A BRIEF ANALYSIS OF NEURONAL SYNCHRONIZATION AND CONNECTIVITY

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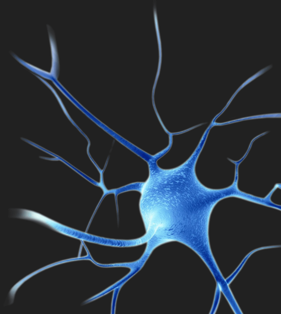
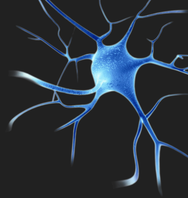
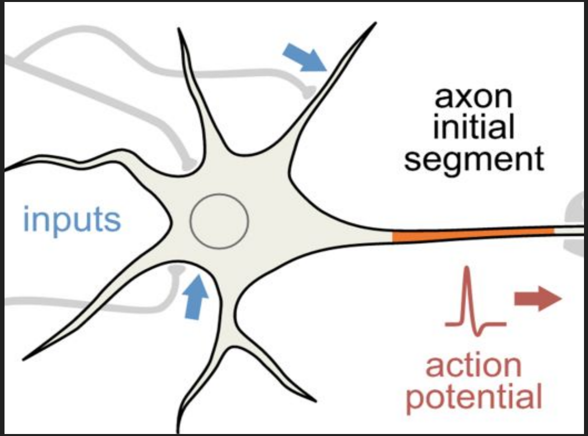
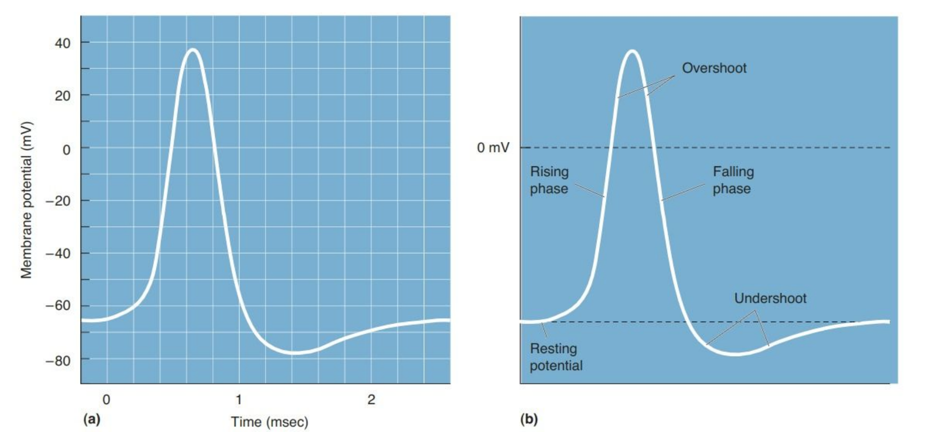




SPIKING NEURONS

- Non-linear firing pattern: take into account the time dynamics of entries and answer generating action potentials in specific moments





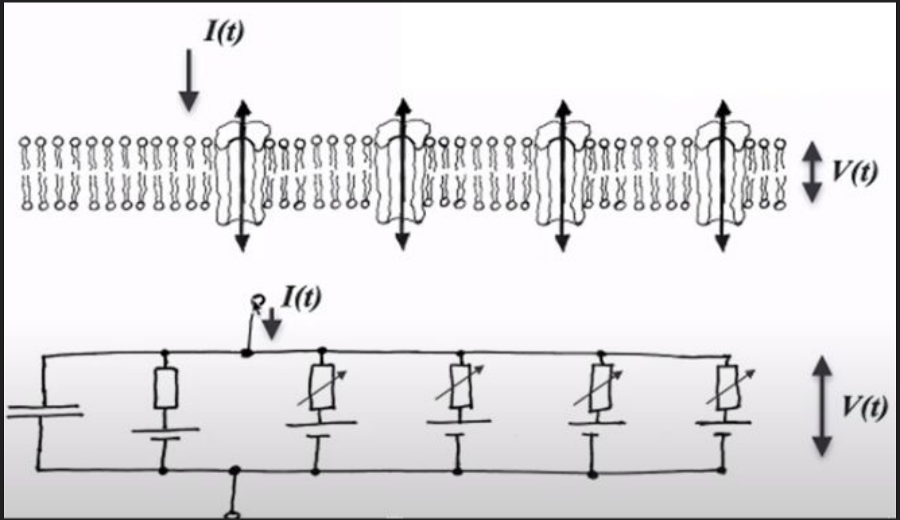
(Bear, M. F., Connors, B. W., & Paradiso, M. A. (2016). Neuroscience: exploring the brain. Fourth edition. Philadelphia, Wolters Kluwer.)

