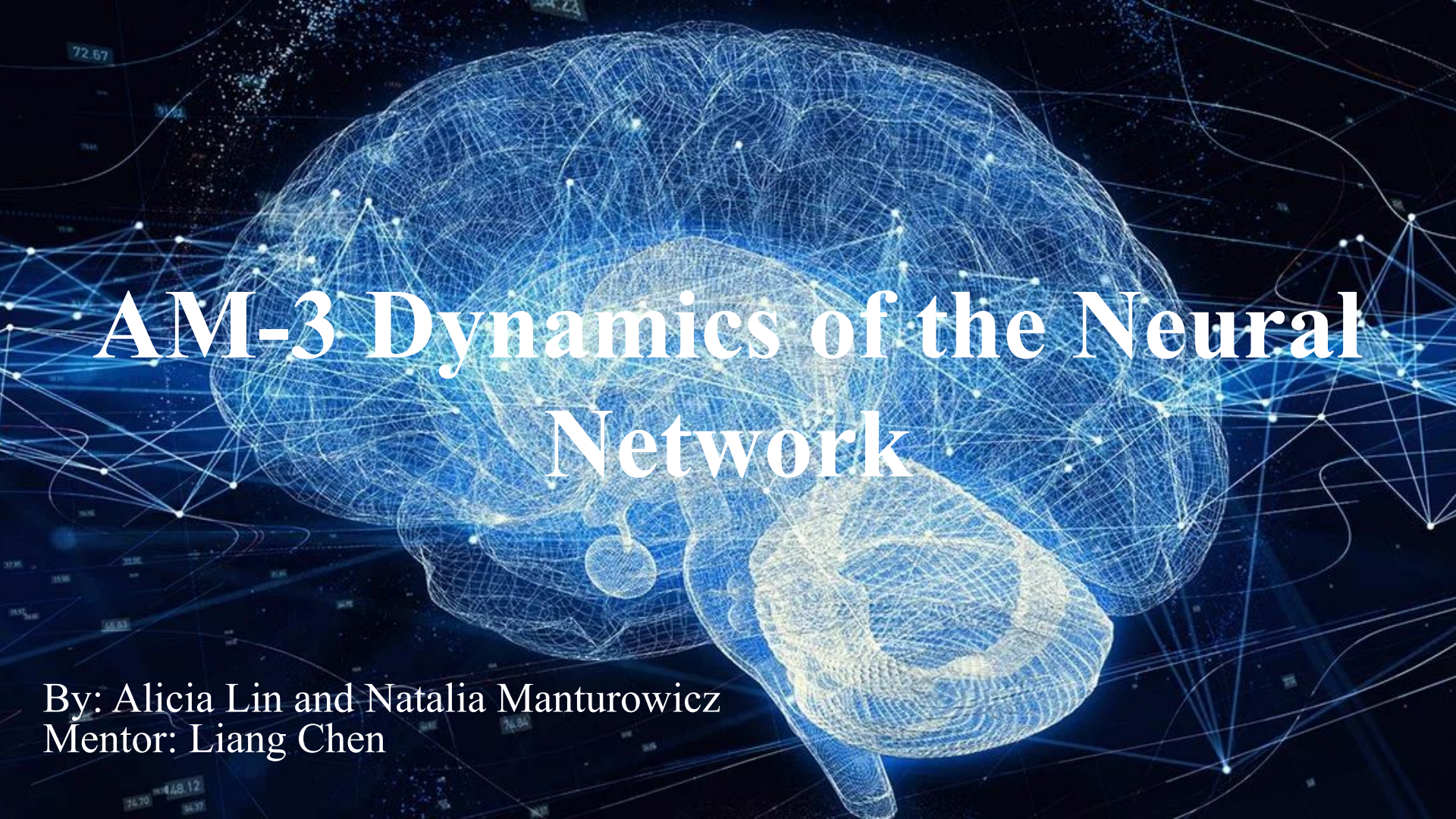

AM-3 Dynamics of the Neural Network

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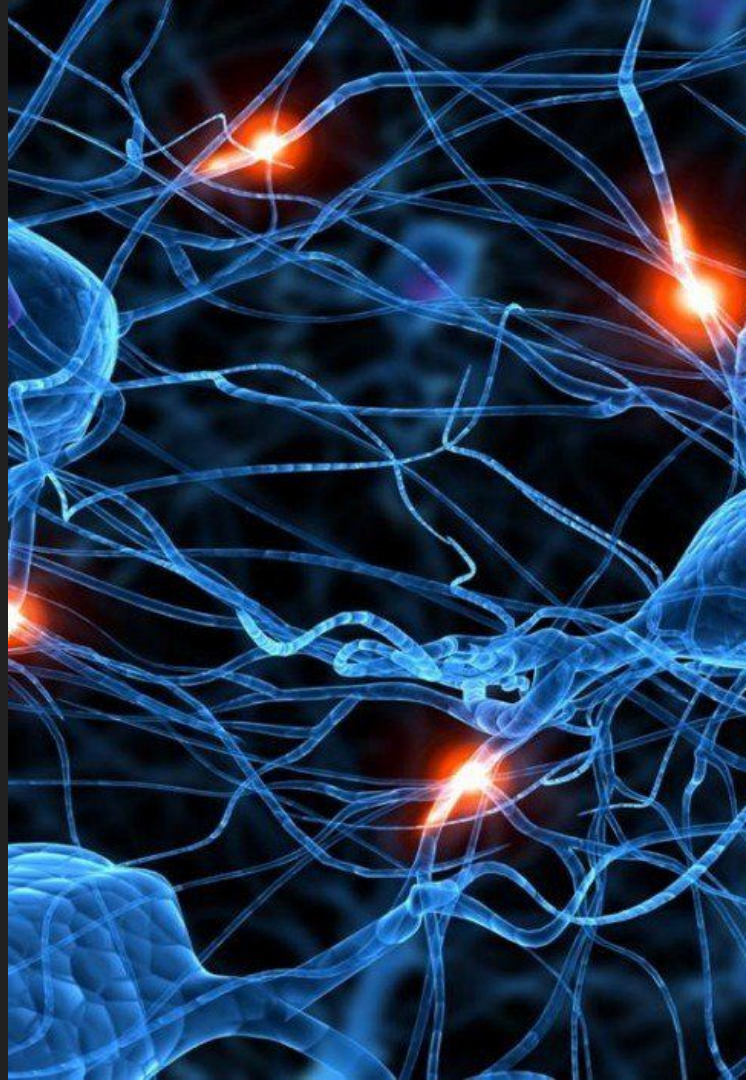
Mentor: Liang Chen

