BT6270: Computational Neuroscience

Assignment-1: The Hodgkin-Huxley Model

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References Used

1. Professor VS Chakravarthy's Classnotes and Slides
2. BT6270 Computational Neuroscience Aug-Nov 2021 Playlist by CNS Lab IITM
3. Lectures 4 and 5 of MIT 9.40 Introduction to Neural Computation, Spring 2018 by Michale Fee
4. Seaborn documentation

Assumptions

The following assumptions were made for successfully carrying out this study and constructing the relevant plots:

- The **voltage threshold of a peak is set to 10mV**. The spike count includes all voltage peaks greater than 10mV.
- The input current (**I1**) at which spiking occurs is calculated by identifying the current at which the **number of spikes becomes non-zero for the first time**.
- The applied current corresponding to the next threshold value (**I2**) is calculated by identifying the current at which the **number of spikes in the next current instant increases by more than four**.
- The applied current corresponding to the next threshold value (**I3**) is calculated by identifying the current at which the **number of spikes in the next current instant decreases by more than two.**

  The Hodgkin-Huxley Model is based on the following equation:

$$C\frac{dV_m}{dt} + g_{Na}(V_m - E_{Na}) + g_K(V_m - E_K) + g_l(V_m - E_l) = I_{ext}$$

$$g_{Na} = g_{Na}{}^{max} m^3 h \qquad g_K = g_K{}^{max} n^4$$

- In order to simulate the model we have assumed a set of constants in the equation, which are: gkmax = 0.36, vk = -77, gnamax = 1.20, vna = 50, gl = 0.003, vl = -54.387, cm = 0.01, v = -64.998, m = 0.0530, h = 0.5960, n = 0.3177.
- 10000 iterations are performed for each current value to generate plots for Voltage v/s Time, Gating variable Probability v/s Time, and Conductance v/s Time.

Threshold values of applied external current

The threshold values of the external applied current currents (in microA/mm^2) are as follows:

- **I1 = 0.03**
- **I2 = 0.06**
- **I3 = 0.45**

These values were obtained using a sampling interval of 0.01 from 0 to 0.6. For each current instance, 50,000 iterations are performed.

