NEURONS AND NEURONAL NETWORKS

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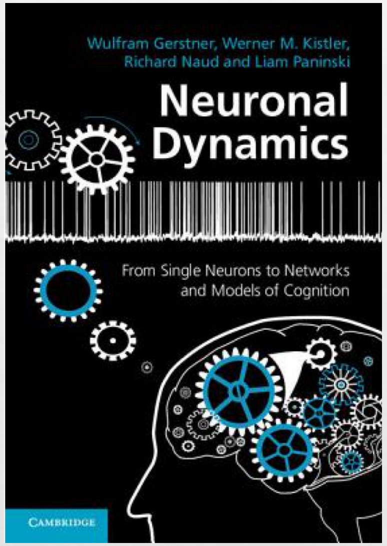
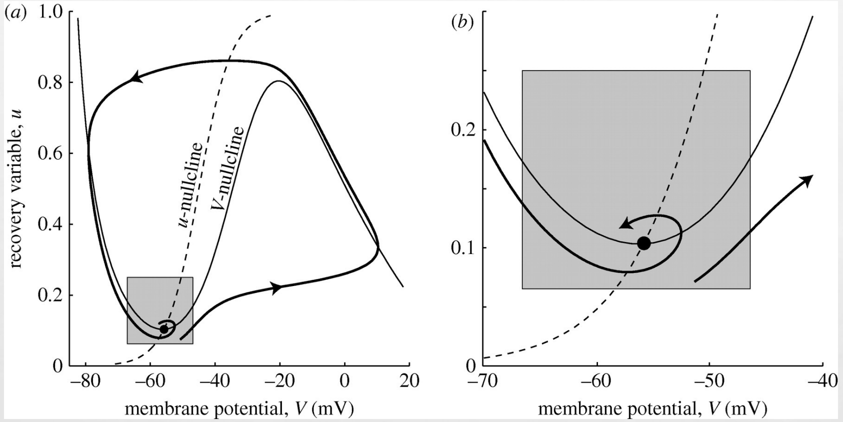
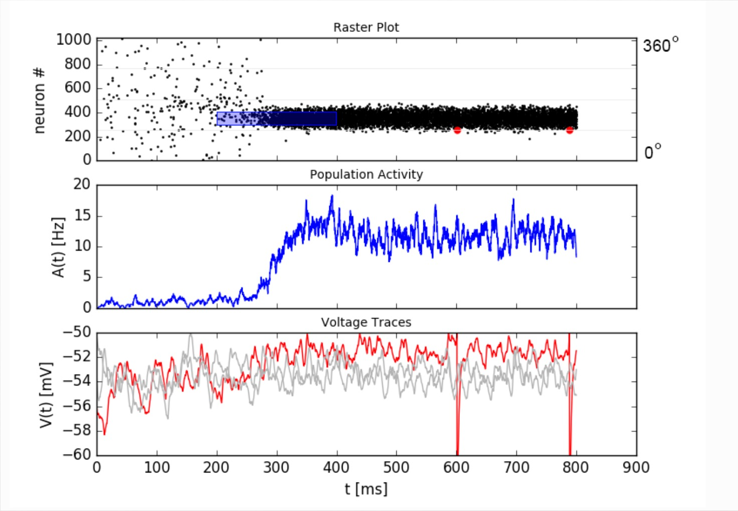
ABOUT PROJECT



