University of Tehran

COMPUTER SCIENCE DEPARTMENT

COMPUTATIONAL NEUROSCIENCE

REPORT 2

NEURON POPULATION WITH IZIKEVICH MODEL

Student Name	Student ID
AMIR NADERI	610398126

Lecturer in charge:

M.Ganjtabesh

Submission Date : 28/06/2023

1 Izhikevich Neuron Model

In this project we want to analyze neuron populations using the model that we used in the last project which is Izhikevich. The Izhikevich neuron model reproduces spiking and bursting behavior of known types of cortical neurons. It takes the biological plausibility of Hodgkin and Huxley neurons while being as computationally efficient as integrate-and-fire neurons. Now we review the formula and parameters used for this model:

$$\frac{dv}{dt} = 0.04v^2 + 5v + 140 - u + I \tag{1}$$

$$\frac{du}{dt} = a(bv - u) \tag{2}$$

Now we got the resetting part:

$$if\ v > 30\, mv,\ then\ [v = c\ and\ u = u + d] \tag{3}$$

Here are the parameters used in equations:

- v: Represents the membrane potential of the neuron
- u: Represents a membrane recovery variable, which accounts for the activation of k^+ ionic currents and inactivation of Na^+ ionic currents, and it provides negative feedback to v. After the spike reaches to its threshold, the membrane voltage and the recovery variable are reset according to the (3).
- I: The input current or injected dc-currents
- a: It describes the time scale of the recovery variable u. Smaller values result in slower recovery. A typical value is $a = 0.02$.
- b: It describes the sensitivity of the recovery variable u to the subthreshold fluctuations of the membrane potential v. A typical value is $b = 0.2$. Greater values couple and more strongly resulting in possible subthreshold oscillations and low-threshold spiking dynamics, because u parameter will try to decrease the neuron's potential.
- c: after-spike reset value of v. A typical value of -65 mV. It will be reset because of the fast high-threshold k^+ conductances.
- d: after-spike reset value of membrane recovery variable. A typical value of 2. It will be reset because the slow high-threshold Na^+ and K^+ conductances. It will cause to lower the membrane potential value, so the spike frequency adaption will happen and after a while the neurons will spike with bigger and distinguished inter-spike values, in other word the inter-spike period of neurons will increase. This keeps homeostasis of neurons.

We are going to make two homogeneous populations. One is consisted of excitatory neurons and the other is consisted of inhibitory ones. We have 1000 neurons in total, the size of the excitatory population is 800 and the size of inhibitory population is 200. Also we are going to make a random input current for each population. At the end we analyze types of connections between populations and see what is happening for each type of the connections. In fact after injecting current to the model and running some iterations, we observe neuron activities and show you the raster plot of activities and try to analyze the behavior of populations. We test a lot of Izhikevich model parameters and input current in this report.

2 Types of Connections

Here we try four types of connections, in each we test different parameters of model and input current. The first one is inhibitory to excitatory connection:

2.1 INH to EXC

Here is the diagram of this type of connection:

Figure 1: INH to EXC connection

In this condition every time that inhibitory neurons spike, the current of the post-synaptic excitatory neurons will decrease. Now we test different set of parameters and currents:

1. In this case we set the parameters of both the excitatory and inhibitory neurons to be Regular Spiking. the parameters are:

    - $a : 0.02$
    - $b : 0.2$
    - $c : -65$
    - $d : 8$

    Also both the currents are from the normal distribution. The parameters for currents are:

    - $mean - exc : 7$
    - $std - exc : 2.5$
    - $mean - inh : 10$

- $std - inh : 0.1$

Now we see the raster plot of the activities for both population. We got:

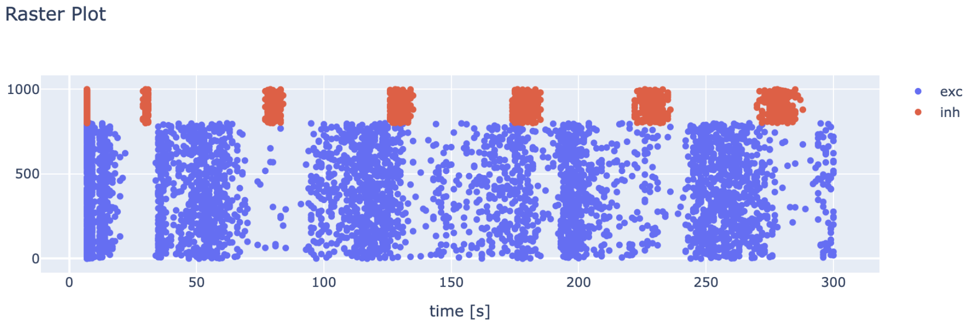


Figure 2: Raster plot

As you see, the red dots are the spikes of inhibitory neurons and the blue ones are for the excitatory neurons. Now check the population activity plot:

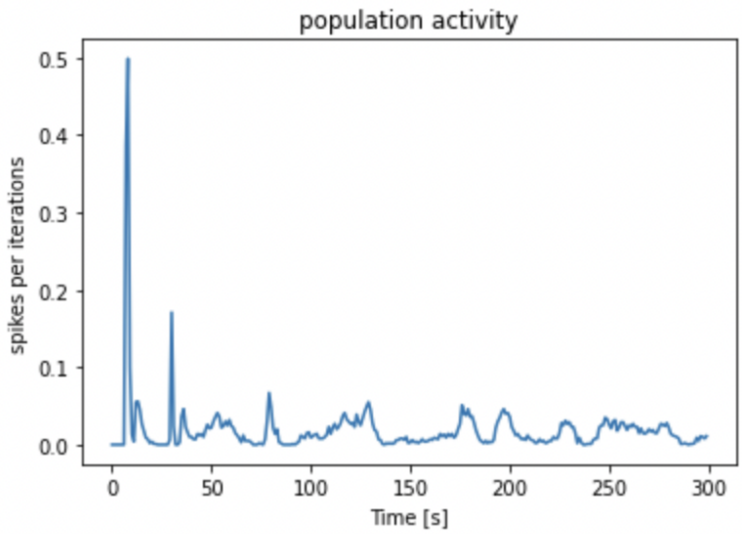


Figure 3: Populations activity

This plot shows the activity of populations. It counts the number of spikes for both inhibitory and excitatory populations per iteration. As you see at first near half of the neurons spike and after that, the number of spikes decreases. Now Let's see the diagram of current for the excitatory population:

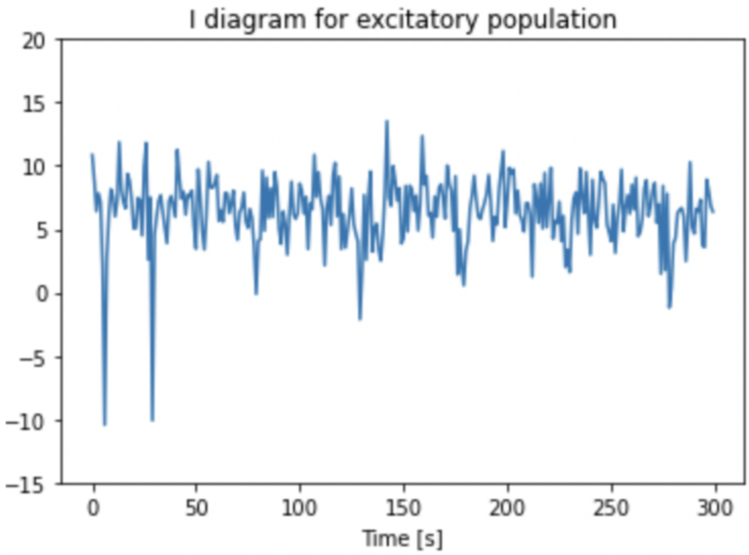


Figure 4: current of excitatory population

If you see closely, in some iterations the current will decrease. That's because when the inhibitory neuron spikes, the amount of current will decrease. These are the neurons that prevent excitatory neurons from spiking. They do this operation by decreasing the amount of the current of the excitatory neurons. In fact they decrease the current using the weights of afferent synapses. You can see this in the code. Now in the beginning of the diagram, the amount of decrease is the way more compare to the amount of fall when we go forward thorough the iterations. that's because at first when we inject the current to the population of inhibitory neurons, most of them will spike and the amount of fall for the excitatory current increases. And when we go forward, the amount of spikes will decrease, so the amount of fall for the excitatory current decreases.

2. Now according to the biology, we set the parameter of inhibitory population in a way that they behave like a fast spiking neurons. That's because in the biology, the inhibitory neurons are one quarter the number of excitatory neurons, in result they should spike fast. So the parameter of the excitatory population are like the last part(regular spiking). the parameter of fast spiking are:

   - $a : 0.1$
   - $b : 0.2$
   - $c : -65$
   - $d : 2$

   In this case the parameter a is large, so the membrane recovery variable will recover fast. On the other hand the parameter d is small, so the membrane recovery variable will increase smaller than before. In result the membrane potential reach to the threshold faster and spike. Now let's see the raster plot of this situation(the parameter of currents are like the last part):

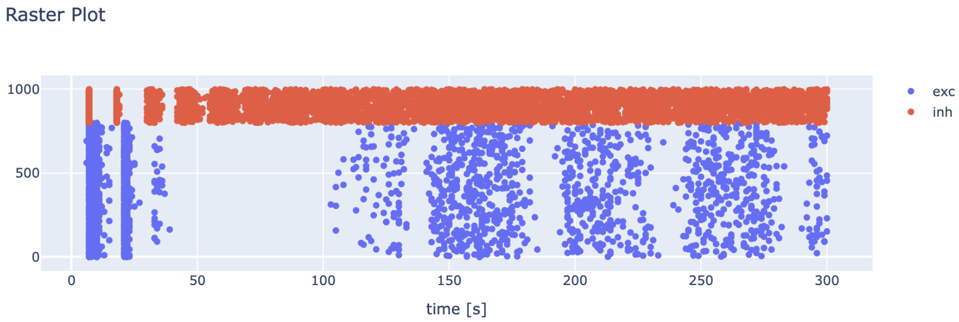


Figure 5: Raster plot

As expected, the number of spikes for the excitatory neurons decrease. That's because the inhibitory neurons spike fast. So when they spike, the amount of current for excitatory neurons will decrease and this process causes the membrane potential of the excitatory neurons to reach to the threshold slowly. As result the number of spikes decrease compare to the last part. You can see this in the diagram above. Now let's see the diagram of the populations activity:

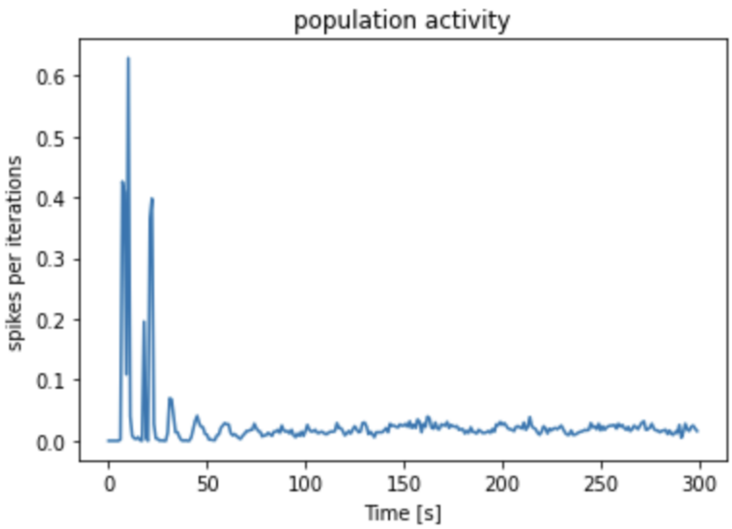


Figure 6: Populations activity

Below let's see the diagram of current for the excitatory population:

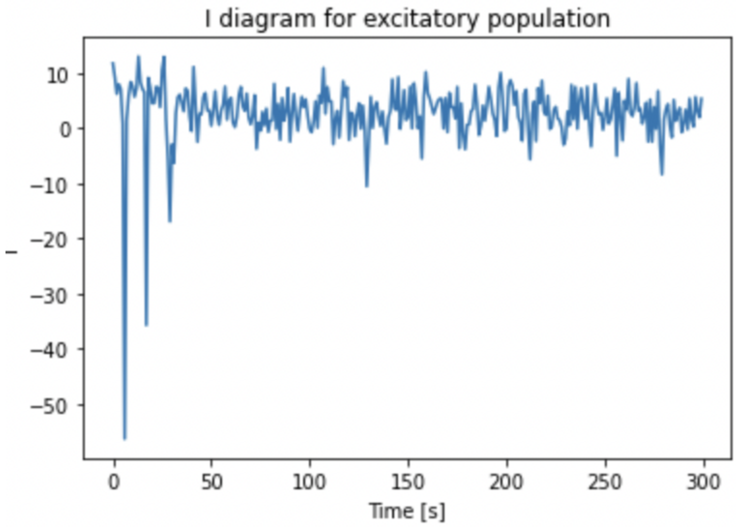


Figure 7: Current of excitatory population

2.2 EXC to INH

Here is the diagram of this type of connection:

Figure 8: EXC to INH connection

In this case every time that excitatory neurons spike, the current of the post-synaptic inhibitory neurons will increase. Now we test different set of parameters and currents:

1. n this case we set the parameters of both the excitatory and inhibitory neurons to be Regular Spiking. the parameters are:

   - $a : 0.02$
   - $b : 0.2$
   - $c : -65$
   - $d : 8$

   Also both the currents are from the normal distribution. The parameters for currents are:

   - $mean - exc : 6$
   - $std - exc : 0.5$
   - $mean - inh : 3$

- $std - inh : 0.5$

Now we see the raster plot of the activities for both population. We got:

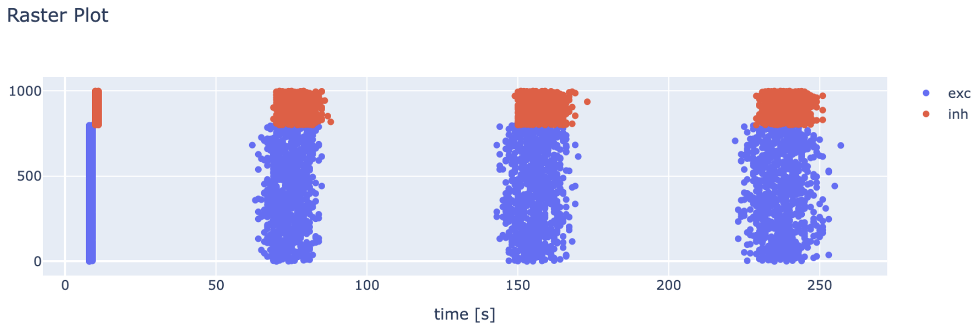


Figure 9: Raster plot

The amount of noise is low, so the current will be injected to the neurons similarly and we got spikes like the diagram above. Now when the excitatory neurons spike, the amount of current will rise in the inhibitory neurons and they spike too. Let's check the populations activity diagram in this situation:

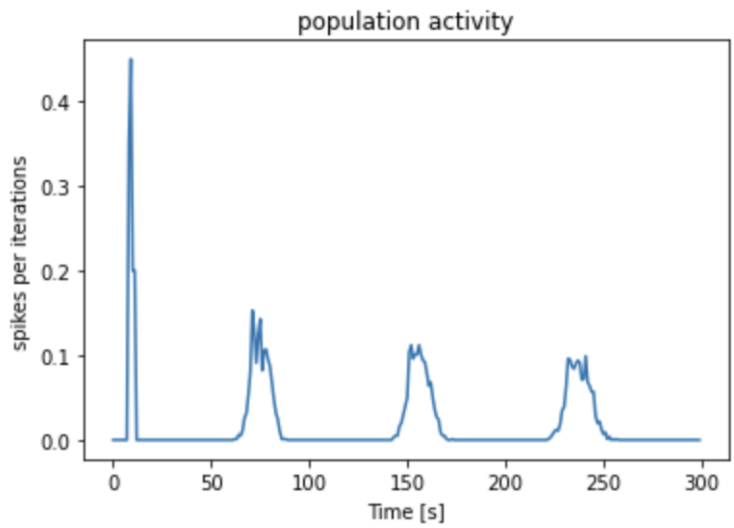


Figure 10: Populations activity

As we said before, in the beginning, the number of spikes is high. That's because we have same amount of current for neurons and most of them spike. As we go forward the spikes decrease. Also because of low amount of noise, we may have no spikes in some iterations(see diagram above). Now we see the diagram of current for inhibitory neurons. What do you expect? Let's see:

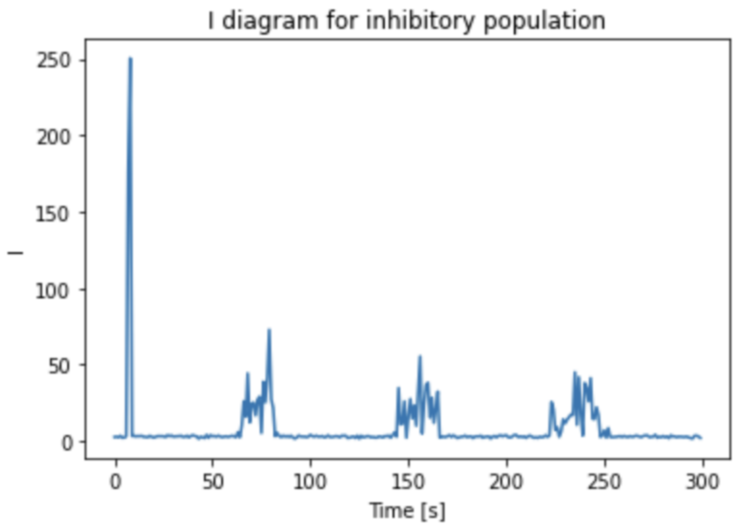


Figure 11: Current of inhibitory population

As we expected when the excitatory neurons spike, the current for the inhibitory neurons rises and this make the inhibitory neurons to spike. the amount of increase, is came from the impact of weight multiply by a coefficient. The formula for the rise and fall of the current are:

$$I = I \pm coef * (W * spikes)/size(pop) \tag{4}$$

Which I is the current, $coef$ is a factor that shows how much we should increase or decrease the amount of current. W is the matrix of weights, its rows are the pre-synaptic neurons and its columns are the post-synaptic ones. $spikes$ is a sparse matrix which indicates which neuron of the pre-synaptic spiked a post-synaptic. At the end, pop indicates the population. If an inhibitory neuron spikes, we will decrease the current and if an excitatory neuron spikes, we will increase that.
Now we will decrease the amount of $coef$ and observe the activities.

2. In this case the parameters didn't change but the $coef$. As we said, parameter $coef$ indicates how much we should increase or decrease the amount of current. we will decrease $coef$. Now let's check the raster plot:

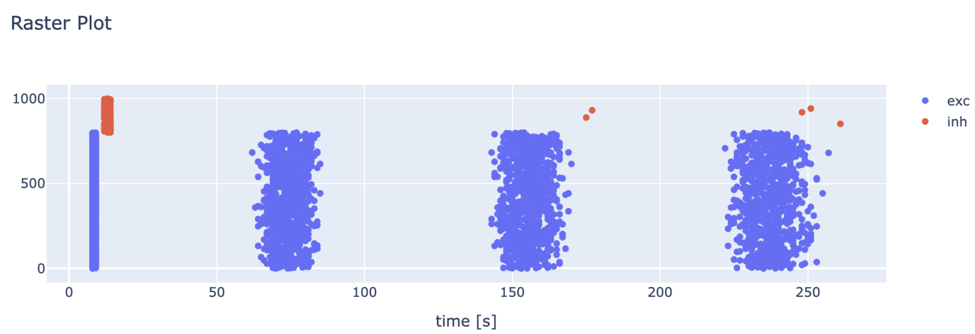


Figure 12: Raster plot

Well we decrease the amount of $coef$, as result when the excitatory neurons spike, the current of the post-synaptic won't rise that much. So those neurons reach to the threshold very late or they don't reach to it at all. Finally the number of spikes fall a lot. You can see this in the diagram above which we just have five spikes of inhibitory neurons when we go forward thorough the simulation. Now what do we expect from the current diagram of the inhibitory neurons? Well they should have lower rise compare to the last part. Let's see:

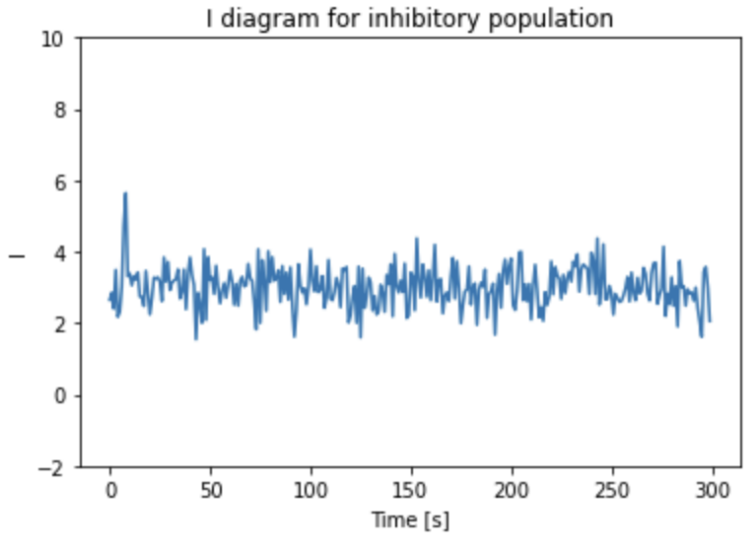


Figure 13: Current of inhibitory population

3. We set the *coef* value as it was in the first experiment. Now we set the parameters of excitatory neurons in a way that they spike fast. The parameters of inhibitory population and also both currents of excitatory and inhibitory neurons remain intact. The parameters of excitatory populations are:

   - $a : 0.1$
   - $b : 0.2$
   - $c : -65$
   - $d : 6$

   Now let's see the raster plot of this simulation:

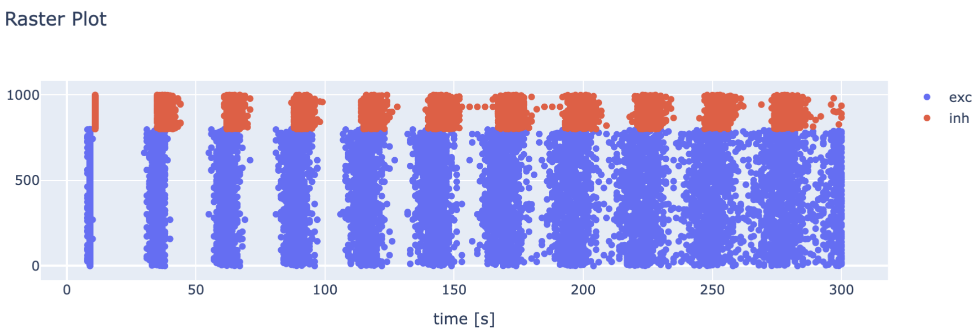


Figure 14: Raster plot

Now if we compare this diagram to figure 9, we can see that spikes of the excitatory population increases, so the spikes of inhibitory neurons increases too. That's because when spike happen, the value of current will rise, therefore inhibitory neurons spikes a lot. Actually in the first experiment the number of spikes for the inhibitory population was 2397 but the number of spikes in this experiment is 4503. Now let's see the populations activity plot:

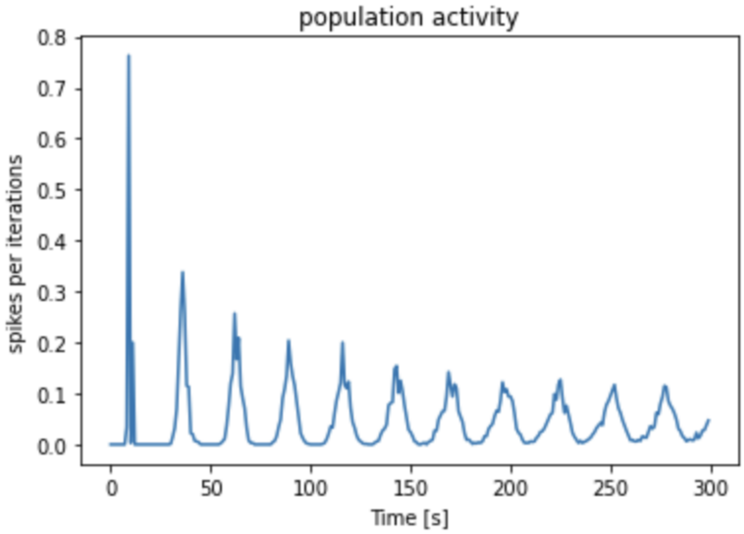


Figure 15: populations activity

We can see that the range of spikes per iteration is high compare to figure 10. That's because the excitatory neurons in the population spike fast.
At the end let's check the diagram of current for the inhibitory neurons:

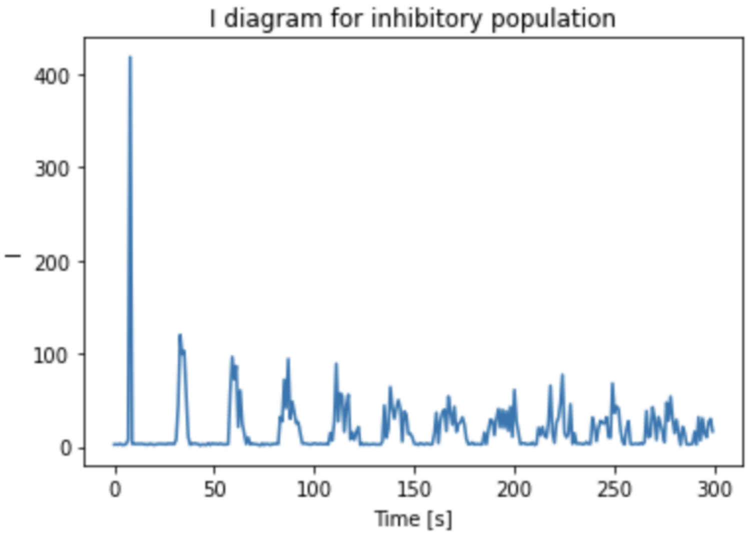


Figure 16: Current of inhibitory population

Comparing to the figure 11 we have more rises of current. This is because the pre-synaptic excitatory neurons spike, therefore the current of the inhibitory ones rise more, so we have the diagram above.

4. Now we set both the parameters of excitatory and inhibitory population in a way that they spike regularly:

   - $a : 0.02$
   - $b : 0.2$
   - $c : -65$
   - $d : 8$

   Now we play with the current of the excitatory neurons. We want to increase the value of current(mean of the distribution). we got:

   - $mean - exc : 12$
   - $std - exc : 0.5$
   - $mean - inh : 3$
   - $std - inh : 0.5$

   In this case, value of current is large so the the number of spikes for the excitatory populuation is large. When they spike, inhibitory neuron current will increases and it is more likely that an inhibitory neuron will reach the threshold. Let's see the plots of this test:

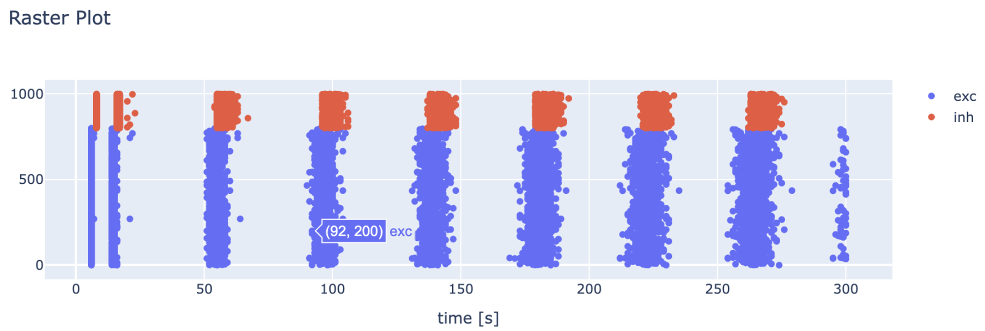


Figure 17: Raster plot

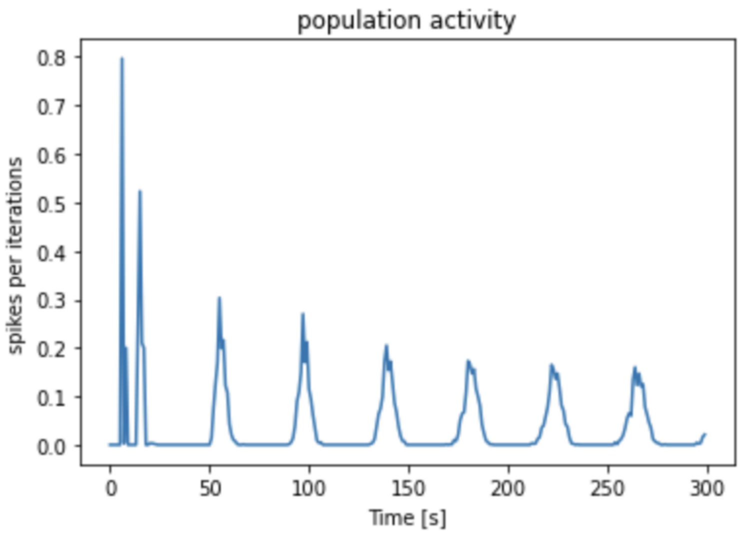


Figure 18: Populations activity

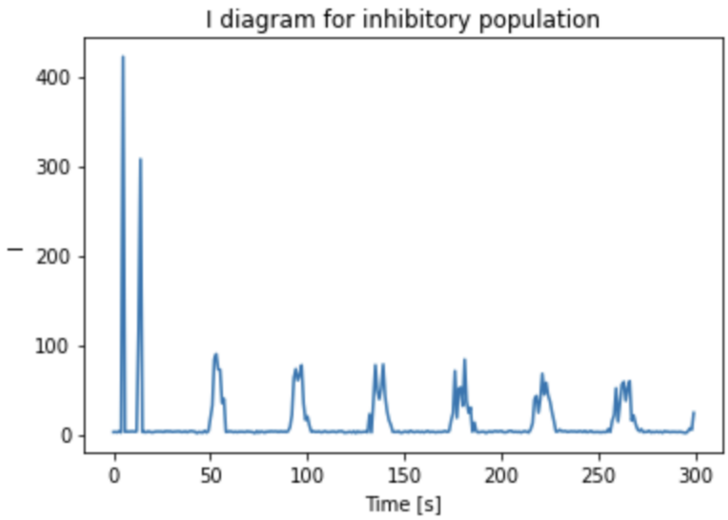


Figure 19: Current of inhibitory population

The number of spikes for the inhibitory population in this test is 3941 which is high compared to the experiment in which the mean of the distribution was 6.