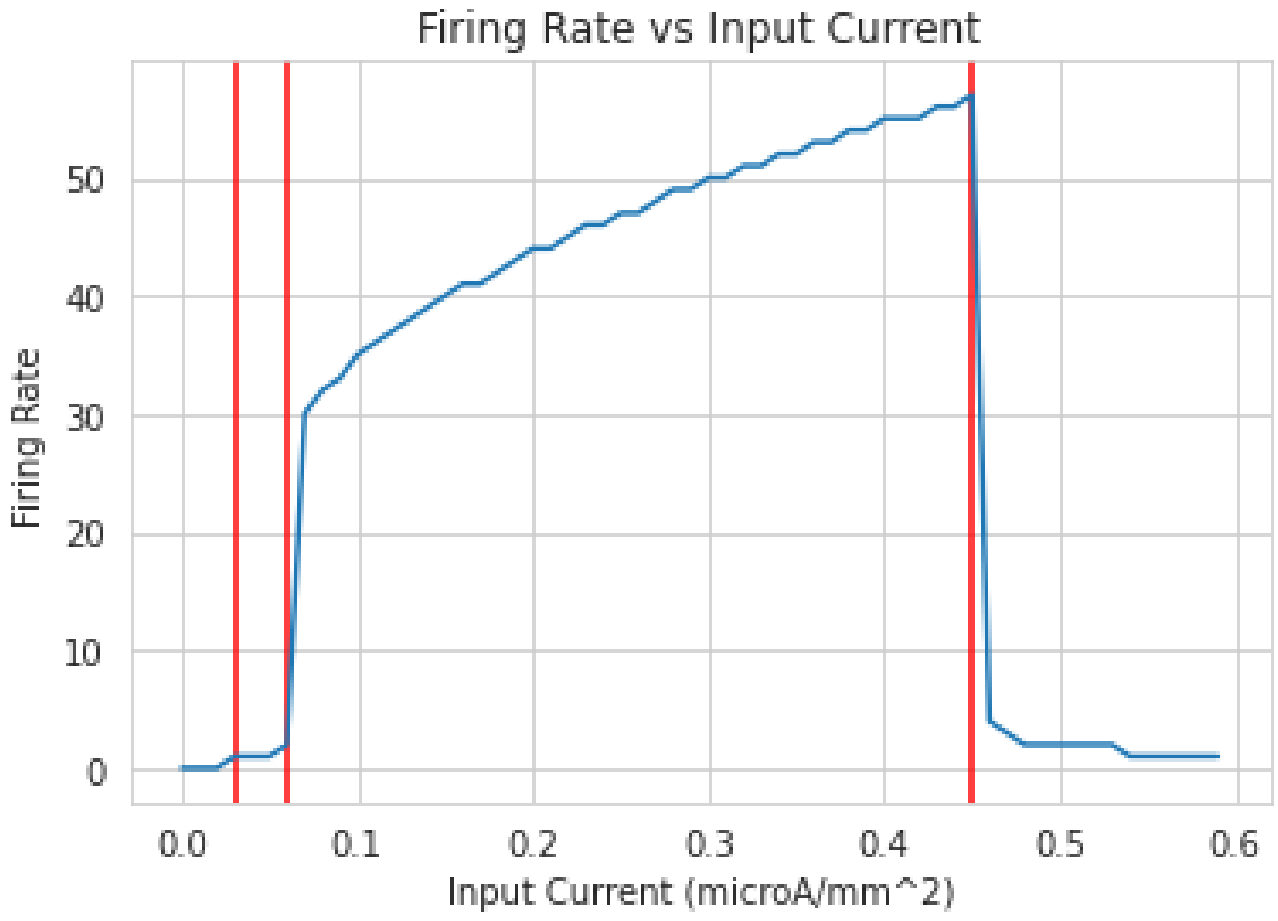

Figure-1: The variation in firing frequency as a function of input current. 50,000 iterations have been performed for each current instance. The red vertical bars represent the current thresholds - I1, I2, and I3.

Plots

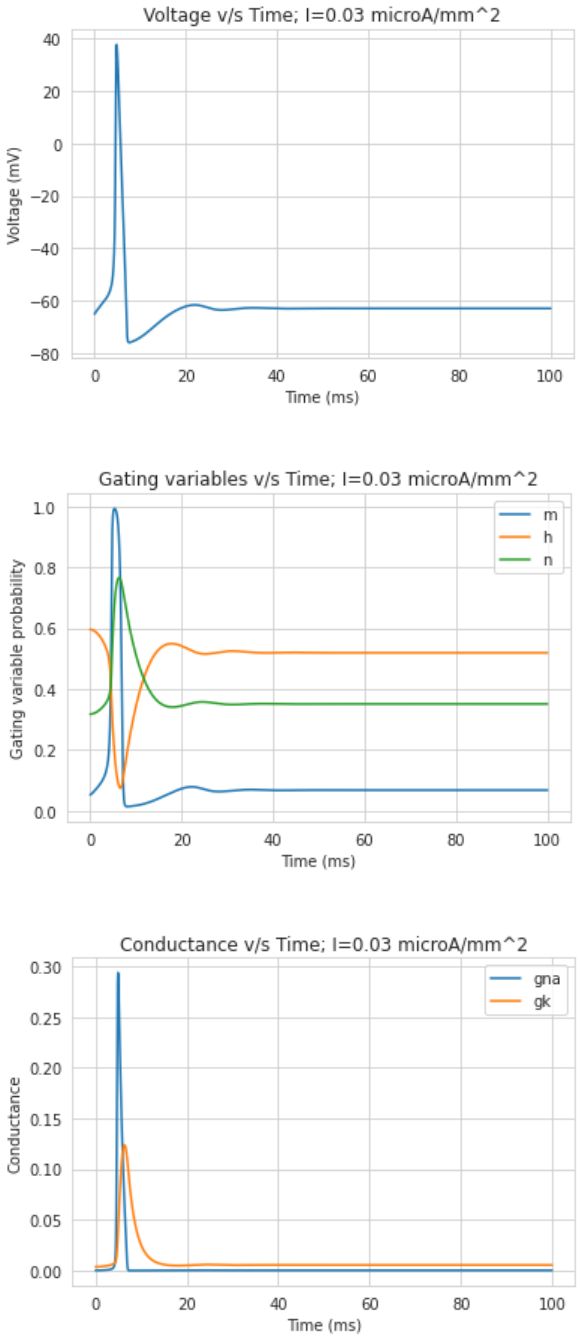

Figure 2: Variation of Voltage, Gating variables, and Conductance at current instant I1. A single voltage spike is observed.

