Single Neuron Simulation Models

PHYS 108 - Group 5
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What is a Neuron Simulation Model?

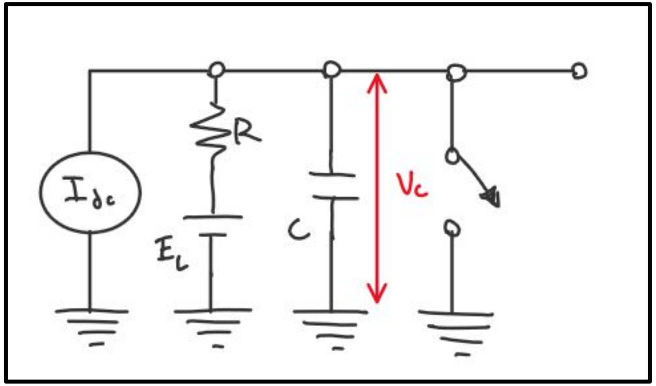
- Leaky Integrate and Fire (LIF)
- Exponential Integrate and Fire (EIF)
- Wang Buzsaki
- Hodgkin Huxley

Leaky Integrate and Fire (LIF)

$$R_m C_m \frac{dV}{dt} = E_L - V + \frac{I_e}{g_L}$$

(note that R_m and C_m are constant and g_L represents the leak conductance)

- Represents the neuron as a simple circuit
- Contains a leak potential variable similar to a leaky circuit
- Not completely biologically accurate



Exponential Integrate and Fire (EIF)

- Similar to the LIF, mainly differing through the leak potential
- Reaches V(threshold) faster than the LIF
- Non-linear threshold for the spike initiation

$$\frac{dV}{dt} - \frac{R}{R_m C_m} I(t) = \frac{1}{R_m C_m} [E_m - V + \Delta_T exp(\frac{V - V_T}{\Delta_T})]$$

Hodgkin Huxley

- Different channels with variable conductance (variable resistors and static batteries)
- Variation of the resistors allow this to accurately represent the behavior of a neuron when a current is introduced

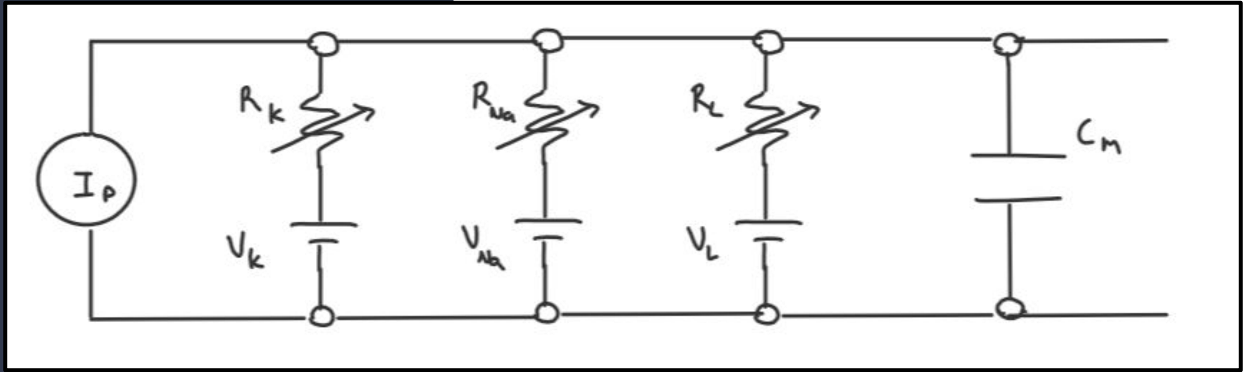
$$\frac{dV}{dt} = \frac{1}{C_m}[I - g_{Na}m^3h(v - E_{Na}) - g_K n^4(v - E_K) - g_L(v - E_L)]$$

