Spatial Information Encoding

The human brain has an incredible ability to represent the world around us in a spatial manner. This fundamental fact led neuroscientists to seeks to understand how the brain encodes and processes spatial information.

Spatial information encoding is a complex process that involves various neurological mechanisms and structures. Researchers are actively investigating the underlying principles and mechanisms behind this fascinating phenomenon.
And here I'm going to show my humble work in this field.

by Anton Pasternak

Head-Direction Cells In Rats

Head direction cells are a type of neuron found in the brains of rats and other animals that fire action potentials in correlation with the animal's perceived head orientation in their environment. These cells play a critical role in the animal's sense of spatial awareness and navigation, helping them find their way in their surroundings.

The firing rate of head direction cells increases as the animal's head points in the preferred direction of the cell and decreases as the head moves away from that direction.

By monitoring the activity of neural cells, we can determine if they are head-direction cells or not by compering them to the actual head direction of the rat.

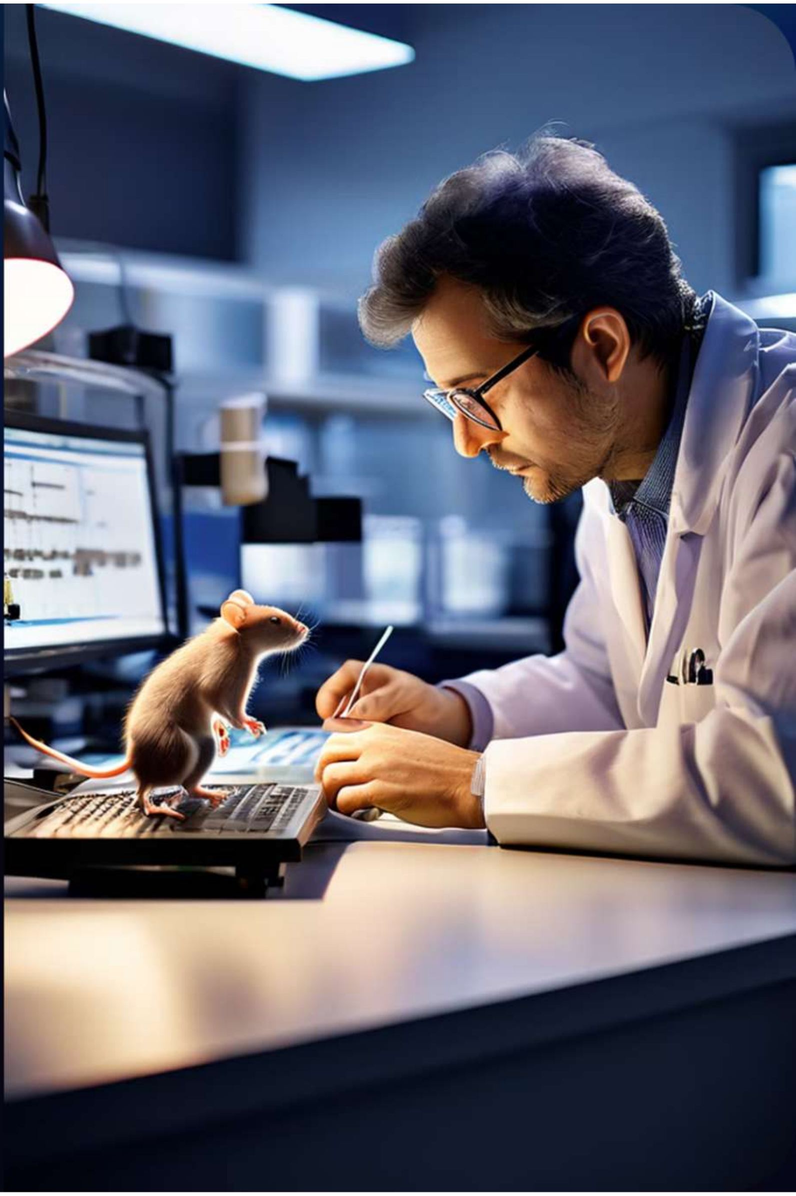
This is what I will try to do in the next slides.

Investigating and Classifying Neurons

I took data from 6 neurons of a rat, that were measured while it was roaming around a squared arena.

I'll try to analyze the neuronal behavior and decide whether each neuron is a head-direction cell or not.

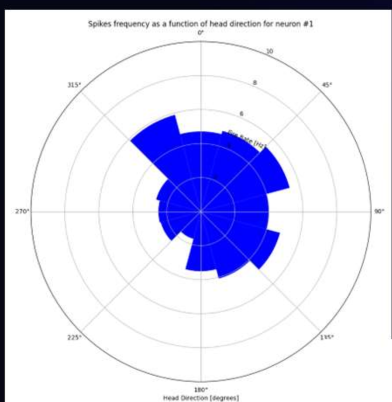
I'll do so by examining their firing rate as a function of the actual head direction and when I'll have neurons that I suspect could be head-direction neurons I'll permutate the data in a way that'll hopefully get rid of the effects of randomization.

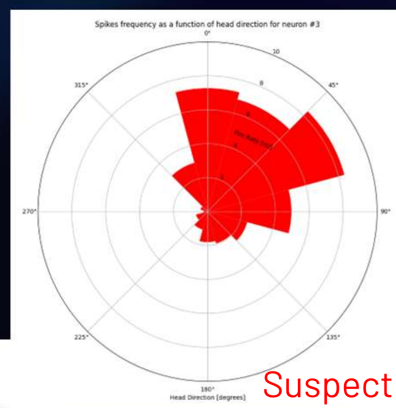


Neurons Firing Rate as a Function of Head Direction

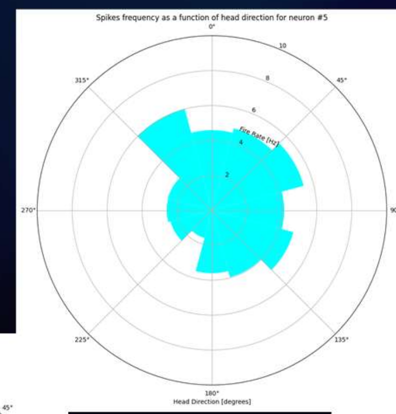
I've sectioned the head-direction data of 360 degrees, into 12 sections (like a clock) for comfort reasons, while each section is of 30 degrees.

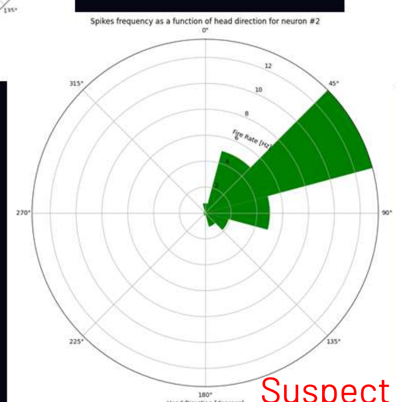
For a neuron to be suspected as a head-direction cell its behavior should show that it fires at a maximum rate for a specific head direction section whilst the firing rate decreases as head direction deviates from this peak, where min is at the furthest deg from max.