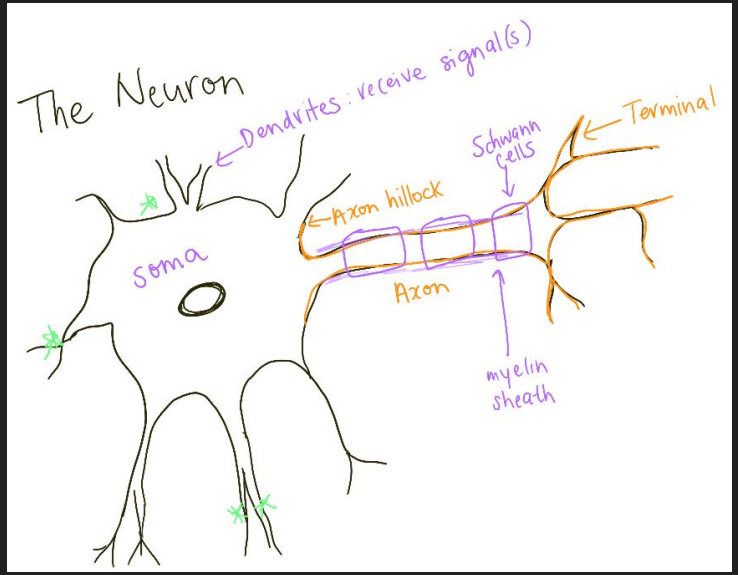
Project Overview

1. Basic terminology and a biological understanding of neurons
2. A phenomenological model for individual neurons
3. The biological model for two neuron models
4. Extending the Izhikevich model to a neural network



Terminology and Biological Overview

The Neuron

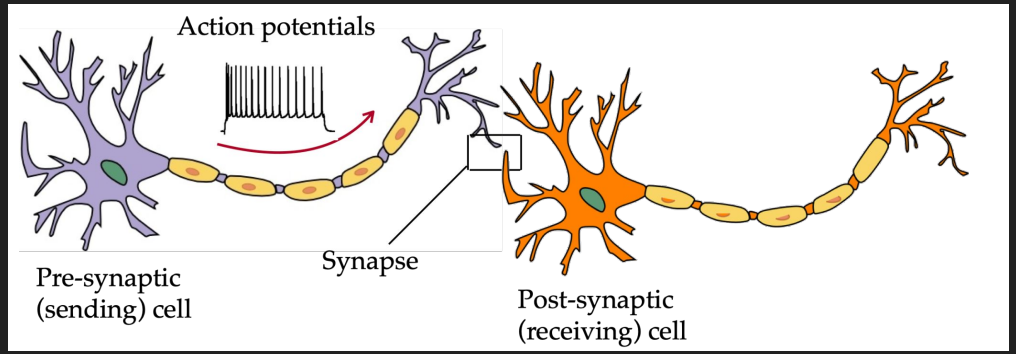


- It is a **nerve cell** that has three basic functions:

    1. Receive signals and/or information
    2. Integrate incoming signals
    3. Communicate signals to target cells

- There are three classes of neurons:
    1. **Sensory**: Receive information about what is going on inside and outside of the body; bring information into the Central Nervous System so it can be processed.
    2. **Motor**: Receive information from other neurons and convery commands to muscles, organs, and glands
    3. **Interneurons**: Found only in the Central Nervous System. Transmit information between neurons.

Terminology



Synapses: Neuron-to-neuron connections made onto dendrites and somas of other neurons.

Neurotransmitters: Chemical messengers triggered by an action potential

Action Potential: A nerve impulse caused by a rapid, temporary change in charge of the membrane potential.

Membrane Potential: The difference in electrical charge between the inside and the outside of a neuron. Denoted by the variable **v**. At rest, it is more negatively charged.

