project-4

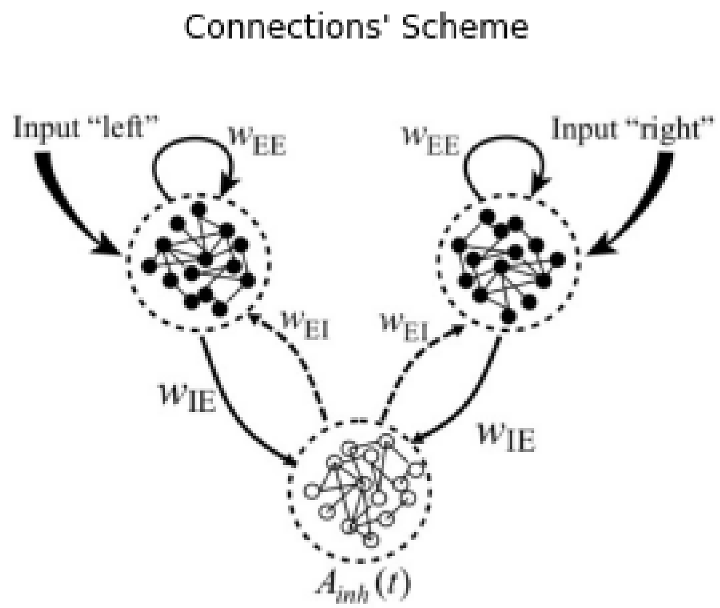
April 30, 2021

Contents

Chapter 1

Introduction

In this project, we simulate a system with two excitatory populations, indirectly connected with an inhibitory population in between. You can see the connections' scheme in the image below. In this system, we assume the two excitatory populations are equivalent (statistically not ideally). This system emulates a decision condition in the brain. Excitatory populations represents the areas of the brain that are making the decision, and the input currents represent the signal that affects the decision-making.



The goal is to apply different inputs to these EPs and see what changes in the activity pattern of the populations. Also, different connection parameters and type of connections will be tested.

Abbreviations:

1. EE: Excitatory to Excitatory connection
2. EI: Excitatory to Inhibitory connection
3. EE: Inhibitory to Excitatory connection
4. EP: Excitatory Population
5. IP: Inhibitory Population

Chapter 2

Experiments

We assume three types of connections for the experiments: EE, EI and IE, and EE1 and EE2 will be equal (in type of connection and the parameters). Likewise for EIs and IEs. connection_types[0] refers to EE, 1 to EI and 2 to IE. the same logic applies for j_0, σ_0 and $n_{connections}$ in random connection.

In all the experiments we fix these parameters unless mentioned:

$\sigma_{n_{time}} = 5$

$\sigma_{n_{neuron}} = 4$

$Total_{N_{neurons}} = 1000$

$EP1_{N_{neurons}} = EP2_{N_{neurons}} = 400$, $EP_{u_{rest}} = -65mv, EP_{threshold} = -50mv, EP_{tau} = 50$

$IP_{N_{neurons}} = 200$, $IP_{u_{rest}} = -65mv, IP_{threshold} = -60mv, IP_{tau} = 25$

$\sigma_{0_{EE}} = \sigma_{0_{EI}} = \sigma_{0_{IE}} = 0.2$

$ I_{base} = 20 $

$time_{sim} = 2000ms$

Note: Savitzky–Golay filter with a degree of 3 is applied to populations' activities before plotting to smoothen out the plots and make them comprehensible.

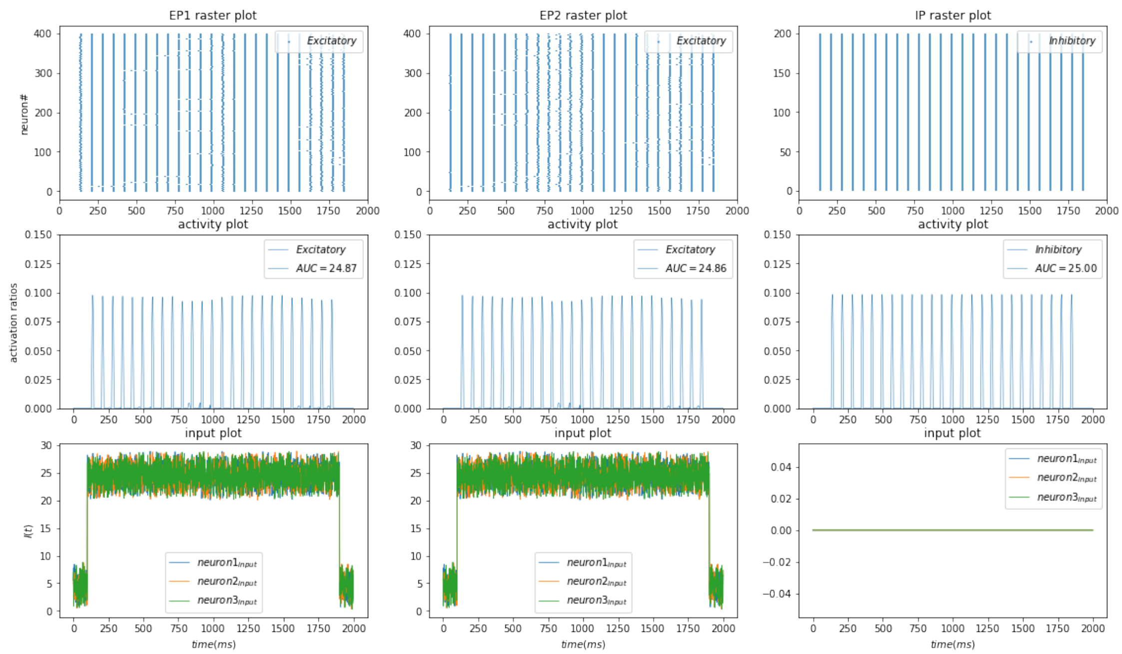
2.1 Experiment #1

In the first experiment, we use dense connection for all three types of connections, Dense connection parameters:

$j_{EE} = 0.1, j_{EI} = 5, j_{IE} = 20$

We also feed the same input to both excitatory populations to create a baseline.

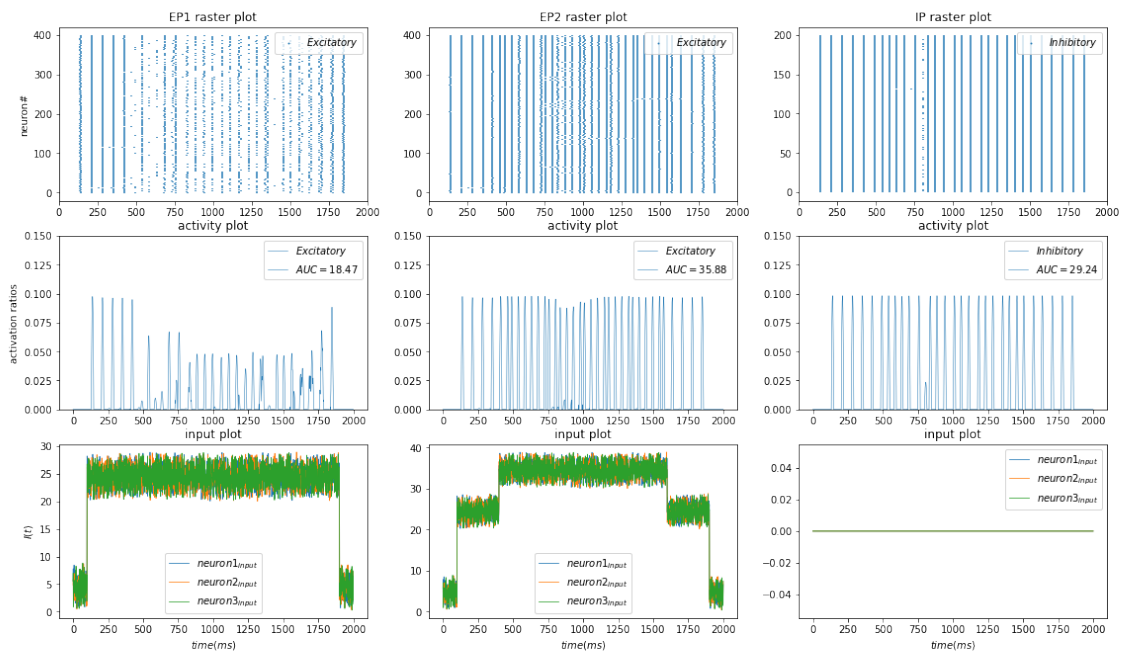
$J_0 = [0.1, 5, 15]$, connection_types: Dense Connection, Same Input



As expected, all populations have almost the same activity pattern.
Now we apply an additional step current with an amplitude of 10 to the second excitatory population.

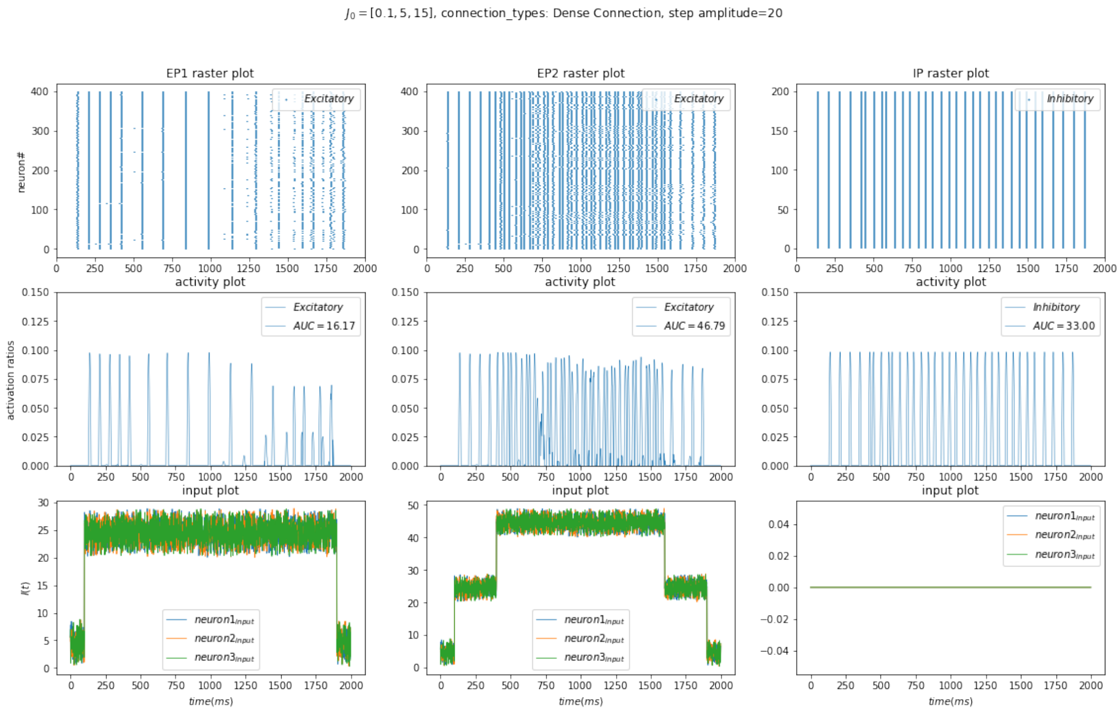
2.1.1 Step inputs

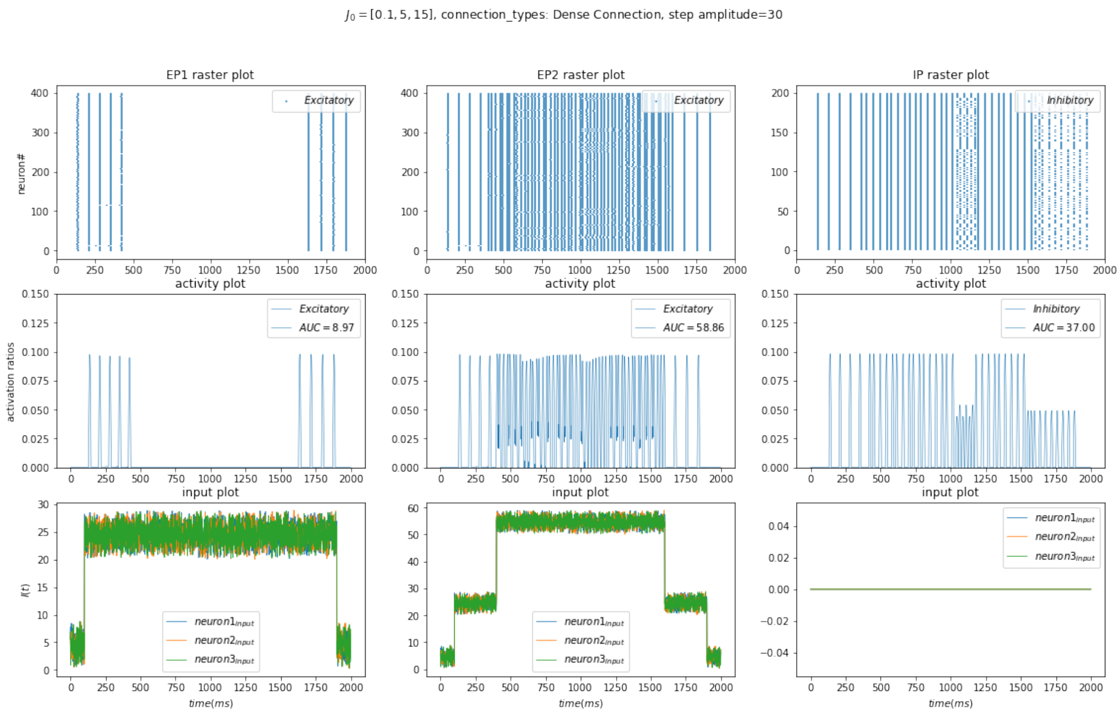
$J_0 = [0.1, 5, 15]$, connection_types: Dense Connection, step amplitude=10



The activity of EP1 decreases after applying the additional step current, and activity of EP2 and IP increases. This is due to effective inhibition; The additional input increases EP1's activation. The increased activation of EP2 increases the activation of IP, this in turn, reduces the activity of both EP1 and EP2, but it cannot fully diminish the effect of additional input on EP2.