5. Now let's play with the parameter of noise for the excitatory current. Both populations of inhibitory and excitatory spikes regularly. It means the parameters are:

   - $a : 0.02$
   - $b : 0.2$
   - $c : -65$
   - $d : 8$

   Now the parameters of currents are like this:

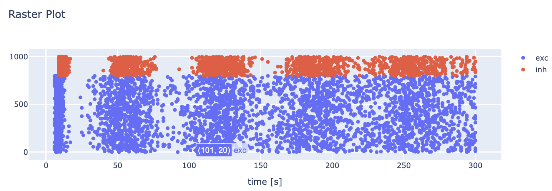
   - $mean - exc : 6$
   - $mean - inh : 3$
   - $std - inh : 0.5$

   We want to play with the variable of noise and see what happens with the number of spikes in the inhibitory population. Let's see the table below:

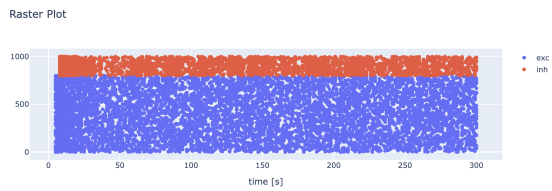
noise	spikes(inh)
0.5	2397
1	2235
2	2330
3	2302
4	2285
5	2332
6	2402
7	2542
8	2717
9	2961
10	3229

Table 1: Number of spikes related to noise

The table shows that, as you can see, if we increase the noise of the current in the excitatory population, the number of spike won't increase. That's because the noise is not that much to effect the inhibitory neurons to spike because it is more scattered. But if we increase the number of noise to 7 or higher, the current of the excitatory neuron rise a lot therefore the number of spikes in the inhibitory population increases. Now let's compare the raster plot of the case which the noise are 4 and 10:



(a) noise is 4



(b) noise is 10

Figure 20: Raster plots

As you can see, when the noise is 4, spikes of the excitatory population is more scattered compared to the case when noise is 10. So when they are scattered, it's less likely that the inhibitory neurons' current increases and reaches the threshold, but when the noise is 10 (big enough), They spike enough and the current of the inhibitory neurons increases a lot, so they spike more.

2.3 EXC to INH and INH to EXC

Here is the diagram of this type of connection:

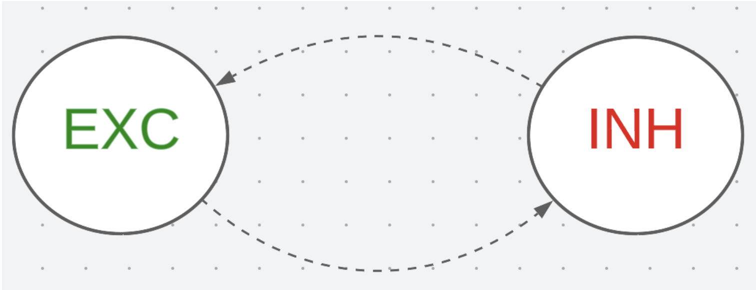


Figure 21: INH to EXC and EXC to INH connection

Now let's see some tests:

1. In this test, the parameters of both inhibitory and excitatory neurons are like regular spiking which are:

    - $a : 0.02$
    - $b : 0.2$
    - $c : -65$
    - $d : 8$

    Also the parameters of two currents are:

    - $mean - exc : 6$
    - $std - exc : 0.5$
    - $mean - inh : 3$
    - $std - inh : 0.5$

    Now check the raster plot:

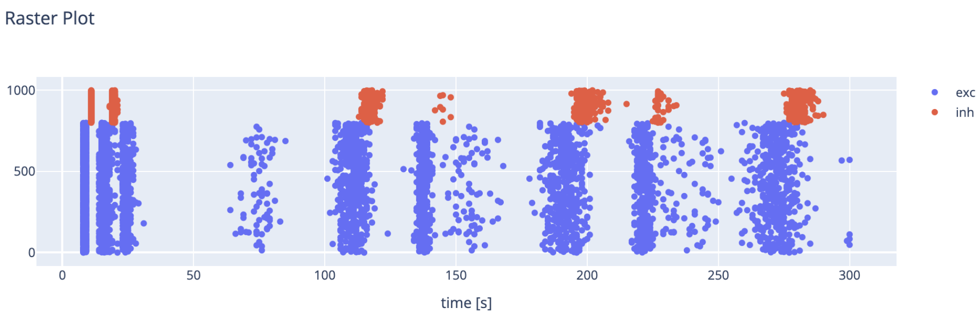
    

    Figure 22: Raster plot

    As you see when excitatory neurons spike, the current of the inhibitory neurons will rise And the inhibitory ones spike more. In this case when the inhibitory neurons spike, the current of the excitatory neurons will fall. Now they spike less than before and inhibitory neurons spike less as well. Now it's excitatory neuron's turn to spike a lot and this cycle goes on. That's you see in the diagram above. Now let's check the diagram of the populations activity:

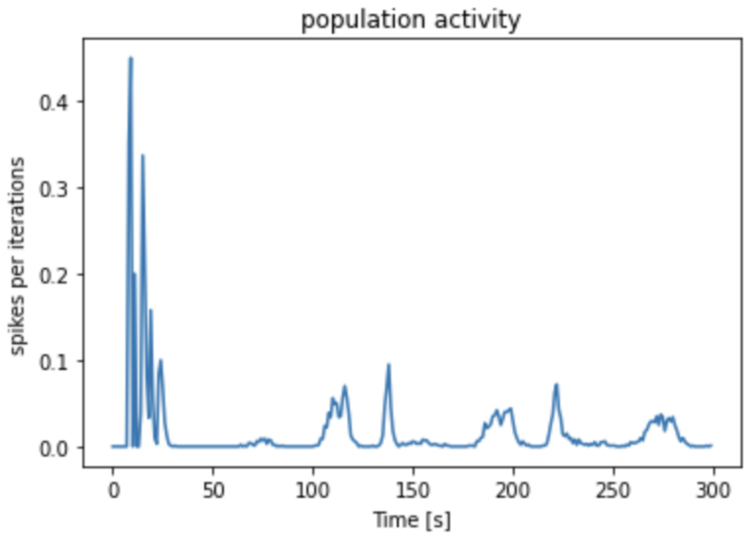
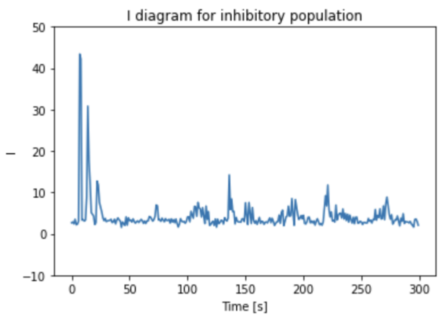
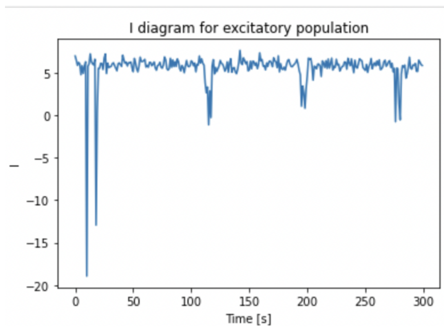


Figure 23: Populations activity

The diagram above shows the cycle that has been described.
Here check the current diagram of both inhibitory and excitatory populations:



(a) Current of inhibitory population



(b) Current of excitatory population

Figure 24: Current

As expected, inhibitory current increases in some iterations while excitatory current decreases.

2. Now we set the parameter of inhibitory population to spike fast. We got:

   - $a : 0.25$
   - $b : 0.2$
   - $c : -65$
   - $d : 2$

   Now we check the raster plot:

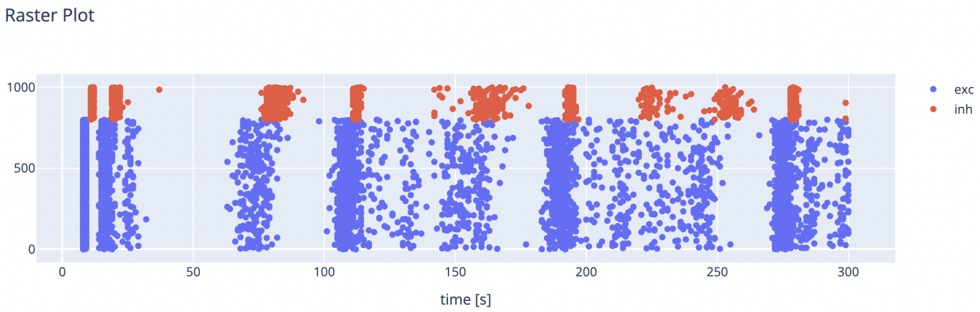
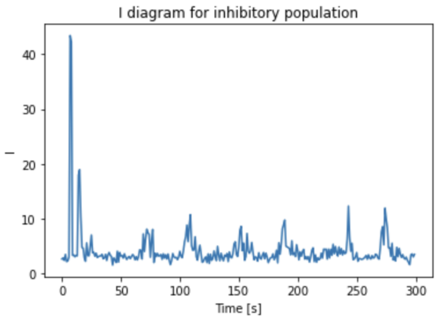
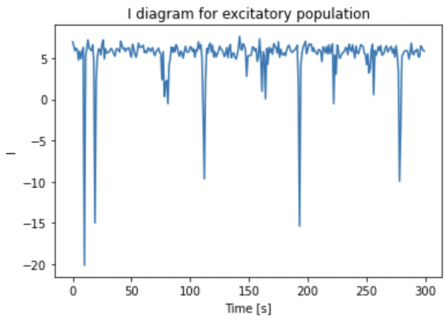


Figure 25: Raster plot

See the current diagrams as well:



(a) Current of inhibitory population



(b) Current of excitatory population

Figure 26: Current

If you compare figure 25 to figure 22, you will notice that the behavior is still the same. But the point is this process is faster. That's because the inhibitory neuron decreases the current of the excitatory ones fast, then the excitatory neurons spike and this cycle goes on. Actually the value of fall in the current of excitatory population will increase and at the end the spikes of the excitatory neurons will decrease. This case shows a decrease of 200 in the number of spikes.