INTEGRATE-AND-FIRE MODEL

- [1] “The model of a single neuron must be (1) computationally simple and (2) capable of producing rich firing patterns exhibited by real neurons.”

- What are these firing patterns? : Integrate-and-fire model

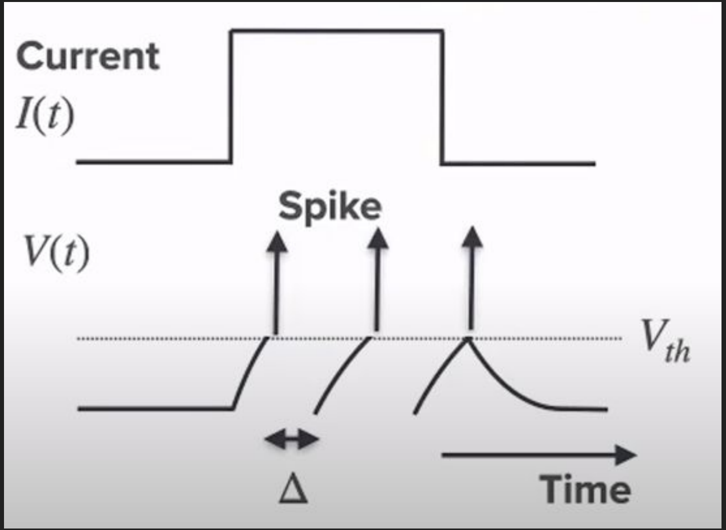
- The model assumes that the neuron integrates incoming signals over time and, once the membrane potential reaches a certain threshold, it "fires" or generates a spike

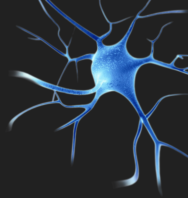


INTEGRATE-AND-FIRE MODEL

- The neuron's membrane potential starts at a resting state and gradually increases as it receives inputs from other neurons or sensory sources

- If the integrated input surpasses a firing threshold, the neuron undergoes a depolarization, resulting in a spike. After firing, the membrane potential is reset, and the process begins again





THE MODEL USED

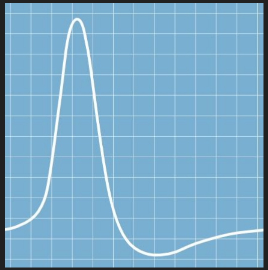
- Biological plausible as the Hodgkin-Huxley model [2] and as computationally efficient as the integrate-and-fire model

- Reduce HH models to 2D-systems of ODE:

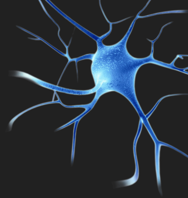
v represents membrane potential of the neuron, u represents a membrane recovery variable

$$v' = 0.04\,v^2 + 5v + 140 - u + I$$

$$u' = a(bv - u)$$



$0.04v^2+5v+140$ obtained by fitting the spiking initiation dynamics of a cortical neuron



THE MODEL USED

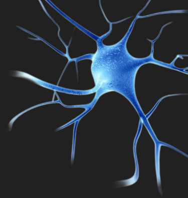
- We use the 2D ODE system with an auxiliary after-spike resetting:

$$if \quad v \geqslant 30\,mV \longrightarrow \begin{matrix} v \leftarrow c \\ u \leftarrow u + d \end{matrix}$$

- What does it mean?

After the spike reaches its apex (30 mV), the membrane voltage and the recovery variable are reset accordingly

v has mV scale, t has ms scale
Resting potential in the model ~60-70 mV



THE MODEL USED

-

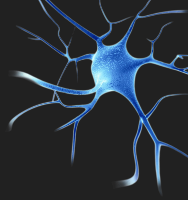
$$v' = 0.04\,v^2 + 5v + 140 - u + I$$

$$u' = a(bv - u)$$

$$if \quad v \geqslant 30\,mV \longrightarrow \begin{array}{l} v \leftarrow c \\ u \leftarrow u + d \end{array}$$

Various choices of the parameters result in different firing patterns!

