Circular Neural Network – The vestibular system model

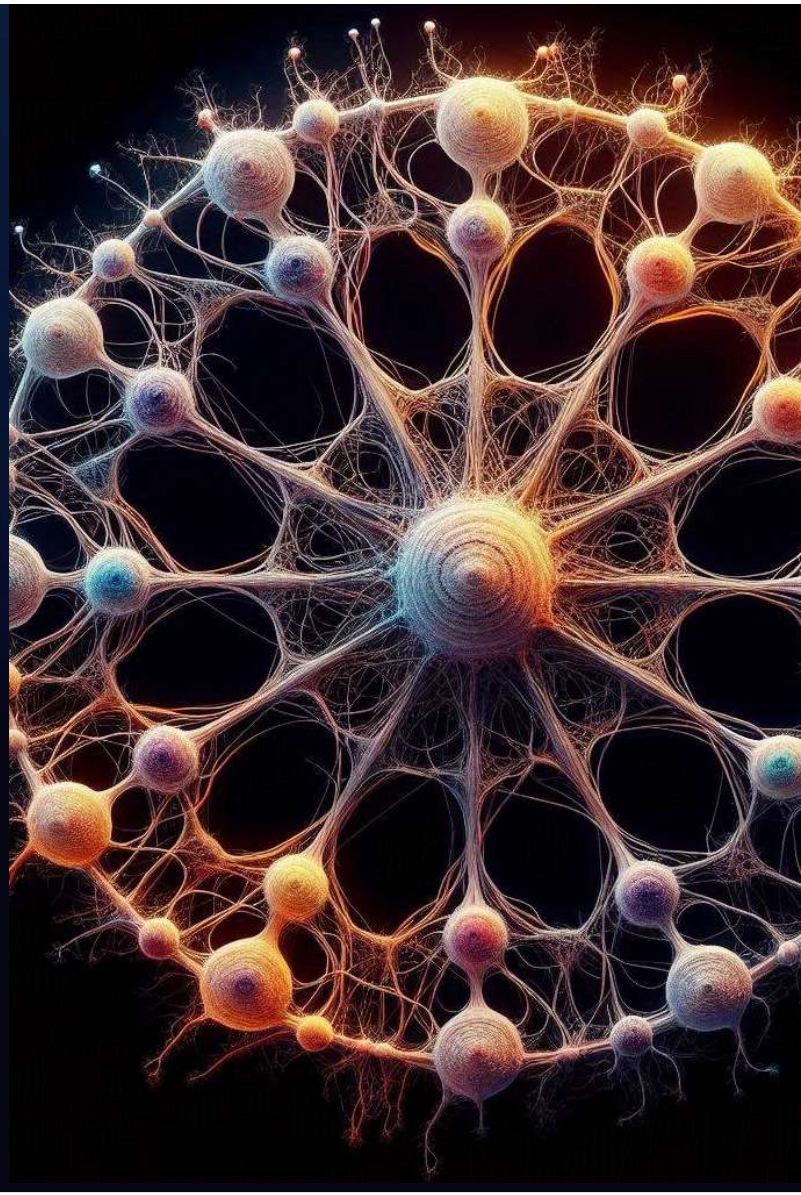
In this part I'll visit again a circular neuron network which consists of 200 neurons that are interconnected to each other. I'll show two variations of this network when a shift is applied to it and finally I'll connect all three versions together in order to simulate a model that represents the way the brain remembers which direction he is at, by the sensory signals that come from the vestibular system.

This is the main formulas that I attempt to recreate in python code:

$$\tau \frac{dr_i^{\text{main}}}{dt} = -r_k^{\text{main}} + \text{f}\left(\sum_i^{200} W_{kj} r_j^{\text{main}} + \sum_h^{200} W_{kh} r_h^{\text{left}} + \sum_n^{200} W_{kn} r_n^{\text{right}} \right)$$

$$\tau \frac{dr_i^{\text{left}}}{dt} = -r_k^{\text{left}} + \text{f}\left(\sum_i^{200} W_{kj} r_j^{\text{main}} + \sum_h^{200} W_{kh} r_h^{\text{left}} + \sum_n^{200} W_{kn} r_n^{\text{right}} \right) + I_{\text{left}}$$

$$\tau \frac{dr_i^{\text{right}}}{dt} = -r_k^{\text{right}} + \text{f}\left(\sum_j^{200} W_{kj} r_j^{\text{main}} + \sum_h^{200} W_{kh} r_h^{\text{left}} + \sum_n^{200} W_{kn} r_n^{\text{right}} \right) + I_{\text{right}}$$