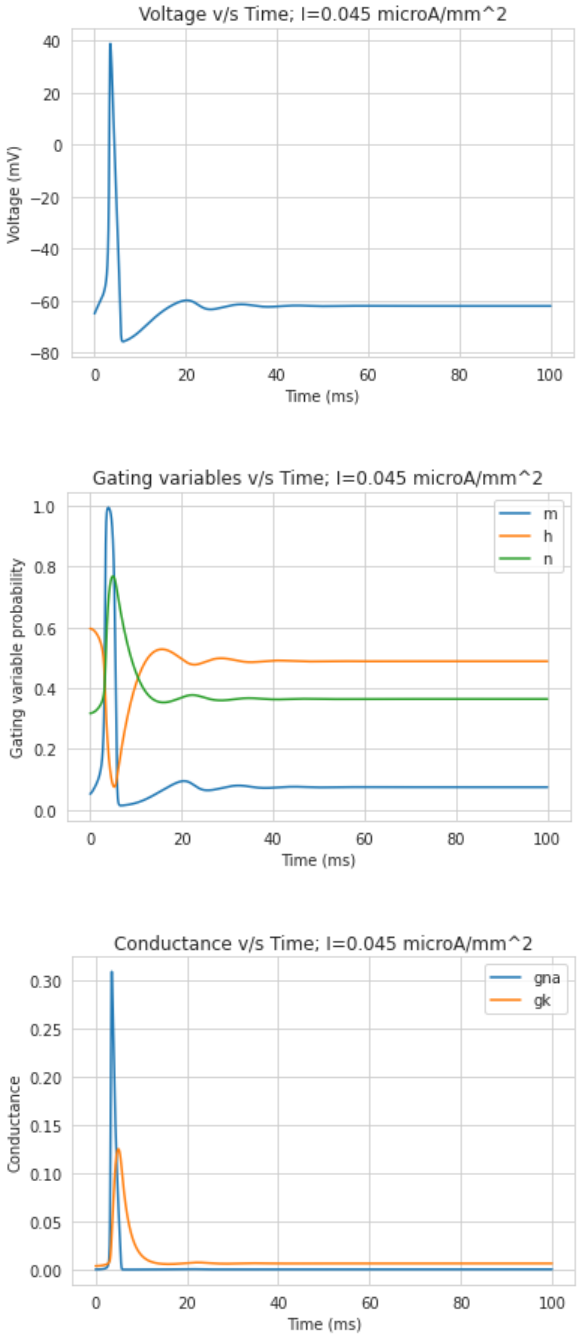

Figure 3: Variation of Voltage, Gating variables, and Conductance at a current instant between I1 and I2. A clear single voltage spike is observed; however, there is a slight increase in the equilibrium potential seen after the spike.

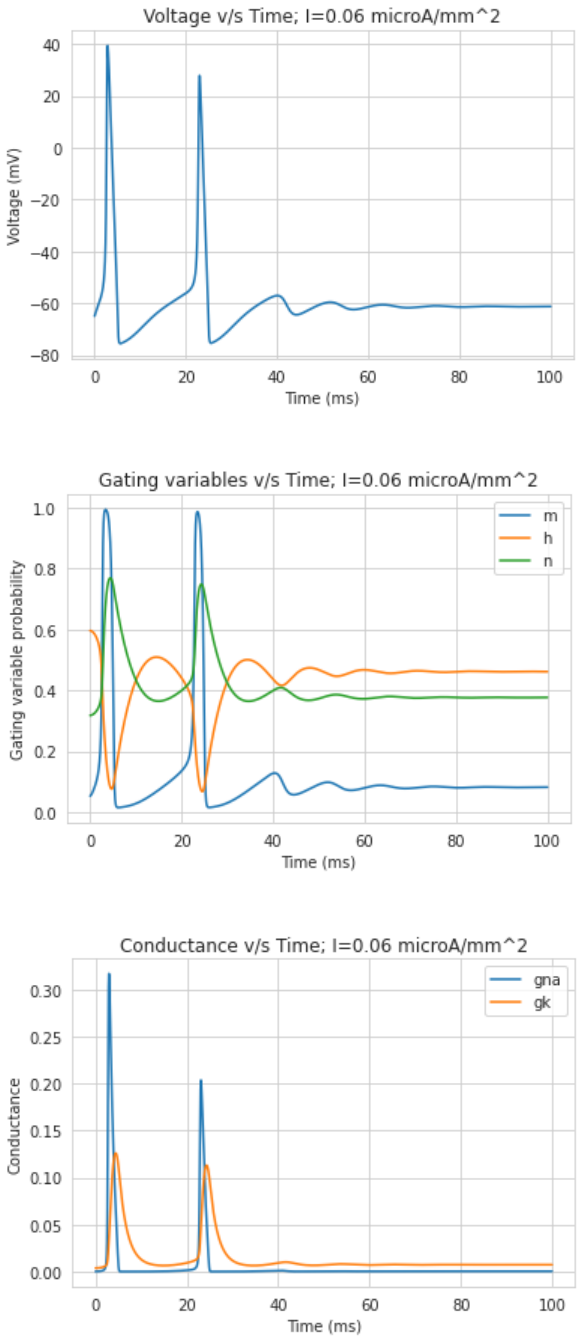

Figure 4: Variation of Voltage, Gating variables, and Conductance at current instant I2. A finite number of spikes in voltage are observed.