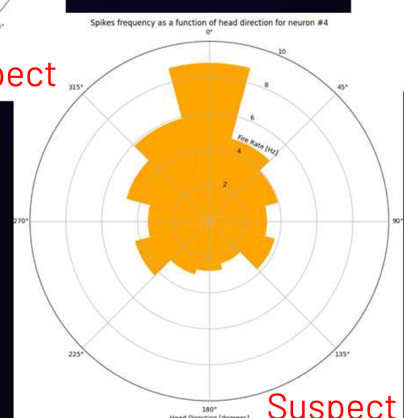


Suspect

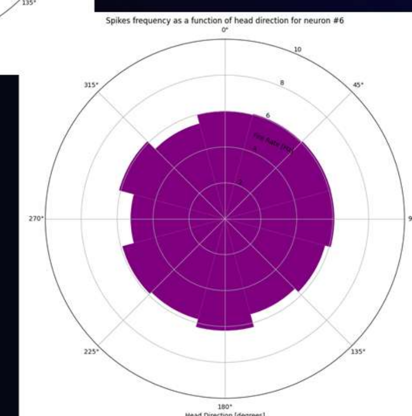




Suspect

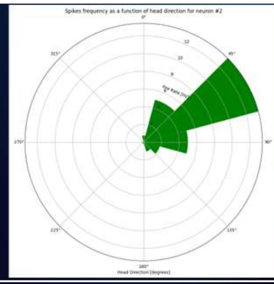
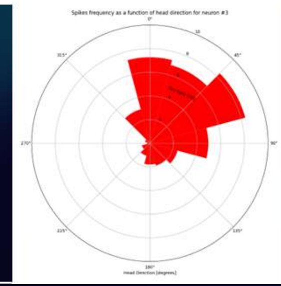
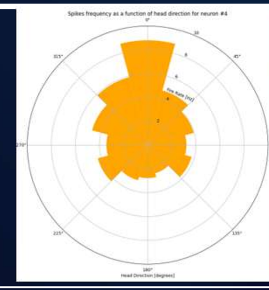
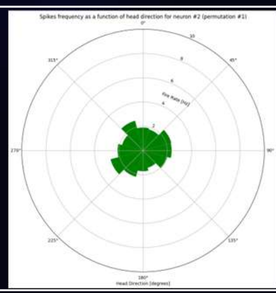
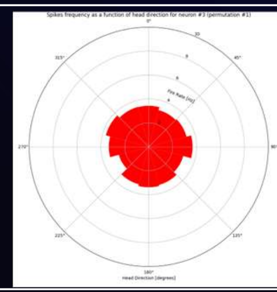
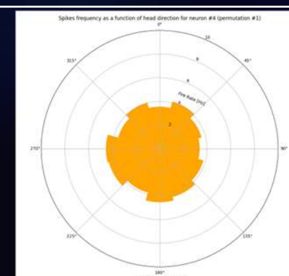
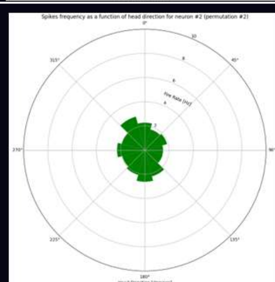
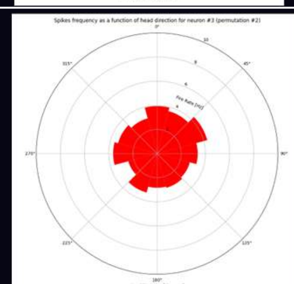
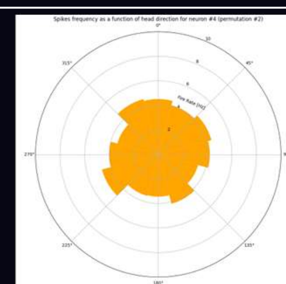


Suspect



Analysis of the Data

Tabulating the data and permutating the spiking intervals

	Neuron #2	Neuron #3	Neuron #4
Original Suspect			
Initial Suspicion	Fires at the direction of “2-o’clock” (~60 deg)	Fires at general direction of “straight left“ (~0 to ~60 deg)	Fires at the direction of “12-o’clock” (~0 deg)
Permutation #1			
Permutation #2			

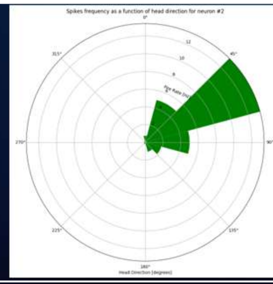
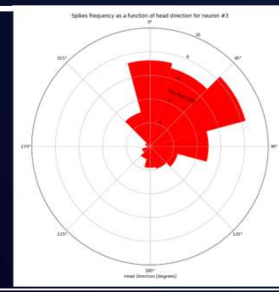
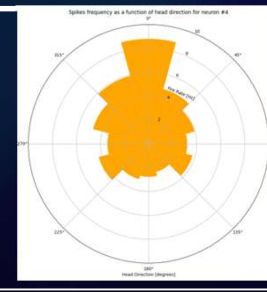
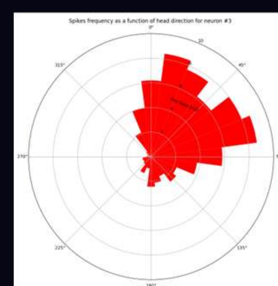
~ : means “around”, ±15deg

Analysis of the Data - Classification

~ : means “around”, ±15deg

~~ : ±7.5deg

Time to classify neurons as head direction cells.

	Neuron #2	Neuron #3	Neuron #4
Original Suspect			
Initial Suspicion	Fires at the direction of “2-o’clock” (~60 deg)	Fires at general direction of “straight left” (~0 to ~60 deg)	Fires at the direction of “12-o’clock” (~0)
Classification	Directional Neuron ~60 deg	Bi-directional Neuron (~~15 deg and ~~75 deg)	Directional Neuron
Main Reason	Original graph + Permutations	Permutations + this graph of 24 section instead of 12: 	Original graph + Permutations

Circular Neural Network - Basic Data Data

In this part I take 50 neurons that are interconnected to each other and are organized in a circle.

I'll show some interesting behaviors that a network like this shows.

The main formula I used looks like this:

$$\tau\frac{dr_i}{dt} = -r_i + f(I_{inj} + \sum_{j}^{50} W_{ij} r_j)$$

This formula shows the firing rate [Hz] of each neuron as a function of time [msec].

