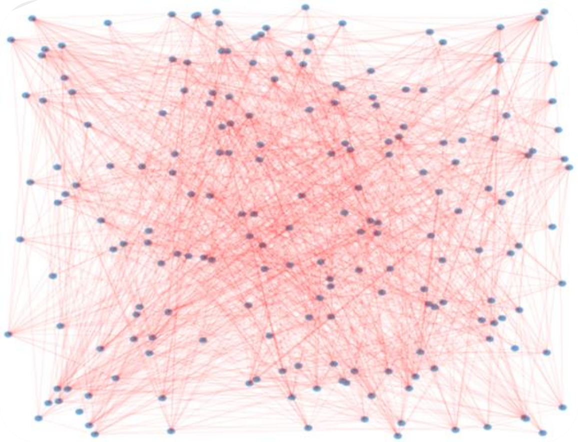
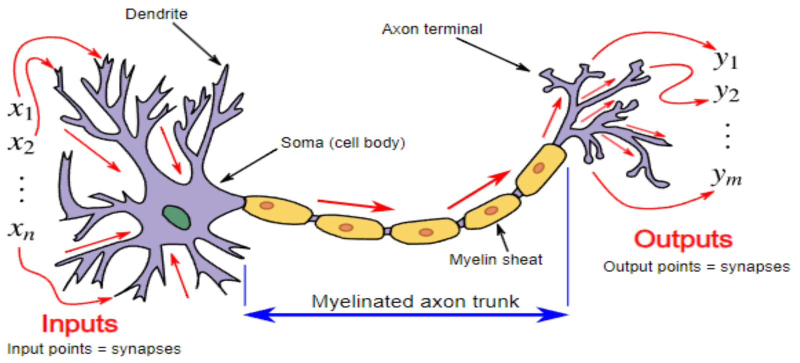


Hands-on Workshop: Building & Simulating Neural Networks with NetPyNE

Mathematical Modeling of Neurons

Biological neuronal model



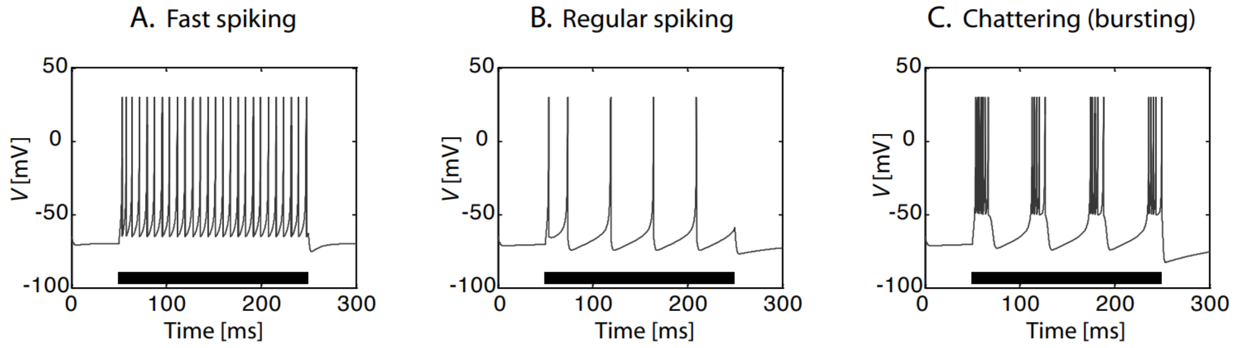
➢ Izhikevich Neuron Model

➢ **Membrane Potential (v):**

$$\frac{dv(t)}{dt} = 0.04v^2(t) + 5v(t) + 140 - u + I(t)$$

➢ **Recovery Variable (u):**

$$\frac{du(t)}{dt} = a(bv - u)$$



Different spike pattern of a Izhikevich neuron(neuronal Behavior)

- Fundamentals of Computational Neuroscience Third Edition Thomas P. Trappenberg Dalhousie University

Definition of Parameters

Parameter	Symbol	Typical Values	Description
Membrane Potential	v	-65 to 30 mV	Represents the neuron's voltage over time
Recovery Variable	u	-14 to -10 pA	Tracks slow adaptation and resets the neuron after a spike
Input Current	I(t)	0 - 20 pA	External stimulation applied to the neuron
Time Constant of Recovery	a	0.01 - 0.1	Defines the **timescale** of recovery variable uuu
Sensitivity of Recovery	b	0.1 - 0.2	Determines the response of uuu to changes in vvv
Reset Voltage After Spike	c	-65 to -50 mV	**Resets** the neuron’s voltage after a spike
Reset of Recovery Variable	d	2 - 8 pA	Controls how much the recovery variable **increases** after a spike