Now we increase the step current's amplitude to 20 and 30.

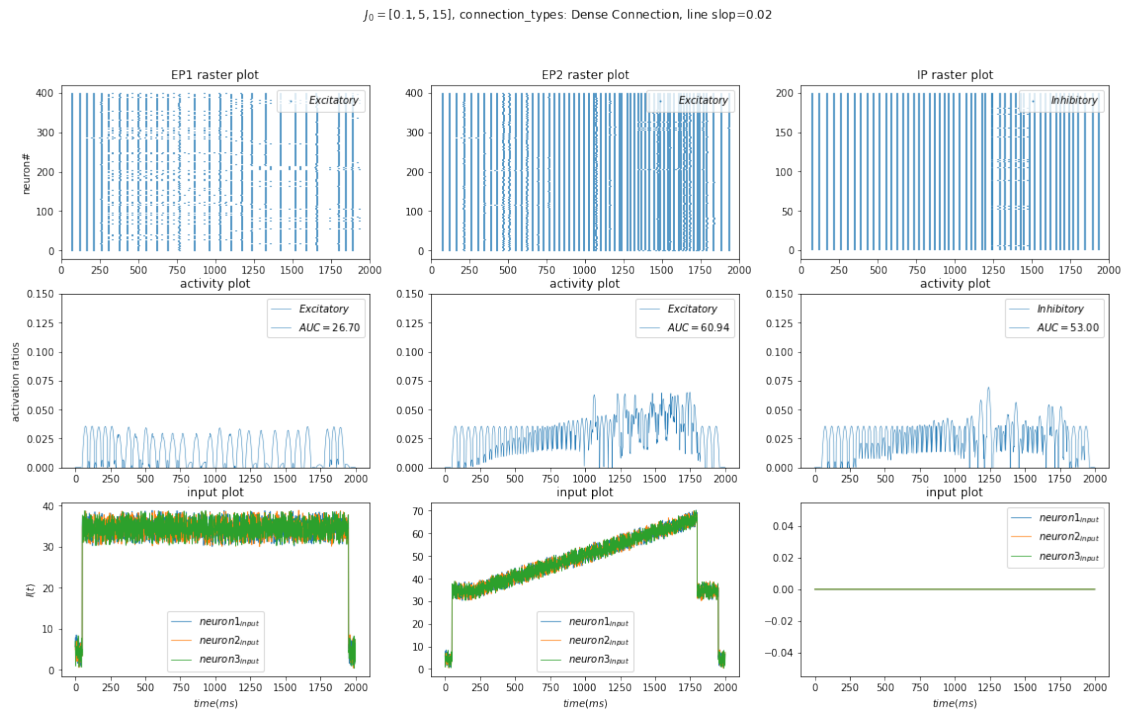


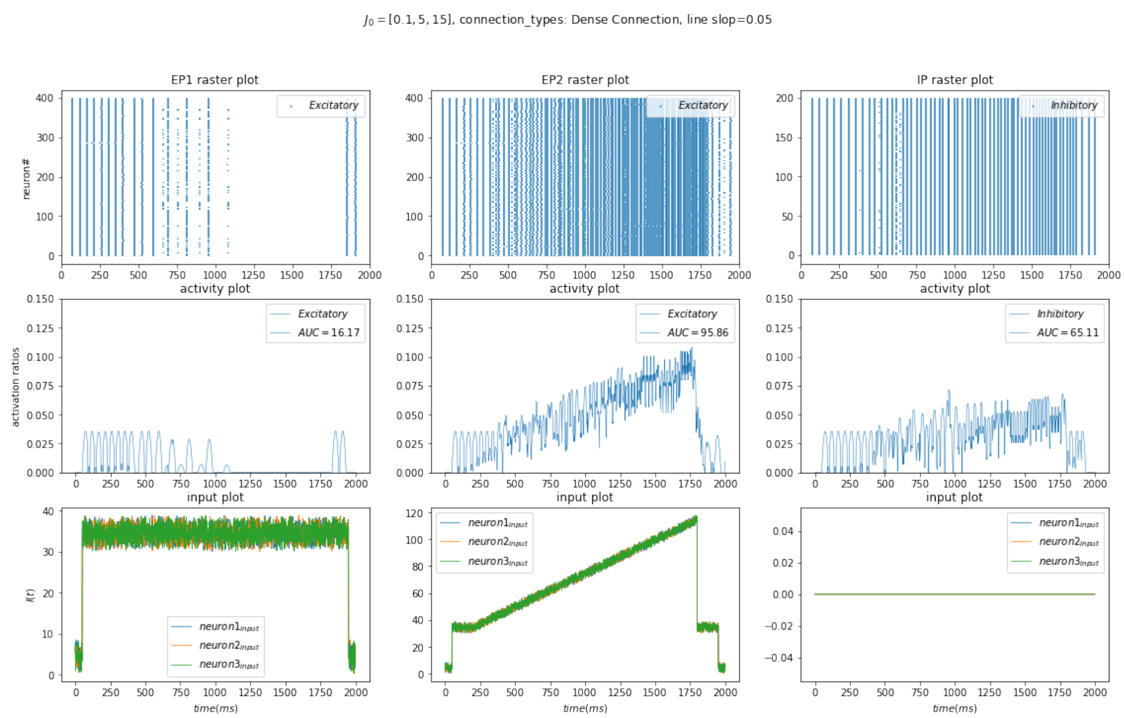


The more the additional current, the activation of EP1 will be decreased more, until at some point it stops being active due to enormous amount of inhibition it receives from the inhibitory population.

2.1.2 Linear inputs

We apply different types of additional inputs to the second excitatory population to see the difference in the activity patterns.

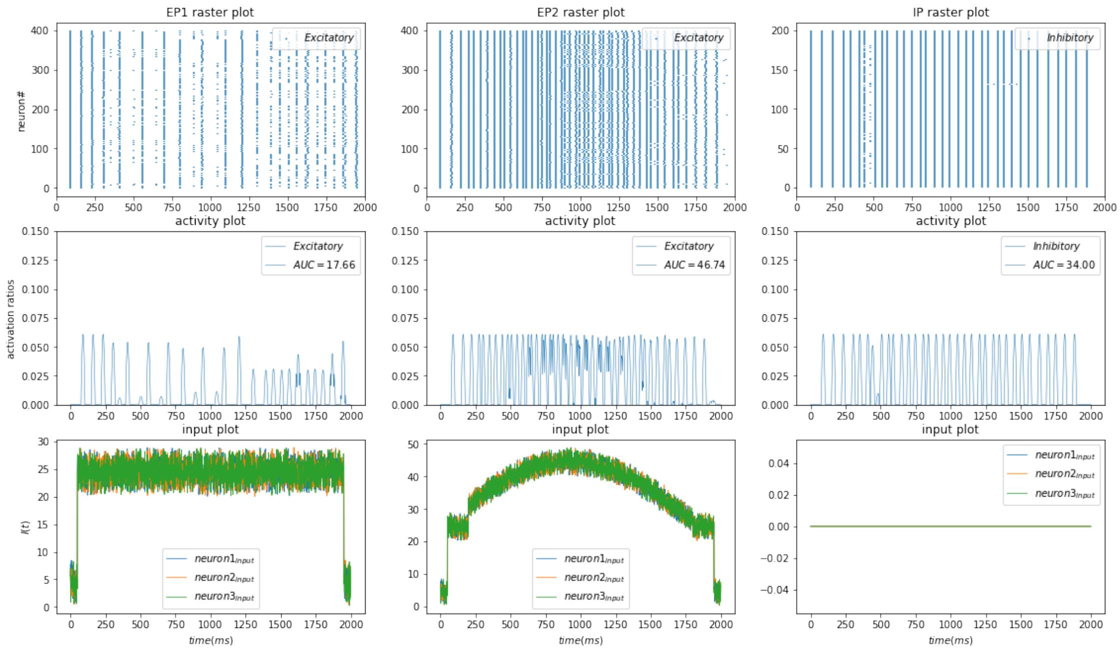




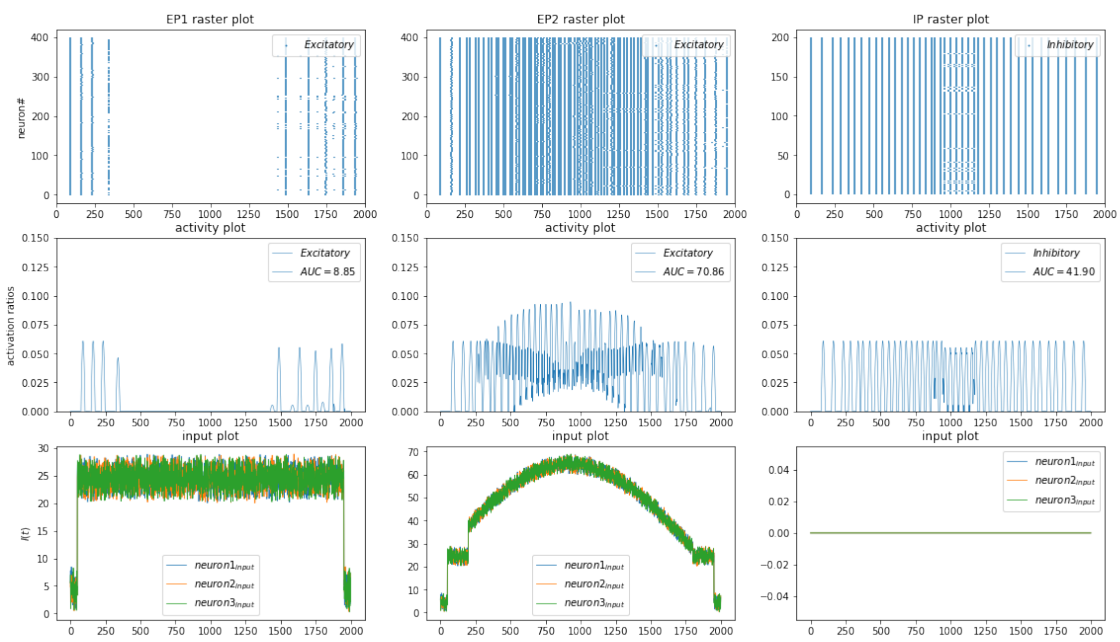
2.1.3 Sinusoidal inputs

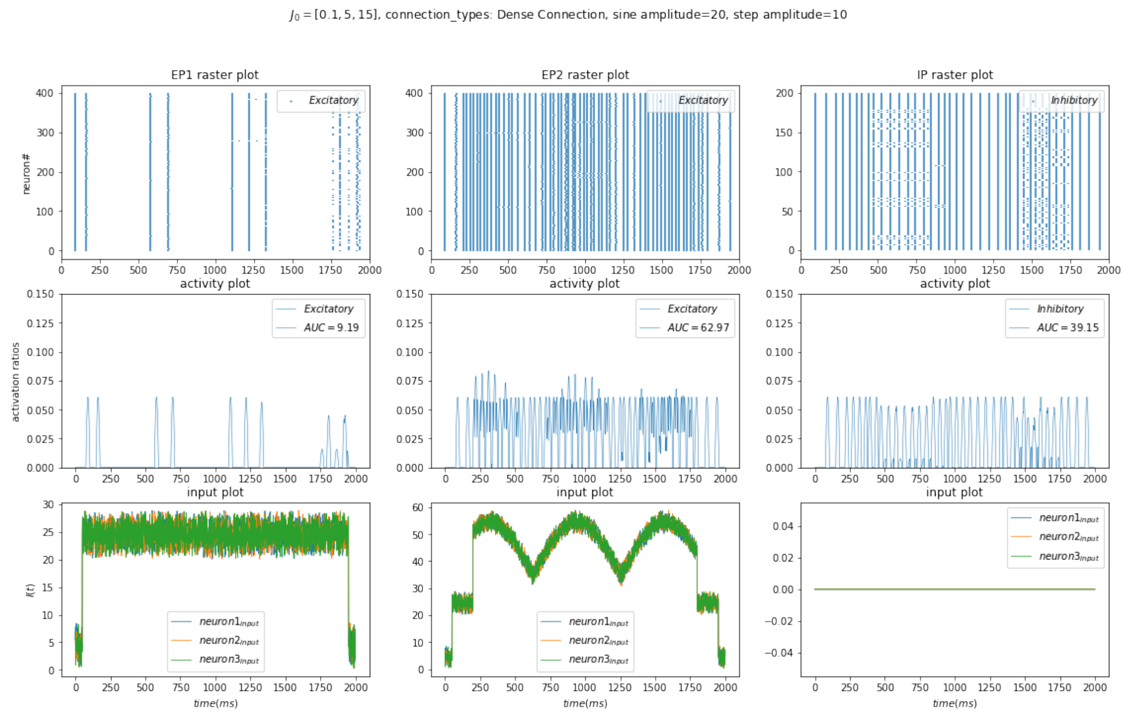
Now, we apply additional sine waves to the second excitatory population.