Research



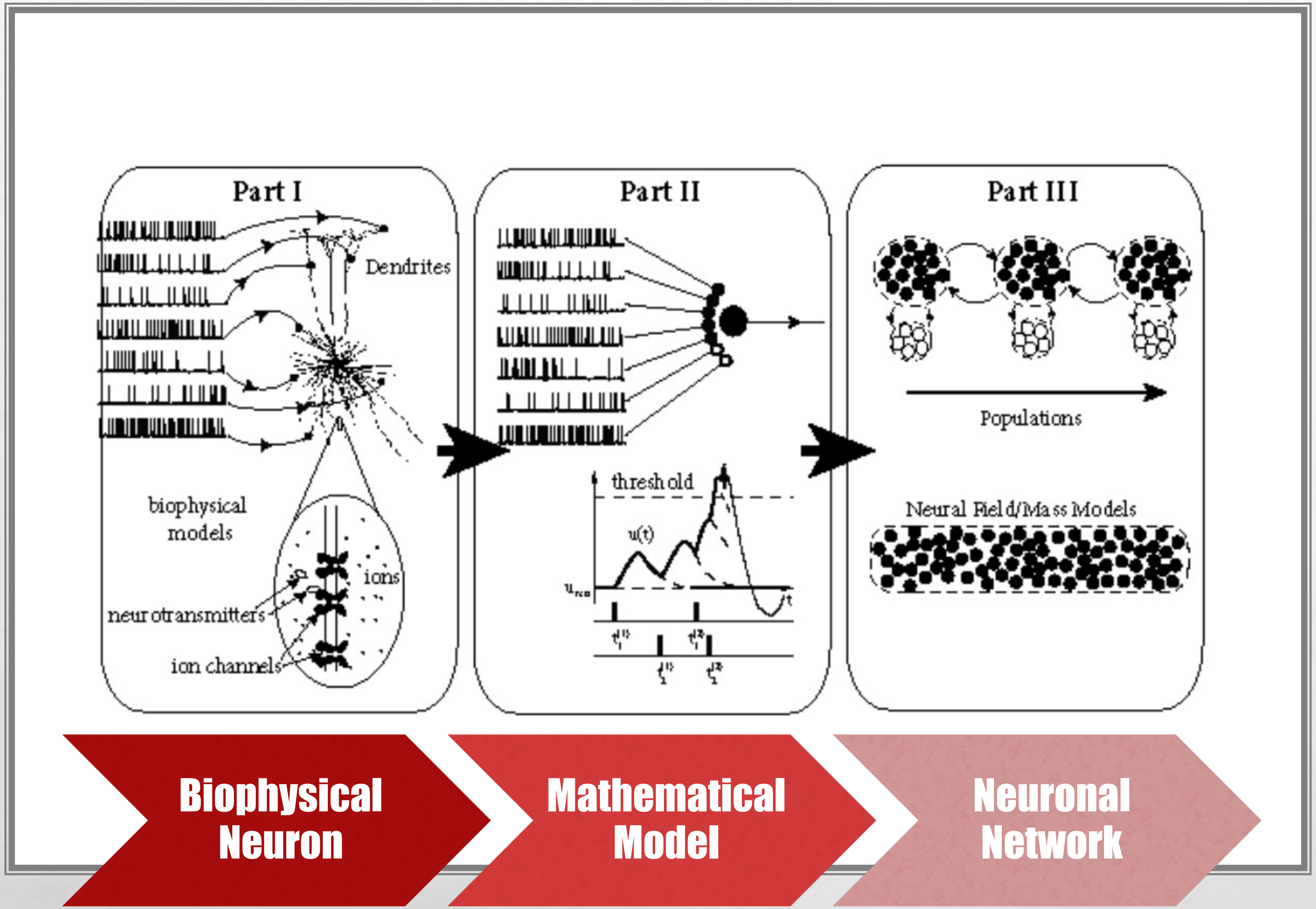
Modelling



Simulation

GOALS

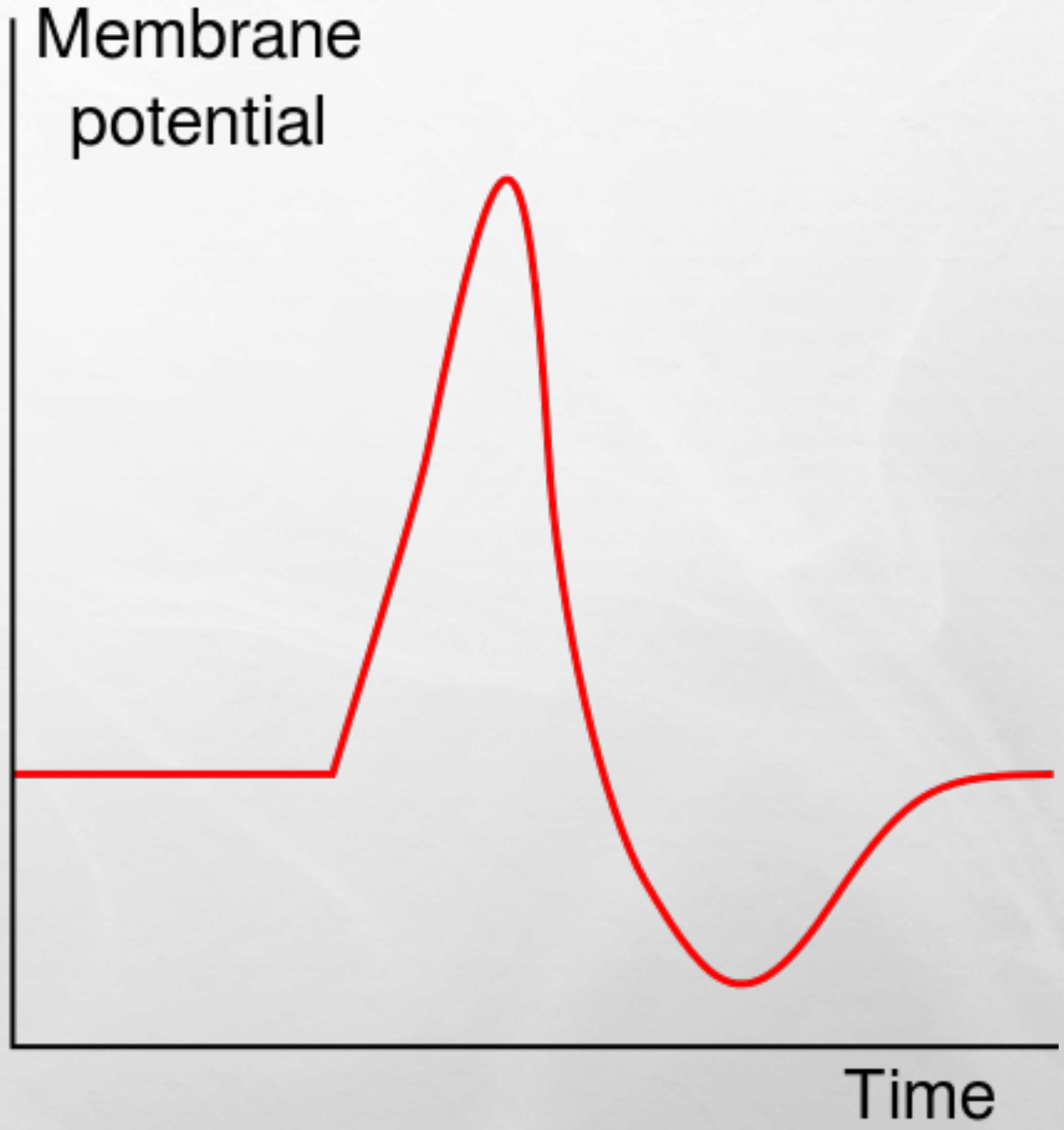
- Use Hebbian rule to mathematically model synaptic plasticity
- Integrate the models with the neuronal networks
- Analyze how synaptic plasticity affects neuronal networks behaviours


Part I
Dendrites
biophysical models
ions
neurotransmitters
ion channels
Part II
threshold
u(t)
Part III
Populations
Neural Field/Mass Models
Biophysical Neuron
Mathematical Model
Neuronal Network