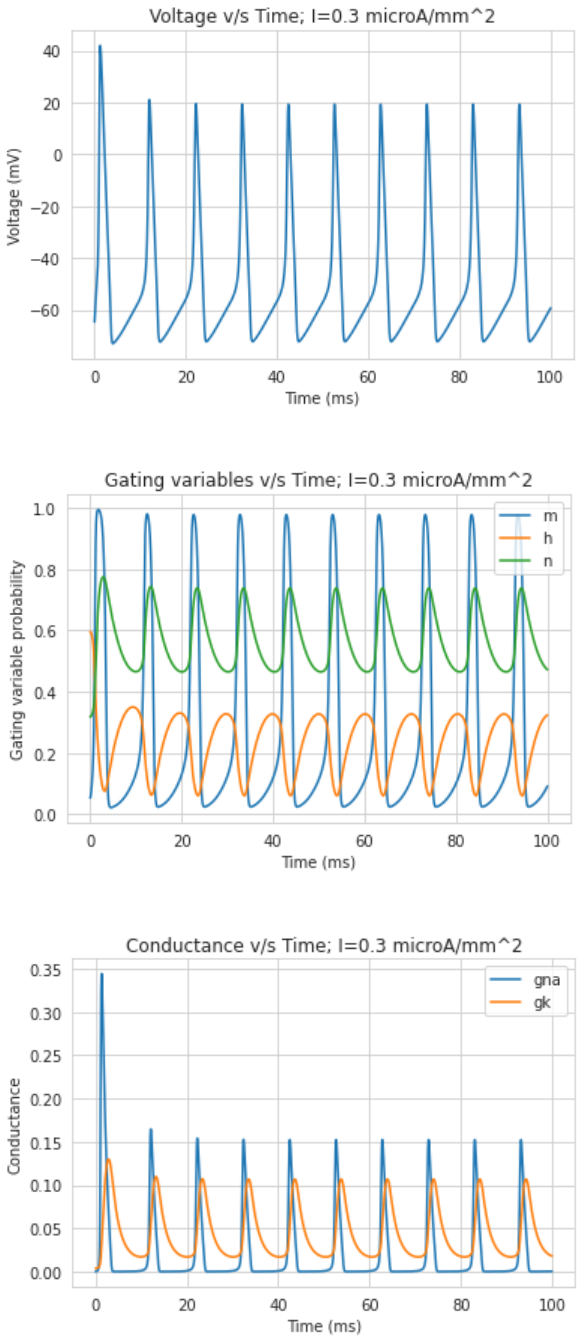

Figure 5: Variation of Voltage, Gating variables, and Conductance at a current instant between I2 and I3. Multiple voltage spikes are observed. Gating probabilities exhibit clear oscillatory behavior, meaning the channel subunit keeps switching between the two states (activation/inactivation), as can be seen based on the location of the maxima/minima.