Typical Parameter Values for Different Neuron Types

Neuron Type	a	b	c	d	Behavior
Regular Spiking (RS)	0.02	0.2	-65	8	Standard cortical neuron
Intrinsic Bursting (IB)	0.02	0.2	-55	4	Produces bursts of spikes
Chattering (CH)	0.02	0.2	-50	2	Very high firing rate
Fast Spiking (FS)	0.1	0.2	-65	2	Inhibitory interneurons
Low-Threshold Spiking (LTS)	0.02	0.25	-65	2	Slow-adapting inhibitory neurons
Resonator (RZ)	0.1	0.26	-65	2	Shows resonance-like behavior

What is NetPyNE?

- A **Python package** for creating and simulating **spiking neural networks** using **NEURON**.
- **High-level, intuitive interface** for neuroscience research.

Why Use NetPyNE?

✓ Easy model definition

✓ Automatic network visualization

Installing

Hands-on Exercise 1 - Simulating a Single Neuron

```
!pip install neuron
!pip install netpyne
!nrnivmodl
```

- Simulate **a single Izhikevich neuron**.
- Inject current (IClamp) and observe firing patterns.

1) izhi200b.mod
2) Python File: single_izhikevich.py

Hands-on Exercise 1 !☺

(For Simulating a Single Neuron)

1. *Increase input current: Change `amp` in `IClamp` from 10 to 20 pA → Does the neuron fire more frequently?*

2. *Modify adaptation: Change `b` in the neuron model from -2 to -1 → Does the firing pattern change (faster or slower adaptation)?*

3. *Change reset voltage (`c`): Modify `c` from -50 to -55 mV → Does this affect how quickly the neuron recovers after a spike?*

4. *Increase membrane capacitance (`C`): Change `C` from 1 to 2 → Does a larger capacitance slow down the response of the neuron?*

Hands-on Exercise 2 - Building a Network of 20 Neurons

- Create a network of 20 Izhikevich neurons.
- Apply random Poisson stimulation (NetStim).
- In neuroscience, it **models synaptic input from external sources**, like **sensory stimulation or background noise**.
- Observe spike activity using raster plots.

Python File: izhikevich_network.py

Expected Plots:

- ✓ 2D network visualization
- ✓ Raster plot (spike activity)
- ✓ Voltage trace (activity of a single neuron)

Raster Plot Analysis

• Each **dot** represents a **spike** of a neuron.
• **X-axis = Time (ms)**, **Y-axis = Neuron ID**.
• Excitatory neurons (blue) vs Inhibitory neurons (yellow).Reduced synchrony due to inhibition.

Observation from Our Model:

- Excitatory neurons fire at ~29.8 Hz.
- Inhibitory neurons fire at ~36.8 Hz.

Voltage Traces

How to Interpret?

- ➢ Neurons spike based on excitatory & inhibitory input
- ➢ Look for bursts, suppression, and adaptation.

Observation from Our Model:

- Inhibition causes fluctuations in firing patterns.
- Spikes are irregular due to external Poisson input (NetStim).

Hands-on Exercise 2 !! ☺

(For Building a Network of 20 Neurons)

1. *Increase connectivity: Change the connection probability (probability) from 0.1 to 0.5 in IZH->IZH → How does increased connectivity affect firing patterns?*

2. *Increase synaptic weight: Change 'weight': 0.005 to 'weight': 0.02 in excitatory synapses → Does stronger synaptic input lead to more synchronized activity?*

3. *Increase number of neurons: Change 'numCells': 20 to 'numCells': 50 → How does increasing network size influence overall activity and spike rate?*

4. *Modify external input (Poisson stimulation): Change rate in NetStim from 100 to 200 Hz → Does higher Poisson input increase or decrease network synchrony?*

Expected Observations

Parameter Change	Expected Effect
Higher connectivity (probability = 0.5)	More neurons connected, increased firing synchrony.
Higher synaptic weight (weight = 0.02)	Stronger synaptic transmission, higher activity.
More neurons (numCells = 50)	Larger network, denser activity.
Higher Poisson rate (rate = 200 Hz)	Increased randomness, more frequent firing.