$J_0 = [0.1, 5, 15]$, connection_types: Dense Connection, sine amplitude=20



$J_0 = [0.1, 5, 15]$, connection_types: Dense Connection, sine amplitude=40





As we see, EP2's activation plot shape, follows the trend of its input. EP1's activation plot on the other hand, is, in some sense, the complement of EP2's activation plot.

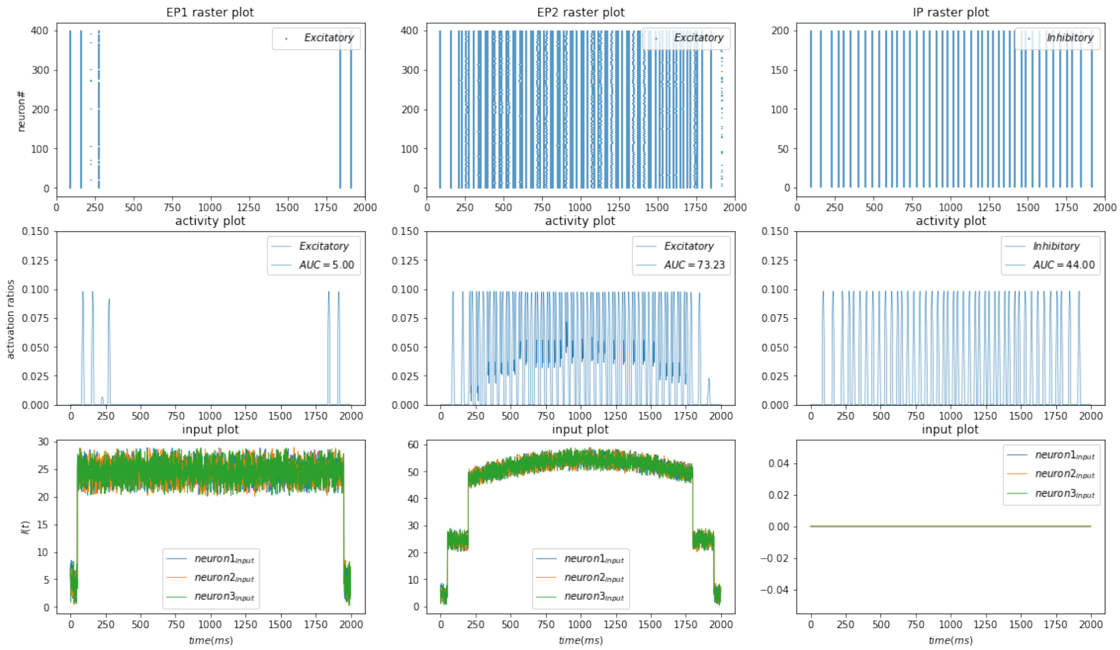
2.2 Experiment #2

2.2.1 Effect of J_0

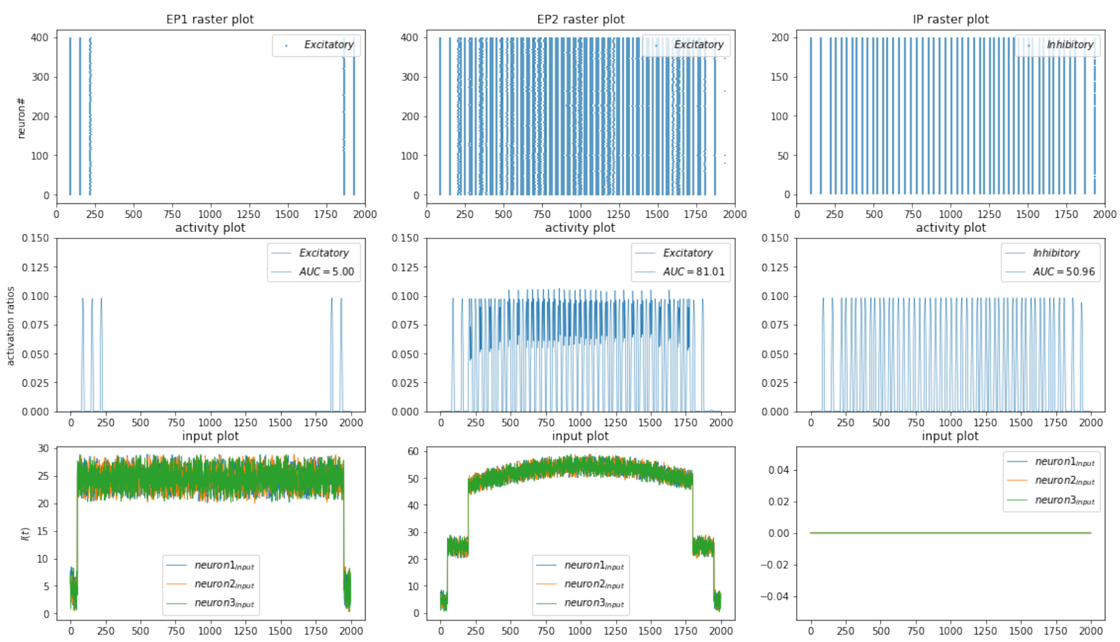
Here we repeat the previous experiment with only different values of j_0. We know from the previous project that if we increase the value of j_0, the connection becomes stronger.

We fix the inputs to a stepped sine wave to focus on effects of J_0s.

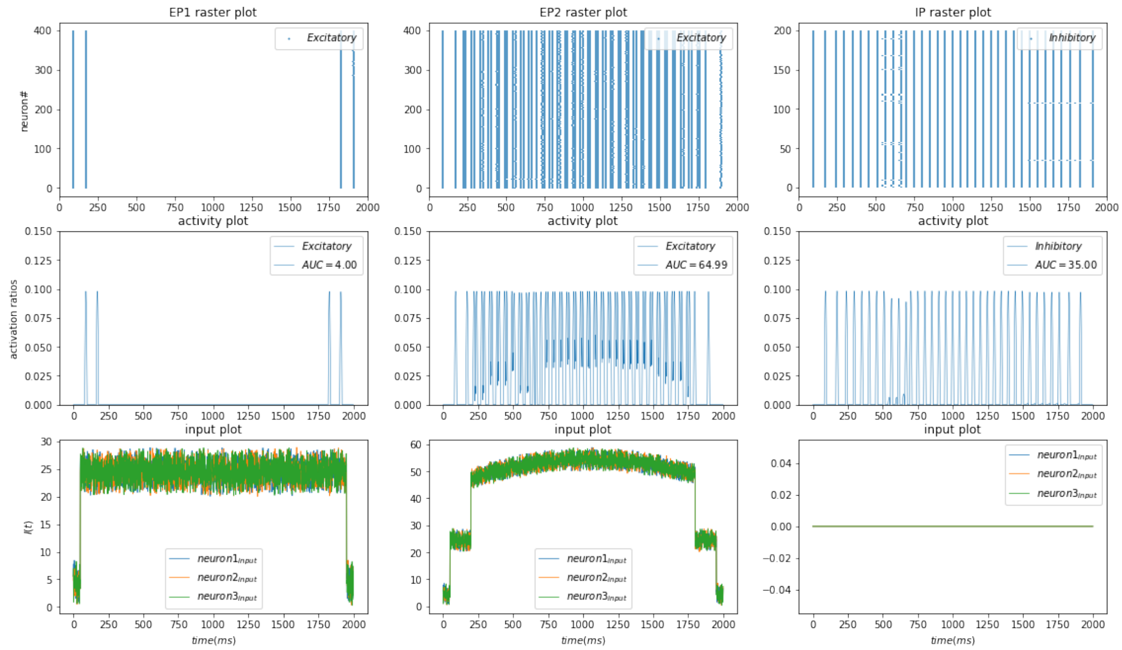
$J_0 = [2, 5, 15]$, connection_types: Dense Connection, sine amplitude=10, step amplitude=20



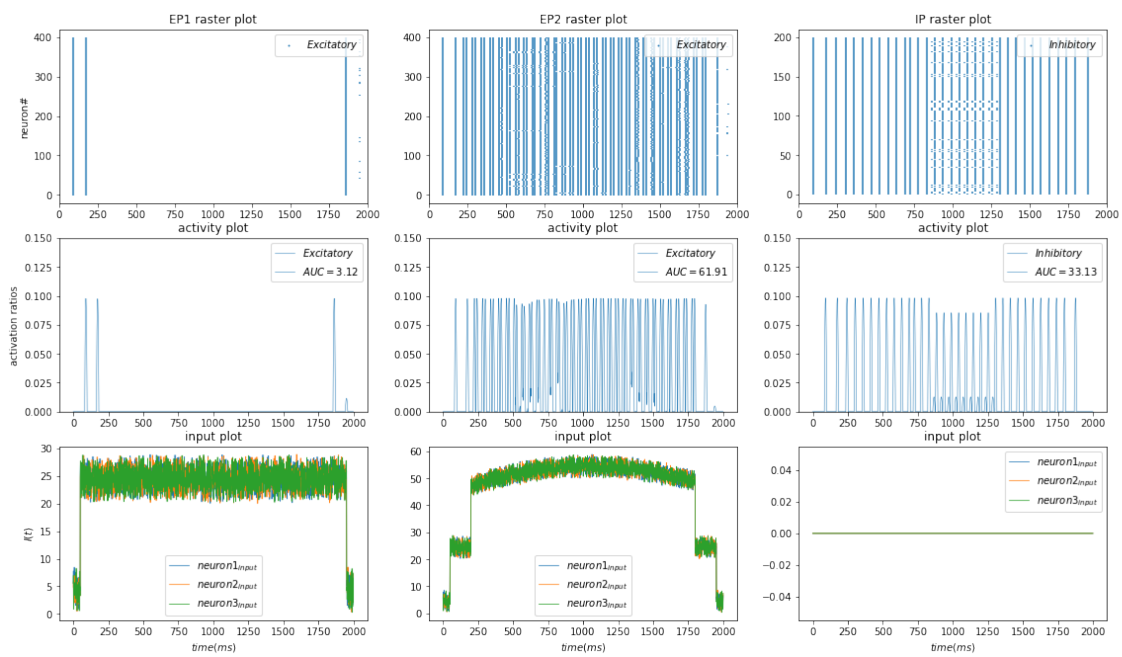
$J_0 = [5, 5, 15]$, connection_types: Dense Connection, sine amplitude=10, step amplitude=20

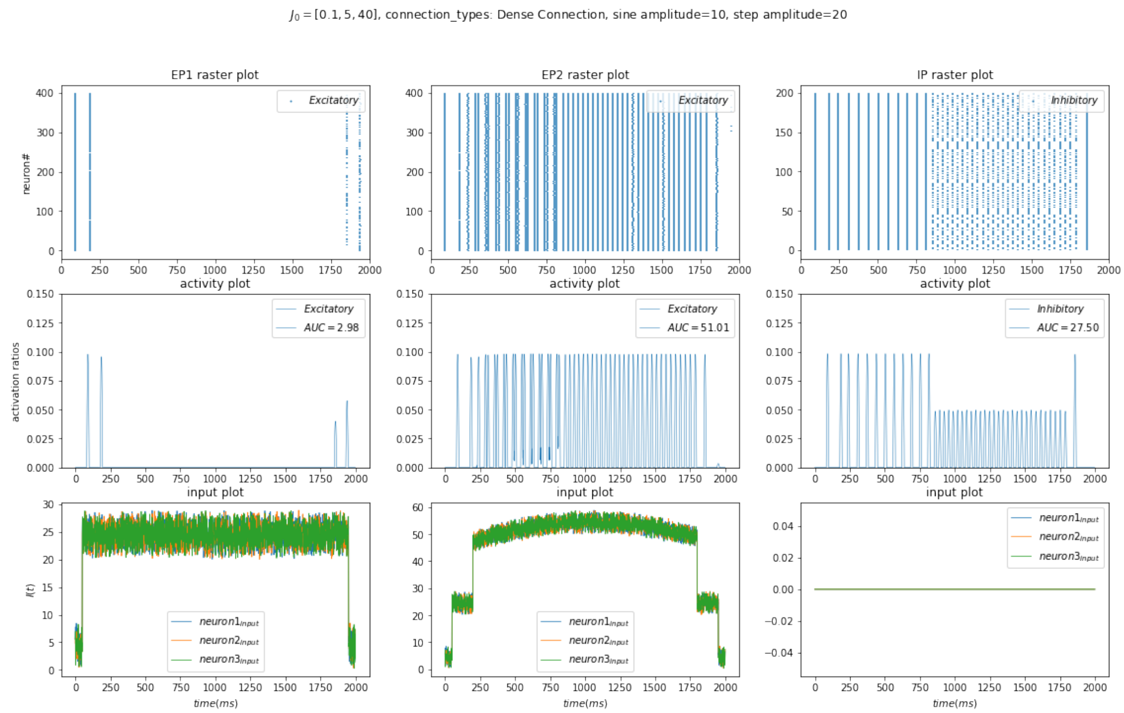


$J_0 = [2, 5, 25]$, connection_types: Dense Connection, sine amplitude=10, step amplitude=20