Circular Neural Network – More Data

$$\tau \frac{dr_i}{dt} = -r_i + f\left(\sum_{j=1}^{N} W_{ij} r_j\right)$$

Here on the left, is the original formula that turned into the those ones down here:

$$\tau \frac{dr_i^{\text{main}}}{dt} = -r_k^{\text{main}} + f\left(\sum_{i}^{200} W_{kj} r_j^{\text{main}} + \sum_{h}^{200} W_{kh} r_h^{\text{left}} + \sum_{n}^{200} W_{kn} r_n^{\text{right}}\right)$$

$$\tau \frac{dr_i^{\text{left}}}{dt} = -r_k^{\text{left}} + f\left(\sum_{i}^{200} W_{kj} r_j^{\text{main}} + \sum_{h}^{200} W_{kh} r_h^{\text{left}} + \sum_{n}^{200} W_{kn} r_n^{\text{right}}\right) + I_{\text{left}}$$

$$\tau \frac{dr_i^{\text{right}}}{dt} = -r_k^{\text{right}} + f\left(\sum_{j}^{200} W_{kj} r_j^{\text{main}} + \sum_{h}^{200} W_{kh} r_h^{\text{left}} + \sum_{n}^{200} W_{kn} r_n^{\text{right}}\right) + I_{\text{right}}$$