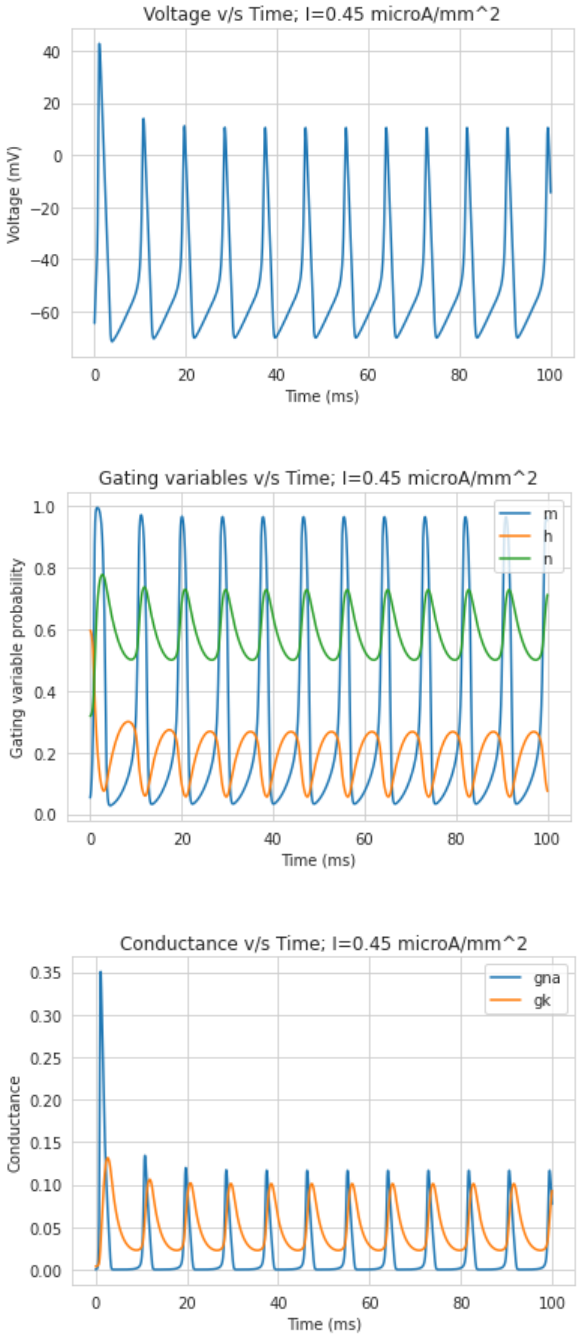

Figure 6: Variation of Voltage, Gating variables, and Conductance at current instant I3. Multiple voltage spikes are observed, and they exhibit limit cycle behavior. Gating Conductance for potassium is almost periodic after the first voltage spike.

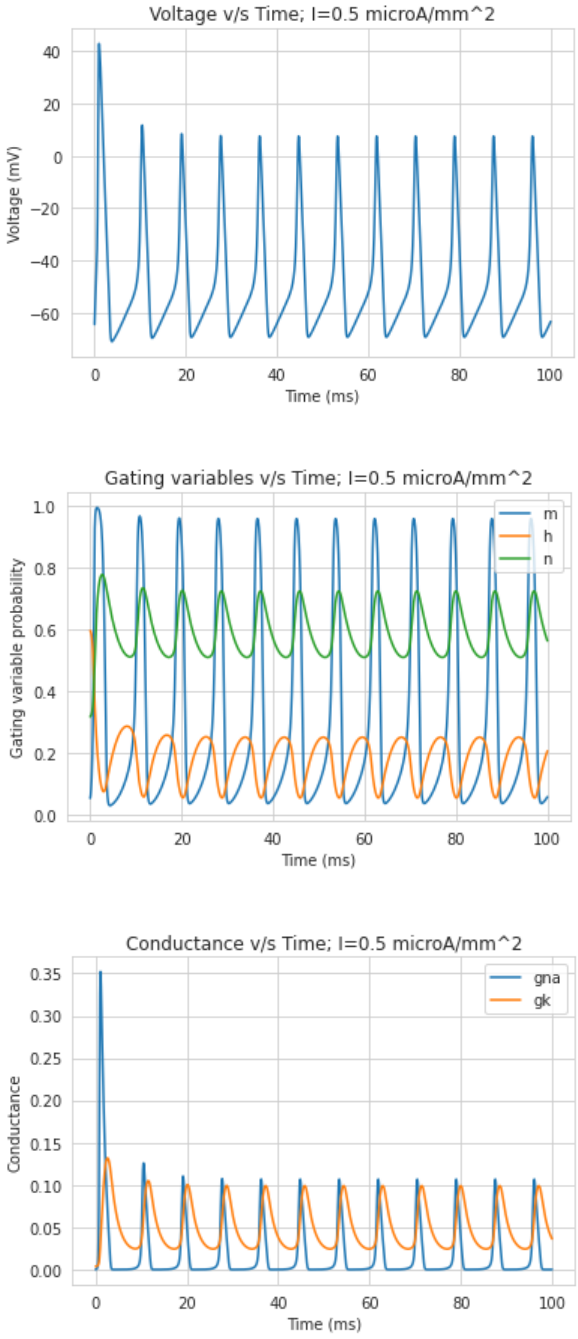

Figure 7: Variation of Voltage, Gating variables, and Conductance at a current instant after I3. There is a significant reduction in the number of spikes with amplitudes greater than 10mV. There is also a small decrease in the amplitude of gating probabilities and an increase in the time period of oscillation as the current is increased.