$J_0 = [0.1, 5, 25]$, connection_types: Dense Connection, sine amplitude=10, step amplitude=20





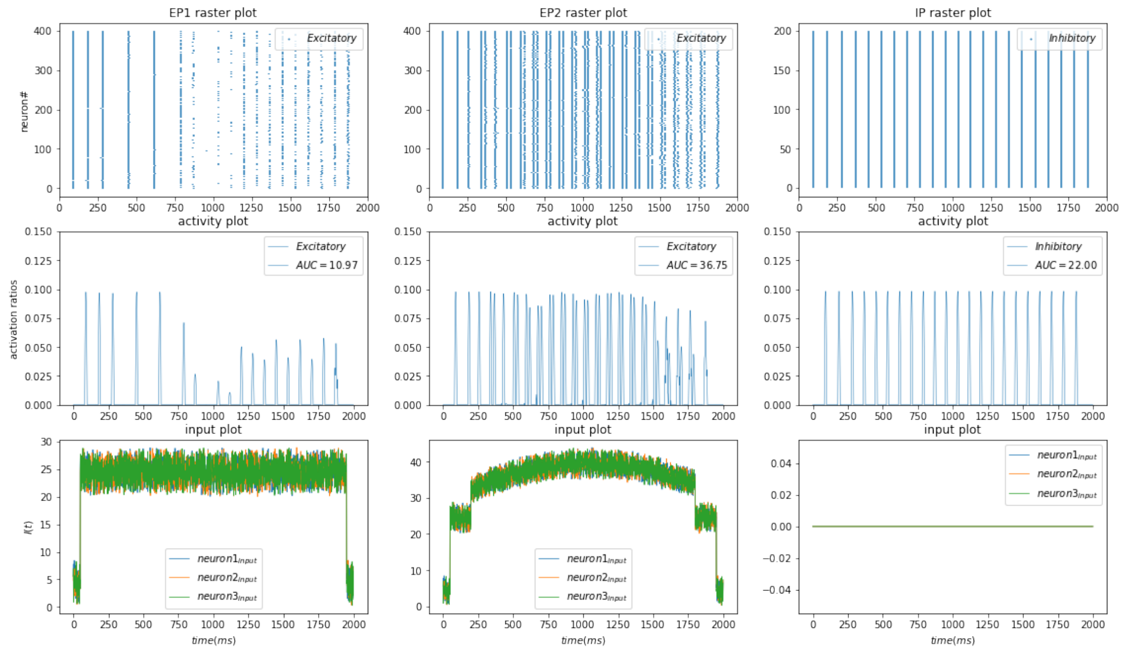
The overall activation pattern of the populations are preserved with changing the values of j_0 in a normal range (which do not cause exploding activities). The effect of this parameter is as just we talked about in the previous project.

2.3 Experiment #3

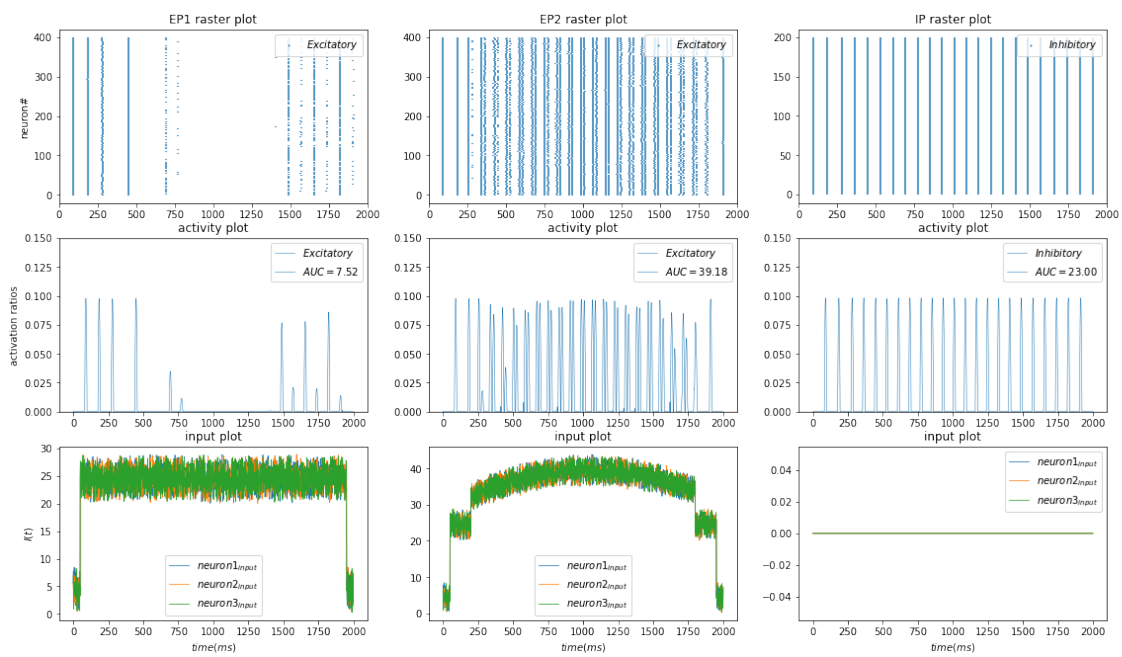
Testing the effect of different connection schemes.

2.3.1 EE connection type -> Random

connection_types: Random, Dense, Dense, num_connections: [2, -1, -1], sine amplitude=10, step amplitude=5

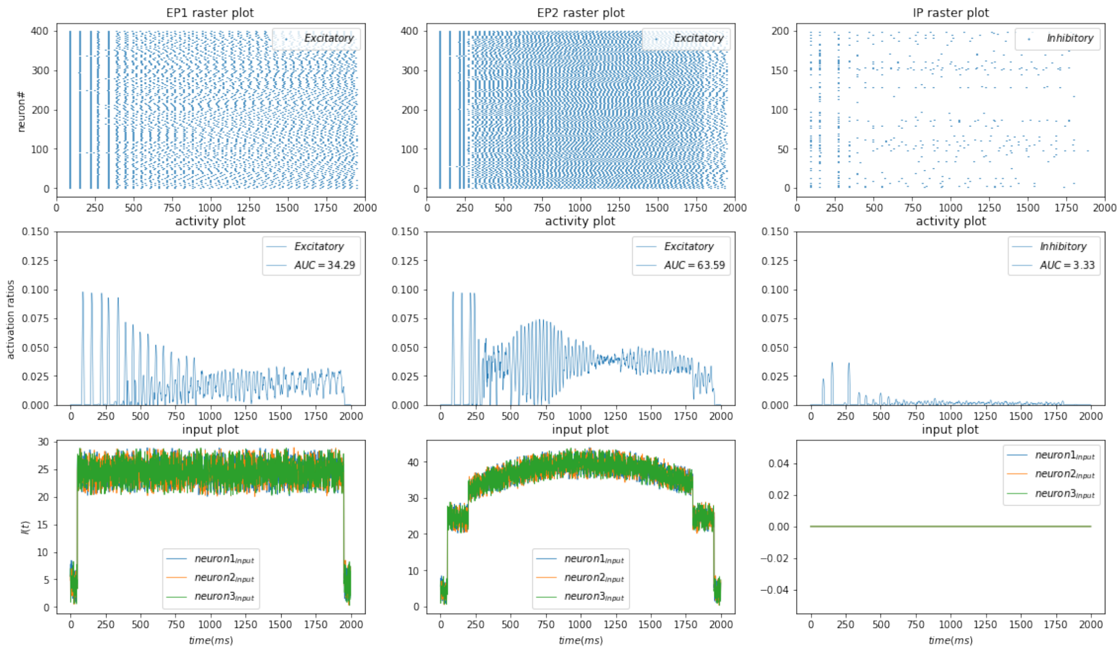


connection_types: Random, Dense, Dense, num_connections: [5, -1, -1], sine amplitude=10, step amplitude=5

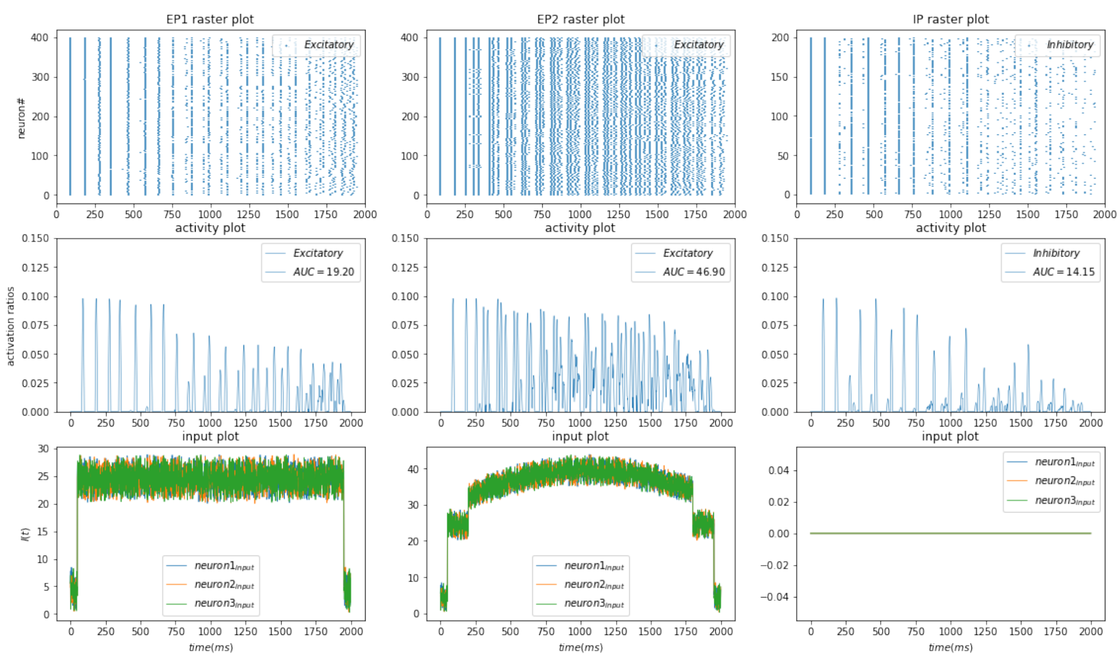


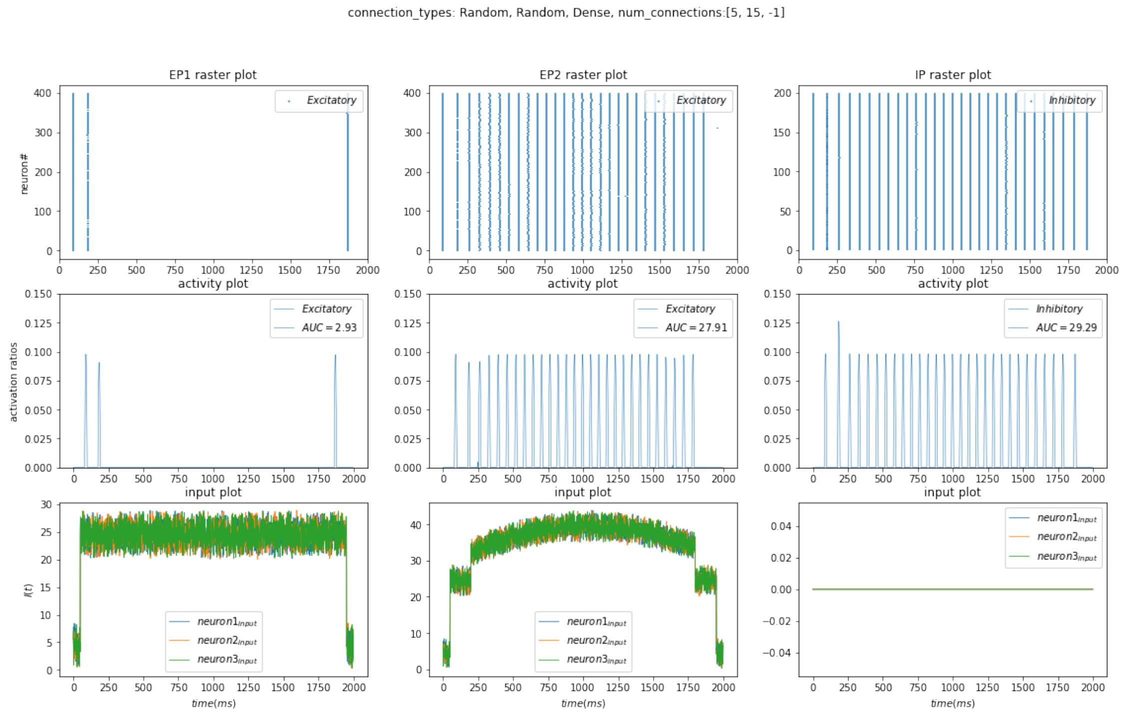
2.3.2 EE and EI connection type -> Random

connection_types: Random, Random, Dense, num_connections:[2, 5, -1]