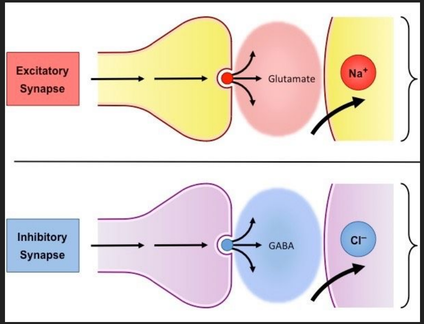
a	b	c	d
Time scale of the recover variable u (tipically ~ 0.02). The larger is a, the faster the firing function will decrease	Sensitivity of the recover variable u to the subthreshold fluctuations of the membrane potential v (tipically ~0.2)	After-spike reset value of the membrane potential caused by fast high-threshold K+ conductances (tipically ~-65 mV)	After-spike reset of the recover variable u caused by slow high-threshold Na+ and K+ conductances (tipically d=2)

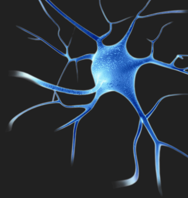


EXCITATORY AND INHIBITORY NEUROTRANSMITTERS

- Excitatory neurons are nerve cells that have the ability to stimulate electrical activity in other neurons (Ne)

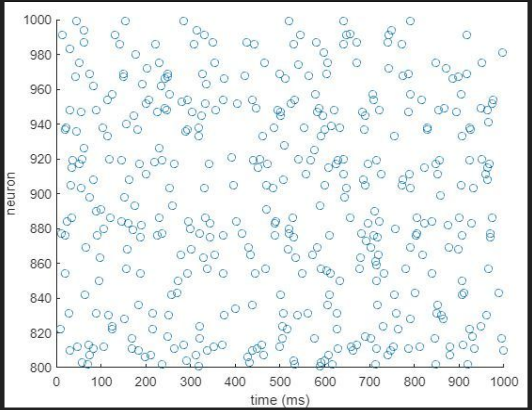
- Inhibitory neurons are nerve cells that have the ability to inhibit or reduce electrical activity in other neurons (Ni)

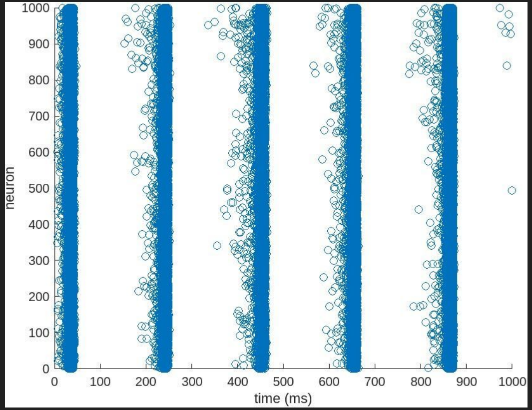


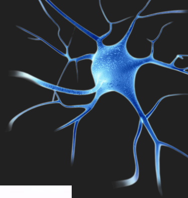


SYNCHRONIZATION

- Coordinated firing of multiple neurons in a network, leading to the generation of rhythmic patterns and enhanced communication within the brain
- When neurons synchronize their activity, they form precise temporal relationships

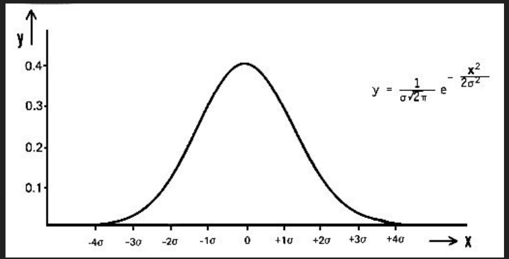


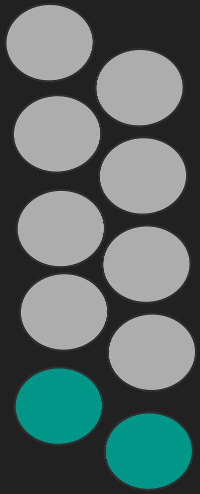




ALGORITHM

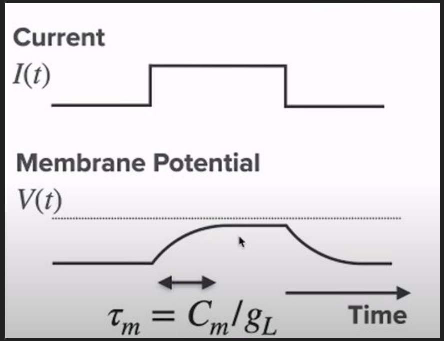
- Ne
- Ni
- Noise
- Peak 30mV (bool)