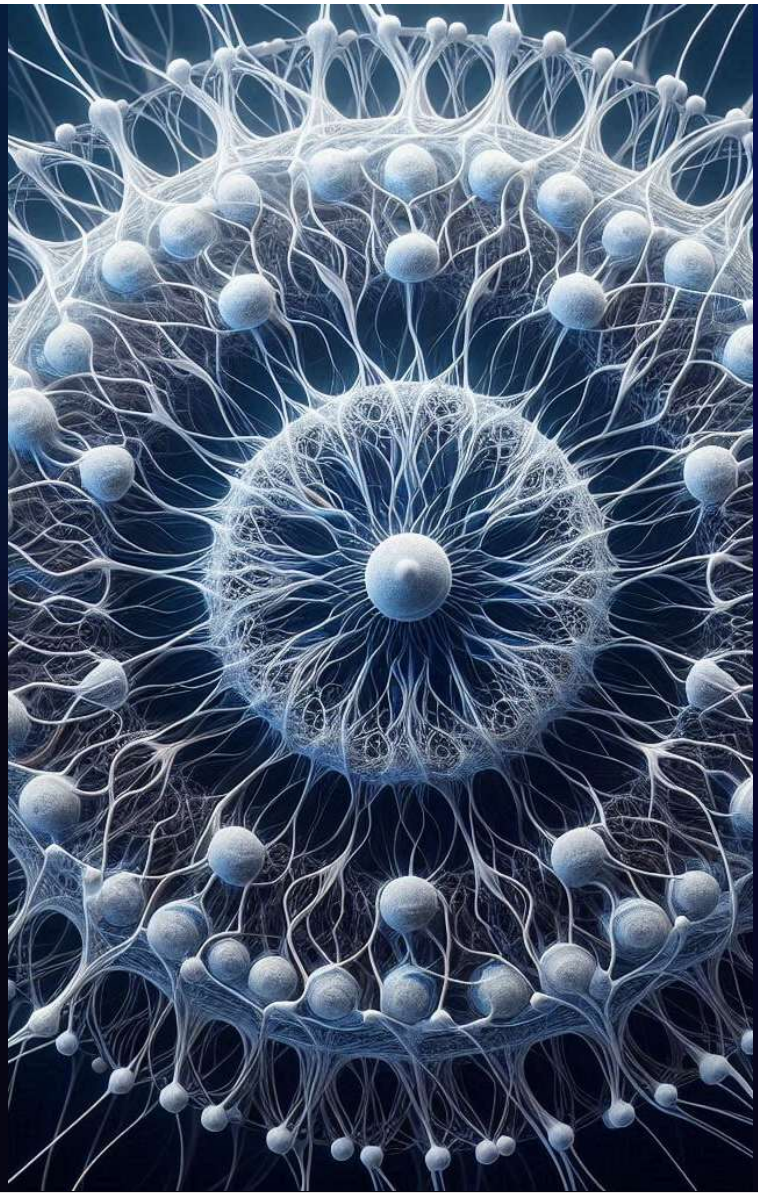
$$\tau = 1$$

$$W_{i,j} = \exp\left(-\frac{d_{ij}^2}{\sigma_1^2}\right) - 0.1$$

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

d_{ij}= the “distance” between the neurons on the circle

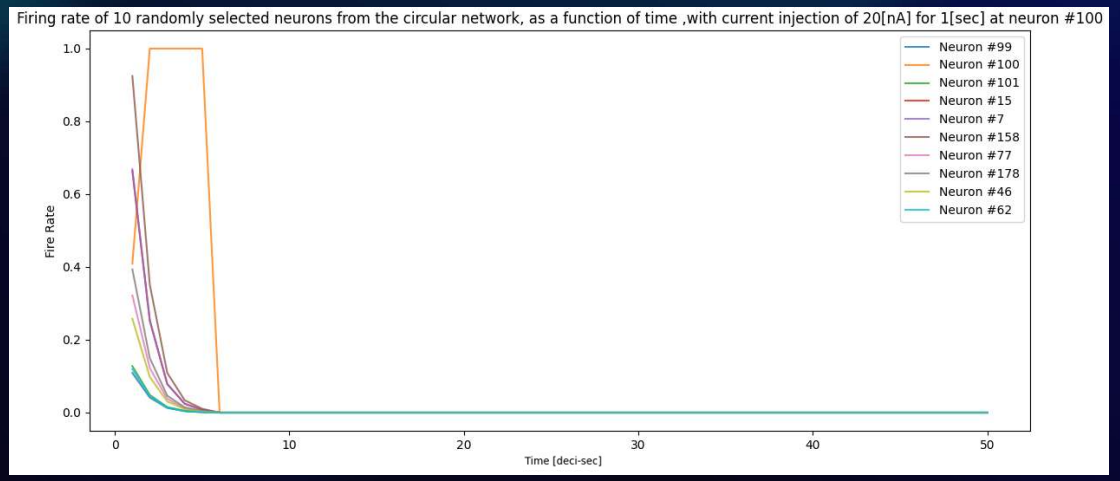
Using these formulas and Euler approximation technique I generated the data of 200 neurons each time (and finally all 600 neurons), and I’ll show some graphs next.