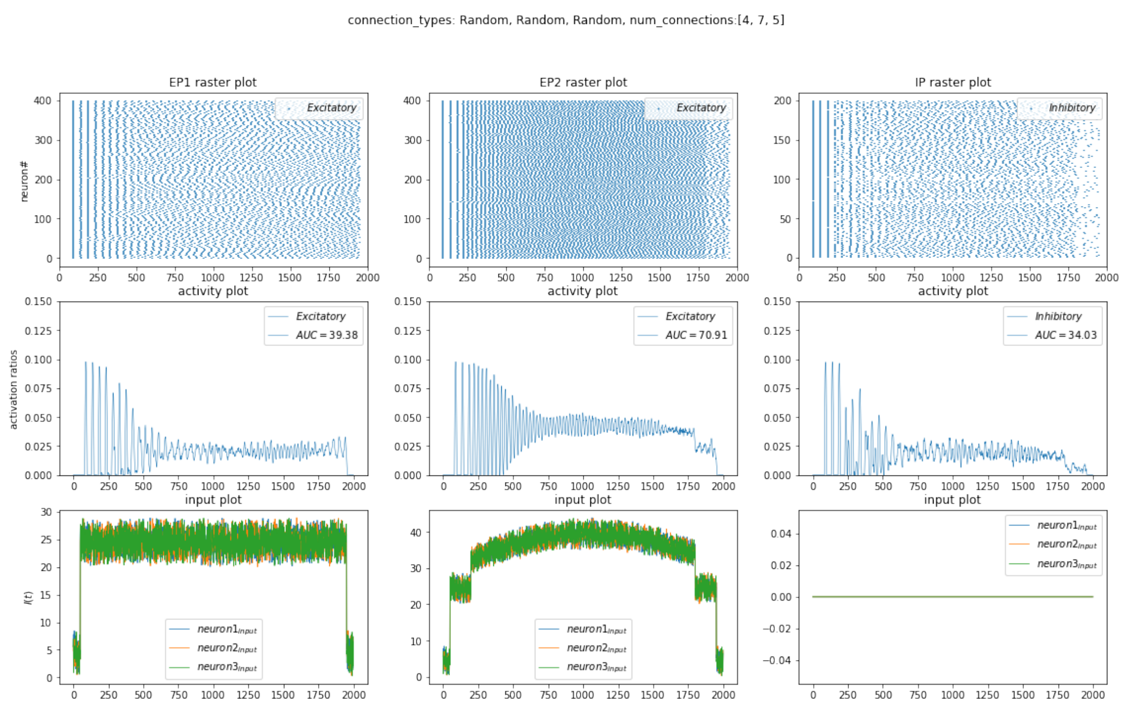
connection_types: Random, Random, Dense, num_connections:[5, 7, -1]



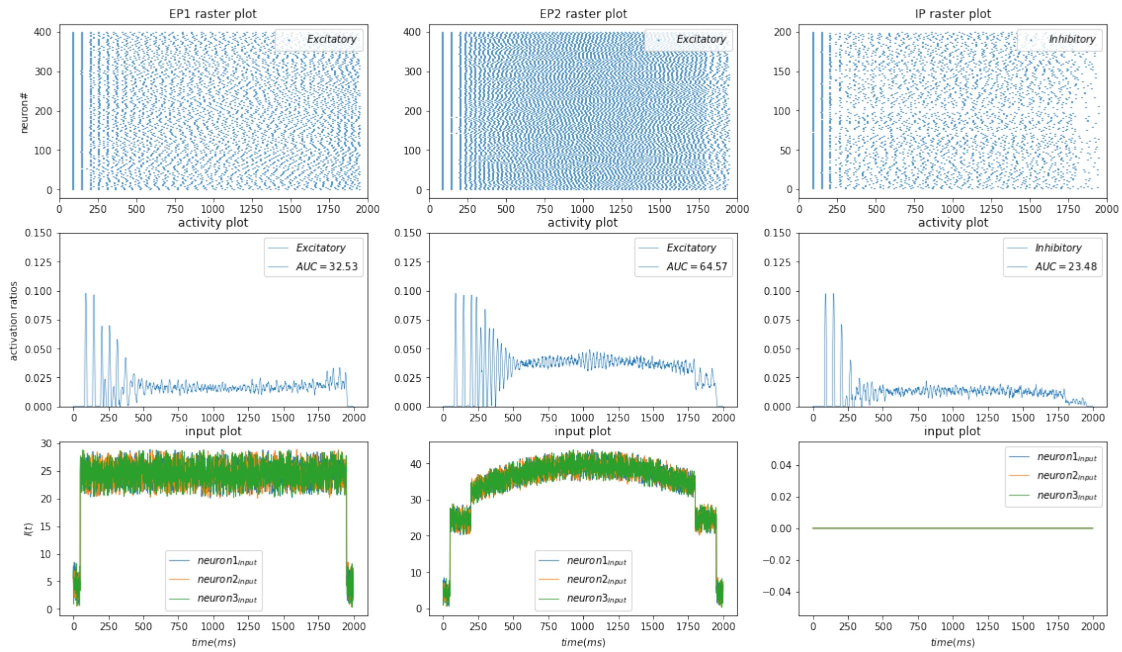


We see that by increasing the strength of the EI connections, the inhibitory population significantly affects the activities of both EPs. In some point, the inhibitory population can stop EP1 activity altogether.

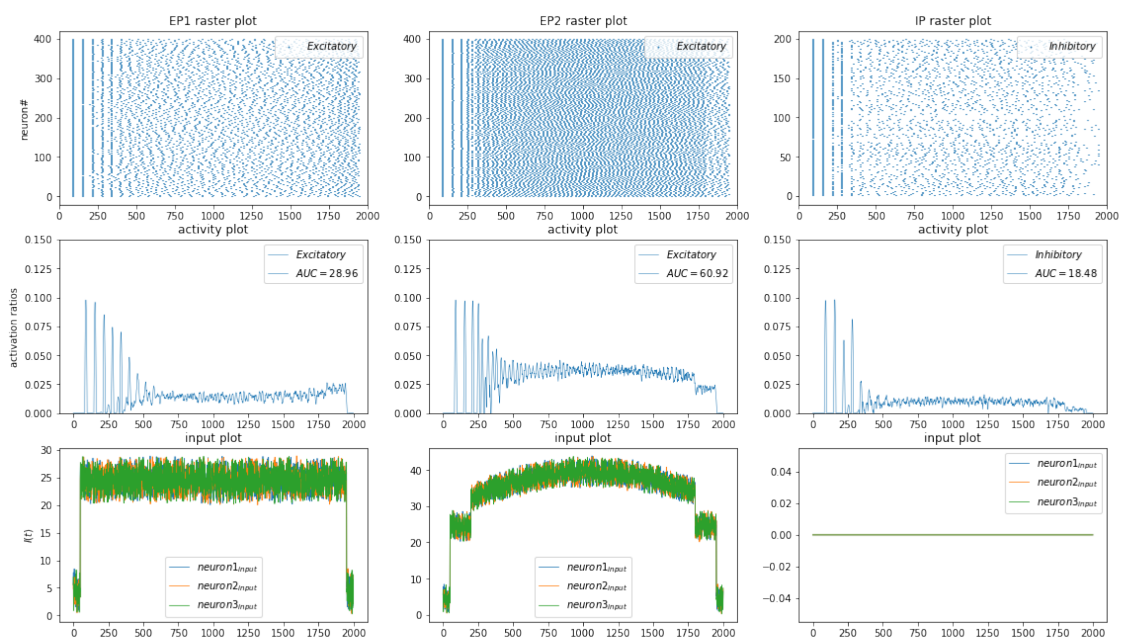
2.3.3 All connection types -> Random

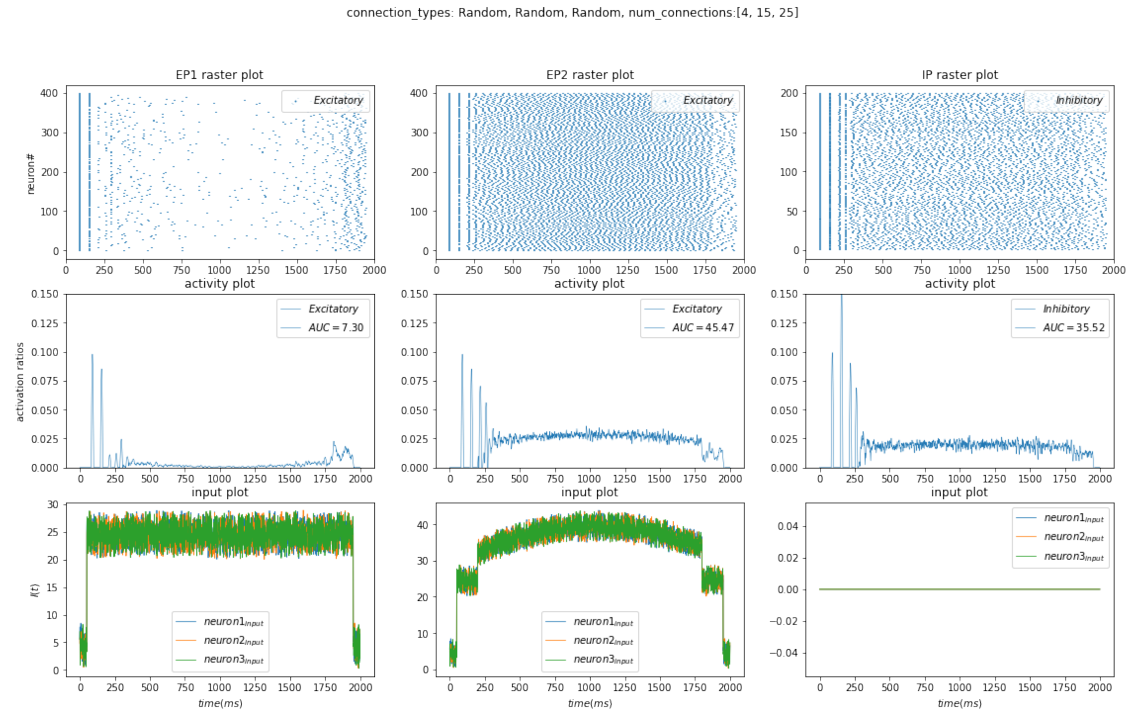


connection_types: Random, Random, Random, num_connections:[4, 7, 15]



connection_types: Random, Random, Random, num_connections:[4, 7, 25]

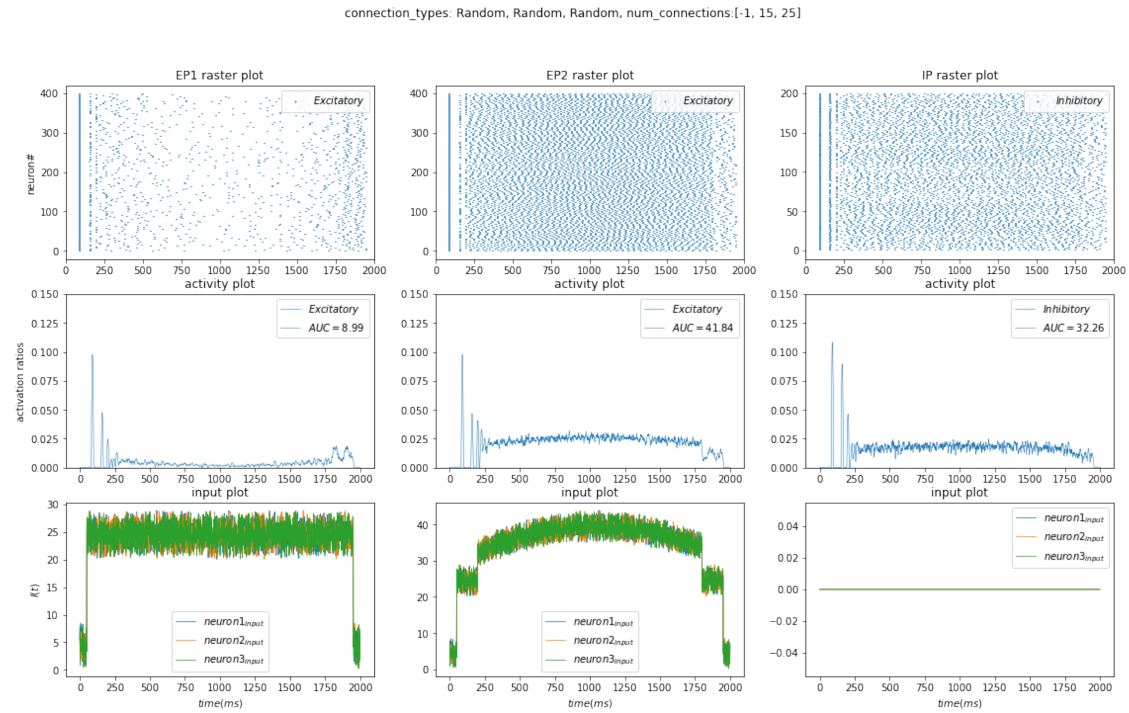




By observing the above plots, the difference between increasing the strength of IE connections and EI connections is visible. Increasing the strength of IE will not change things very much after some point, this is because this change decreases the whole system's activity consistently. But strengthening EI connections affects the excitatory population with lower input more than the other one. It could be explained more in this way: EI connections will be more powerful when the excitatory populations are more active; regardless of the EPs inputs, IP affects both EPs in the same way, if activity of one of them increases, the IP's suppression will be more intense. This intensity will diminish the EP1 activity but cannot fully overcome the activity of EP2. It seems like EP2 is directly inhibiting the activation of EP1.