Ions in the neuron membrane: Na+, K+, Ca+, Cl-

Phenomenological Model: Izhikevich Model

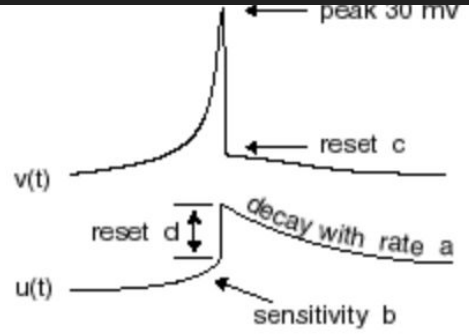
Izhikevich Model

Phenomenological model: a mathematically simplified model used to mimic behaviour of a more complex model

2 components: recovery variable (u) + neuron membrane potential variable (v)

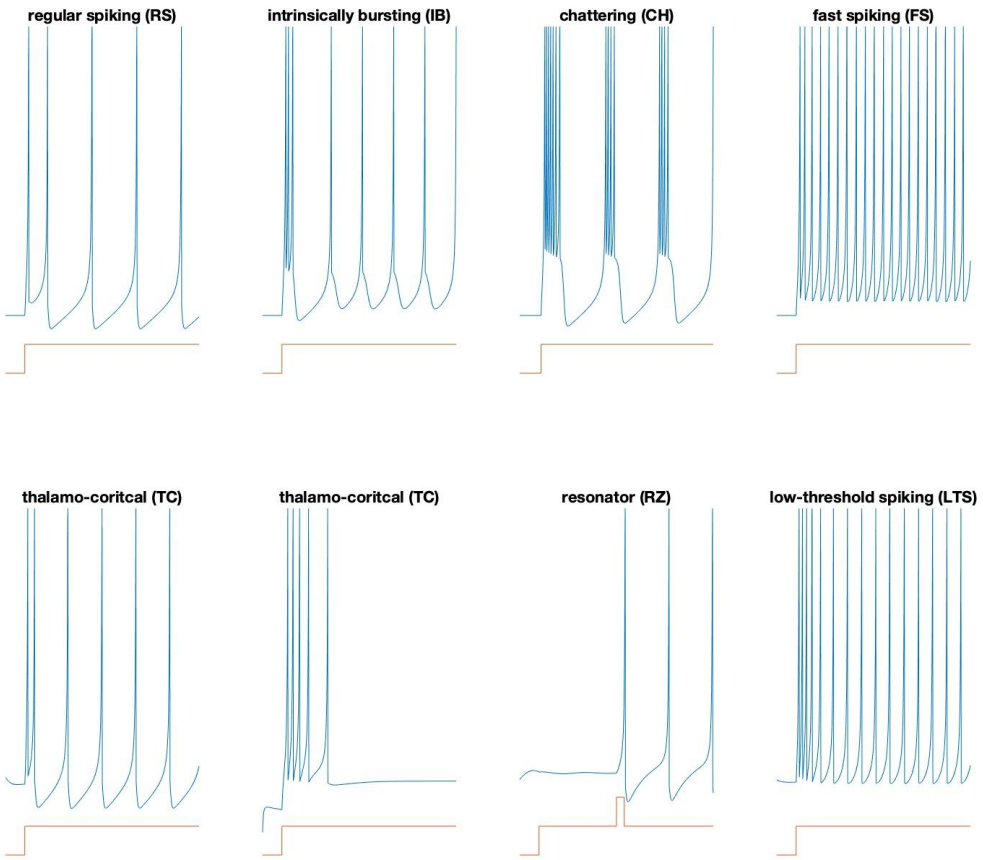
$$v' = 0.04v^2 + 5v + 140 - u + I$$
$$u' = a(bv - u)$$

if $v = 30$ mV,
then $v \leftarrow c$, $u \leftarrow u + d$



Key features:

- After-spike reset condition
- I = injected current
- a = recovery rate of u
- b = coupling variable between u and v
- c = after spike reset value (v)
- d = after spike reset value (u)



Simulations of different spiking behaviour using the Izhikevich model

Biological Model for Two Neuron Interactions

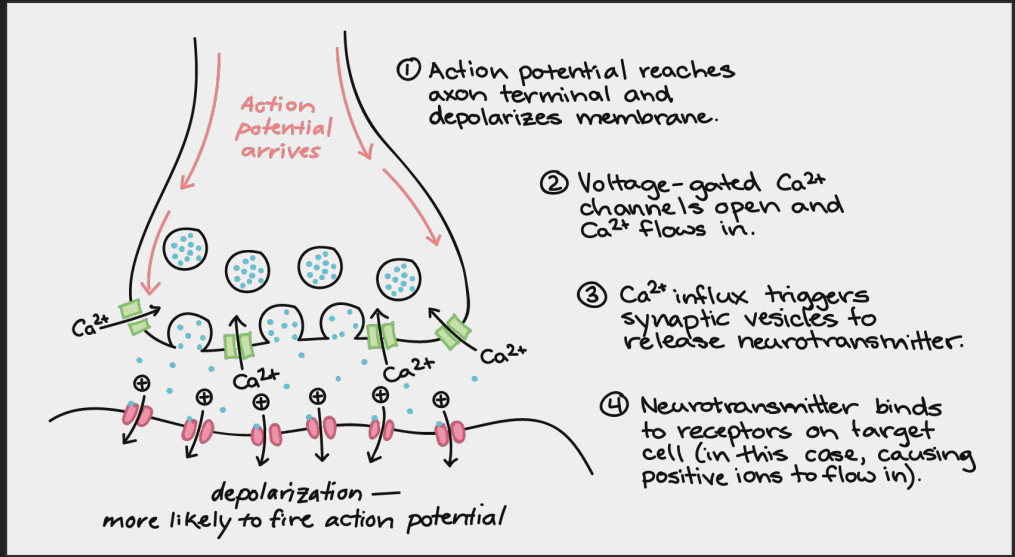
Synaptic Connections between Two Neurons

Types of Synaptic Connections:

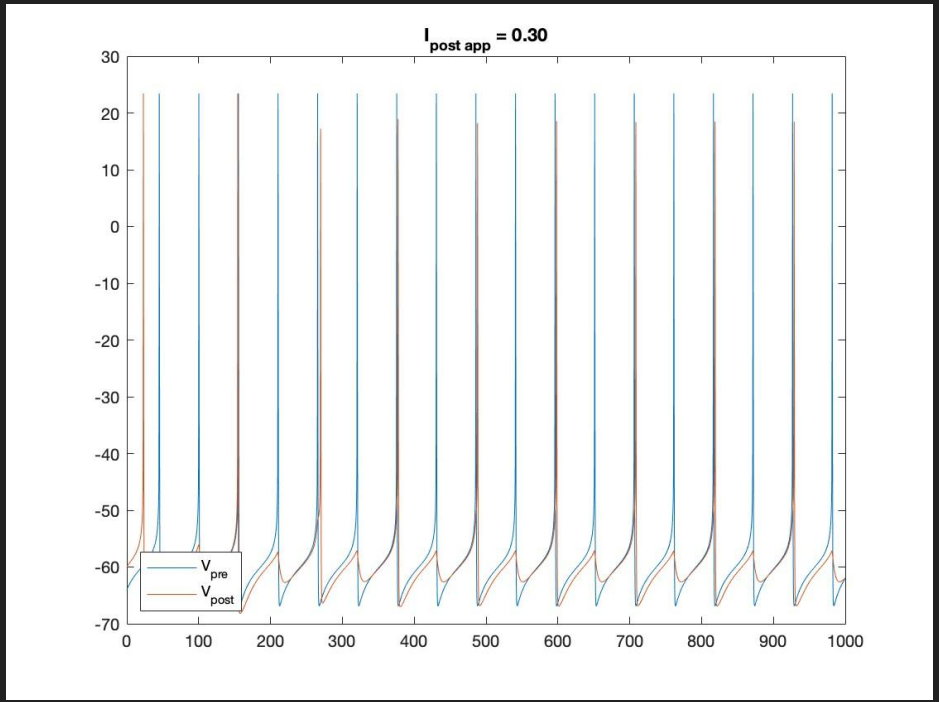
- Chemical (via neurotransmitters)
- Electrical (direct connection, via ions)

The relationship between the presynaptic neuron and the postsynaptic neuron are influenced by the concentration of neurotransmitters.

Key behaviors: phase lock (with varying ratios) and anti-phase lock



$$C_m \frac{dV_{post}}{dt} = -I_{Na} - I_k - I_L + I_{app,post} - I_{syn}$$


I post app = 0.30
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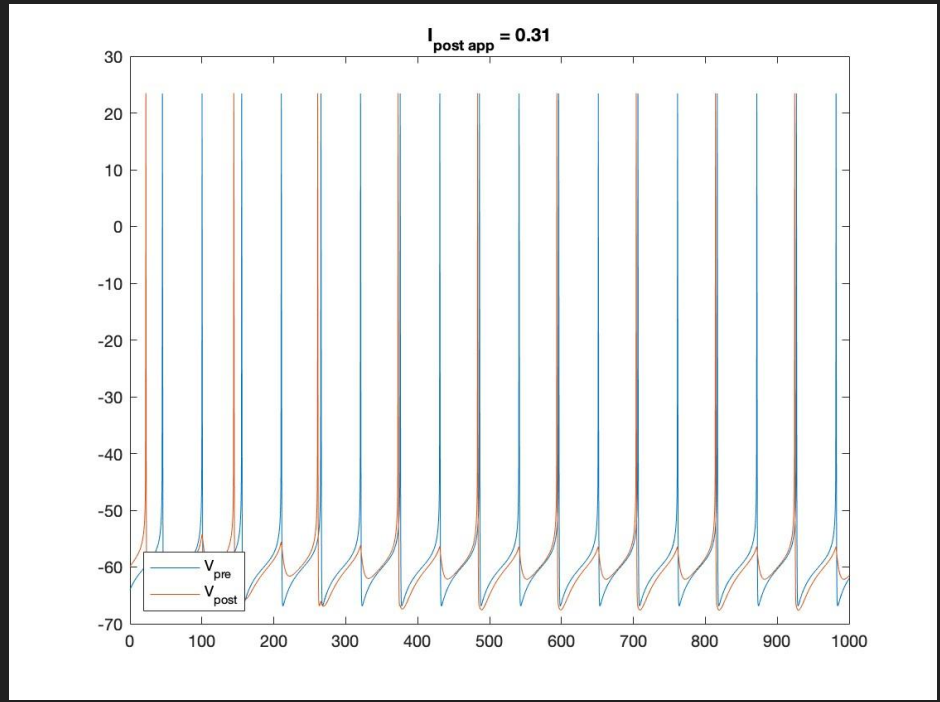
20
10
0
-10
-20
-30
-40
-50
-60
-70
0
100
200
300
400
500
600
700
800
900
1000
V pre
V post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20
10
0
-10
-20
-30
-40
-50
-60
-70
0
100
200
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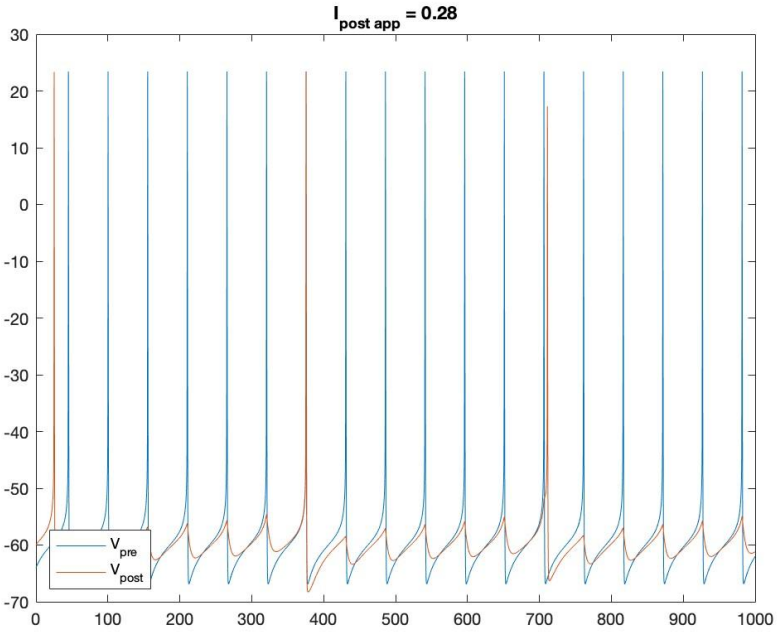
400
500
600
700
800
900
1000
V pre
V post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20
10
0
-10
-20
-30
-40
-50
-60
-70
0
100
200
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400
500
600
700
800
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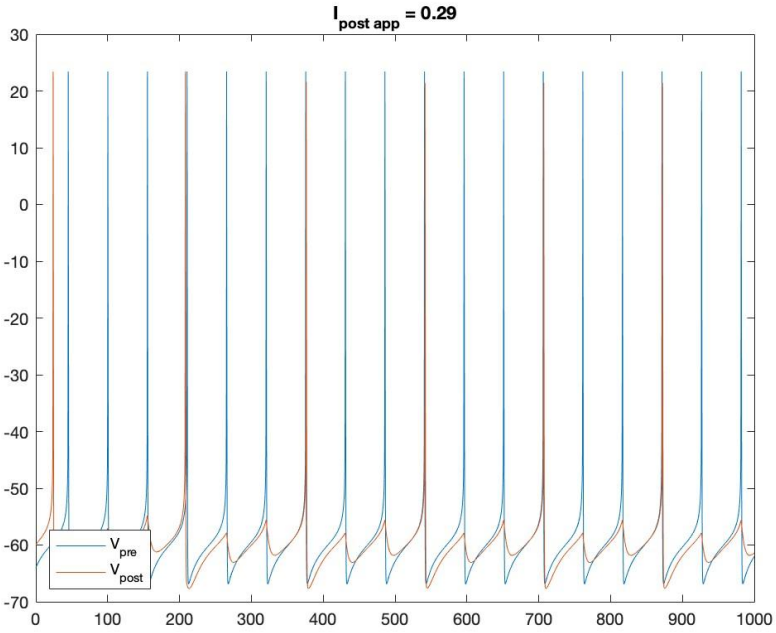
1000
V pre
V post


