike rate increases as the current increases. The rate at which the spike rate increases decreases as current increases.

1.4 Q4 Effect of Noise on LIF Firing

```
In [8]: # Define parameters of the LIF model
        R = 100 * br.Mohm  # membrane resistance
        tau = 10 * br.ms  # membrane time constant
        thr = -50 * br.mV  # spike threshold
        u_rest = -65 * br.mV  # resting potential
        u_r = -70 * br.mV  # reset potential

        # Add noise
        sigma = 1 * br.mvolt
        eqs= '''
        du/dt = ( -(u - u_rest) + R*I ) / tau + sigma*xi*tau**-0.5 : volt
        I = input_current(t) : amp
        '''

        n_spikes_wn = []
        current_range = np.arange(100, 501, 20)
```

```
for current in current_range:
    br.start_scope()
    tmp = np.ones((1000,))
    tmp *= current

    input_current = br.TimedArray(tmp*br.pamp, dt=1*br.ms)

    LIF = br.NeuronGroup(N=1, model=eqs, method="euler",
                         threshold='u>thr', reset='u=u_r')
    LIF.u = u_rest
    rec = br.SpikeMonitor(LIF, 'u', record=True)
    br.run(1*br.second)
    n_spikes_wn.append(rec.count[0])

n_spikes_wn = np.array(n_spikes_wn)
```

In [9]:
```
# Plot number of spikes against current value.
fig, ax = plt.subplots()
ax.plot(current_range, n_spikes, "--", lw=3.,
        label="Without Noise")
ax.plot(current_range, n_spikes_wn, "--", lw=3.,
        label=r"With Noise ($\sigma$ = 1mV)")
ax.set_xlabel('Current (pA)')
ax.set_ylabel('Number of Spikes Across 1000 ms')
ax.set_title("Effect of Current and Noise on Number of Spikes")

legend = ax.legend(frameon=True, loc=(.1, .75))
frame = legend.get_frame()
frame.set_facecolor("white")
frame.set_edgecolor("black")

plt.show(fig)
```



The simulations with noise perform similarly to the siulations without noise at higher values for I, but have increased numbers of spikes at lower levels of I. This is because noise increases the variability of the membrane potential within a simulation, which can cause "spurious" spikes within the neuron. This increases the spike rate when the neuron would not normally fire (i.e, at lower values of I), but doesn't significantly affect the spike rate when the neuron would fire (i.e., at higher values of I).