With these results, we now know that we can leverage number of IE connections in order to control the system in a consistent way.

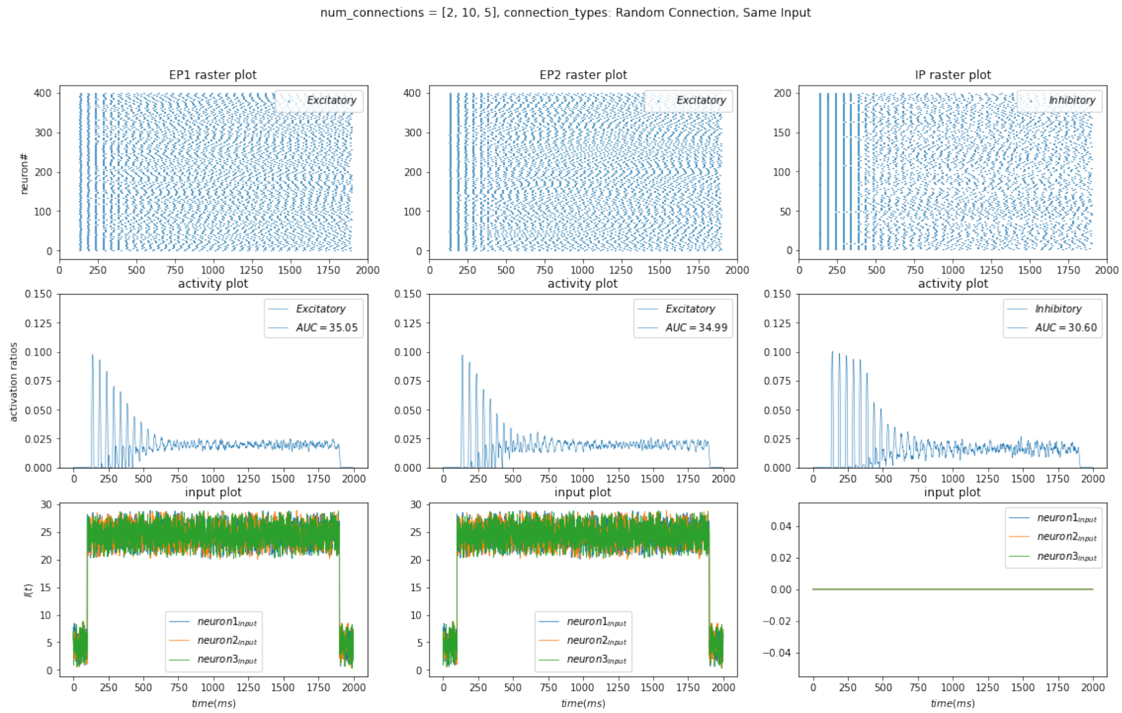
2.3.4 IE and EI connection type -> Random



No big difference is observed with full random scheme. This suggests that the internal connections of EPs do not have significant impact on the results. Also, both EI and IE connections should be random in order to achieve results different from all dense connections scheme.

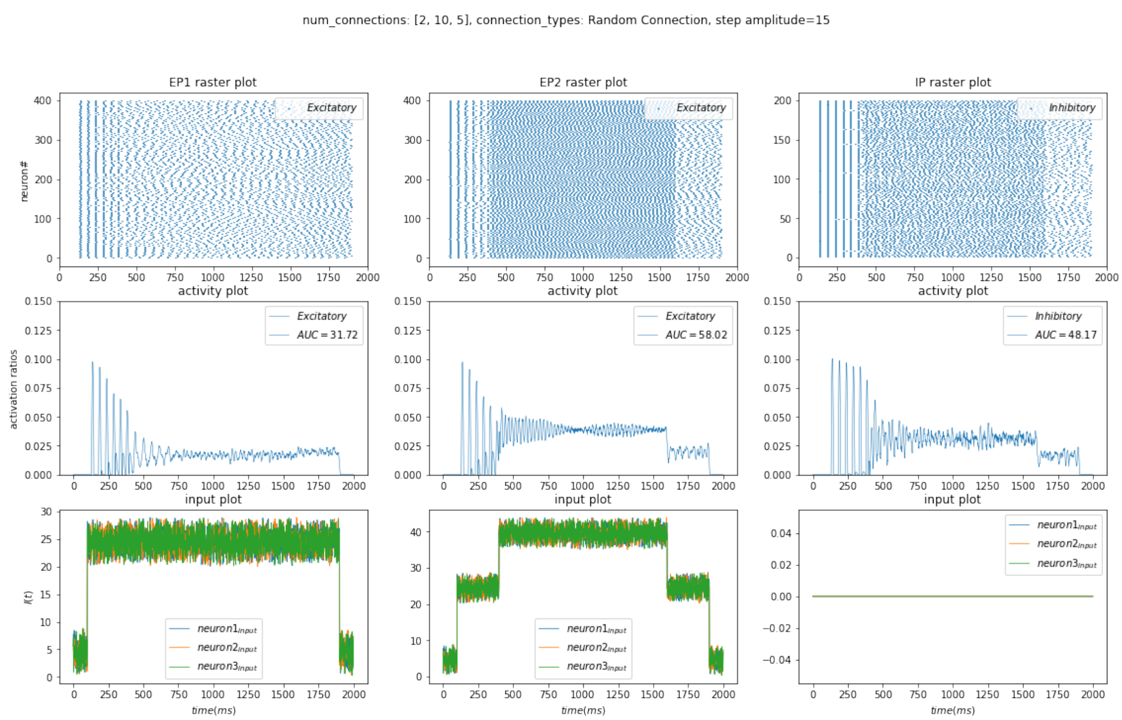
2.4 Experiment #4

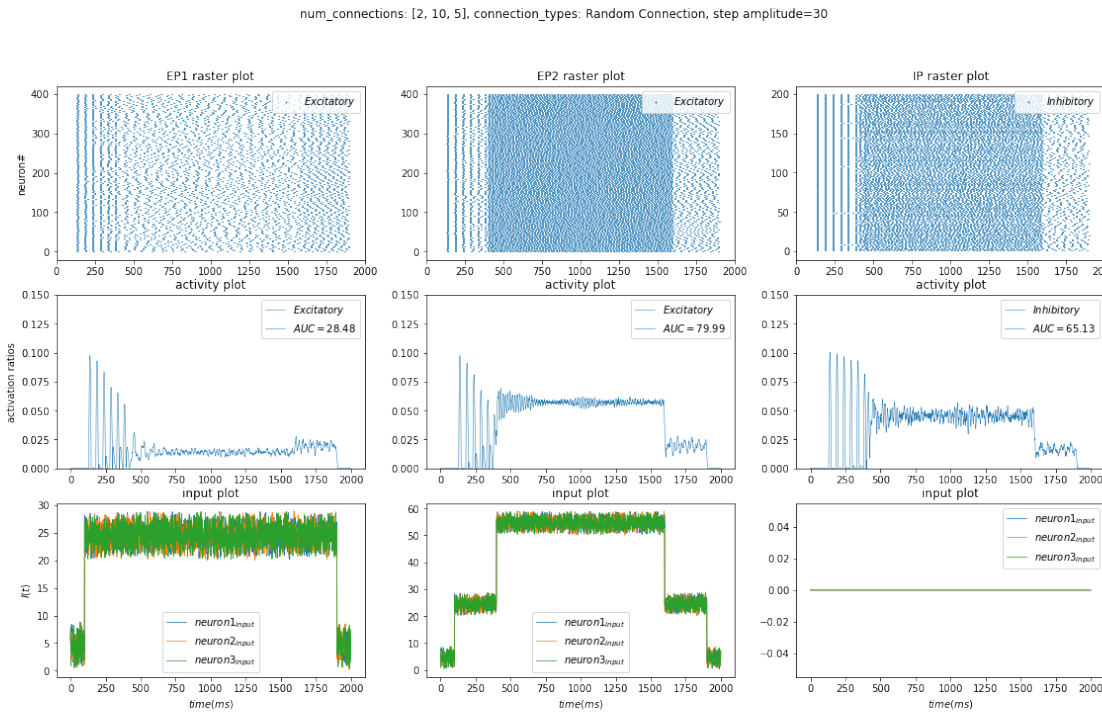
In this experiment, we use random connection for all connections and test the effect of different inputs on the system activity. This is repeating experiment #1 but with random connections.

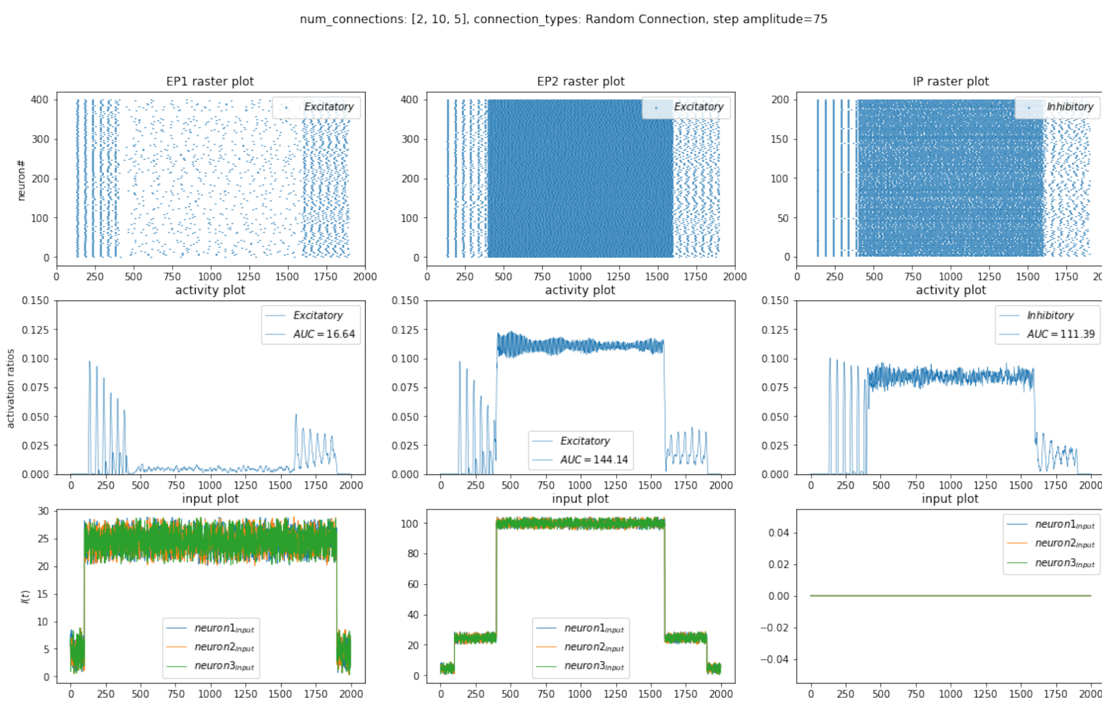


As expected, all populations have almost the same activity pattern.
Now we apply an additional step current with amplitudes of 15, 30, 75 to the second excitatory population.