I post app = 0.29
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20
10
0
-10
-20
-30
-40
-50
-60
-70
0
100
200
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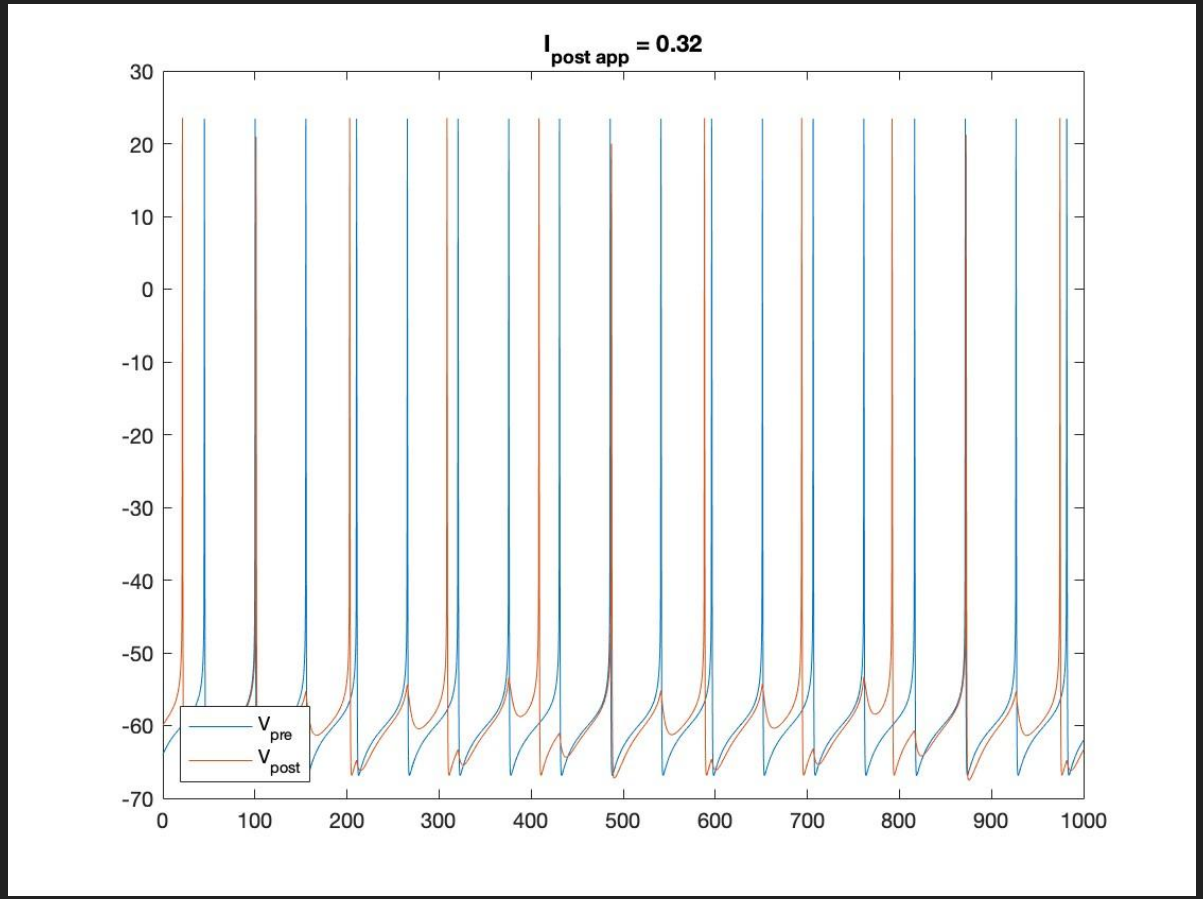
400
500
600
700
800
900
1000
V pre
V post