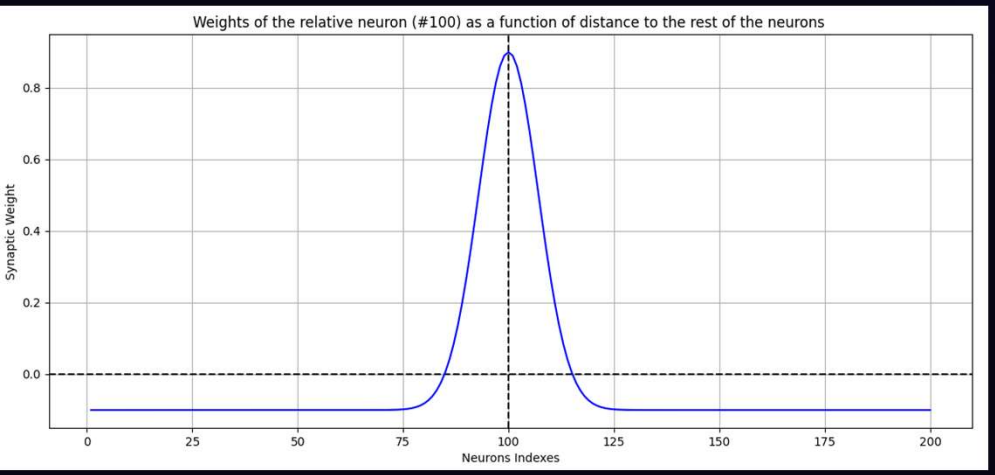


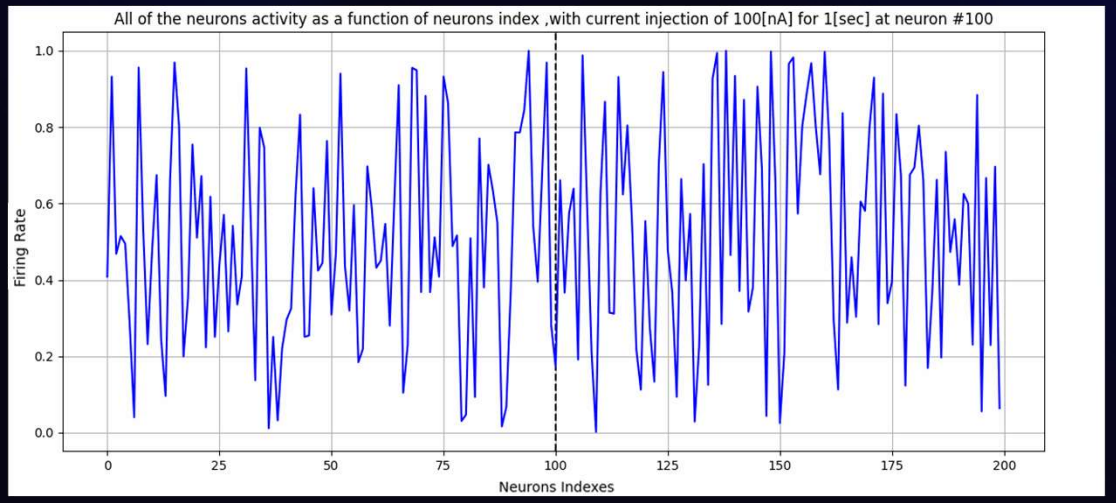
Circular Neural Network – Main Ring

Using these formulas and Euler approximation technique I drew a graph of the synaptic weights as a function of the neuron's indexes (which determines diff) and another graph of the firing rates of the neurons of the first ring ("main ring") which has no shift.