IMPLEMENT

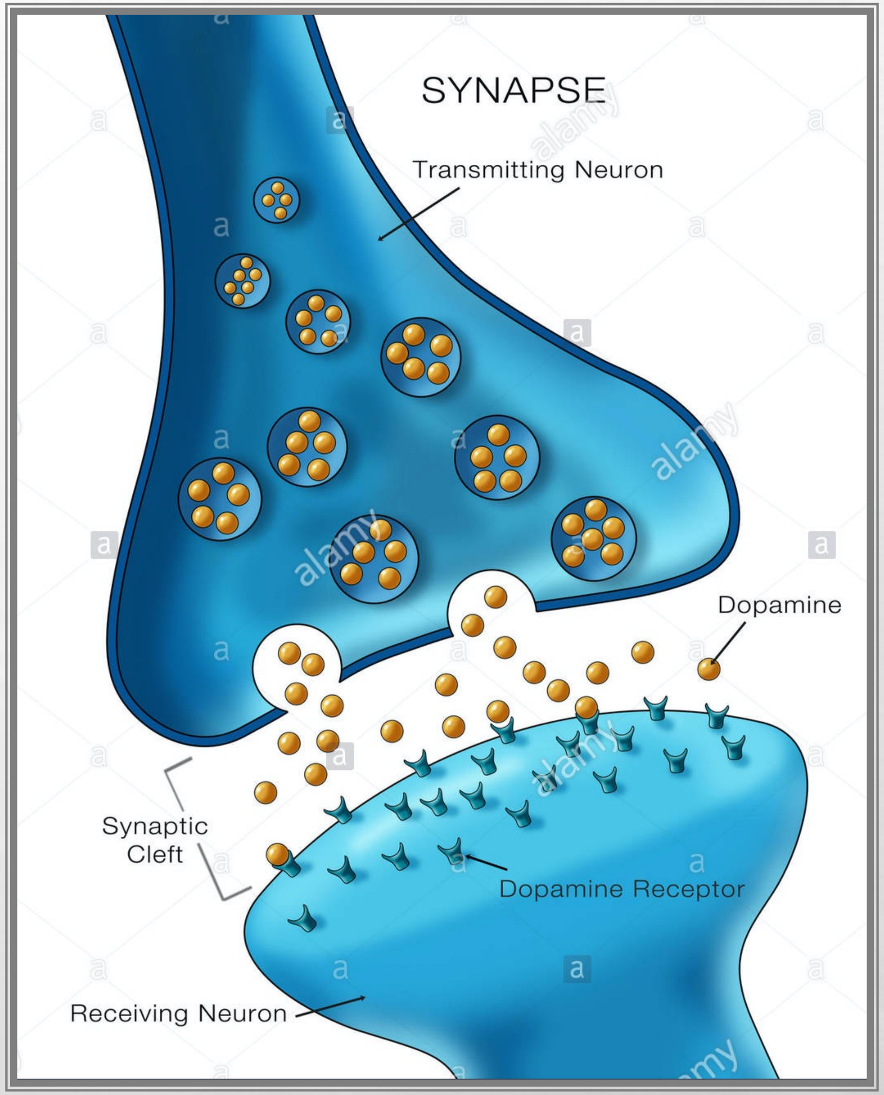
What is a neuron?

- A neuron is an electrically excitable cell that rec eives, processes, and transmits information
- Neuron ‘spikes’ when membrane potential rapidl y rises and falls

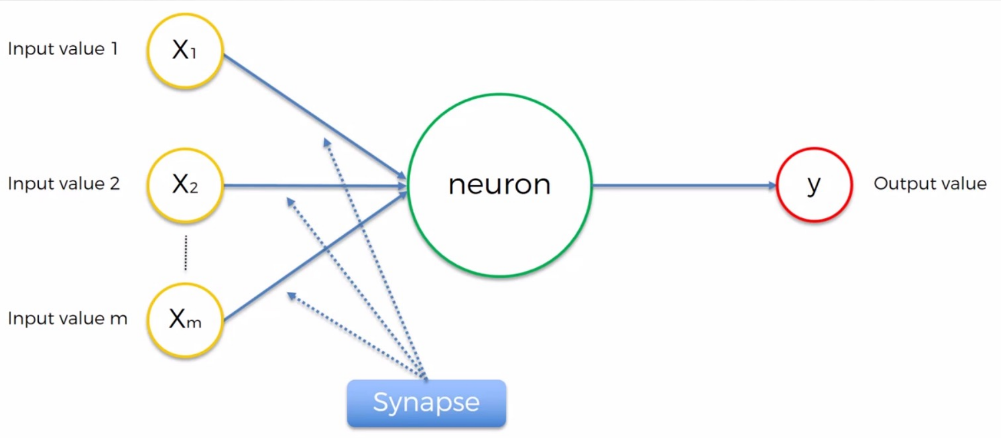


SYNAPSE?

- The junction between two neurons
- Synapse permits a neuron to pass an electrical signal to another neuron
- Synapse plays a role in the formation of memory



MODELLING A SINGLE NEURON



$$I(t) = C_{\mathrm{m}} \frac{dV_{\mathrm{m}}(t)}{dt}$$

Simply a relationship between input membrane current and output membrane voltage

LEAKY INTEGRATE-FIRE MODEL

$$I(t) = C_{\mathrm{m}} \frac{dV_{\mathrm{m}}(t)}{dt}$$

Adding "leak" term

$$I(t) - \frac{V_{\mathrm{m}}(t)}{R_{\mathrm{m}}} = C_{\mathrm{m}} \frac{dV_{\mathrm{m}}(t)}{dt}$$

$$\tau_m \frac{\mathrm{d}u}{\mathrm{d}t} = -\left[u(t) - u_{\mathrm{rest}}\right] + R\, I(t)$$

$$\text{if} \quad u(t) = \vartheta \quad \text{then} \quad \lim_{\delta \to 0; \delta > 0} u(t + \delta) = u_r$$