Circular Neural Network – More Data

$$\tau \frac{dr_i}{dt} = -r_i + f(I_{inj} + \sum_{j}^{50} W_{ij} r_j)$$

$$f(x) = \begin{cases} 0, & x < 0 \\ x, & x \geq 0 \end{cases}$$

$$W_{i,j} = \exp\left(-\frac{d_{ij}^2}{\sigma_1^2}\right) - w * \exp\left(-\frac{d_{ij}^2}{\sigma_2^2}\right)$$

$$\tau = 1$$

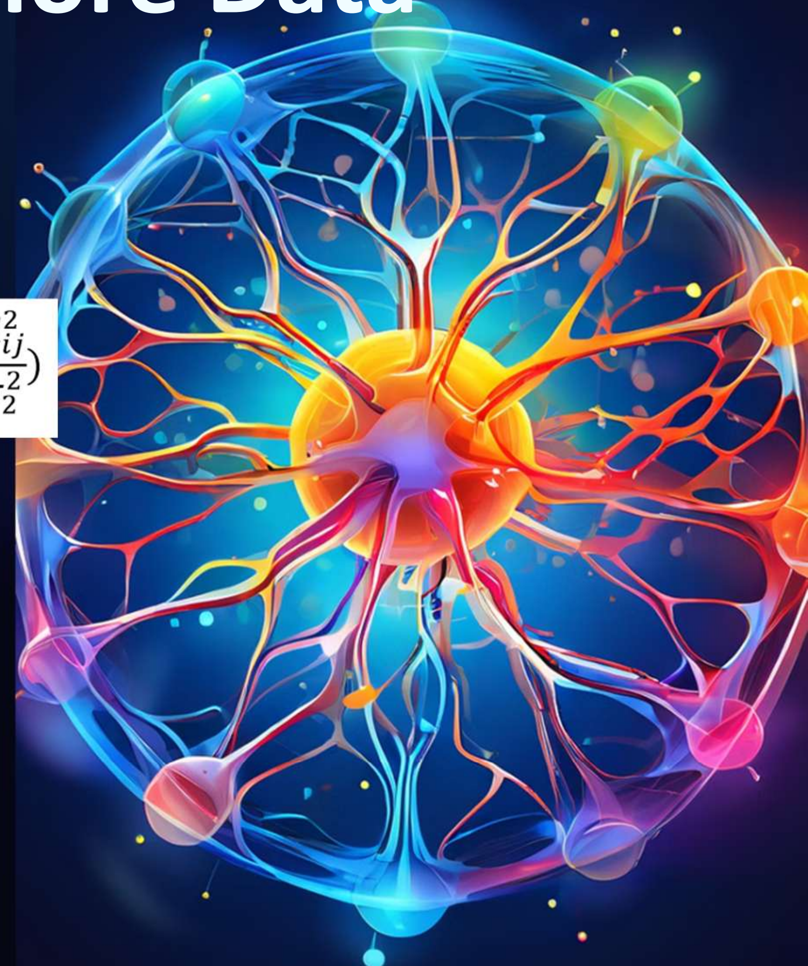
$$\sigma_1 = 30$$

$$\sigma_2 = 60$$

$$w = 0.2$$

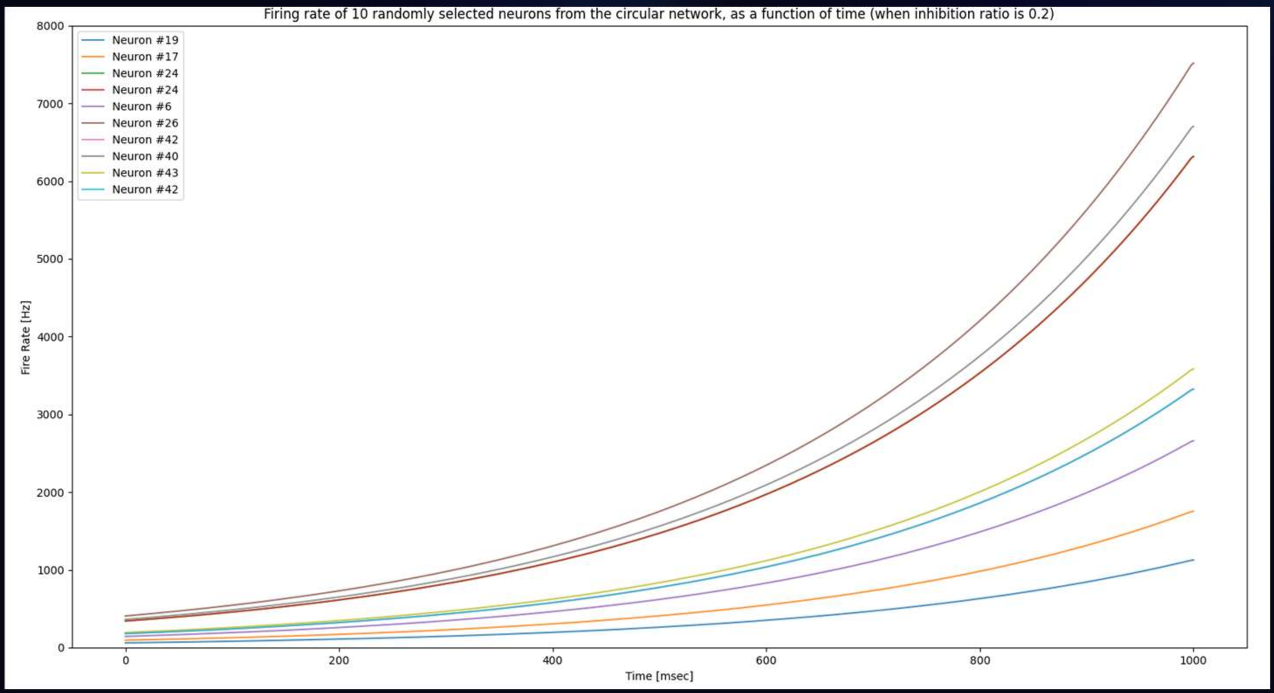
d_{ij}= the "distance" between the neurons on the circle

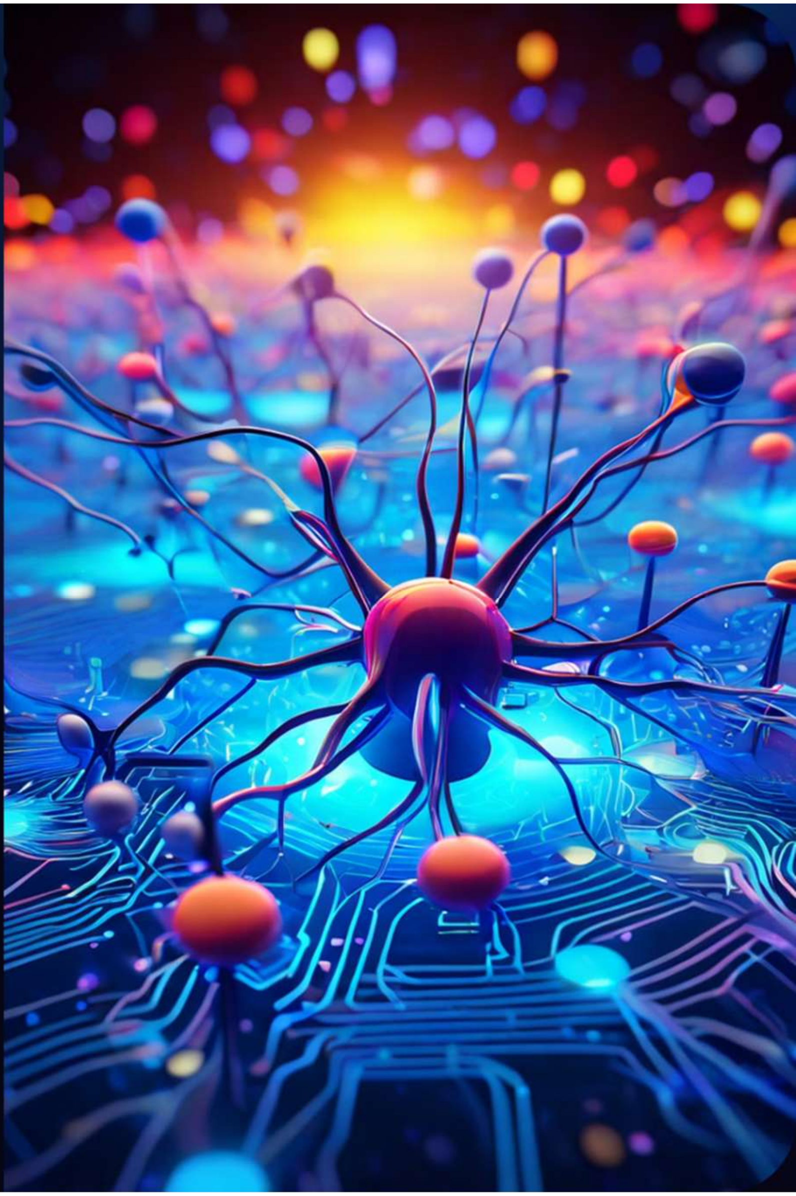
Using these formulas and Euler approximation technique I drew the graphs of some of the 50 neurons, which I'll show next.