2.4.1 Step inputs



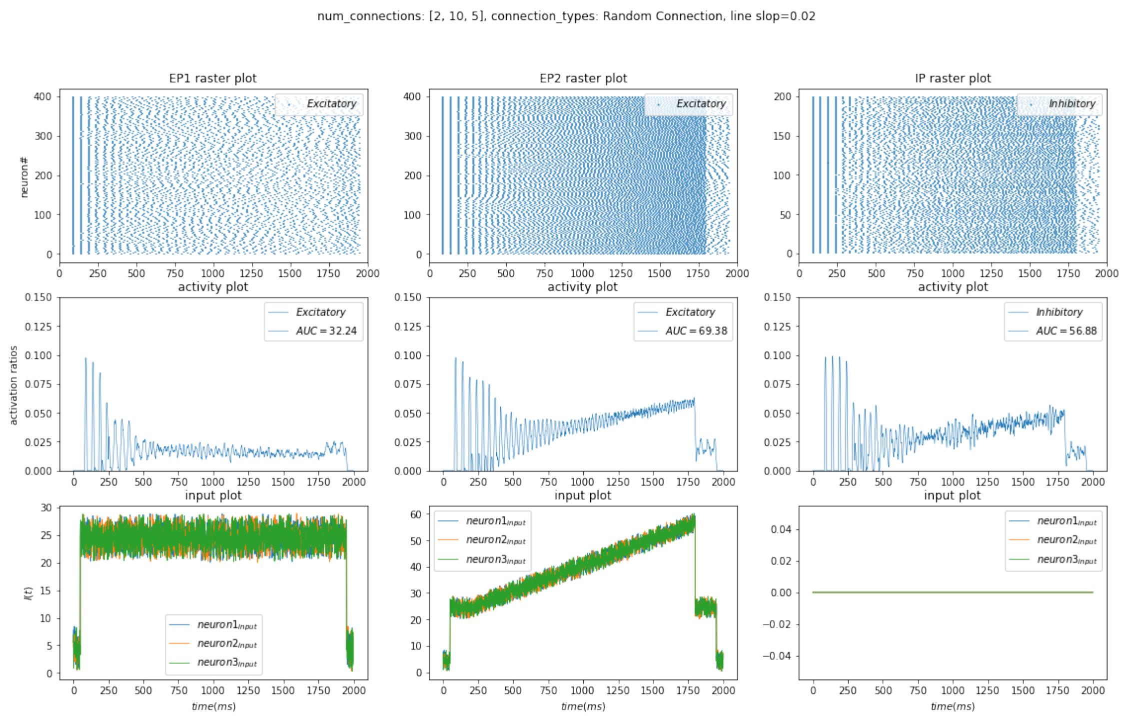

num_connections: [2, 10, 5], connection_types: Random Connection, step amplitude=30
EP1 raster plot
EP2 raster plot
IP raster plot
Excitatory
Inhibitory
neuron#
activity plot
activation ratios
AUC = 28.48
AUC = 79.99
AUC = 65.13
input plot
I(t)
neuron1input
neuron2input
neuron3input
time(ms)


num_connections: [2, 10, 5], connection_types: Random Connection, step amplitude=75
EP1 raster plot
EP2 raster plot
IP raster plot
Excitatory
Inhibitory
neuron#
activity plot
activation ratios
AUC = 16.64
AUC = 144.14
AUC = 111.39
input plot
I(t)
neuron1input
neuron2input
neuron3input
time(ms)

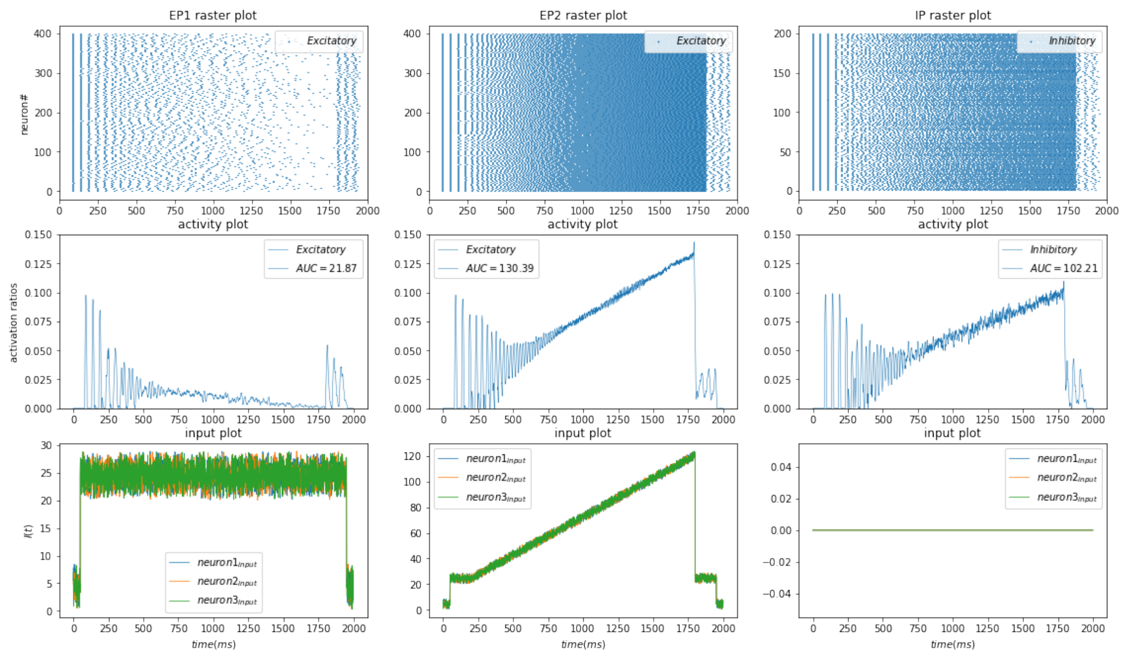
The activity of EP1 decreases after applying the additional step current, and activity of EP2 and IP increases. This is due to effective inhibition. The increased activation of EP1 increases the activation of IP, this in turn, reduces the activity of both EP1 and EP2, but it cannot fully diminish the effect of additional input on EP2.

The more the additional current, the activation of EP1 will be decreased more. Unlike the situation with dense connection types, where EP1 would stop being active with relatively low amount of increase in EP2, here it can resist more and even though its activation decreases it is more robust to input change in the other excitatory population.

2.4.2 Linear inputs



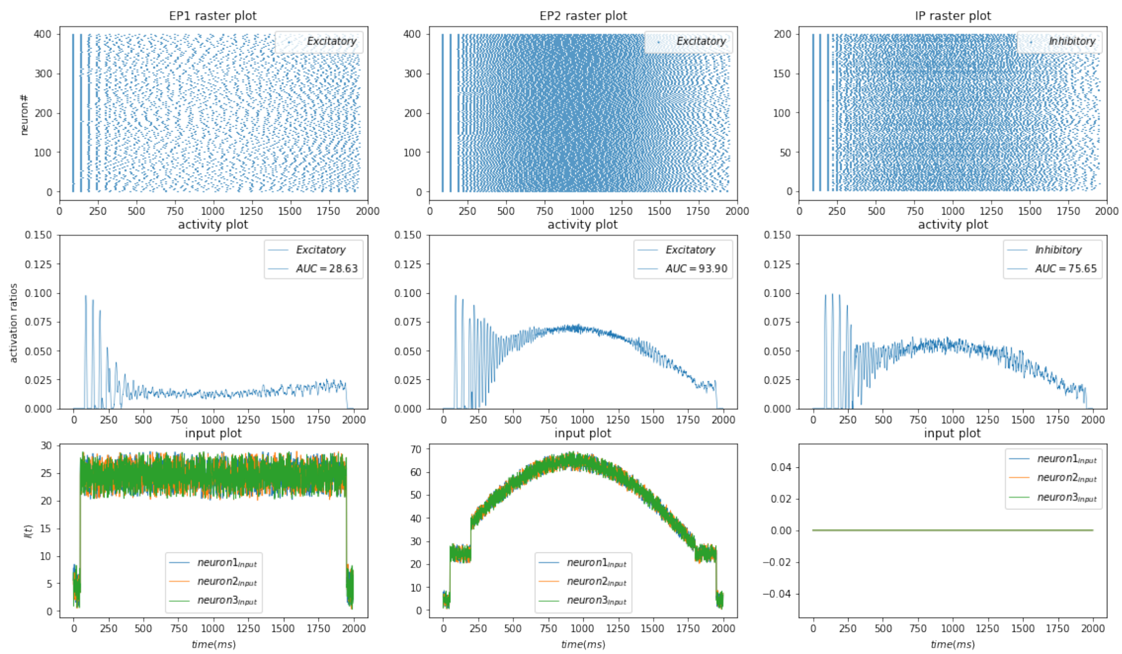
num_connections: [2, 10, 5], connection_types: Random Connection, line slop=0.06

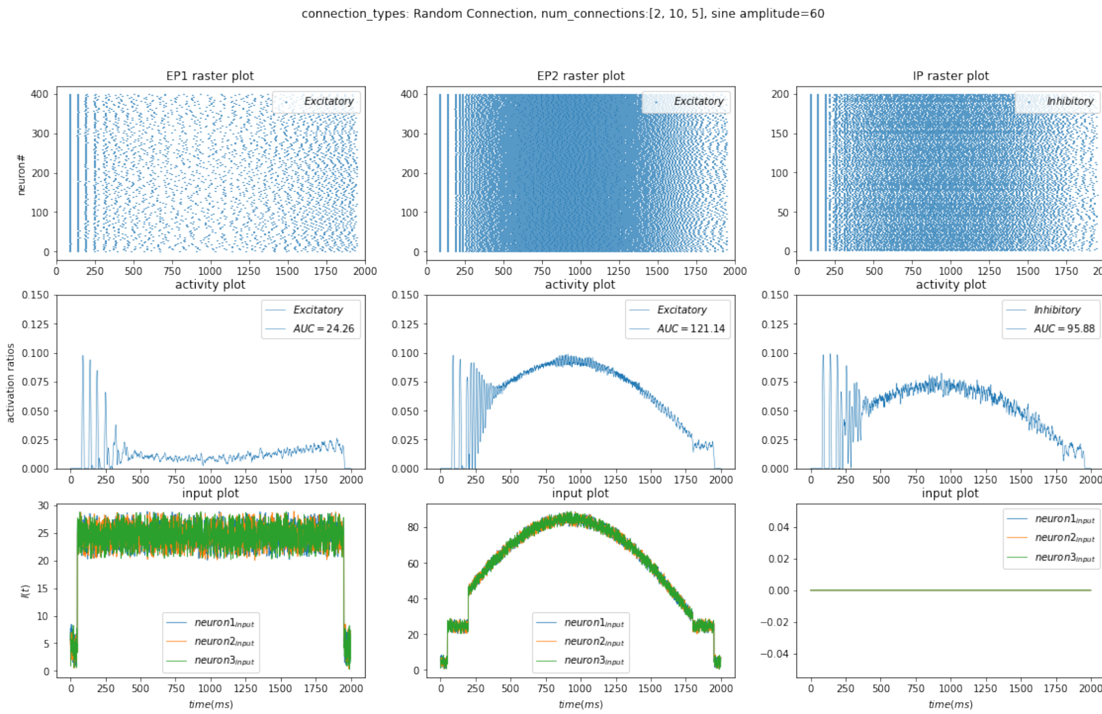


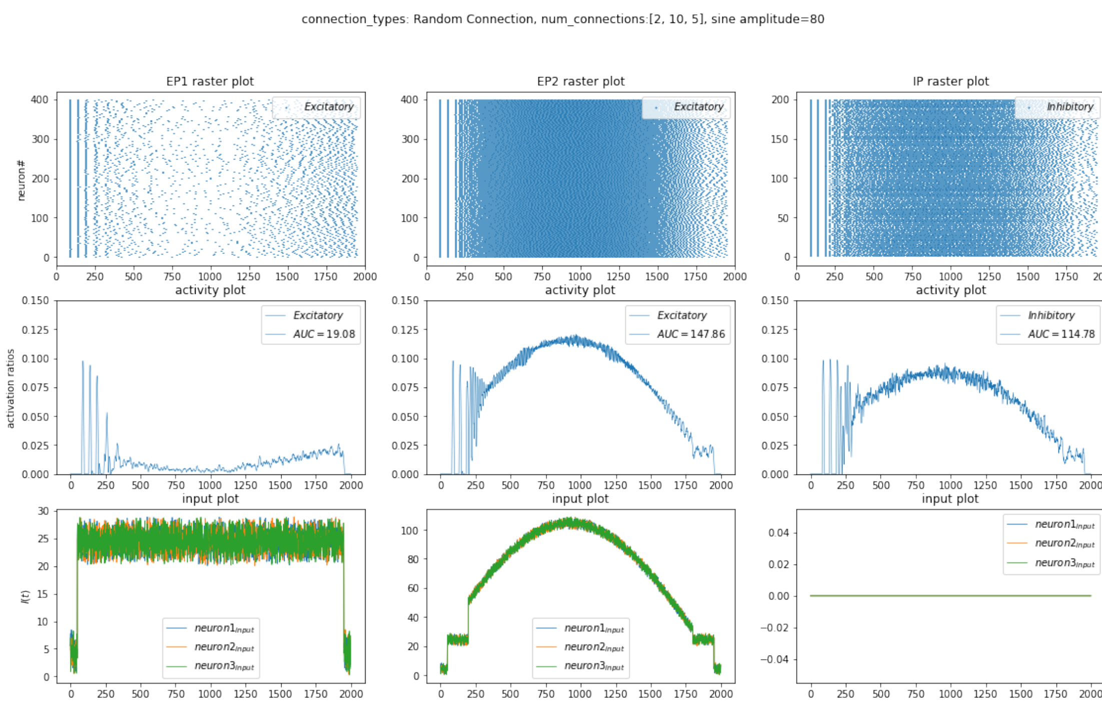
2.4.3 Sinusoidal inputs

Now, we apply additional sine waves to the second excitatory population.