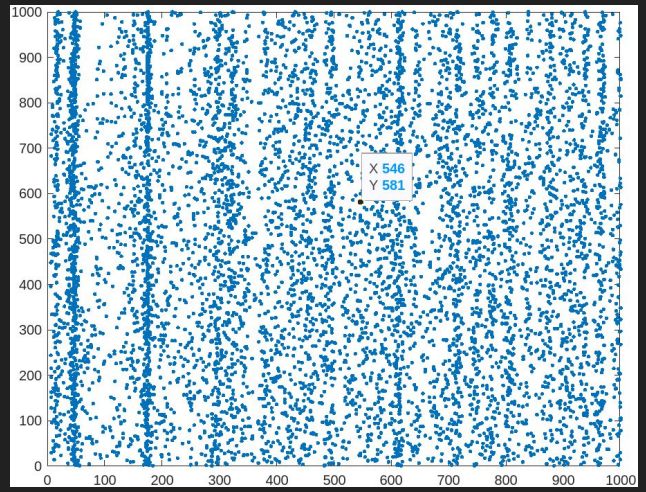

$I_{post\ app}$ = 0.32
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
0
100
200
300
400
500
600
700
800
900
1000
V_{pre}
V_{post}

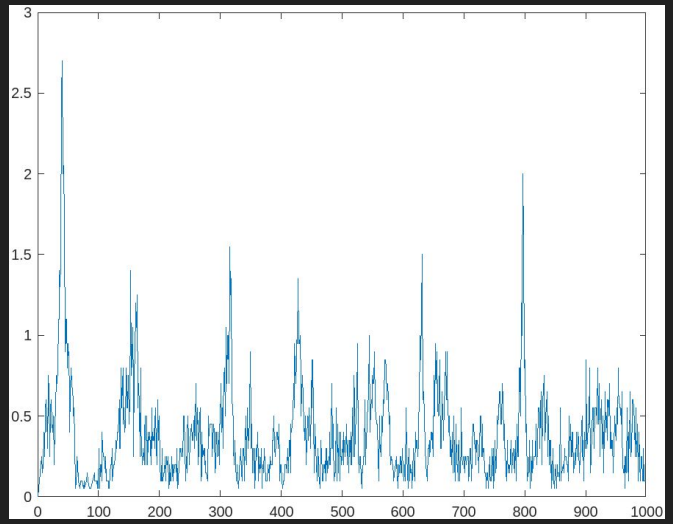
Extending the Izhikevich Model to a Network

Simulation of a Neural Network

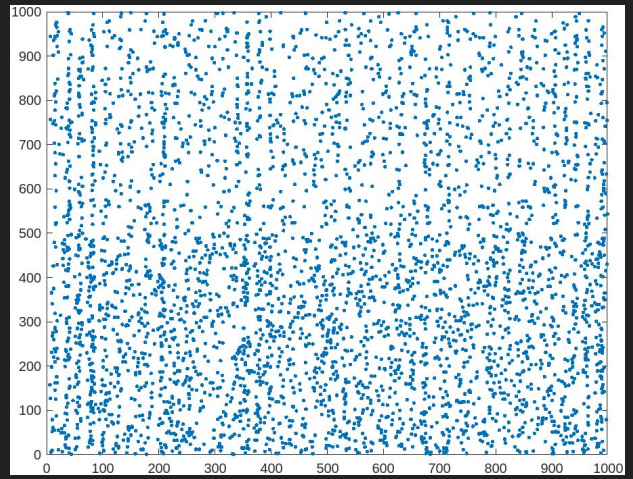
- Ran Izhikevich's MATLAB program to model a network of 1000 randomly coupled spiking neurons and the population firing rate

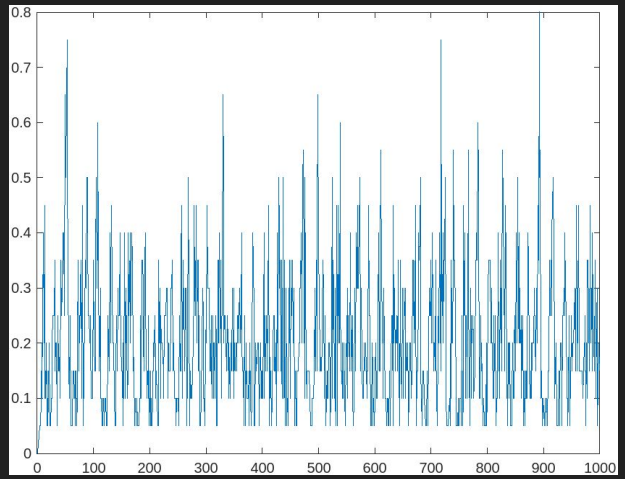
- Changed parameters to see how different neurons and different initial values affect neuron spiking
    - Combination of *inhibitory* and *excitatory* neurons
    - Initial Value pertains to the *membrane potential*