Circular Neural Network – Graphs

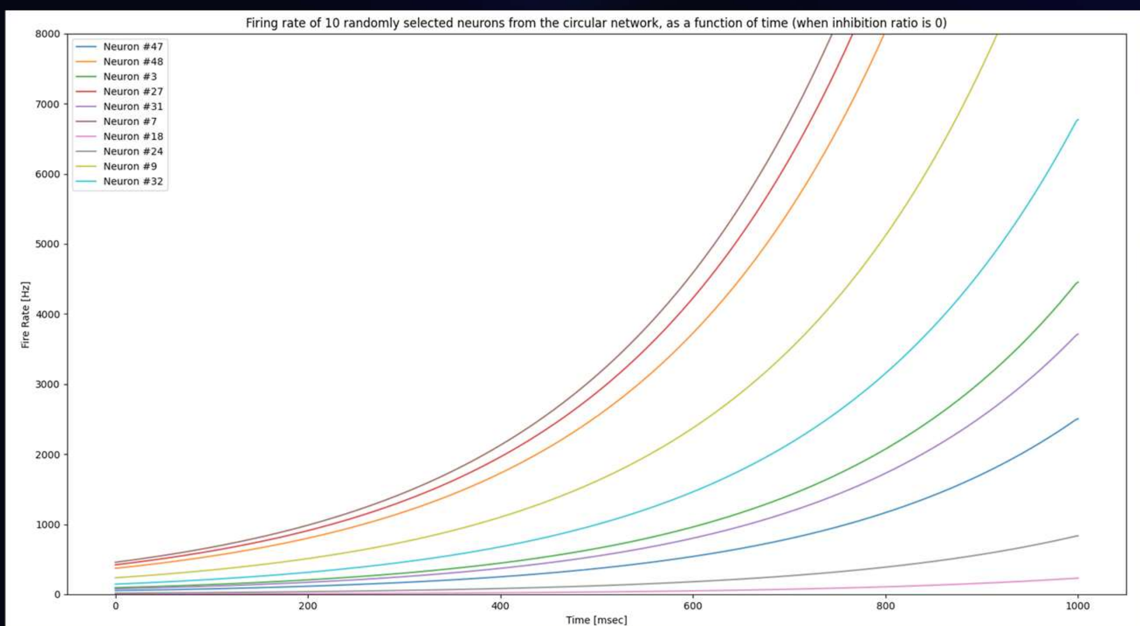
Using these formulas and Euler approximation technique I drew the graphs of 10 of the 50 neurons. The initial firing rate values of each neuron was randomly Generated to be between 0 and 500 [Hz]