LIMITATIONS OF LIF MODEL

Quadratic IF vs Exponential IF

- $\tau_m \frac{dv}{dt} = a_0(v - E_m)(v - v_{thresh}) + R_m I$ f neu

$$\tau \frac{d}{dt} u = -(u - u_{rest}) + \Delta_T \exp\left(\frac{u - \vartheta_{rh}}{\Delta_T}\right) + R I \,;$$

- The model is linear

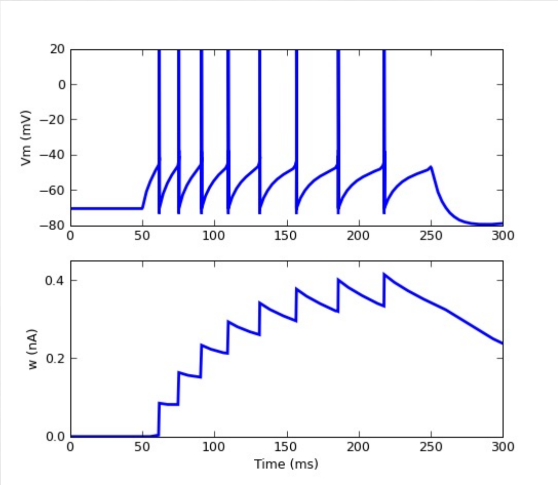
$$a_0 > 0, \quad E_m < v_{thresh} < E_{thresh}$$

- Aft... tial is reset; loses memory of previous spikes

ADAPTIVE EXPONENTIAL INTEGRATE-FIRE MODEL

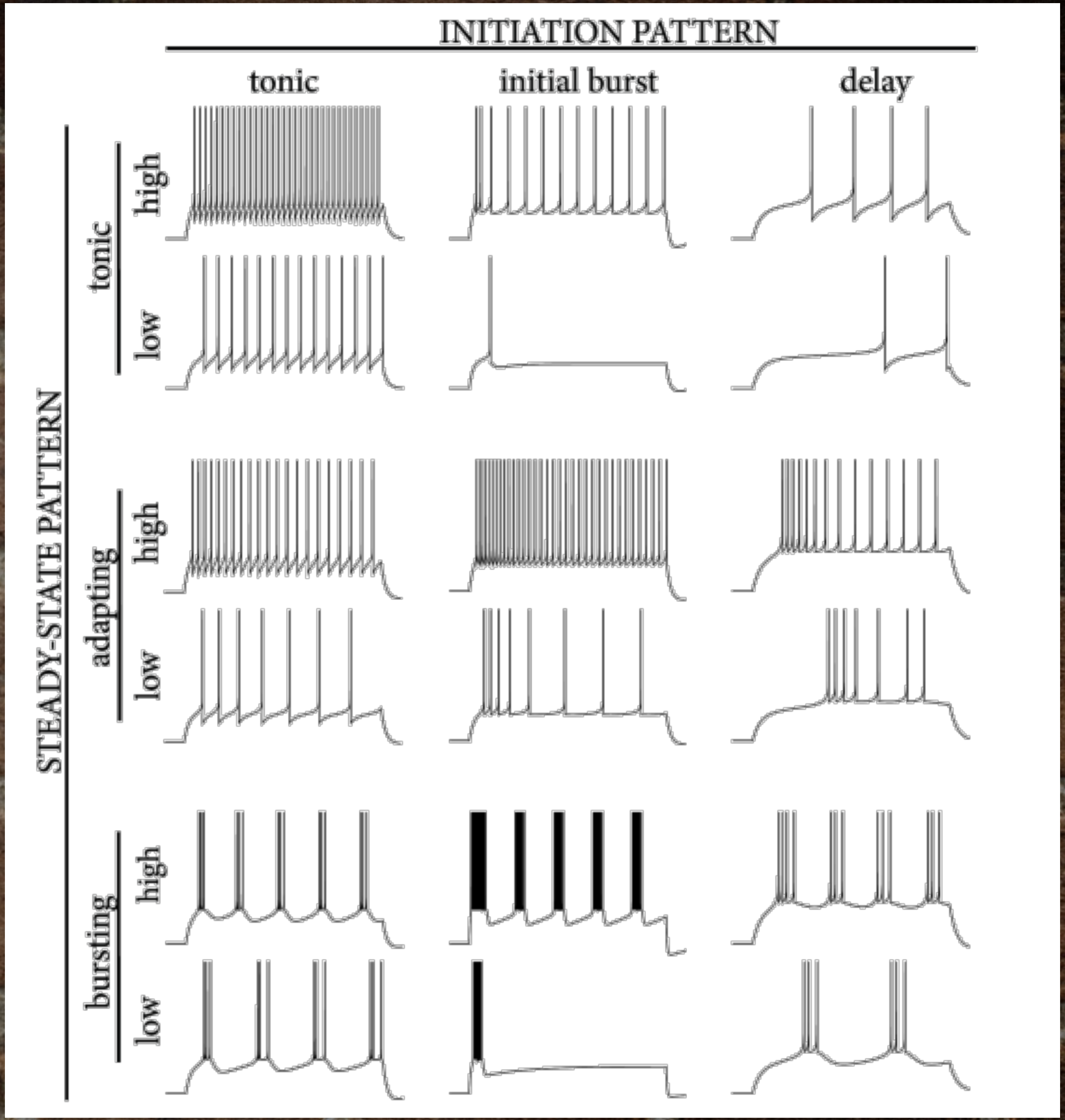
$$\tau_m \frac{\mathrm{d}u}{\mathrm{d}t} = -\left(u - u_{\mathrm{rest}}\right) + \Delta_T \, \exp\left(\frac{u - \vartheta_{rh}}{\Delta_T}\right) - R\,w + R\,I\,(t)$$