- High resistances occurring when the probability of a channel opening is low and vice versa

$$\frac{dm}{dt} = \alpha_m(v)(1 - m) - \beta_m(v)$$

$$\frac{dn}{dt} = \alpha_n(v)(1 - n) - \beta_n(v)$$

$$\frac{dh}{dt} = \alpha_h(v)(1 - h) - \beta_h(v)$$



I_p
R_K
R_{Na}
R_L
V_K
V_{Na}
V_L
C_M

Wang Buzsaki Model

- Designed for hippocampal neurons
- Caters to high frequency gamma oscillations
- Models fast spiking neurons
- Faster polarization -> Faster depolarization -> Faster transmission of action potential
- Ratio between synaptic delay and oscillatory period is sufficiently large

$$\frac{dV}{dt} = \frac{1}{C_m}[I - g_{Na}m^3h(v - E_{Na}) - g_K n^4(v - E_K) - g_L(v - E_L) - I_{syn} + I_{app}]$$

$$\frac{ds}{dt} = \alpha_s F(V_{pre})(1 - s) - \beta_s s$$

$$F(V_{pre}) = \frac{1}{1+exp(-\frac{V_{pre} - \theta_{syn}}{2})}$$

Results

* Input currents are in microamperes (uA), not in mV

* Noise included for LIF and EIF models simulated using the forward Euler methods

* Increased fluctuation in spiking rate for higher inputs due to noise

* LIF shows abnormal fluctuations close to the resting potential

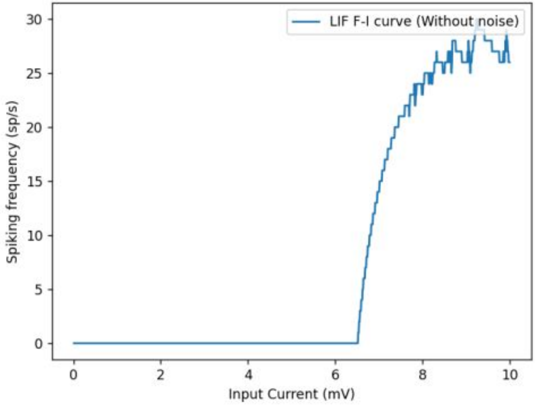


Fig 1.1 LIF curve for varying input currents. Spike rate per second is plotted on the y axis while input currents are on the x axis

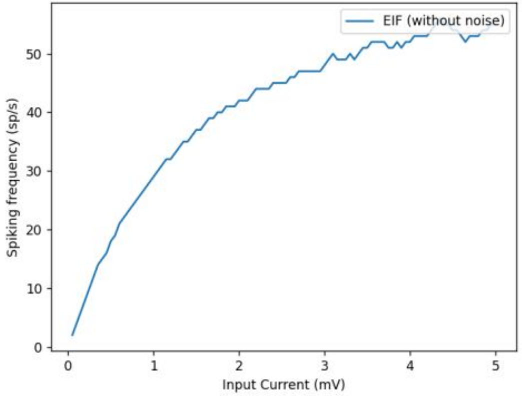


Fig 1.2 Exponential Integrate and fire(EIF) curve for varying input currents. Spike rate per second is plotted on the y axis while input currents are on the x axis

* Noise not added to these exponential models

* WB tapers off at input I ~ 35 uA

* HH falls of at I ~ 63 nA

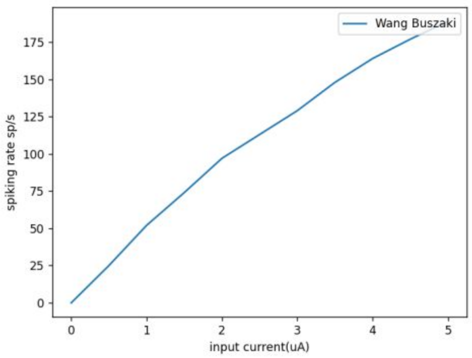


Fig 1.3: Wang Buzsaki model, spiking rate per second (sp/s) plotted on the y axis, input current plotted on the x-axis

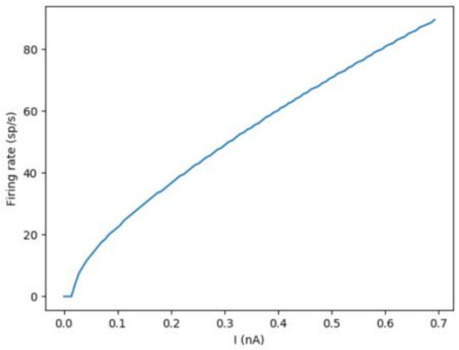


Fig 1.4 Hodgekin Huxley model (HH), spiking rate in second plotted on the y-axis, input current plotted on the x-axis

Questions?