Hands-on Exercise 3 - Adding Inhibition to the Network

- Add 10 inhibitory neurons to our existing network.
- Define inhibitory synapses with Exp2Syn.
- Analyze how inhibition affects firing patterns.

Type	**Neurotransmitter**	**Receptors**	**Effect on Post-Synaptic Neuron**	**Example in Code**
Excitatory	**Glutamate (Glu)**	AMPA, NMDA, Kainate, mGluRs	Depolarization (↑ Na^+, Ca^{2+} influx) → More likely to fire	'e': 0 in Exp2Syn
Inhibitory	**GABA (brain), Glycine (spinal cord)**	GABA-A, GABA-B, Glycine	Hyperpolarization (↑ Cl^- influx) → Less likely to fire	'e': -70 in Exp2Syn

Expected Changes in Plots:

Python File: izhikevich_inhibitory_network.py

- ✓ Less synchronized firing
- ✓ Lower excitatory firing rate
- ✓ More realistic spiking pattern

Hands-on Exercise 3 !!!☺

1. *Increase inhibition: Change 'e': -80 in the inhibitory synapse → Stronger GABAergic effect.*
2. *Increase excitation: Change 'e': 10 in the excitatory synapse → More depolarization.*

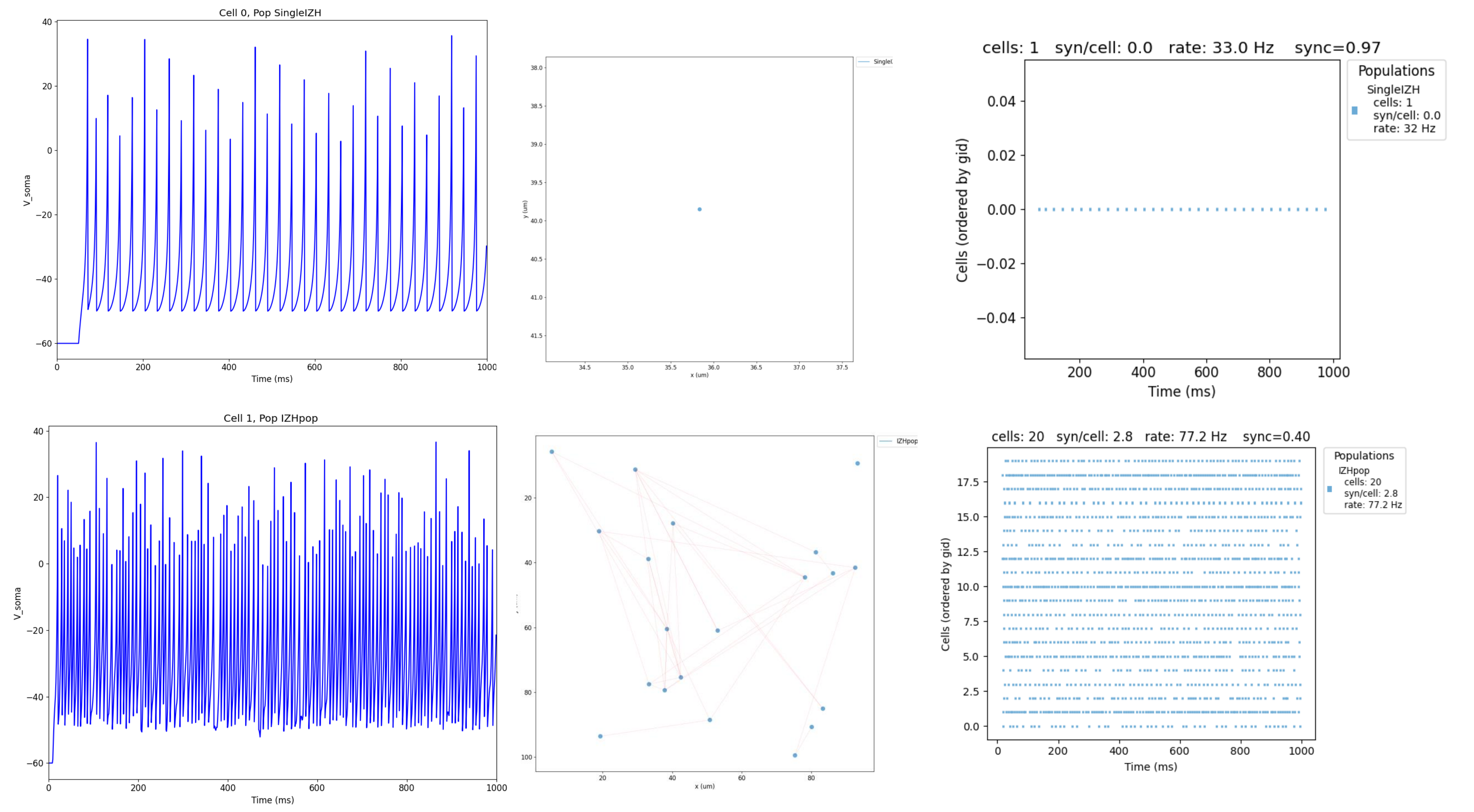
Summarize:

- ✓ We built a network of Izhikevich neurons using NetPyNE.
- ✓ We simulated both excitatory and inhibitory activity.
- ✓ We analyzed network dynamics using raster plots & voltage traces.

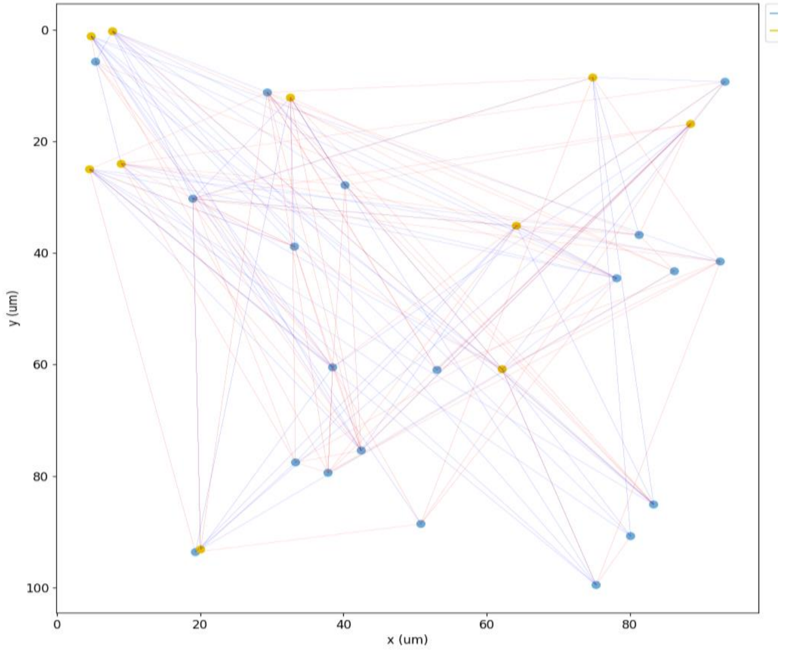
Further Experiments to Try!!!!!!!!!!!☺

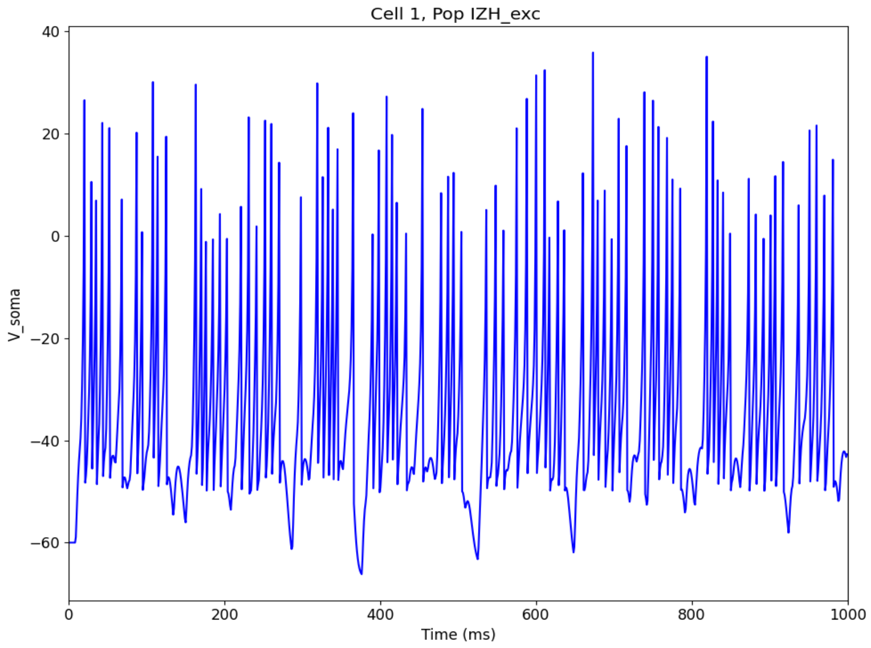
1. *Change connectivity probability (connParams).*
2. *Modify Izhikevich neuron parameters (a, b, c, d).*
3. *Increase inhibition and check its impact on network stability.*