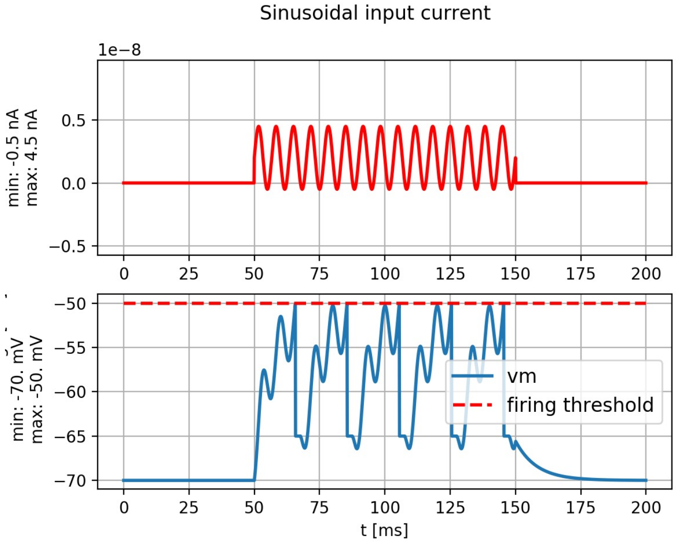
$$\tau_w \frac{\mathrm{d}w}{\mathrm{d}t} = a \, \left(u - u_{\mathrm{rest}}\right) - w + b\tau_w \sum_{t^{(f)}} \delta\left(t - t^{(f)}\right) \; .$$