3. Now let me make the inhibitory population spike very fast. These are the parameters for the inhibitory population:

   - $a : 1$
   - $b : 0.2$
   - $c : -65$
   - $d : 1$

   Let's check the raster plot:

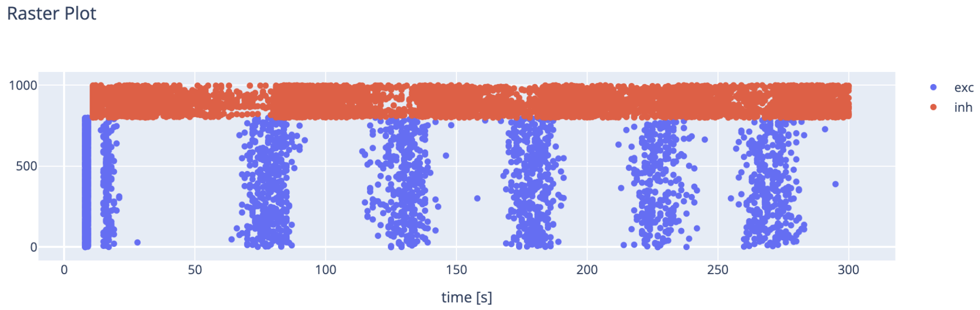
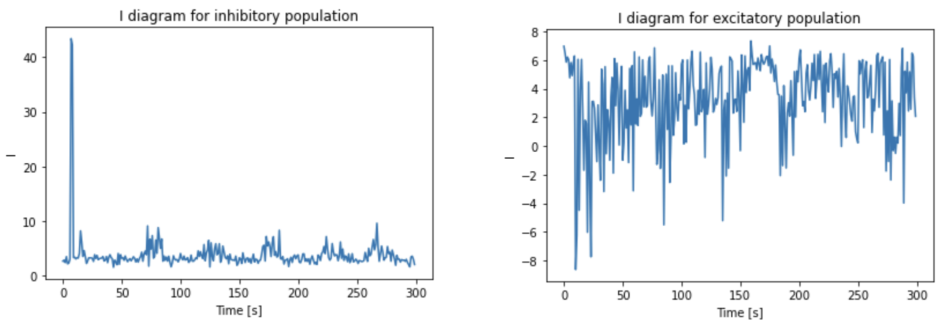


Figure 27: Raster plot

See the current diagrams as well:



(a) Current of inhibitory population (b) Current of excitatory population

Figure 28: Current

What happened? As you see the figure 28 part (b), value of current for excitatory neurons fall a lot. That's because inhibitory neurons spike all the time so the number of spikes in this simulation for excitatory population is less than the number of spikes in those last two experiments. This case shows a decrease of 1200 in the number of spikes.

4. Now we make the network more balanced. Both populations spike regularly and the parameters of currents are:

   - $mean$: 10
   - std : 1

   Synaptic coefficients are set so that the activities look like this:

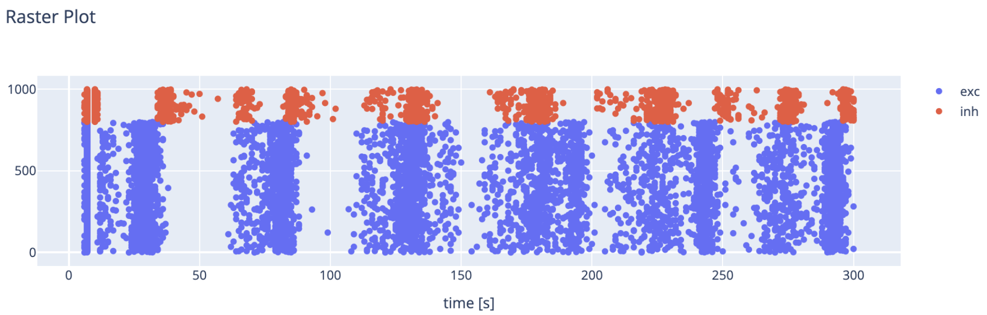
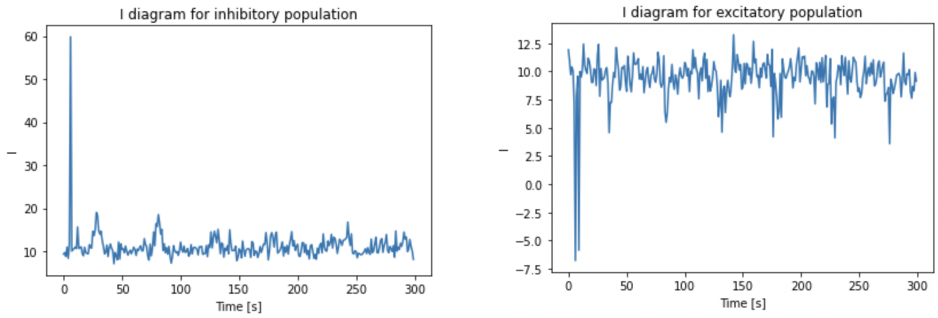


Figure 29: Raster plot

Now check the currents plot:

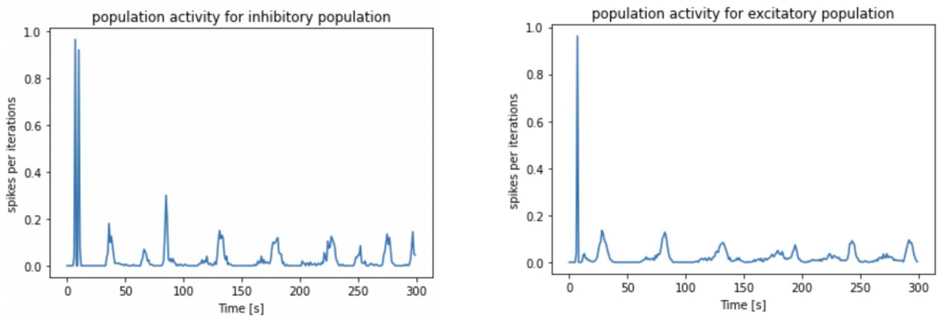


(a) current of inhibitory population

(b) current of excitatory population

Figure 30: currents plot

As you see the currents have ups and down and the range of fluctuation is less than in last experiments (it is more balanced). Still the cycle has been told, goes on. At the end check the population activity of both populations too:



(a) population activity of inhibitory neurons

(b) population activity of excitatory neurons

Figure 31: population activity

Now we increase the chance of connectivity from the excitatory to inhibitory population. Before the probability was 0.1. It means if we observe two neurons from each population, there is a probability of 0.1 that they are connected and there is a synapse between them. Now this chance has increased to 0.5 from excitatory to inhibitory population and the probability from inhibitory to excitatory has remained the same. Let's see what happens:

5. first let's see the raster plot of this case:

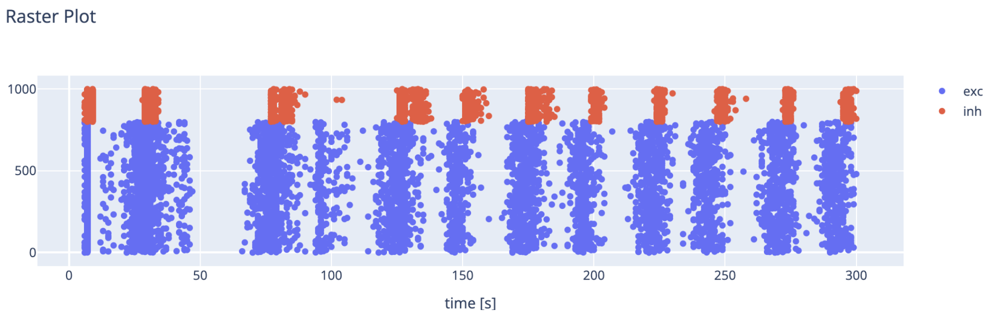
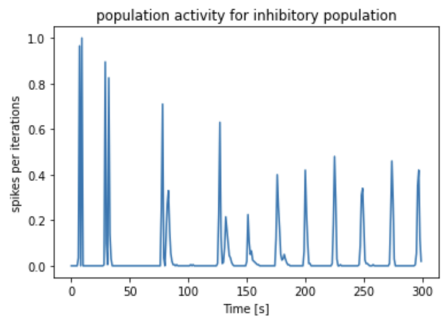
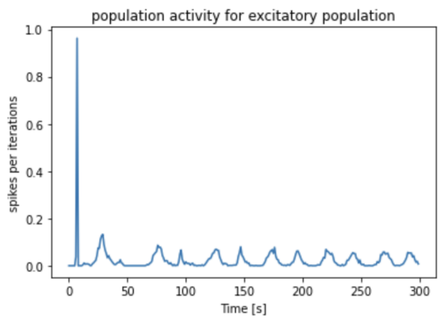


Figure 32: Raster plot

We can see the cycle is on but there are some changes. Let's see the population activity plot:



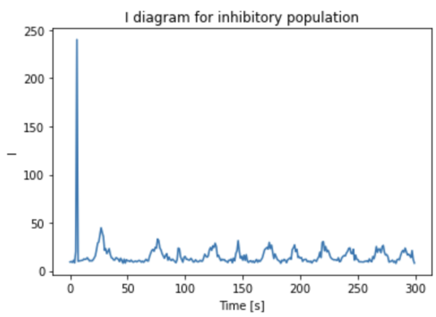
(a) population activity of inhibitory neurons



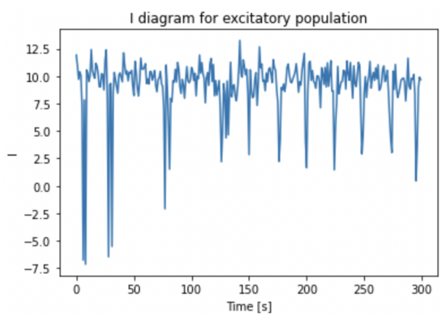
(b) population activity of excitatory neurons

Figure 33: population activity

So we said we have more connections from excitatory population to inhibitory population. Therefore the spikes increases and the activity of inhibitory population increases too. So in figure 33 part(a), we see more activity than figure 31 part (a). So the number of spikes is larger than the number in the last test. Now Let's check the current plot:



(a) current of inhibitory population



(b) current of excitatory population

Figure 34: currents plot

Also here if you compare figure 34 part (a) with figure 31 part(a), you can see the effect of excitatory population to the inhibitory population, there is a larger increase. In the following when inhibitory neurons spike, the current of the excitatory neurons will fall. However, the value of the decrease is not significant, because we have more connection from excitatory to inhibitory population. But the ups and downs in the current of excitatory population is faster than the ups and downs in the last test (See figure 34 part (b) and figure 31 part (b))

2.4 All connections are set

Here is the diagram of this type of connection:

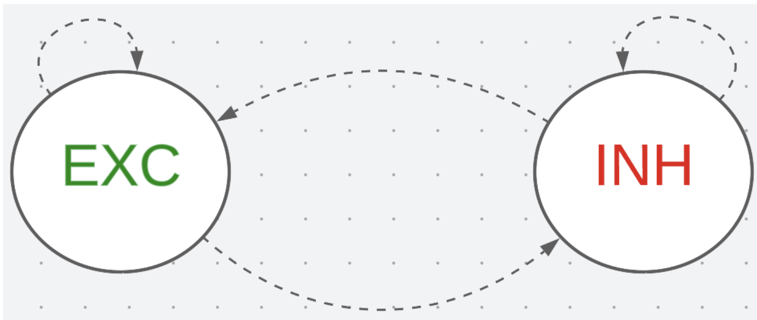


Figure 35: All connections set

This is a balanced network. We set the parameters of both currents like this:

- $mean$: 10
- std : 1

The number of iterations is 300 like the last experiment. Now Let's test some cases:

1. In this situation, we set both the excitatory and inhibitory population to spike regularly. The parameters are:

   - a : 0.02
   - b : 0.2
   - c : -65
   - d : 8

   Let's see the plots:

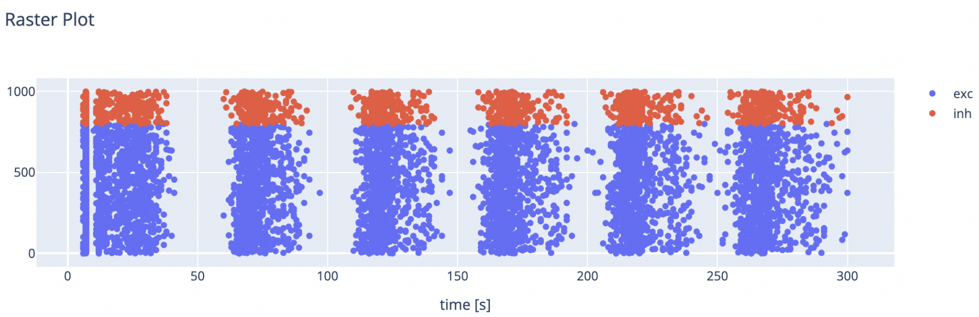
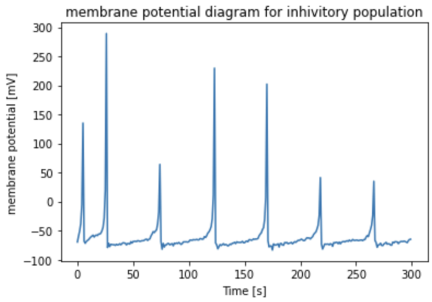
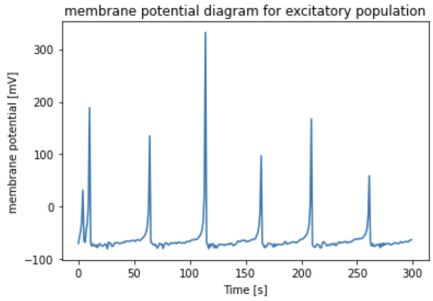


Figure 36: Raster plot

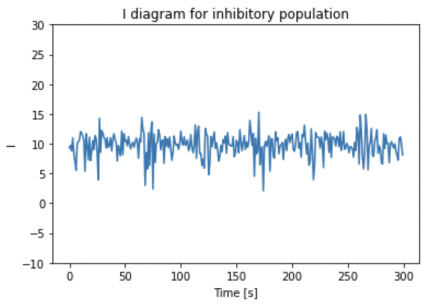


(a) membrane potential of inhibitory population

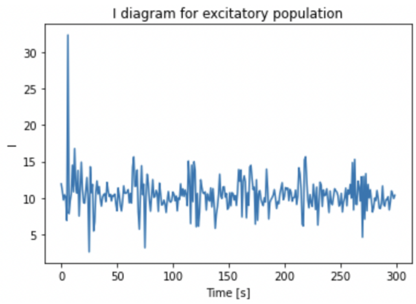


(b) membrane potential of excitatory population

Figure 37: membrane potential plot



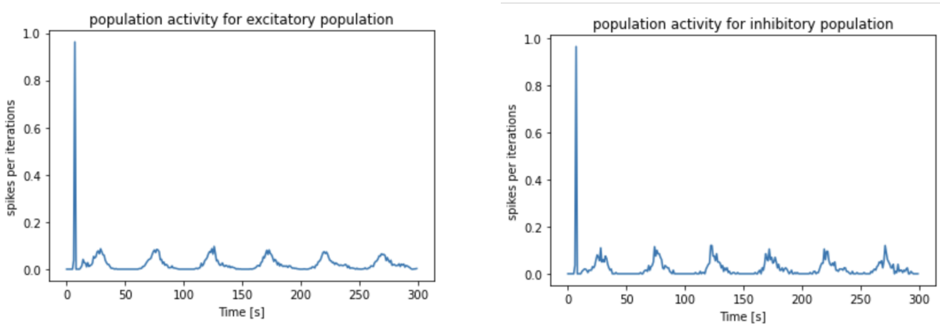
(a) current of inhibitory population



(b) current of excitatory population

Figure 38: currents plot

As you see, both of the populations spike regularly during the simulation. Also the fluctuations of the currents are in the same range. This means this network is balanced. That's because when the excitatory neurons spike, the current of the inhibitory post-synaptic neurons will rise, but here we have connection from inhibitory to inhibitory population. Therefore they inhibit each other and the current decreases. So they don't spike a lot and when they spike, the current of the post-synaptic excitatoey neurons will fall, but here we have connection from excitatoey to excitatory population. As result they neutralize the effect of inhibitory neurons and the current increases. So the number of spikes don't decrease. Therefore all of them spike regularly.
Now see the population activity plots:



(a) population activity of inhibitory neurons

(b) population activity of excitatory neurons

Figure 39: population activity

2. Now we set the parameters of inhibitory neurons to spike fast. The parameters are:

    - $a : 0.1$
    - $b : 0.2$
    - $c : -65$
    - $d : 8$

    Let's see the plots:

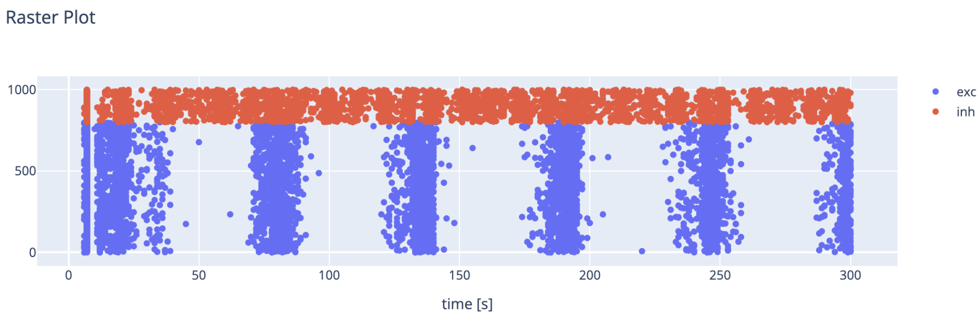
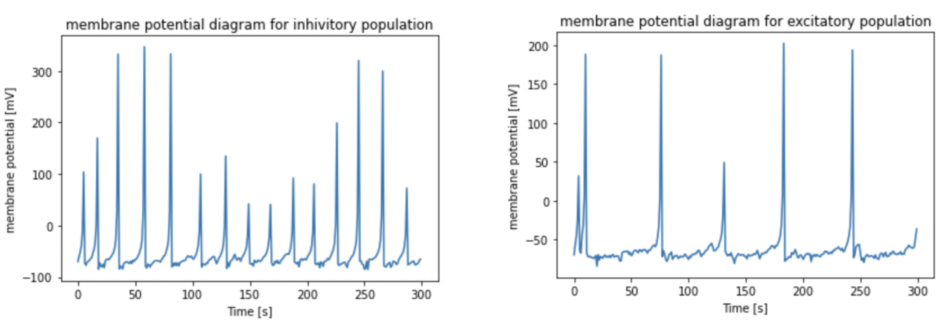


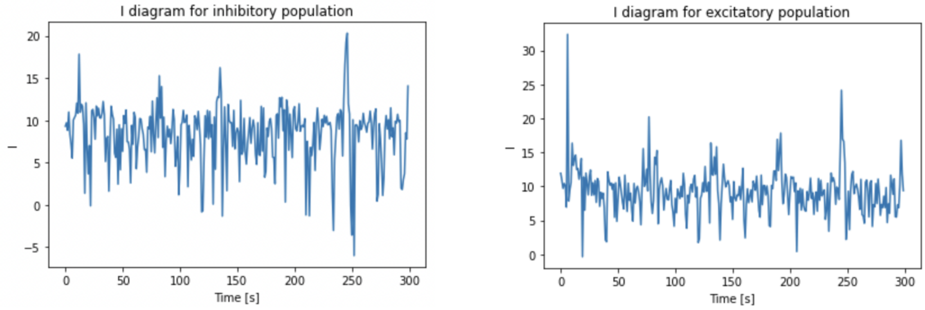
Figure 40: Raster plot



(a) membrane potential of inhibitory population

(b) membrane potential of excitatory population

Figure 41: membrane potential plot



(a) current of inhibitory population (b) current of excitatory population

Figure 42: currents plot

Here the inhibitory neurons spike fast. So when the excitatory neurons spike, the current of the inhibitory neurons will increase and inhibition will happen in the inhibitory population. But This time inhibitory neurons spike a lot and it effects on the excitatory population and decrease its current more than before. So the number of spikes will decrease in the excitatory population. Number of spikes for the excitatory population was 5606 in the last experiment but now it's 5195. As you see in the figure 42 part (a), inhibitory neurons show a smaller decrease in current than the inhibitory neurons in figure 38 part (a).

3. Now let's reverse the situation. The excitatory neurons spike fast and the inhibitory neurons spike regularly. Let's see the plots:

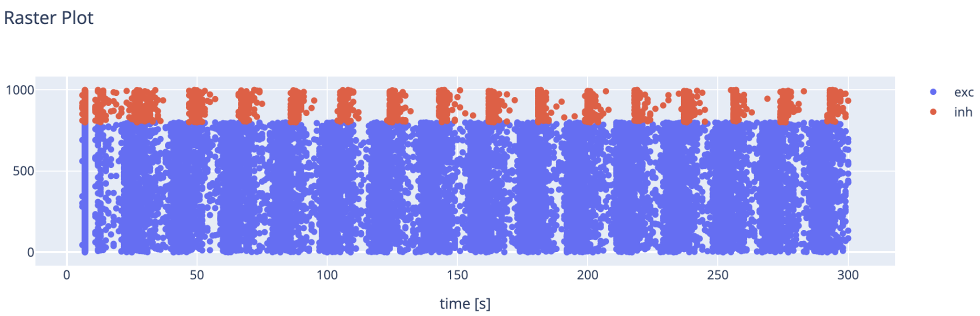
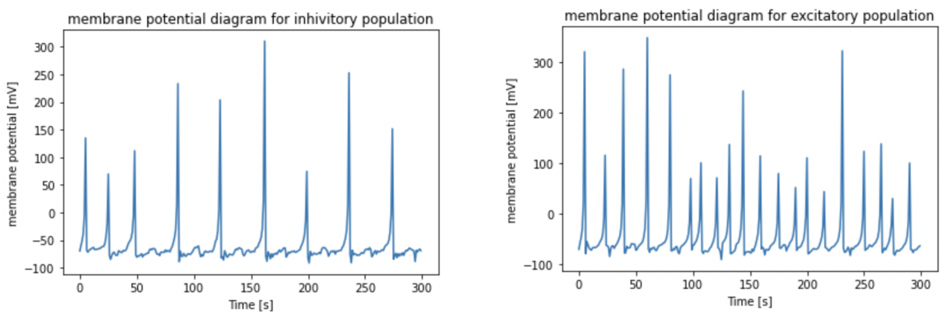
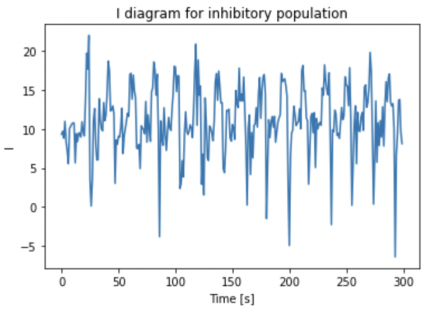