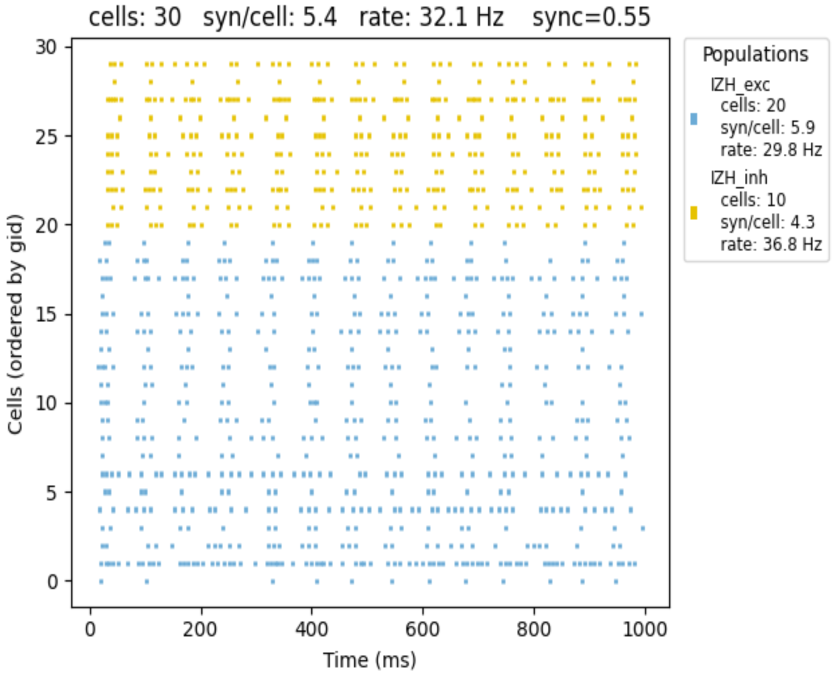
Thank You !! ☺☺☺



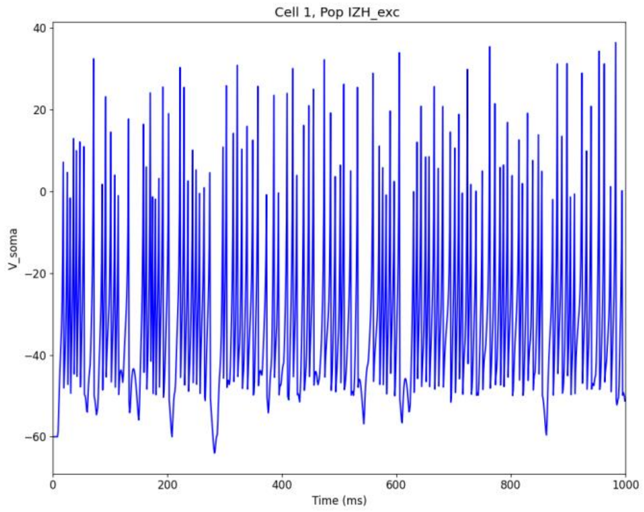
Cell 0, Pop SingleIZH
V_soma
Time (ms)
y (um)
x (um)
cells: 1 syn/cell: 0.0 rate: 33.0 Hz sync=0.97
Populations
SingleIZH
cells: 1
syn/cell: 0.0
rate: 32 Hz
Cells (ordered by gid)
Time (ms)
Cell 1, Pop IZHpop
V_soma
Time (ms)
IZHpop
x (um)
cells: 20 syn/cell: 2.8 rate: 77.2 Hz sync=0.40
Populations
IZHpop
cells: 20
syn/cell: 2.8
rate: 77.2 Hz
Cells (ordered by gid)
Time (ms)