And here on the right, is a graph of couple of normalized neurons activity as a function of time (for esthetical reasons 50deci-sec instead of 200deci-sec), also there is a current injected to the 100th neuro for esthetical reasons.





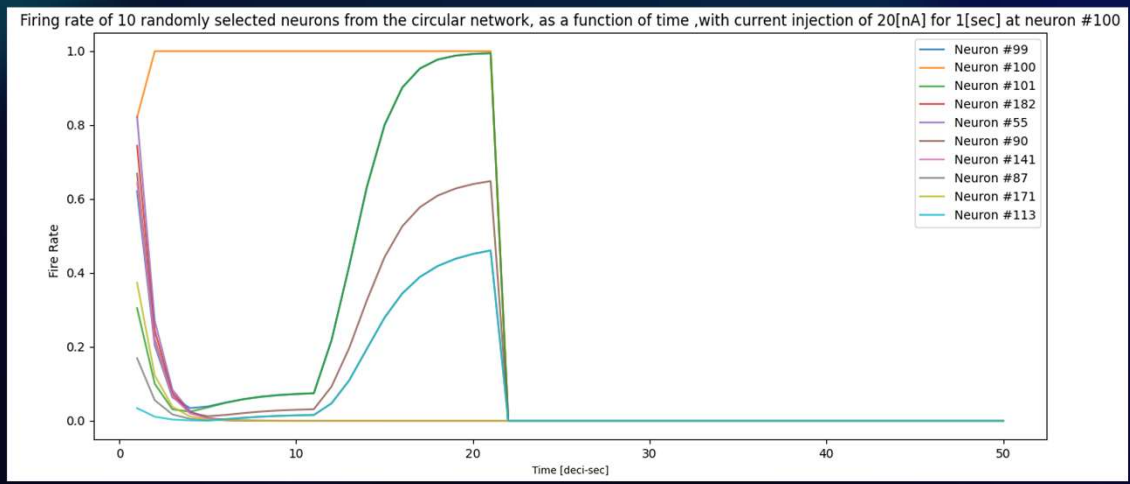


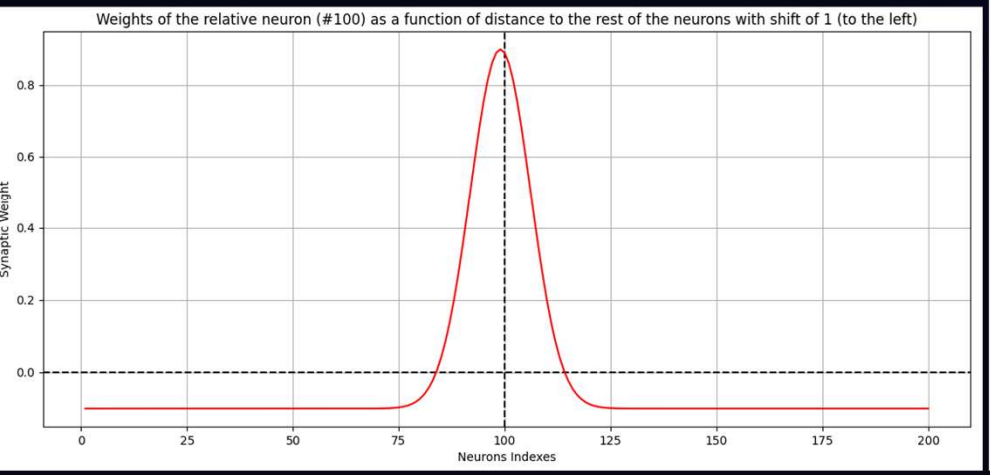
Circular Neural Network – Left Ring

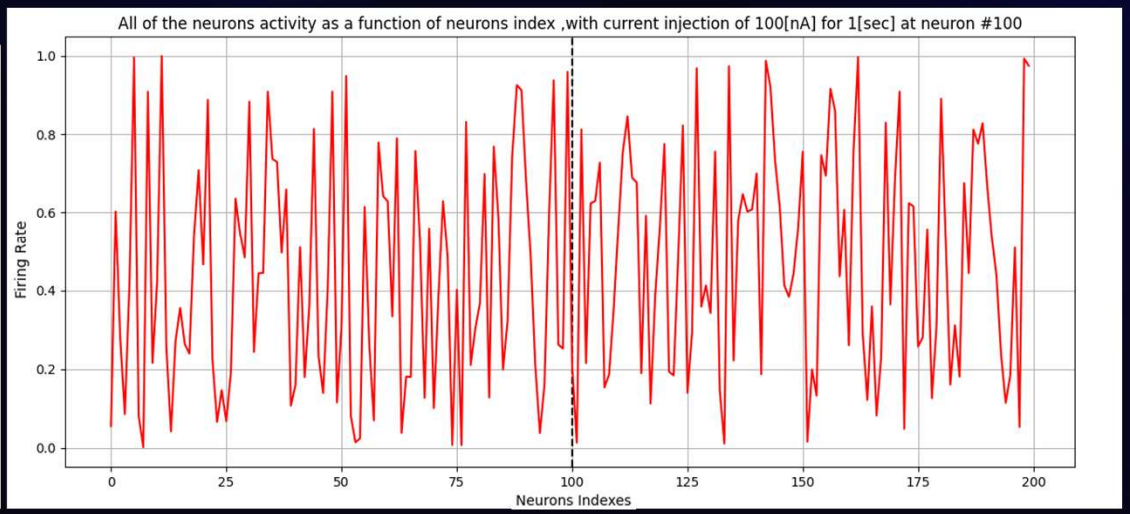
Here I'm plotting the second ring which I called the "left ring" (only because it's synaptic wights are shifted to the left, even though at the animated graph we see a propagation of the firing rate to the right .

Yes, its confusing but the clockwise and counter-clockwise confused me even more so I stayed like this).

And here at the right is a graph of couple of normalized neurons activity as a function of time (for esthetical reasons 50deci-sec instead of 200deci-sec) , also there is a current injected to the 100th neuro for esthetical reasons.