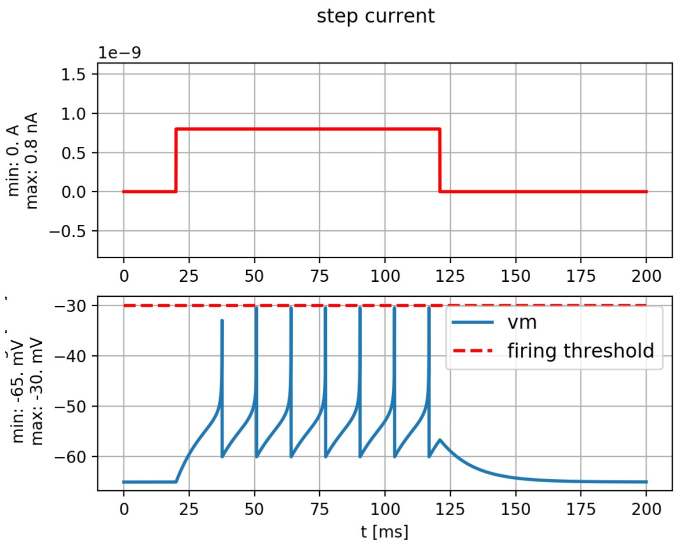
Voltage

Adaptation variable

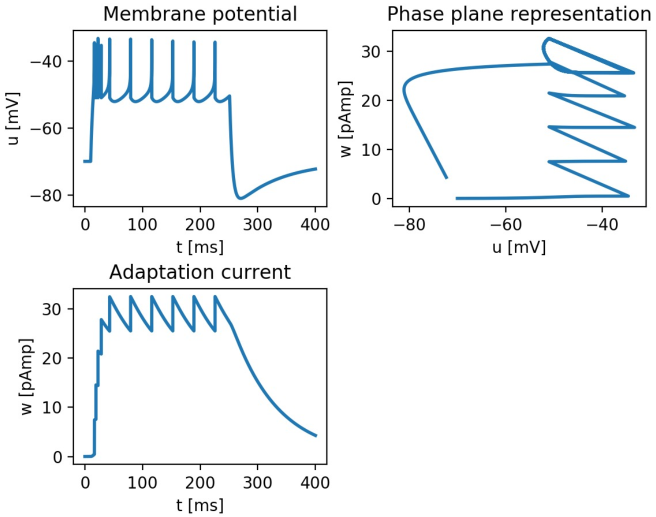




LIF with Sinusoidal Current



EIF with Step Current

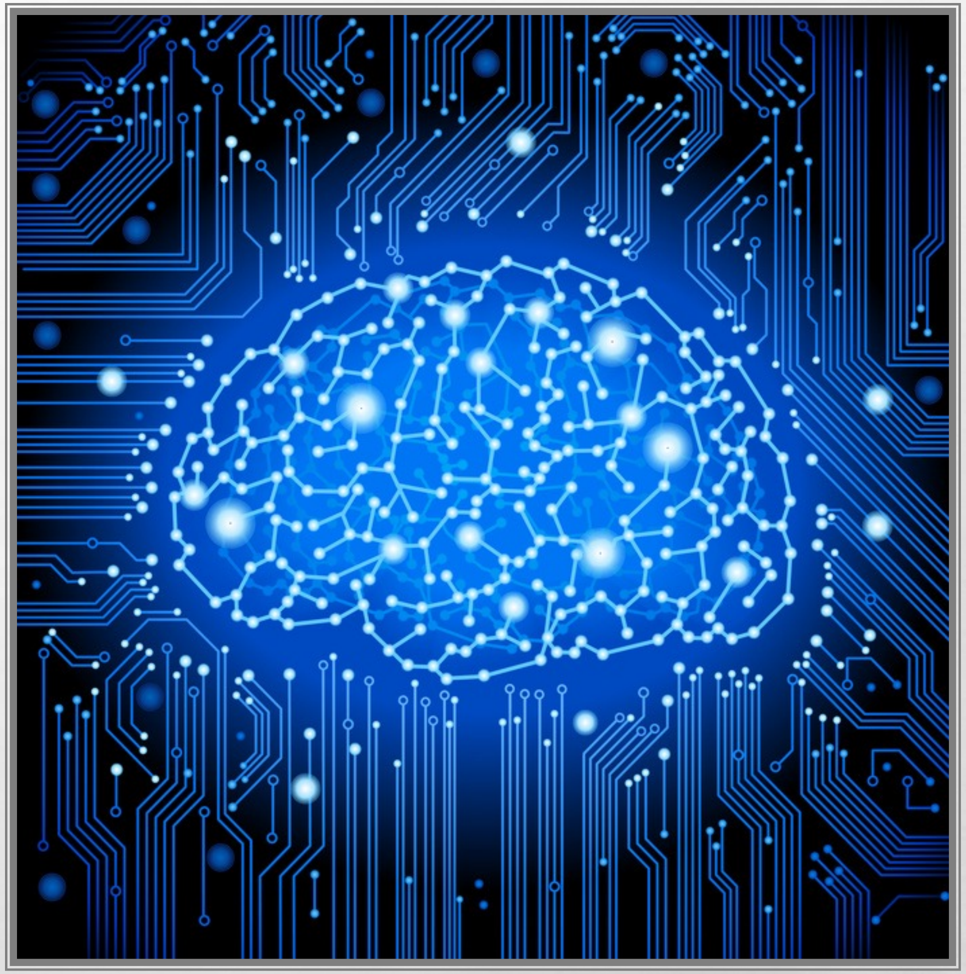


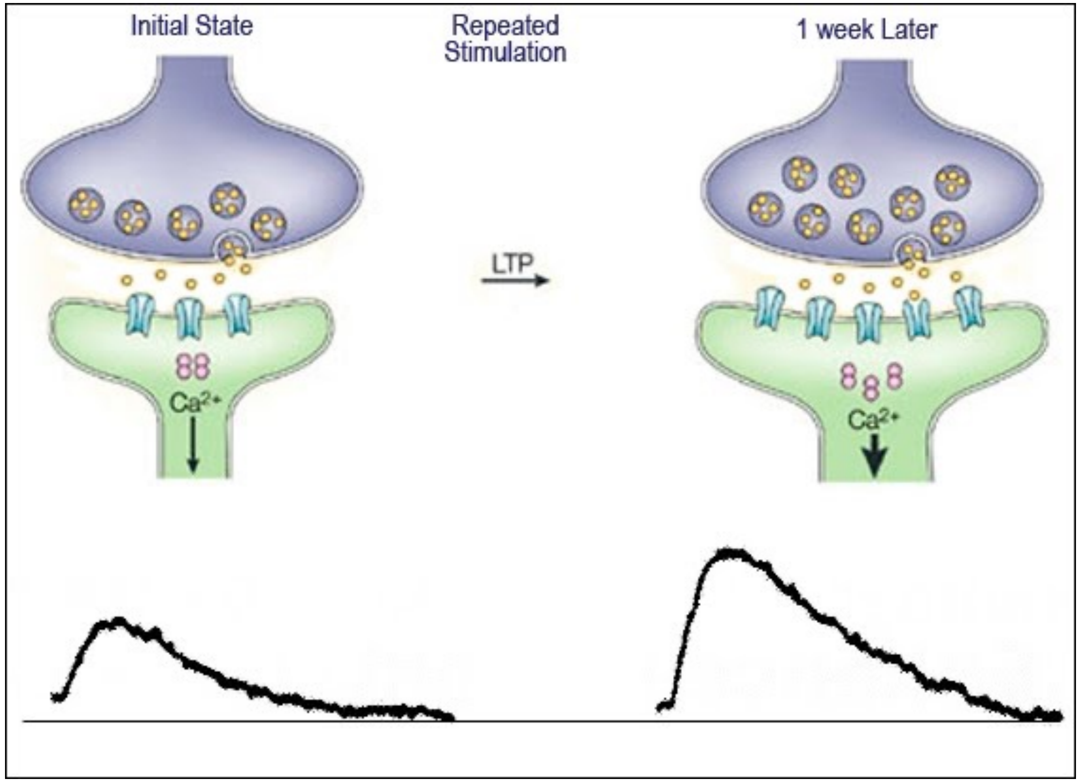
AdEx with Step Current

PRELIMINARY RESULT

HOW TO MODEL A NETWORK?

1. How many neurons should be created in a network?
   Excitatory & inhibitory with a ratio of 4:1
2. How to synchronize neurons?
   Oscillation
3. How to make neurons interact?
   Give certain number of connections and weight





SYNAPSE PLASTICITY

- Ability of synapses to strengthen or we aken over time, in response to increase s or decreases in their activity
- Long-Term Potentiation
- Use Spike-Timing-Dependent-Plasticity Model to measure
- Hebbian Rule

PROJECT PLAN

- ✓ Develop background knowledge and mathematical understanding
- ✓ Test different simulation tools and decide which one to use for research
- ✓ Implement appropriate single neuron model and investigate the behaviour of the single neuron
- ➢ Implement networks of neurons and investigate neuronal behaviours
- Research on synapse plasticity and implement STDP models based on Hebb's rule
- Integrate STDP models to networks and investigate more complicated behaviours
- Analyse how synaptic plasticity can affect neuronal behaviours in short and long period of time

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