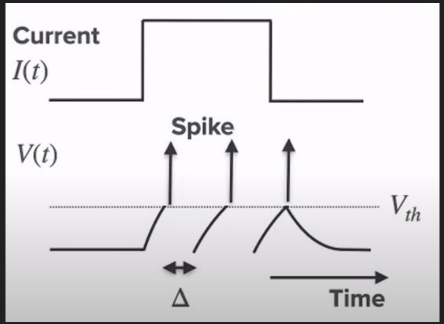




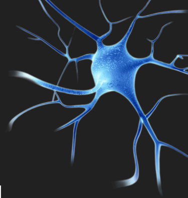
excitatory

inhibitory





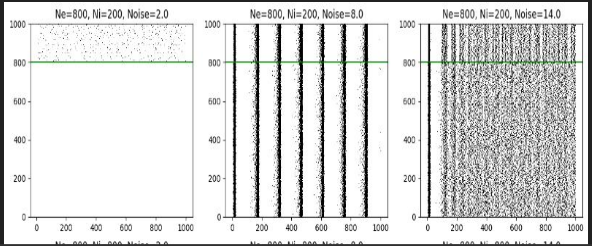
Link to our github project:
github.com/anapaulasandes/nonlineardynamics_school_2023

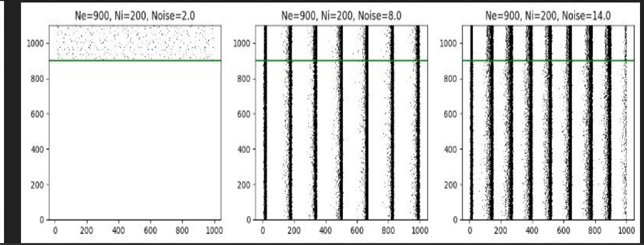


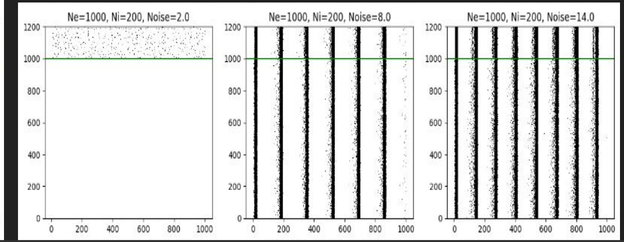
RESULTS

- Synchronization x Noise x Neurons numbers

Ne: [800, 900 e 1000]
Ni: [200, 800, 1000]
Noise: [2, 8, 14]







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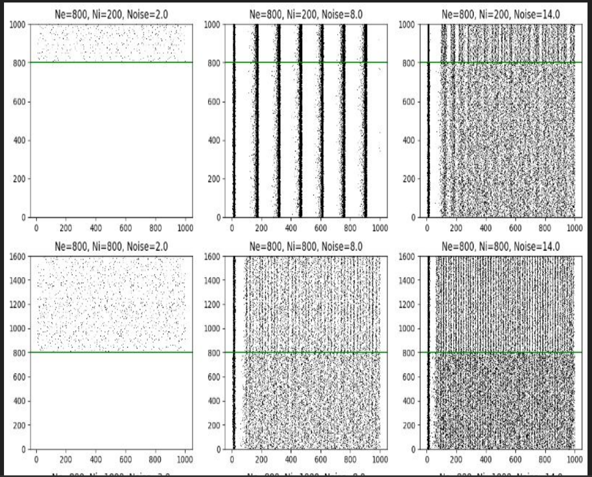

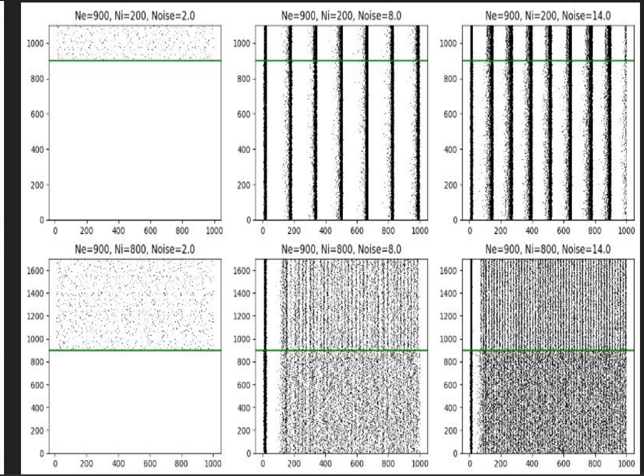

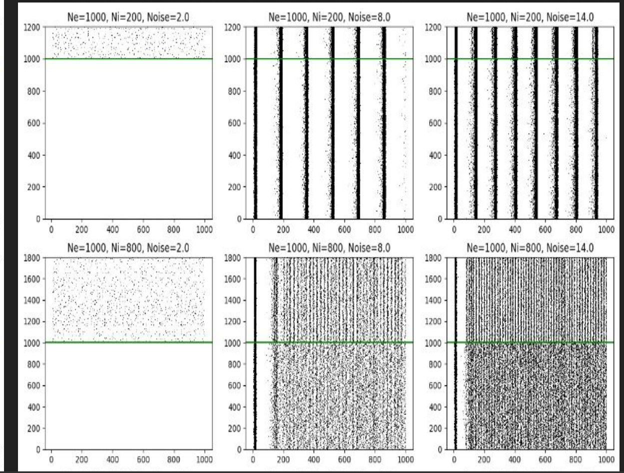

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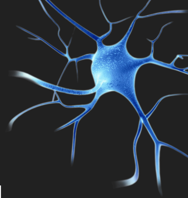