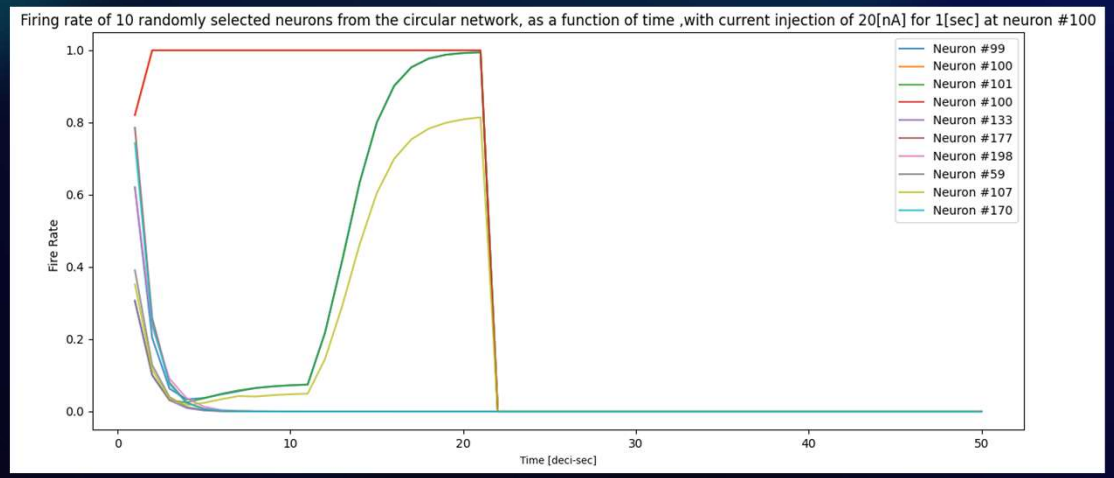


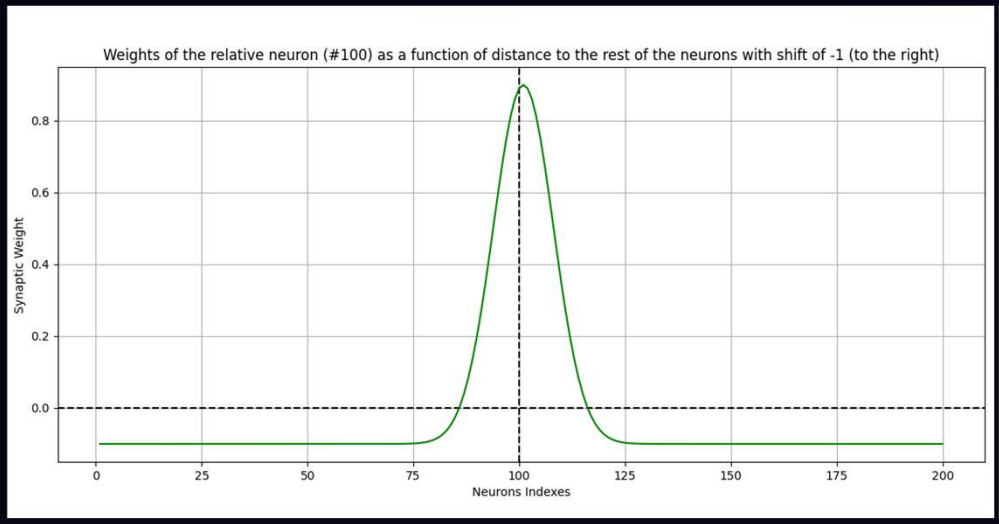
Circular Neural Network – Right Ring

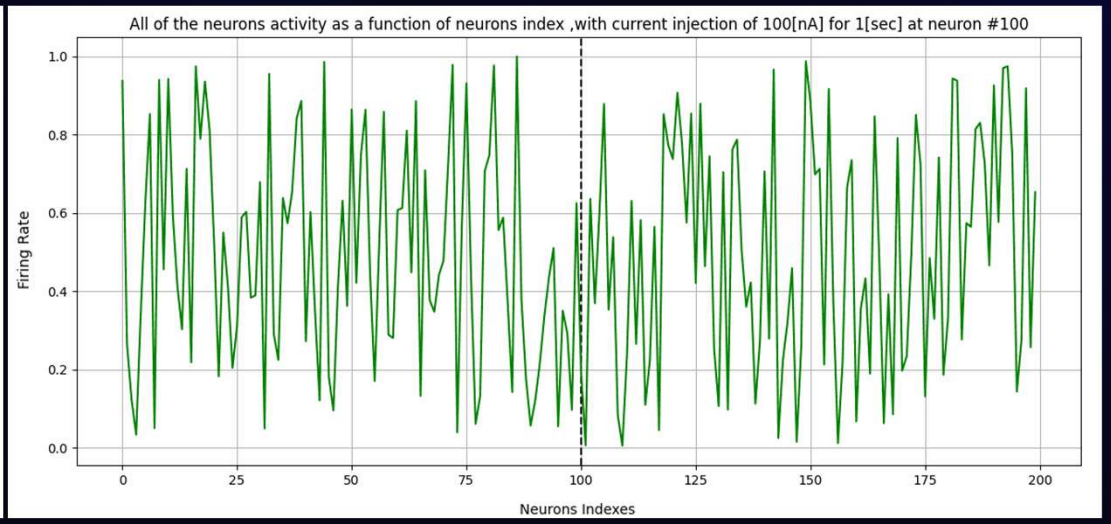
Here I'm plotting the second ring which I called the "left ring" (only because it's synaptic wights are shifted to the left, even though at the animated graph we see a propagation of the firing rate to the right .

Yes, its confusing but the clockwise and counter-clockwise confused me even more so I stayed like this).

And here at the right is a graph of couple of neurons activity as a function of time (for esthetical reasons 50deci-sec instead of 200deci-sec) , also there is a current injected to the 100th neuro for esthetical reasons.







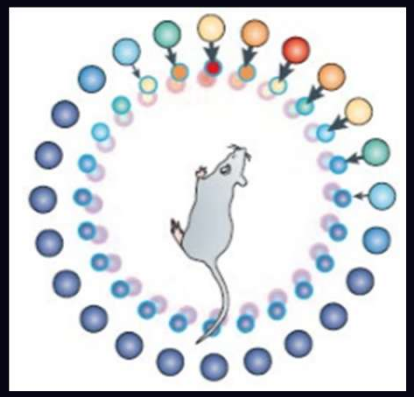
Circular Neural Network – More Data

Next, I'm going to connect the three rings and then stimulate each ring in the way that it would have been stimulated, has it been in the brain (according to the model we were taught). So next, you'll see the network react to the next things:
First, I'll wait 3 seconds for it to stabilize. Then I'll simulate a right head turn for around 225 seconds (227) . And then no turning for 45 seconds, and finally left head turn for ano 225 seconds (total 500 sec)

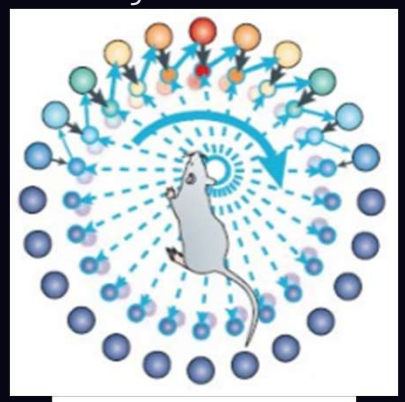
$$I_{right} = \begin{cases} 1 \mid \text{Right head turn} \\ 0 \mid \text{Left head turn} \end{cases}$$

$$I_{left} = \begin{cases} 0 \mid \text{Right head turn} \\ 1 \mid \text{Left head turn} \end{cases}$$