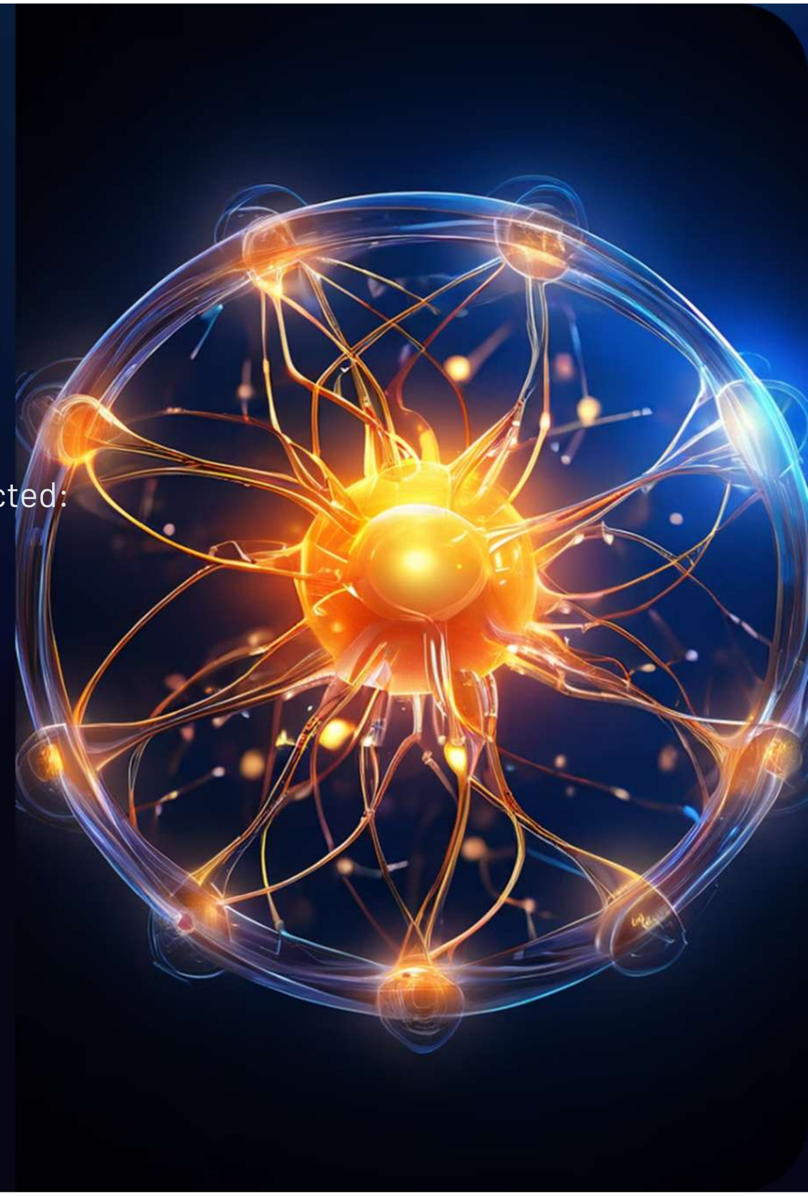




Circular Neural Network - Removing Inhibition

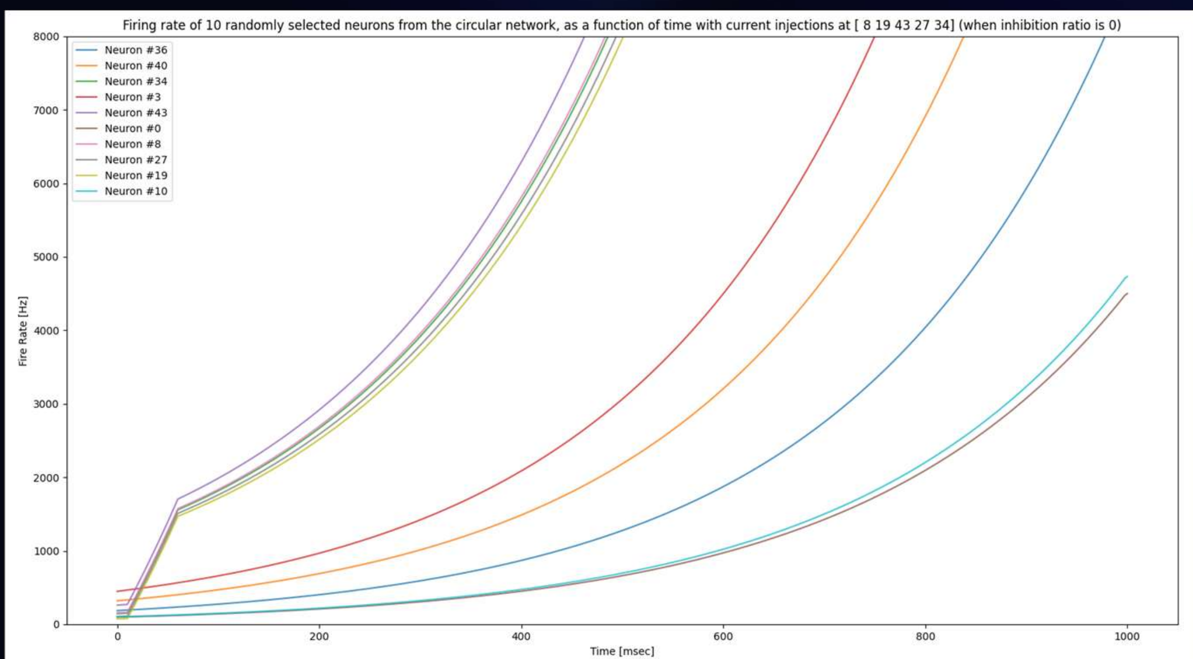
We saw earlier that the network was infinitely growing, and it is to be expected when the ratio of inhibition to excitation (w) is only 0.2. Here I'm simulating the network without inhibition (w=0) that means that the ascension towards infinity will be faster. We can see that all the graphs are steeper in their ascension, as predicted:

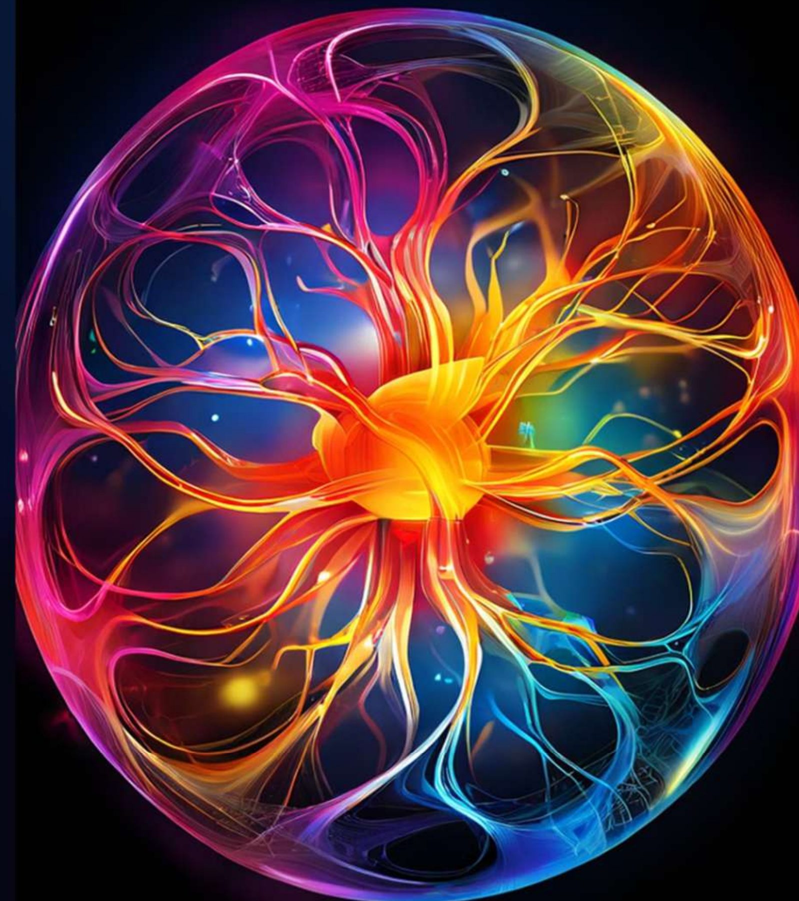




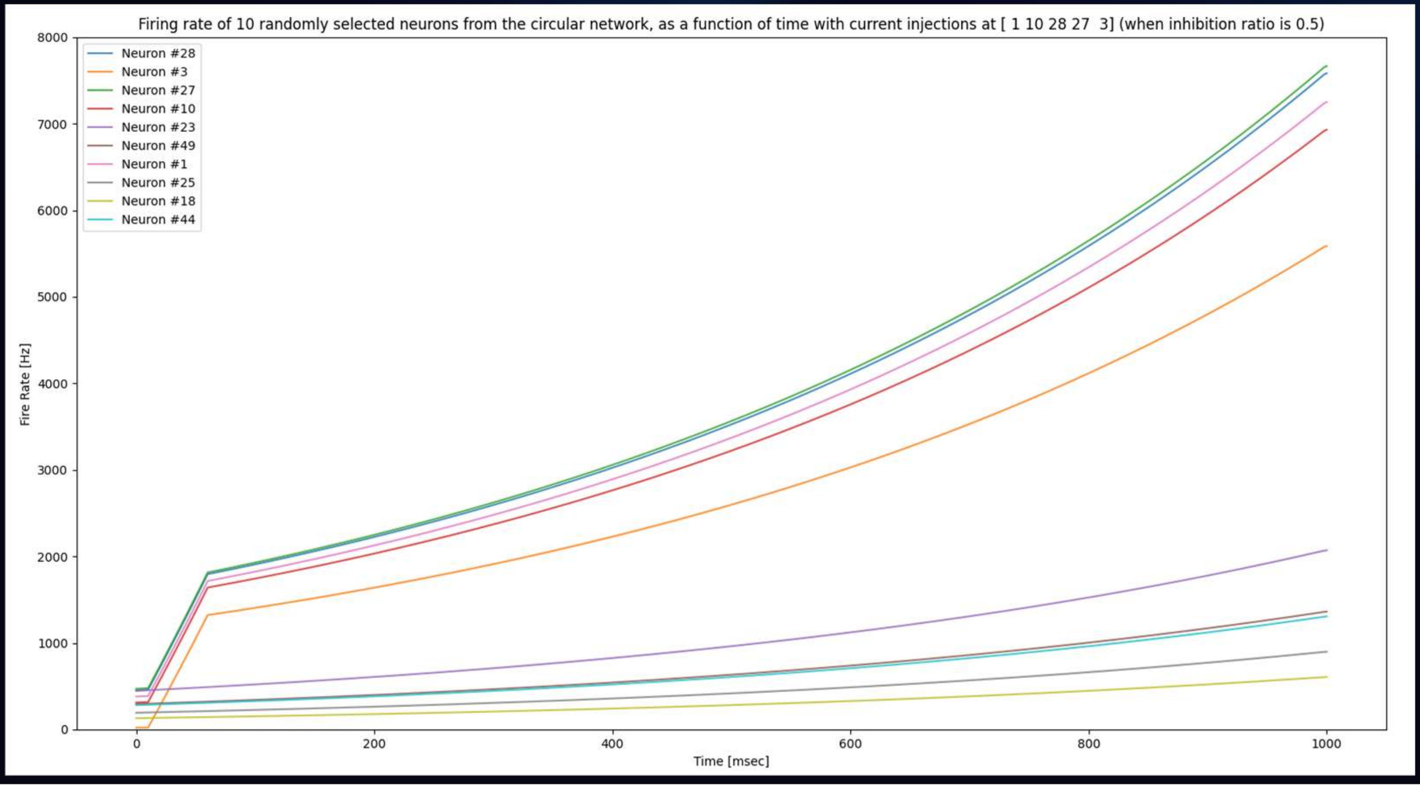
Circular Neural Network - Investigation of Interesting Phenomena