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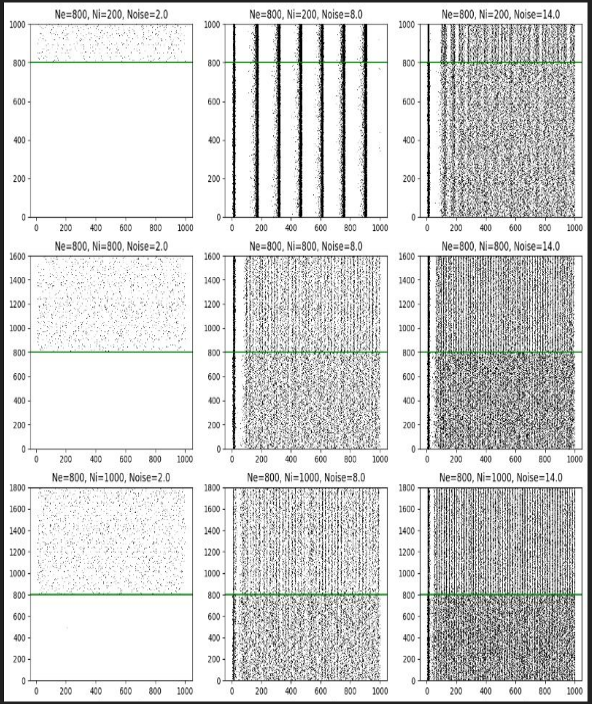
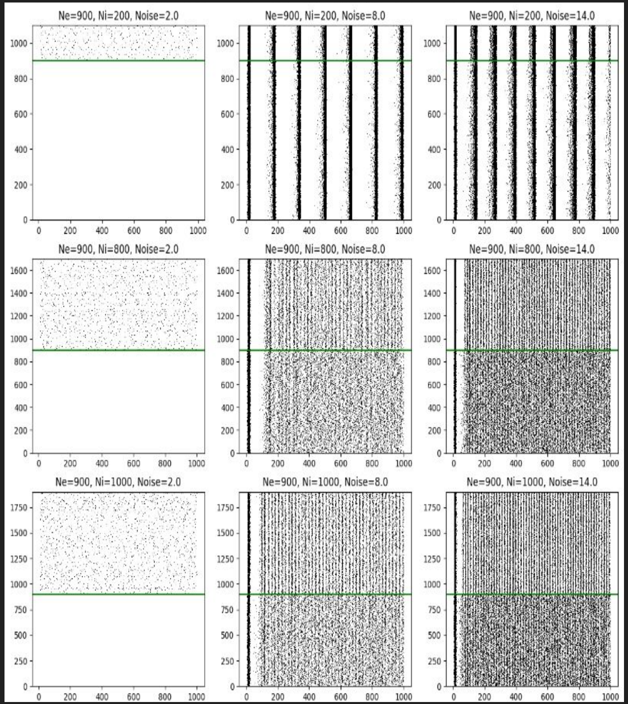
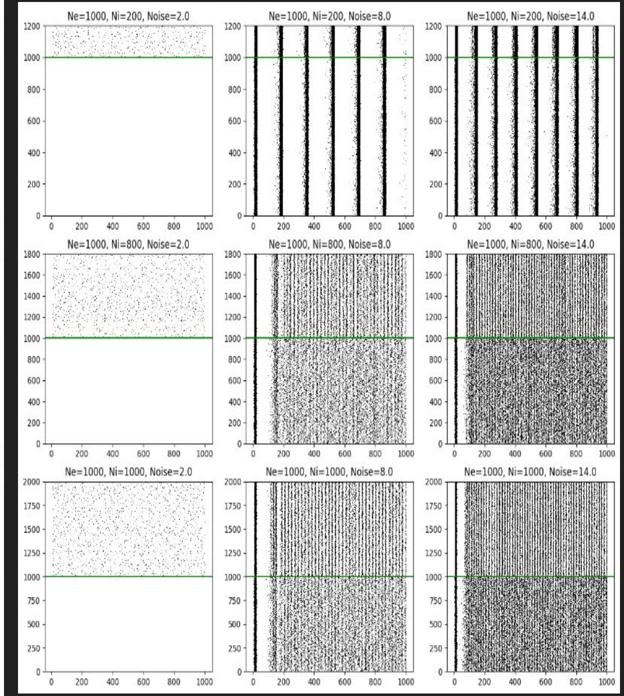
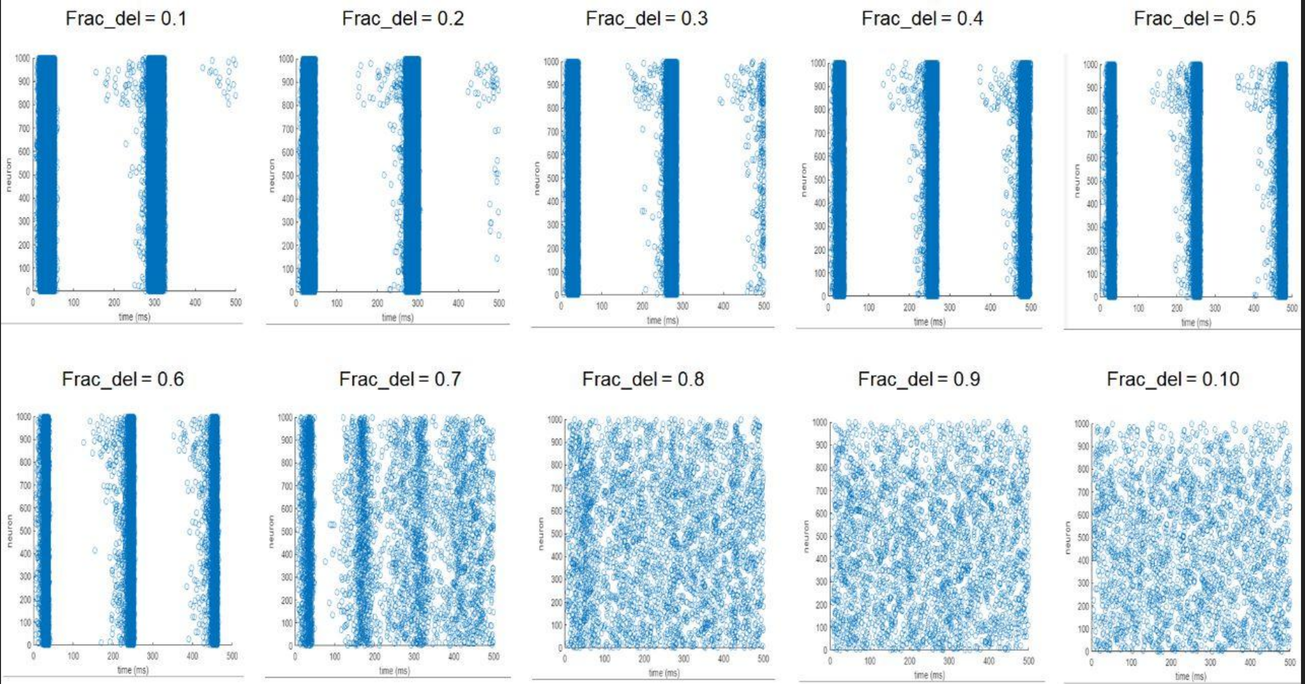