Figure 43: Raster plot

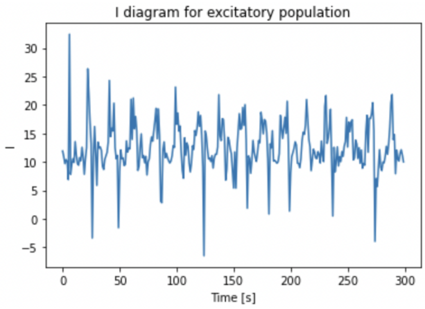


(a) membrane potential of inhibitory population (b) membrane potential of excitatory population

Figure 44: membrane potential plot



(a) current of inhibitory population



(b) current of excitatory population

Figure 45: currents plot

when the excitatory neurons spike, the current of the inhibitory neurons will increase. The point is these neurons spike fast and we have connection from excitatory to excitatory population. Therefore, the current of the exc population has increased more since the last experiments. As result we have more spikes in the inhibitory population. As you see in the figure 44 part (a), we have more spikes in the inhibitory neurons. the number of spikes has increased by the value of 564. Then we have inhibition in the inhibitory population and then they spike and both the currents of inhibitory and excitatory population decreases. Therefore we have ups and down in the plot of currents (figure 45).

2.5 Bi-directional connections and EXC to EXC

The diagram will be:

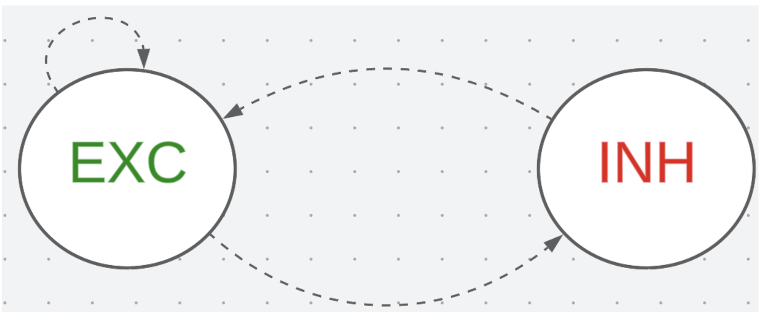


Figure 46: Bi-directional connections and EXC to EXC connection

1. We set the parameters in a way that both populations spike regularly. Now let's see the raster plot:

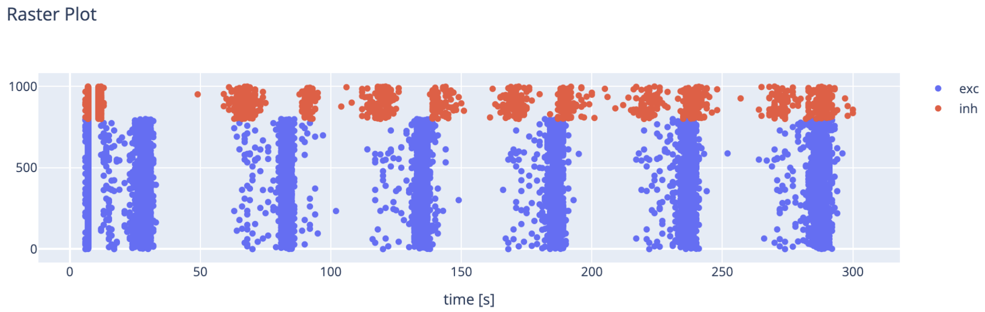
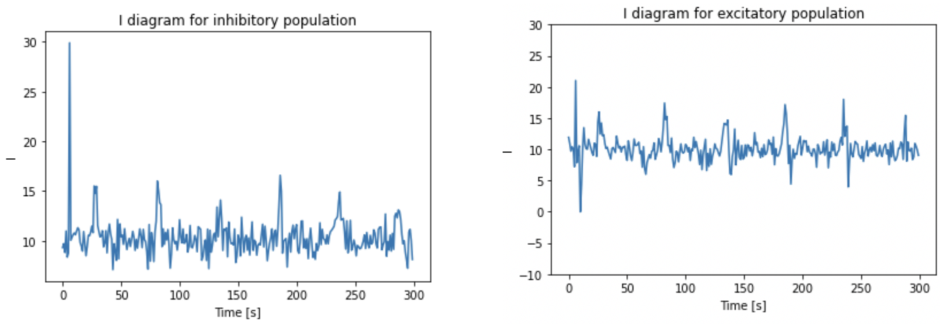


Figure 47: Raster plot

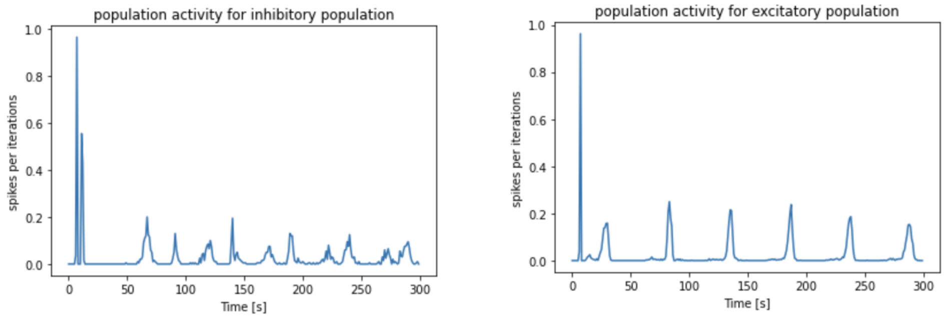
In this case excitatory neurons spike and the current of the inhibitory population increases and they spike more. On the other hand when the inhibitory neurons spike, the current of the excitatory population decreses, but we have connection from excitatory to excitatory, therefore the current increases and the number of spikes in the excitatory population doesn't change that much and we have ups and downs in the diagram of current for the excitatory population in the same range of fluctuation that we see in the figure 38 part (a). In the following excitatory neurons spike and the number of spikes in the inhibitory population increases. That what we see in the raster plot.
Check the current plot:



(a) current of inhibitory population (b) current of excitatory population

Figure 48: currents plot

As you see the plot of current fore the inhibitory neuron is different from figure 38 part (b), that's because we don't have connection from inhibitory to inhibitory population and the current will increase.
Now let's see the population activity plots:



(a) population activity of inhibitory neurons

(b) population activity of excitatory neurons

Figure 49: population activity

2. Now we make inhibitory neurons spike fast. The parameters for the inhibitory population are:
   - $a : 0.1$
   - $b : 0.2$
   - $c : -65$
   - $d : 8$

   Let's see the raster plot:

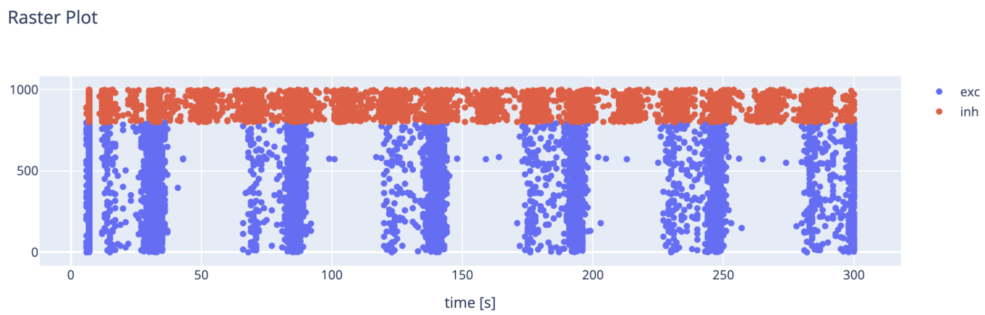
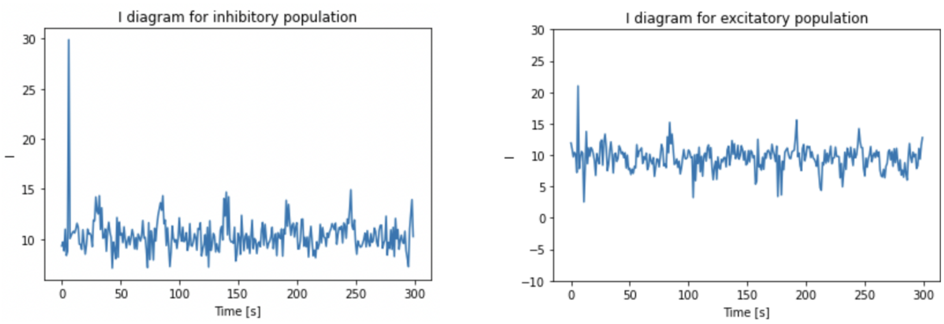


Figure 50: Raster plot

Also see the current plots:

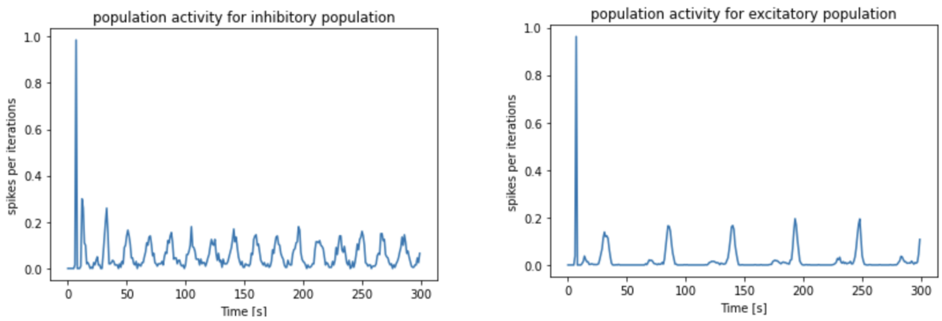


(a) current of inhibitory population

(b) current of excitatory population

Figure 51: currents plot

Now the inhibitory neurons spike fast. when excitatory neurons spike, the current in the inhibitory population will increase and they spike more. Also inhibitory neurons spike fast, so when they spike, the current of the excitatory population decrease a lot and they spike less than before. but we have connection from excitatory to excitatory population and the current rises and it neutralize the impact of inhibitory neurons in a way. That's why we have a more balanced current plot in figure 55 part (b) compared to figure 48 part (b). So activity of inhibitory population increases and it make the excitatory neurons spike less than last experiment but not that much, because we have connection from excitatory to excitatory population.
It's time to see the population activity plots:



(a) population activity of inhibitory neurons

(b) population activity of excitatory neurons

Figure 52: population activity

2.6 Bi-directional connections and INH to INH

The diagram will be:

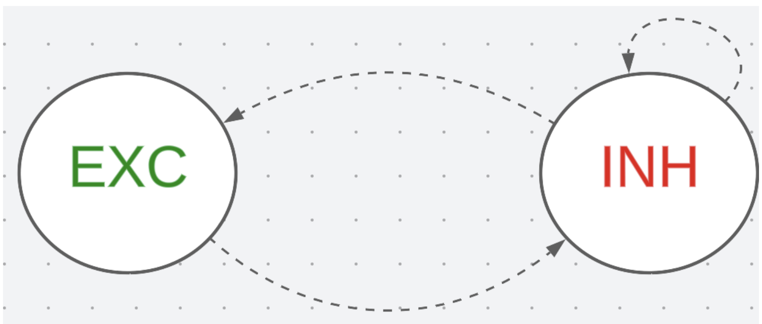


Figure 53: Bi-directional connections and INH to INH connection

1. We set the parameters in a way that both populations spike regularly. Now let's see the raster plot:

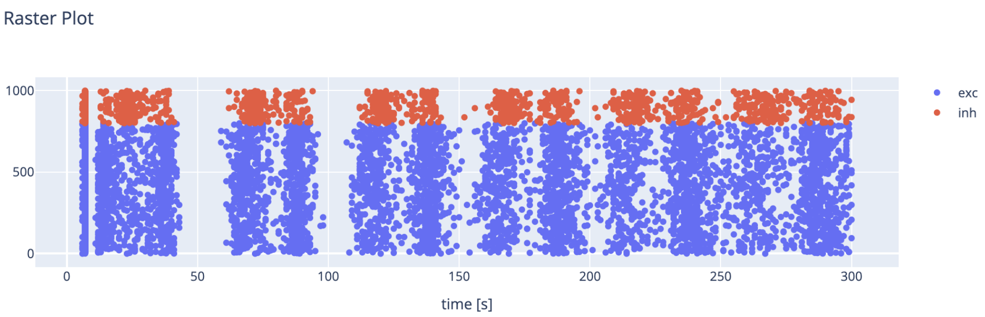
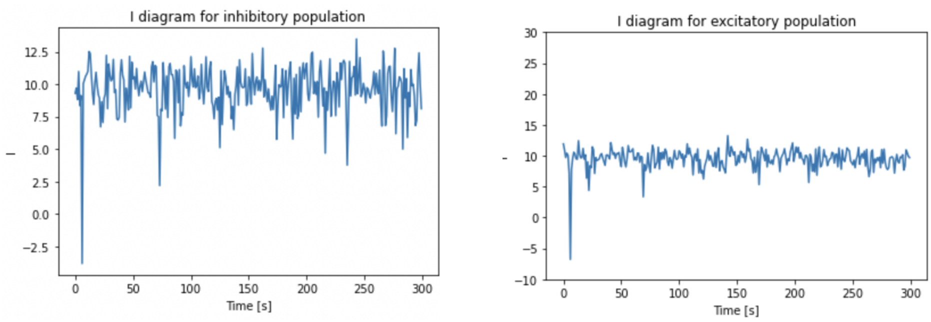


Figure 54: Raster plot

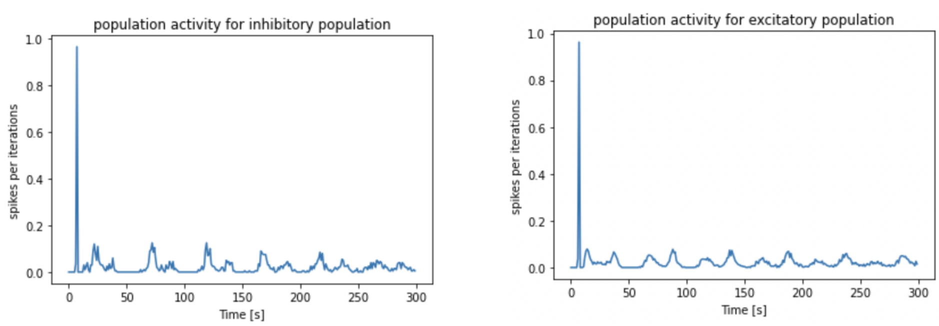
In this case, we have connection from inhibitory to inhibitory neurons. when excitatory neurons spike, the current of the inhibitory neurons will increase and they spike more, but there is connection between them, so they inhibit themselves and the current decreases. Therefore they don't spike as much as figure 47. They spike and the current of the excitatory neurons will decrease a little. Then excitatory neurons spike but this time the amount of rise in the inhibitory population is less than before. That's why we have population activity like figure 56 part (a). At the end we can say there is a steady fluctuation in the current of excitatory population but it tends to decrease in some points. See the plots of population activity and current:



(a) current of inhibitory population

(b) current of excitatory population

Figure 55: currents plot



(a) population activity of inhibitory neurons

(b) population activity of excitatory neurons

Figure 56: population activity

This time unlike figure 48, the current of inhibitory neurons tend to rise, because we have connection from inhibitory to inhibitory population but there is ups and downs, that's because when excitatory neurons spike, the current of inhibitory ones will increase. The other point is we have less range of activity compared to figure 49, because the inhibitory neurons inhibit them and the activity become lower compared to the situation when we had connection from excitatory to excitatory population (in that case neurons excited each other and the activity increase).

2. Now we make inhibitory neurons spike fast. The parameters for the inhibitory population are:

   - $a : 0.1$
   - $b : 0.2$
   - $c : -65$
   - $d : 8$

   Let's see the raster plot:

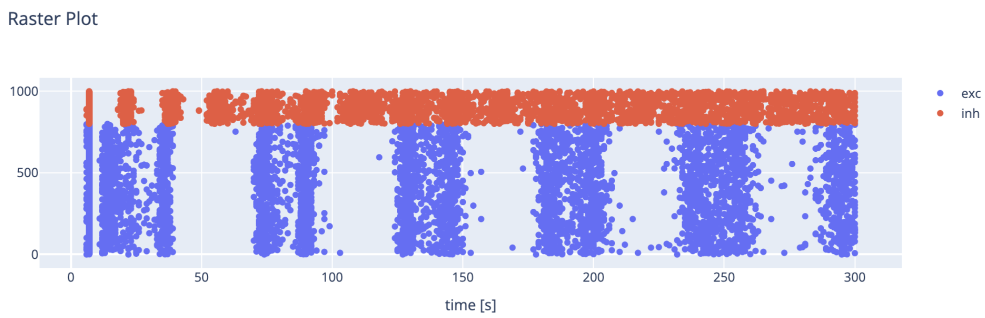
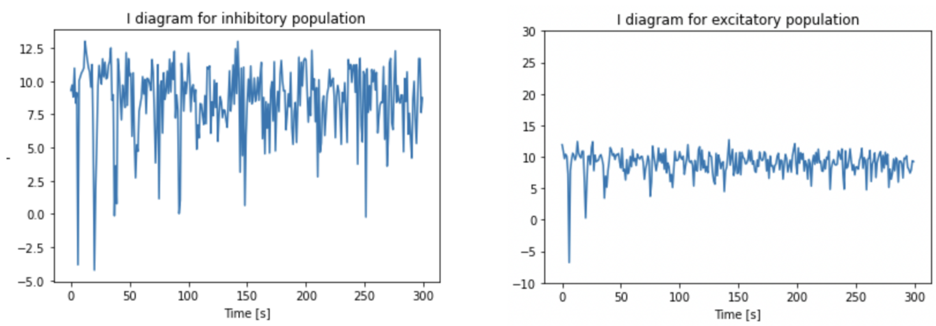


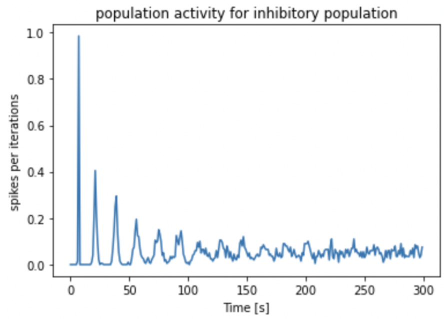
Figure 57: Raster plot

Also see the other plots:

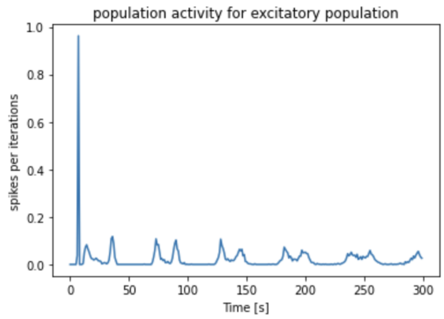


(a) current of inhibitory population (b) current of excitatory population

Figure 58: currents plot



(a) population activity of inhibitory neurons



(b) population activity of excitatory neurons

Figure 59: population activity

In this case when excitatory neurons spike, current in the inhibitory population will increase and they spike more, but there is connection between them so they inhibit each other and the current will decrease. Here the inhibitory neurons are fast spiking, therefore they inhibit more and the current fall lower than last experiment. You can compare figure 58 with figure 55 to see this conduction. After that excitatory neurons spike but this time there are fewer spikes than before, so after inhibitory neurons inhibit themselves, the current become smaller. that's why when we go forward thorough the simulation, we will have less activity for the inhibitory population (see figure 59 part (a)). So the current of the inhibitory population tends to decrease in some points more than last experiment, but the current of excitatory population almost remains the same. Totaly the number of spikes in the excitatory population is less than the number in the last test, that's because we have fast spiking inhibitory neurons.

HAVE FUN !!

3 References

[1] Izhikevich, E.M., 2003. Simple model of spiking neurons. IEEE Transactions on neural networks, 14(6), pp.1569-1572.

[2] Simple Model of Spiking Neurons https://www.izhikevich.org/publications/spikes.html.