Here I wanted to explore what values of w can make neurons that got injected with a huge current (250,000[nA]), nullify it instead of infinitely amplify it in a positive feedback loop. Here I take the previous graph (w=0) and next I'll start to increase w until I reach my goal.





Circular Neural Network – Increasing Inhibition to Nullify Externally injected Current

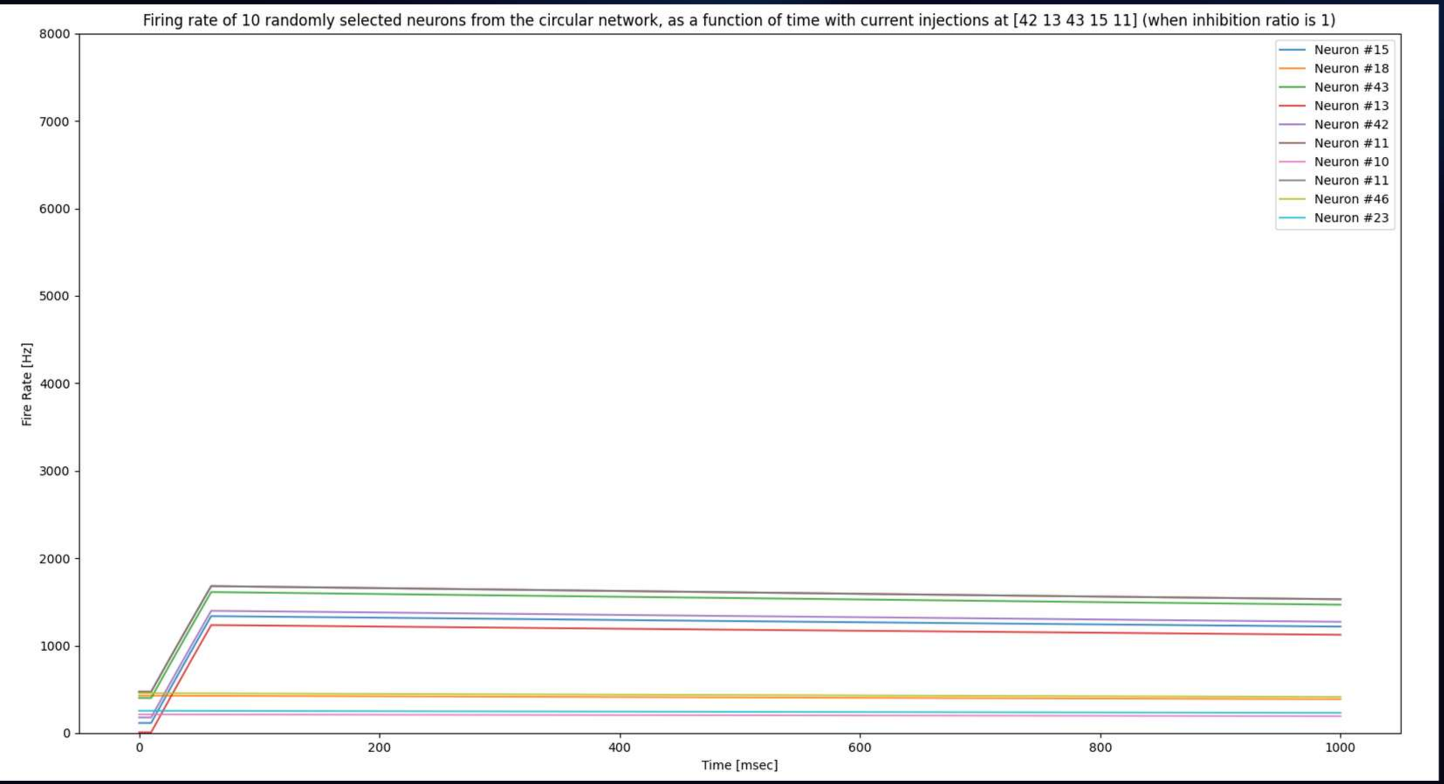


w = 0.5

The ascension is a little less steep.

Next, I'll double w.

Circular Neural Network – Increasing Inhibition to Nullify Externally injected Current