RESULTS

- Synchronization x Fraction delection



RESULTS

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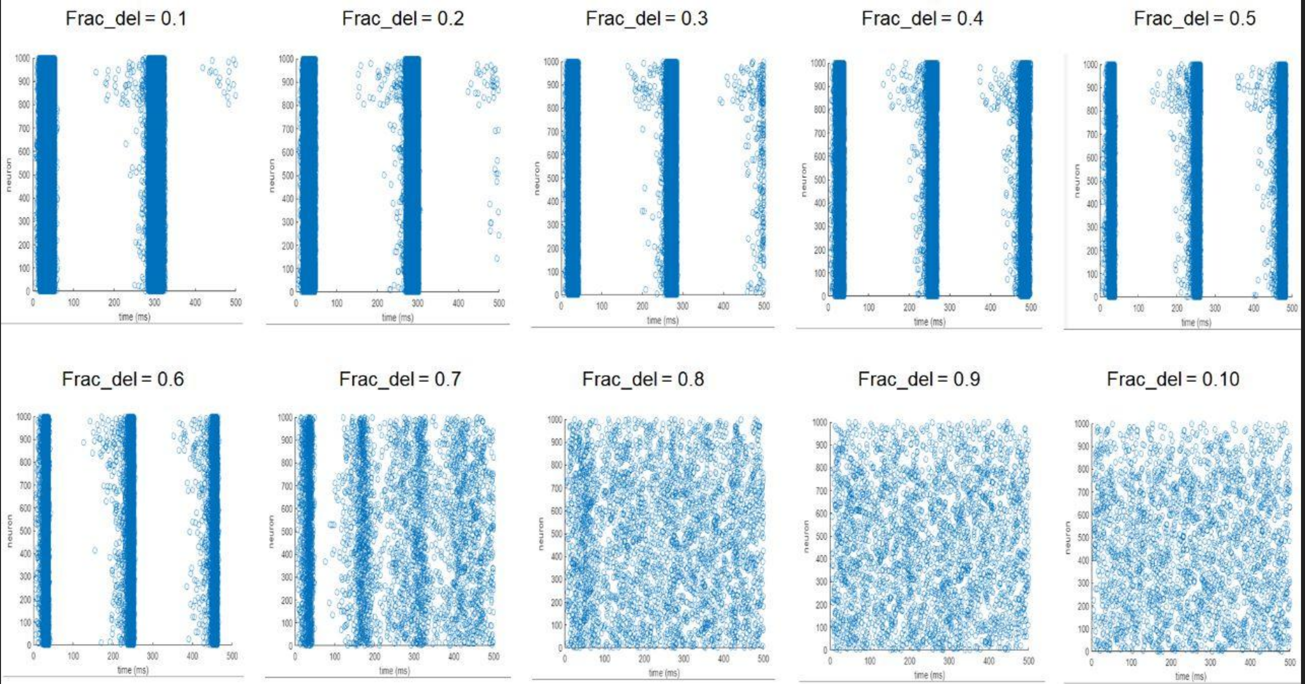