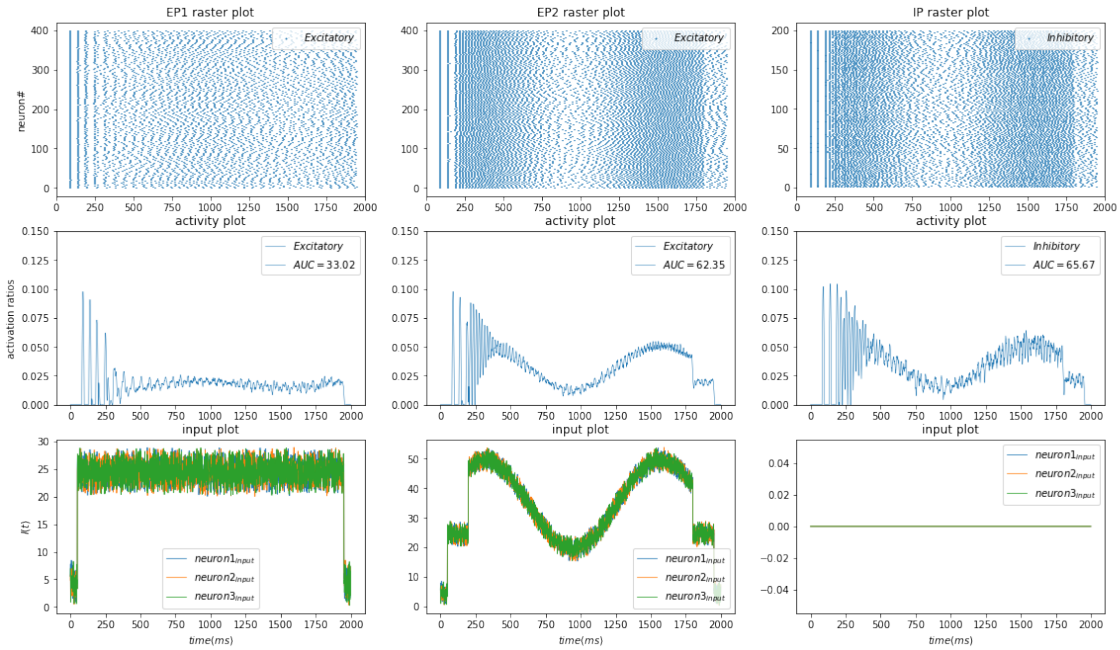
connection_types: Random Connection, num_connections:[2, 10, 5], sine amplitude=40



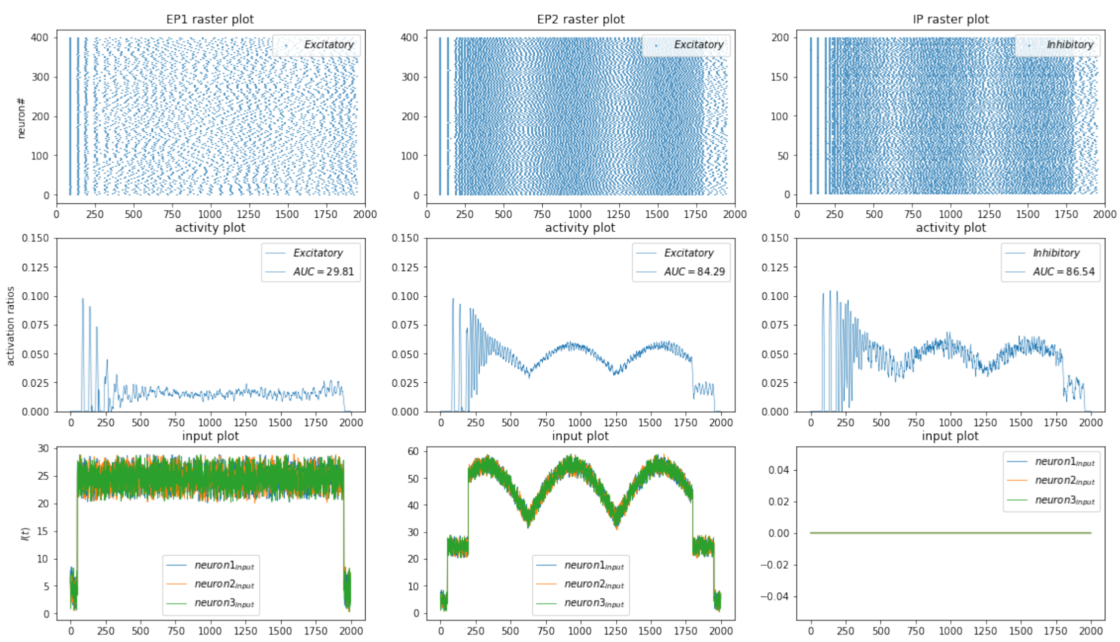

connection_types: Random Connection, num_connections:[2, 10, 5], sine amplitude=60
EP1 raster plot
EP2 raster plot
IP raster plot
Excitatory
Inhibitory
neuron#
activity plot
activation ratios
AUC = 24.26
AUC = 121.14
AUC = 95.88
input plot
I(t)
time(ms)

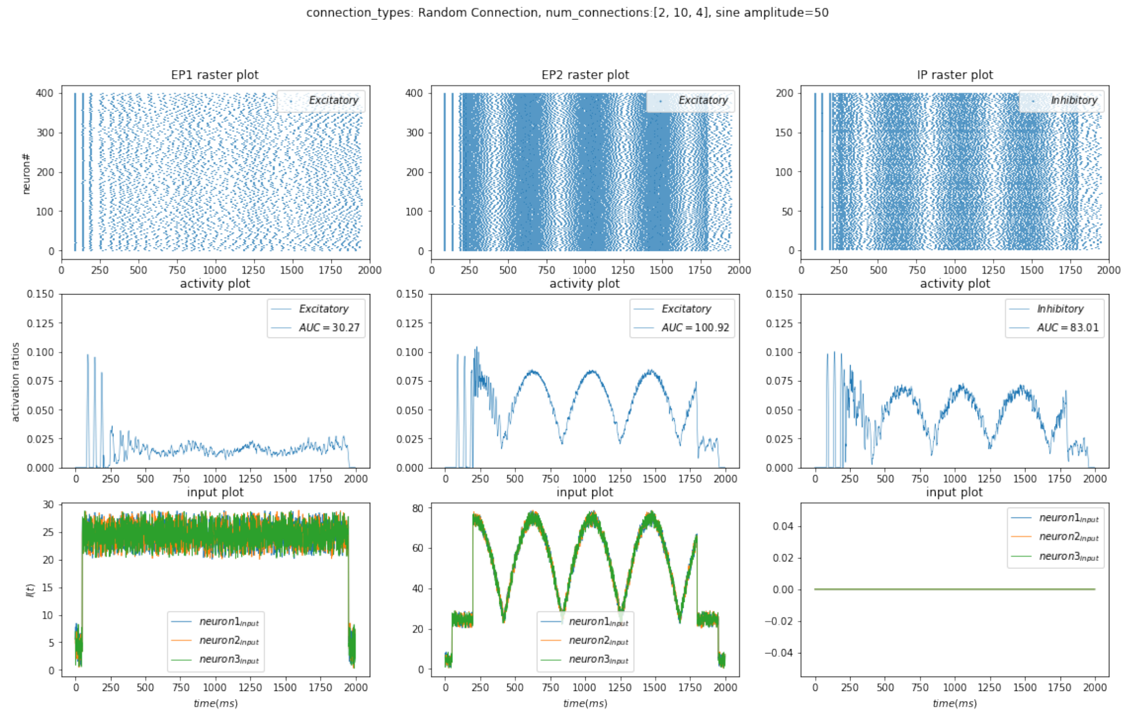

connection_types: Random Connection, num_connections:[2, 10, 5], sine amplitude=80
EP1 raster plot
EP2 raster plot
IP raster plot
Excitatory
Inhibitory
neuron#
activity plot
activation ratios
AUC = 19.08
AUC = 147.86
AUC = 114.78
input plot
I(t)
time(ms)

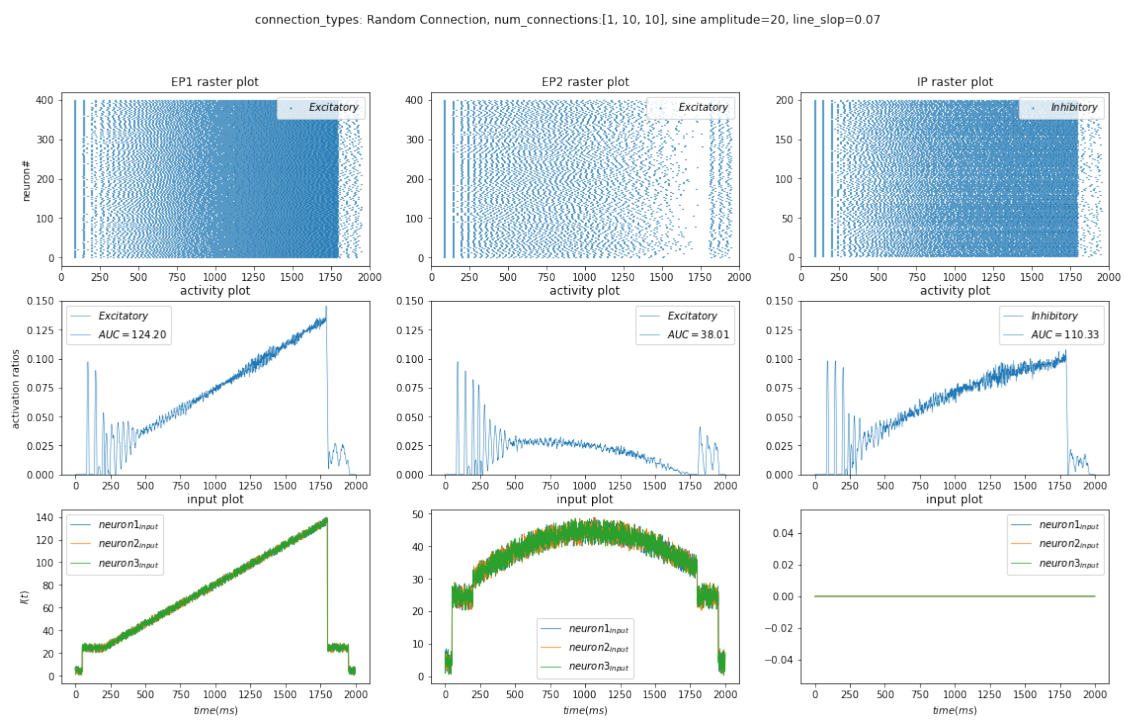
connection_types: Random Connection, num_connections:[2, 12, 4], sine amplitude=15



connection_types: Random Connection, num_connections:[2, 12, 4], sine amplitude=20, step amplitude=10







Using random connections, we clearly can see that the EP with dominant input and IP activities are following the dominant EP's input, and the other EP's activity is following the opposite of the dominant one's activity but with a smaller slope.

Chapter 3

Summary

1. The activities of populations are affected by the EP with dominant input current.
2. The activities of IP and dominant EP follow the dominant EP's input current. The EP with lower activity will follow the inverse of dominant EP input current.
3. The dense connections are very susceptible to difference in EPs inputs; that is with small amount of difference in the inputs, the activation of EP with lower input will be diminished drastically.
4. In contrast, the random connections are very robust, and even with large amount of difference in EPs inputs, the one with lower input will stay active.
5. The randomness of connections have more effect in EI and IE connections compared to internal EE connections.
6. In all random connections scheme, slight increase in number of EI connections makes the system to suppress the activity of EP with lower input intensely. However, the increase in number of IE connections, decreases the system's activation almost uniformly in all populations. This also applies to j_0 parameters in dense connections.
7. Increase in number of EE connections will increase the overall activity of populations.
8. The activity plots of the system with random connections, more accurately follow the dominant population's input current. These plots in the system with dense connection scheme are very noisy and cannot be interpreted without heavy smoothing.