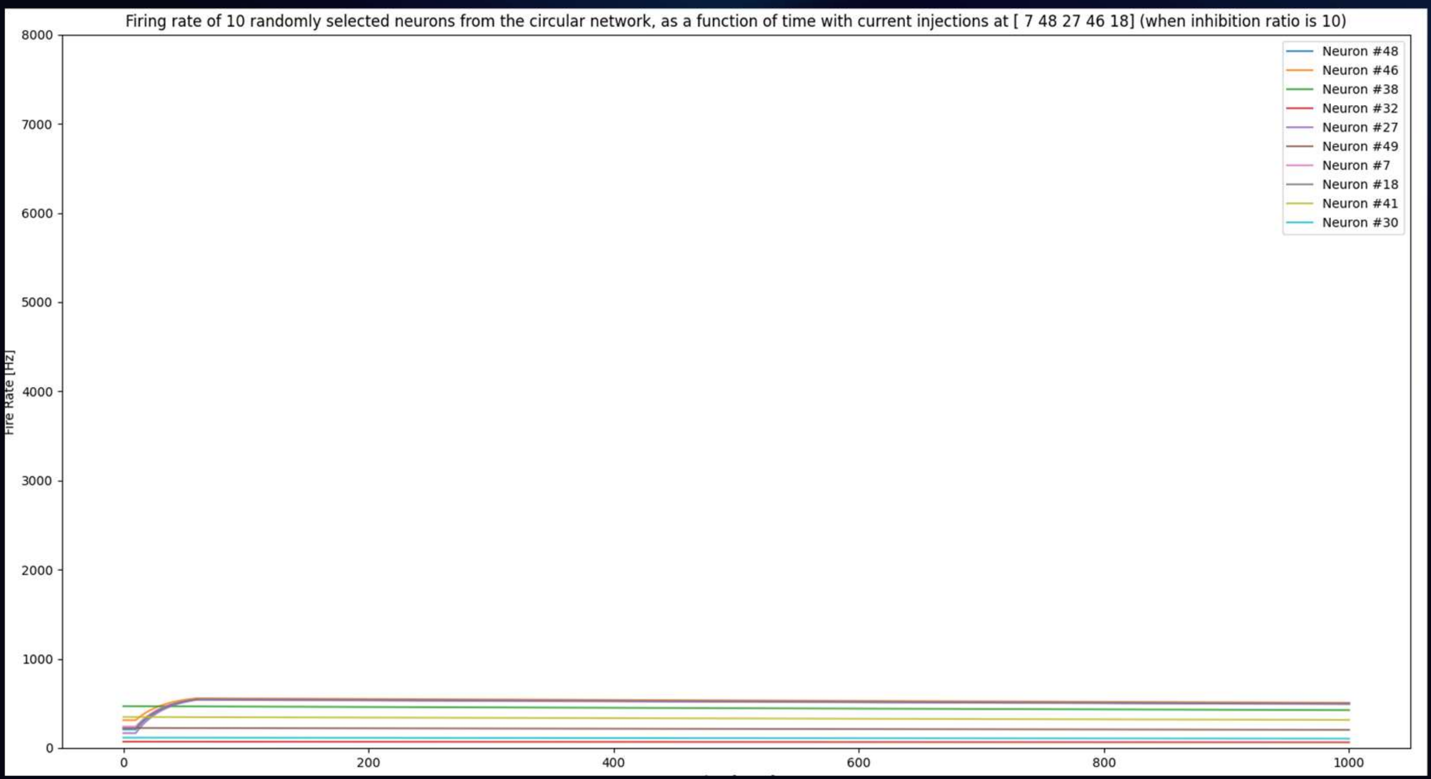


w = 1

Here we can see that the ascension stopped but I still want the current to be nullified, and I still see it.

Next, I'll increase by ten folds.

Circular Neural Network – Increasing Inhibition to Nullify Externally injected Current

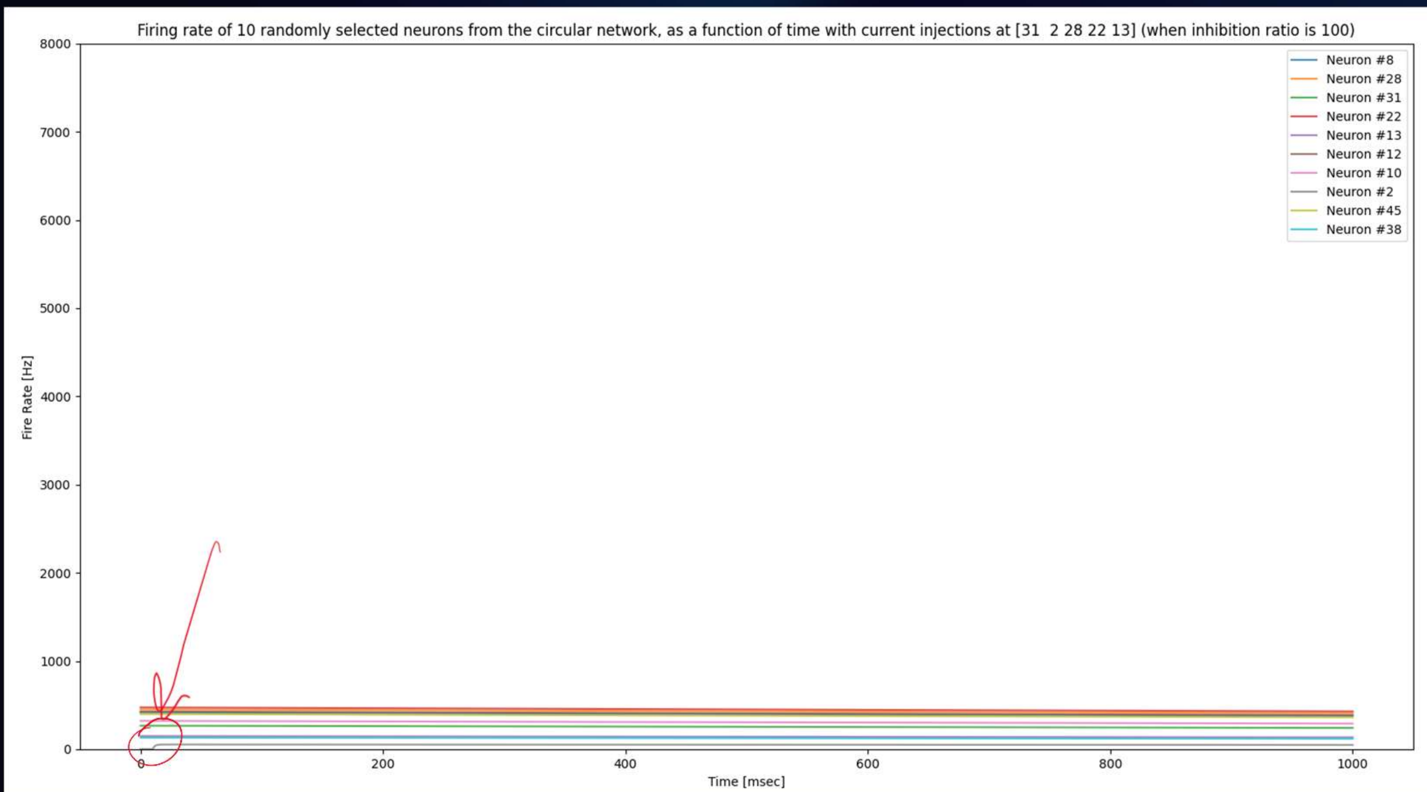


w = 10

I still see the currents affect.

Next, I'll increase by MORE ten folds.

Circular Neural Network – Increasing Inhibition to Nullify Externally injected Current