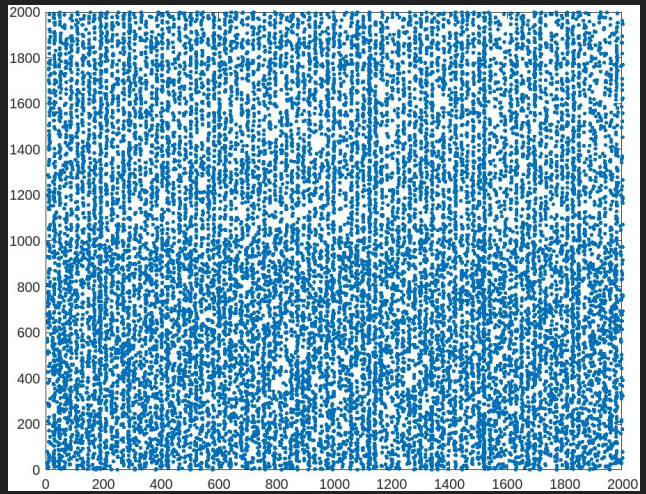


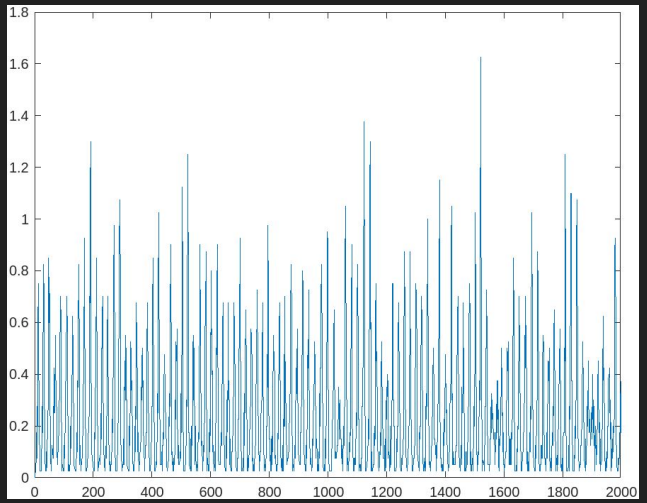
800 Ne, 200 Ni





500 Ne, 500 Ni

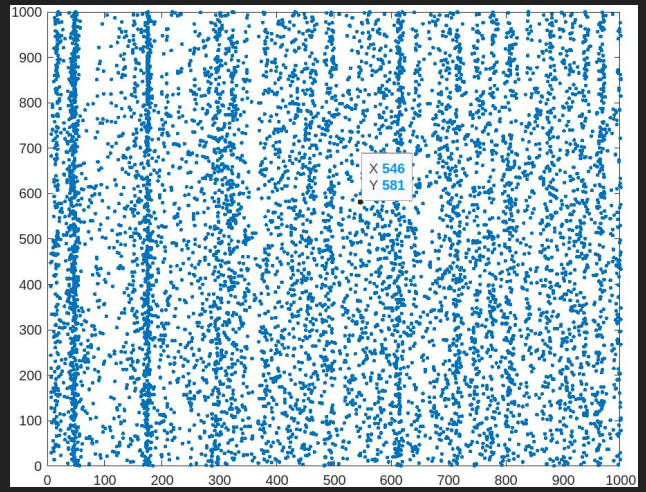


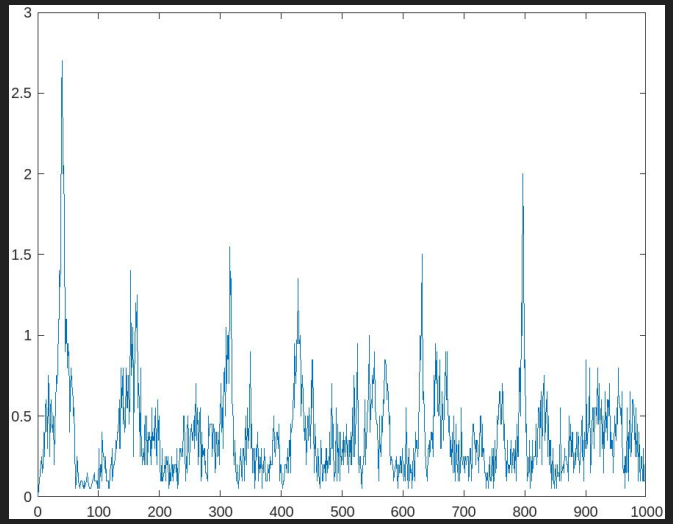


1000 Ne, 1000 Ni

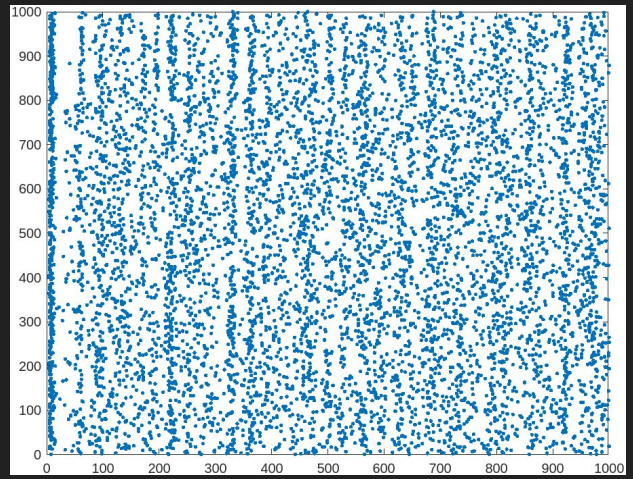
Observations

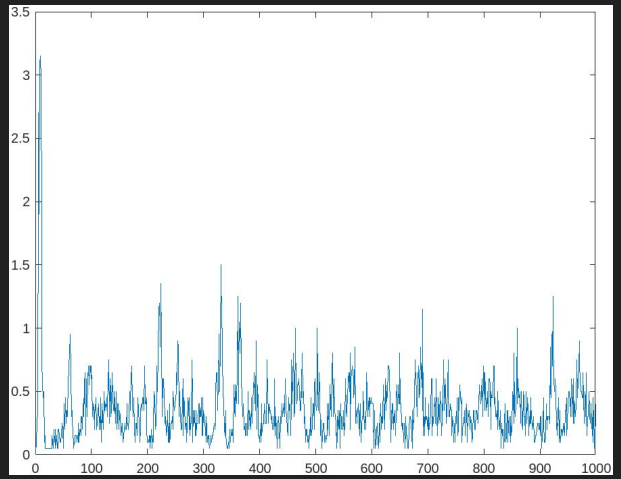
- More synchronizations occur with an increased amount of excitatory neurons
- If a group of neurons send signals, the “power” of the signal is greater
- Change in the strength of synaptic connections can produce other behaviour