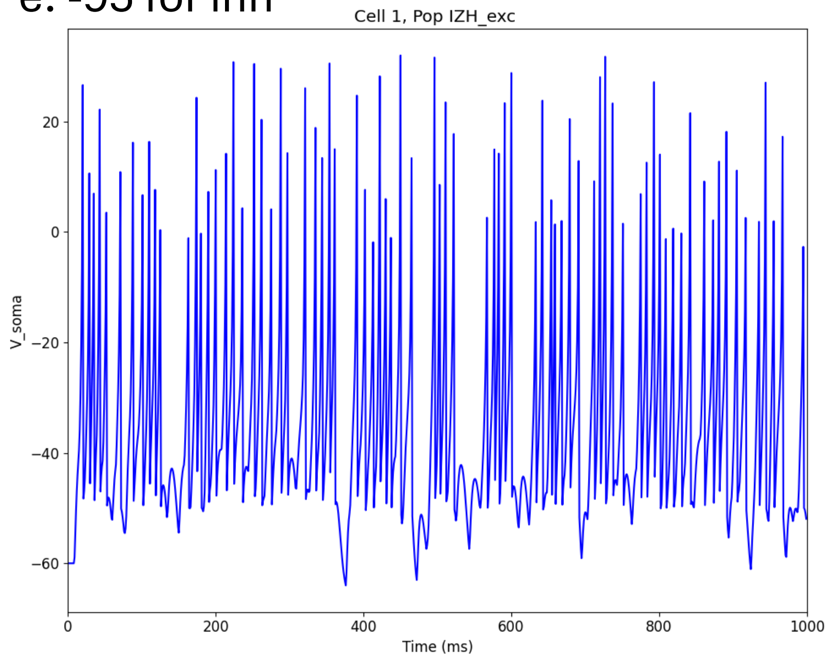


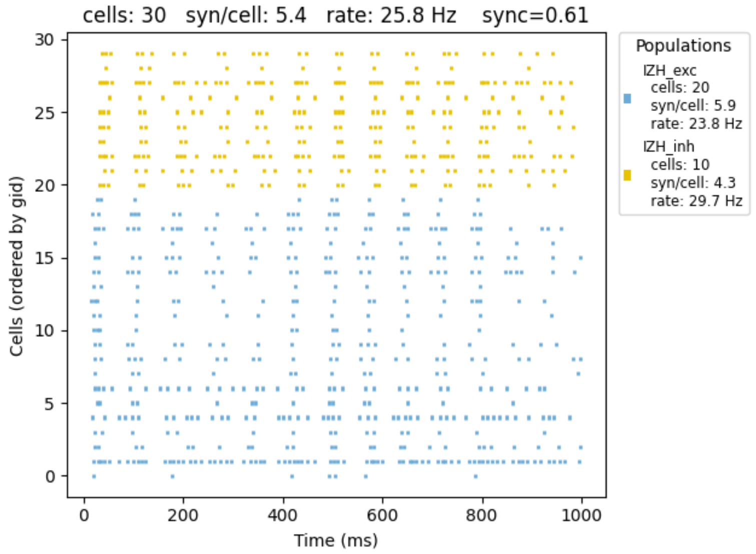


e: 10 for exc



e: -95 for inh





How to Interpret syn/cell?

syn/cell (synapses per cell) = Total number of synaptic connections / Total number of neurons
This value indicates network connectivity:
Higher syn/cell → More synaptic connections per neuron → Denser network.
Lower syn/cell → Fewer synaptic connections per neuron → Sparser network.

Analysis of the Two Raster Plot
First Plot (Single Izhikevich Neuron)Label: syn/cell: 0.0

Meaning:The single neuron has no synaptic connections.
Only external input (IClamp or NetStim) is driving the neuron.

Second Plot (Network of 20 Izhikevich Neurons)Label: syn/cell: 2.8

Meaning:Each neuron, on average, has 2.8 synaptic connections with other neurons.
Networked activity is present, meaning neurons influence each other.
Some neurons receive more input than others due to probabilistic connectivity.
SummaryPlot Neurons syn/cell Value InterpretationFirst Plot 1 (Single Neuron) 0.0 No connectivity, only external input. Second Plot 20 (Network) 2.8
Each neuron has ~2.8 synaptic inputs, showing network activity.
Conclusion: For a single neuron (syn/cell = 0.0) → It only fires due to external input.
For a network (syn/cell = 2.8) → Neurons influence each other, causing network-wide activity.