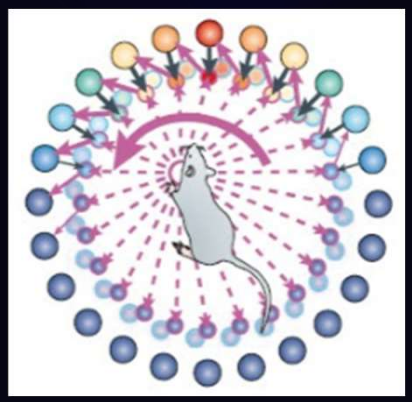
No motion



Right head turn



Left head turn



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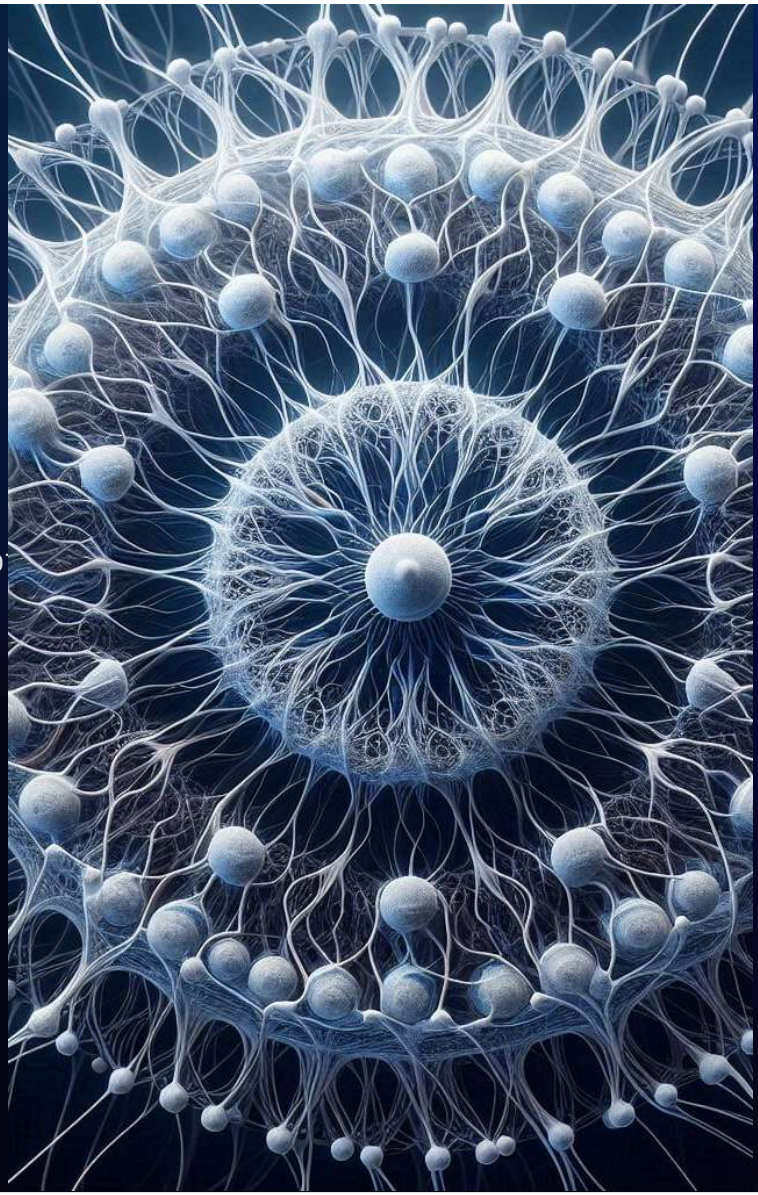
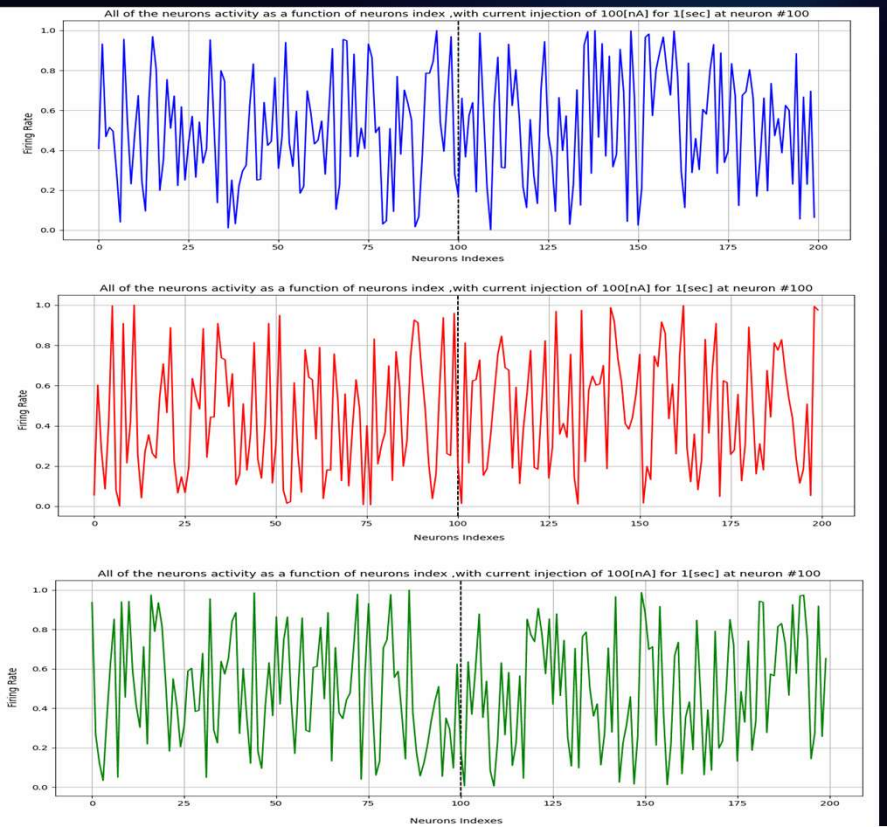
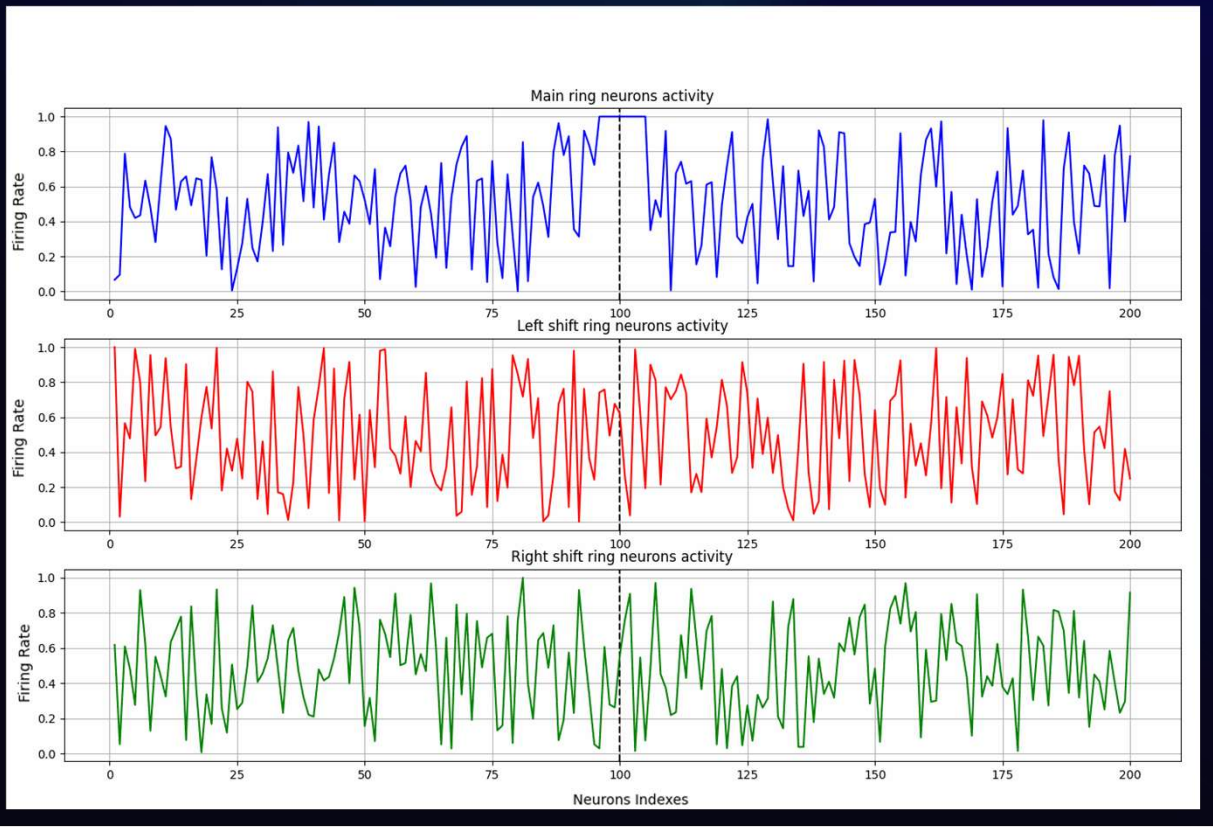


Circular Neural Network – Final graphs

Here we can see the difference between the behavior of the three rings on their own vs a triple ring network that is interconnected. The time scales are different here because I ran the interconnected network through more time to see better the movement effect. Here also I started with injection of the 100th neuron to centralize it (the black line in the left graph shows the injection place, and at the right graph it shows the index with the maximum firing rate, just in order to see better the movement of the graph).





And another small disclaimer: in the last graph in order to see the movements better I've changed the shift of the rings to be 10 instead of 1 , and it really did look better. The code now is set to be as in the original graphs to be shift of 1 and to set it to 10 there is a single line to uncomment that will do the trick, I've written there which one.