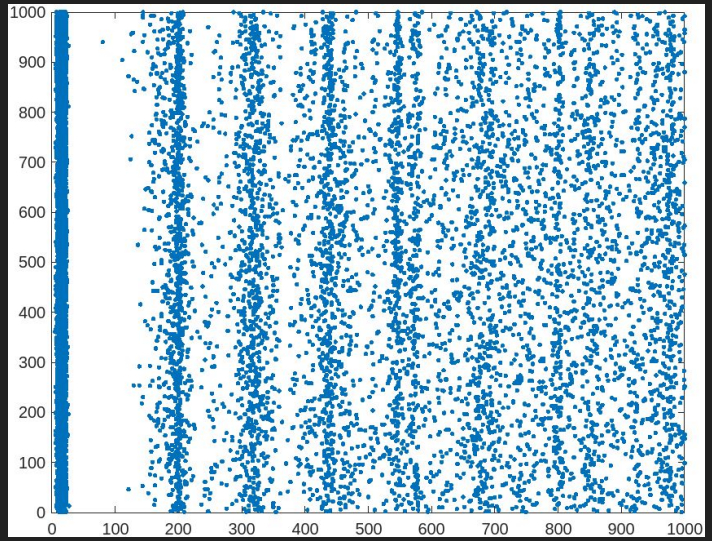


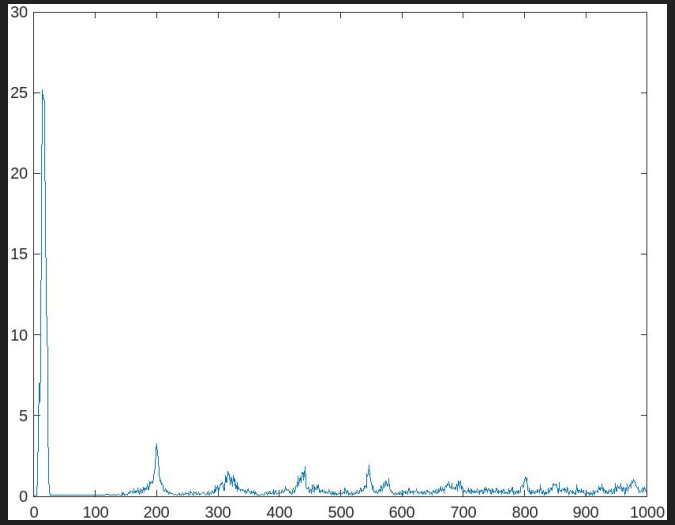
v=-65*ones(Ne+Ni,1)



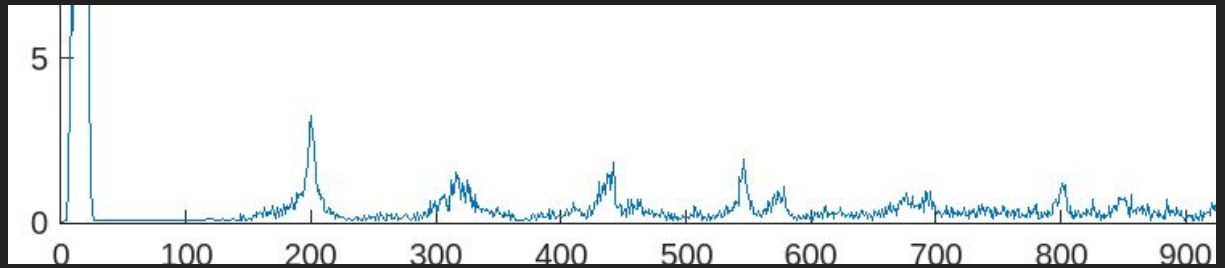


v=-55*ones(Ne+Ni,1)





`v=-90*ones(Ne+Ni,1)`
(*hyperpolarized*)



Observations

- Dark vertical lines indicate *synchronized* firings
- Increased initial value => synchronized spiking at time 0, followed by a break in spiking.

Three Projects:

Izhikevich Model
Biological Model for Two Neurons
Extending the Izhikevich Model to a Network

Questions?