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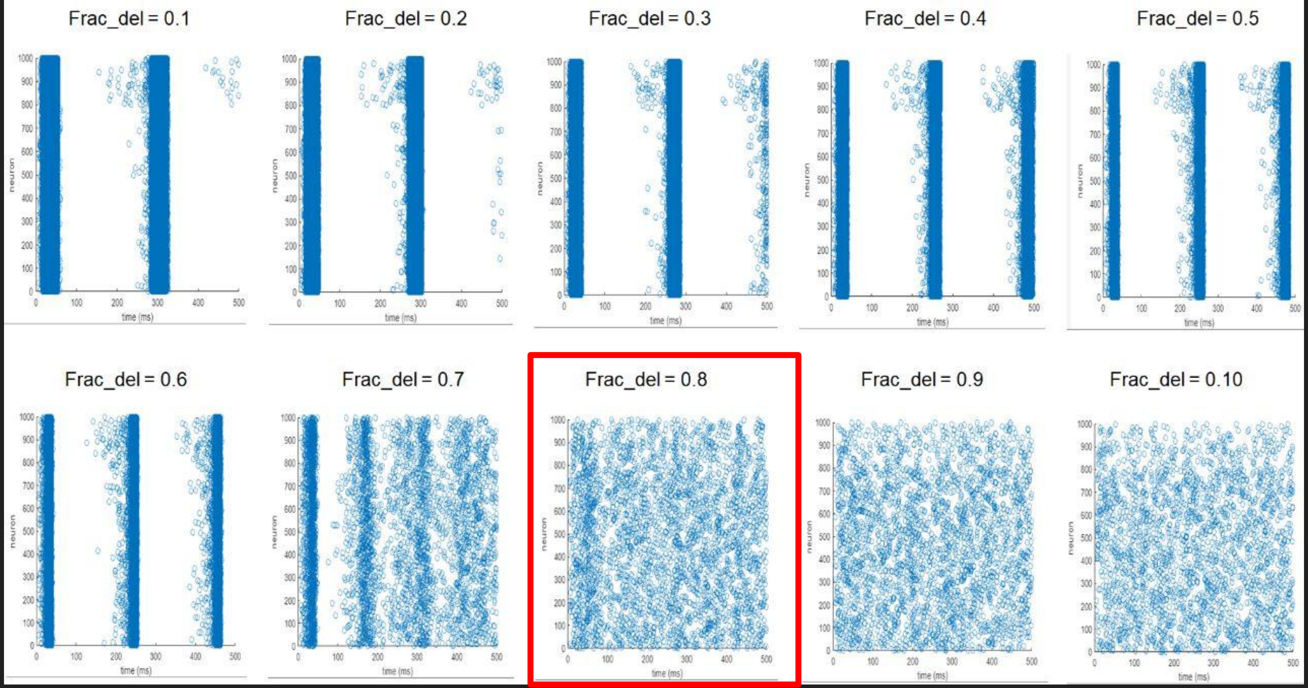
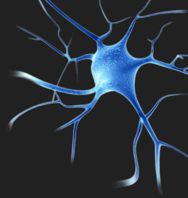
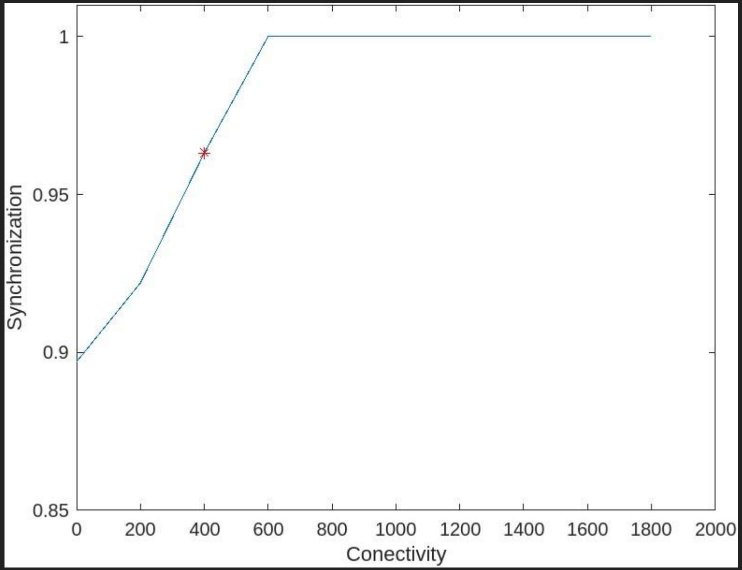