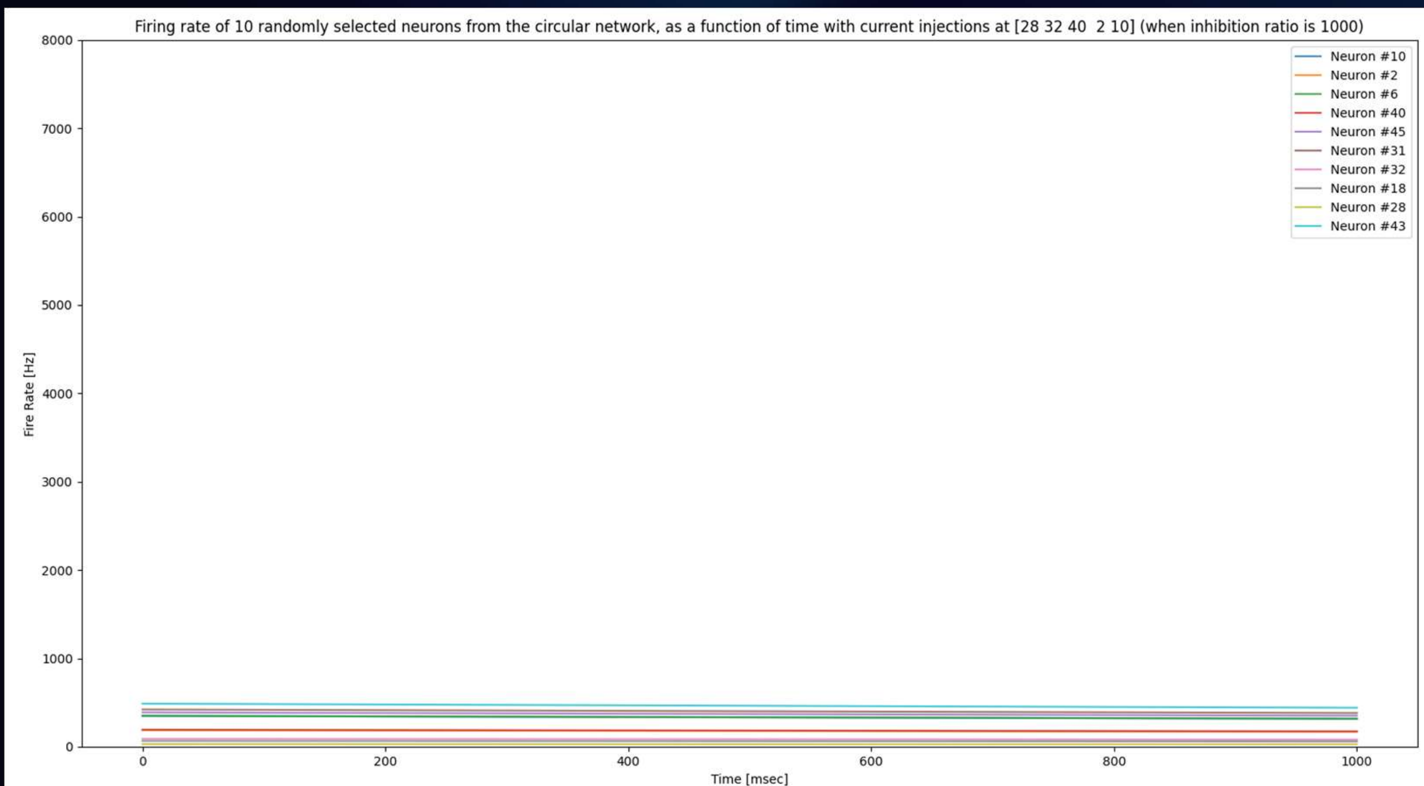


w = 100

I STILL SEE IT.

Next, I'll increase by EVEN MORE ten folds.

Circular Neural Network – Increasing Inhibition to Nullify Externally injected Current

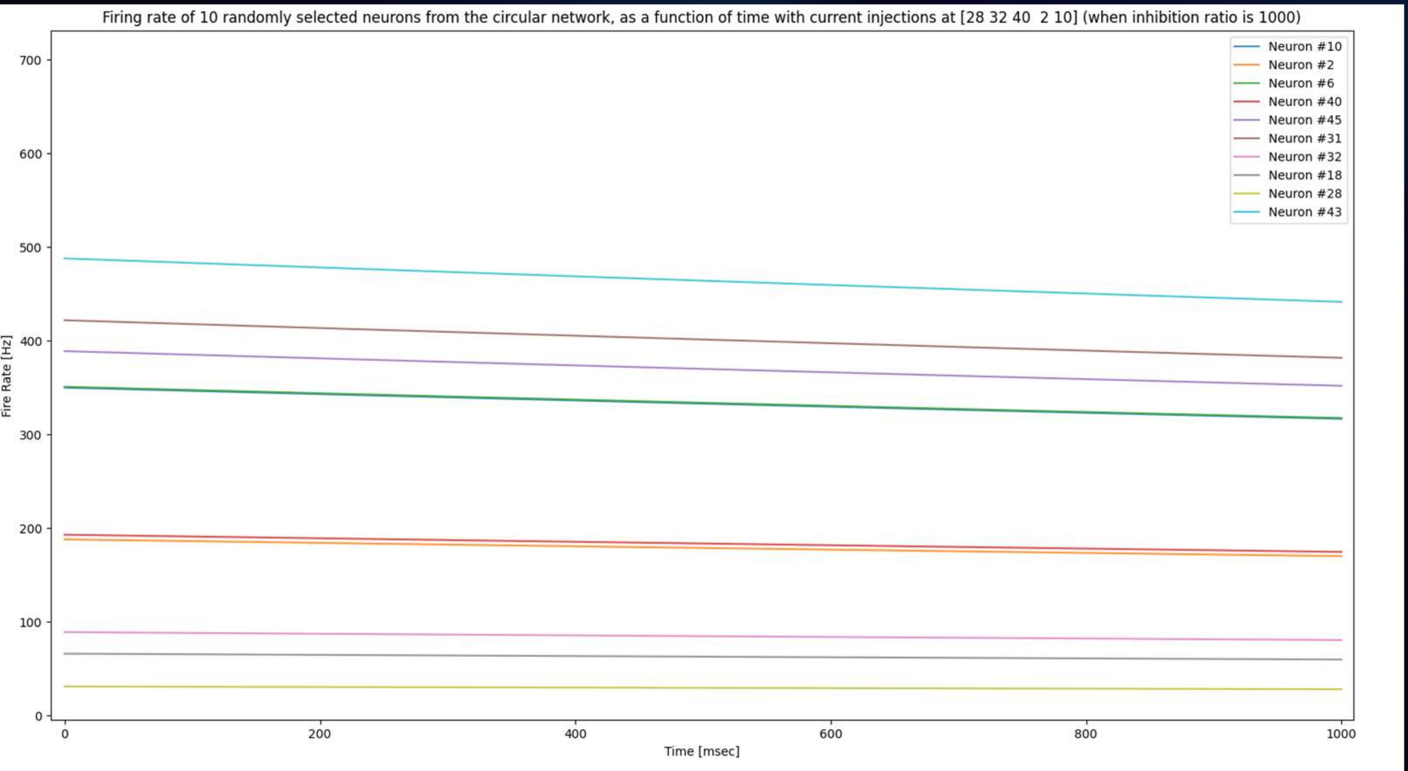


w = 1000 !!!

I see no current, hmm maybe it's hiding,

Next, I'll zoom in

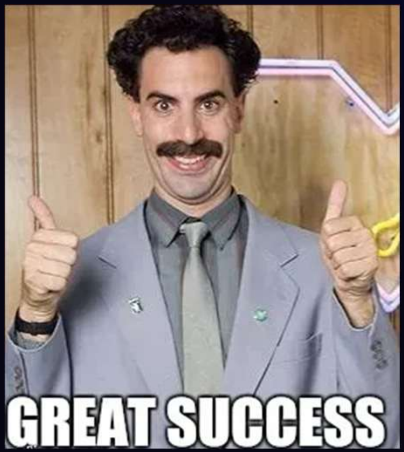
Circular Neural Network – Increasing Inhibition to Nullify Externally injected Current



w = 1000

I see no affect of the current even after the zoom in.

Success.



Thank you for reading