RESULTS

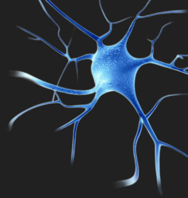
- Synchronization x Connectivity



Connections

$$< k > \; = \frac{2L}{N}$$

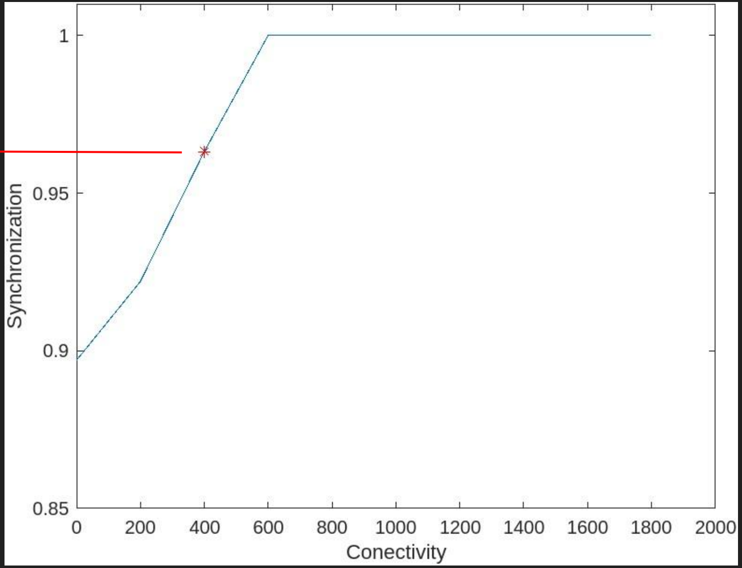
Neurons



RESULTS

- ⬆Synchronization x Connectivity⬆

Threshold



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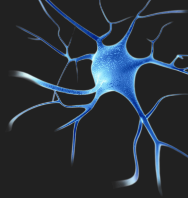


CONCLUSIONS

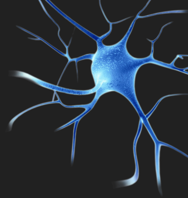
- For this network, synchronization occurs best when:
  - Ne = 2*(Ni)
  - Noise = 8.0
  - Fraction deletion is minimal

- Transition:
  - Fraction deletion = 0.8 (80%)
  - - Connectivity = 400

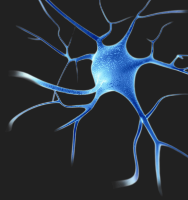
- Desynchronization happened when:
  - Ni > Ne
  - Noise > 14.0

- For bigger values of Ni, the noise simply can't compensate for it

CONCLUSIONS



Synchronization is directly influenced by the connections between the network and we can establish a threshold to know the transition from synchronized to desynchronized



REFERENCES

[1] Simple model of spiking neurons (Eugene M. Izhikevich)

[2] A quantitative description of membrane current and its application to conduction and excitation in nerve (A. L. Hodgkin and A. F. Huxley)

[3] Neuroscience: exploring the brain (Bear, M. F., Connors, B. W., & Paradiso, M. A.)