P02 report file

Darya Ansaripour

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Abstract

This report consists of an overview on the second project.

1 INTRODUCTION

As requested, synapse behaior have been implemented using the Dirac delta function, 3 connection schemes are also provided and various parameters have been tested on them.

2 ANALYSIS AND BEHAVIORS

2.1 Synapse Implementation

2.1.1 Dirac Delta Function

Model parameters are listed in Table 1, 2 and 3, and the corresponding results are presented in Figure 1 and 2. Synapse has been implemented by a behavior, It integrates the spikes of presynaptic neurons and adds an amount of current proportional to the synaptic weight. For simplicity, the LIF model was selected for the test. As we can see in the figure, everytime presynaptic neurons spike, there is an increase of input current for postsynaptic nuerons which leads to an increase of their membrane potential.

Table 1: Neuron group parameters

Model	**Parameters**				
	thresh	**R**	**u rest**	**u reset**	**tau**
LIF	-37	5	-67	-75	10

Table 2: Synapse group parameters

Model	Parameters	
	coefficient (scaler)	**weight distribution**
Dirac δ	100	uniform

Figure 1: Synapse behavior (drawn for two neurons, coef=100)

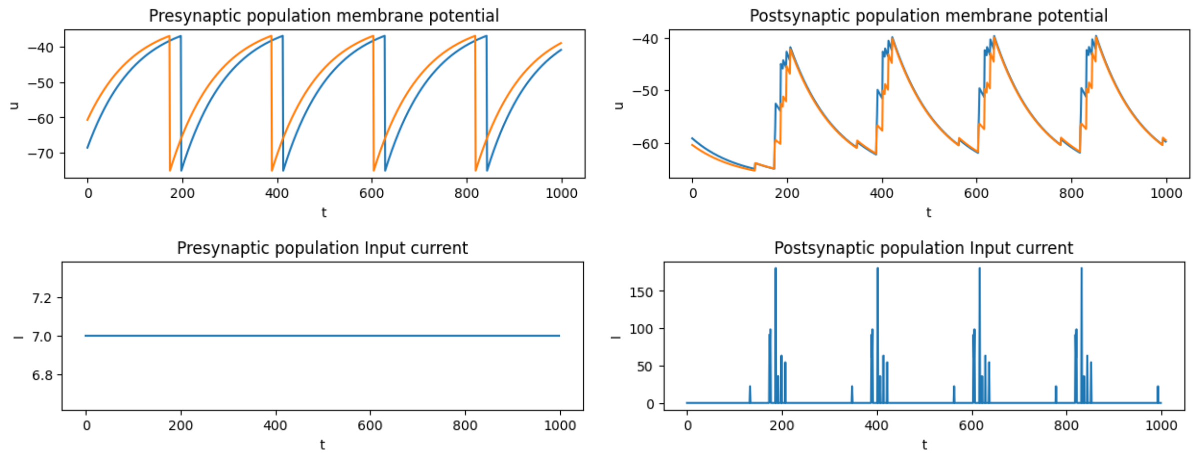
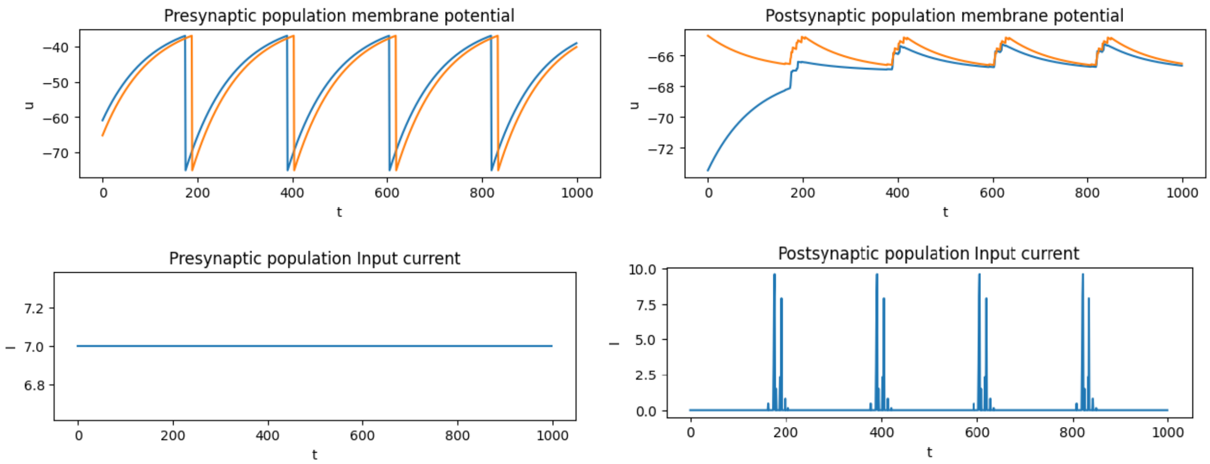


Table 3: Synapse group parameters

Model	Parameters	
	coefficient (scaler)	**weight distribution**
Dirac δ	10	uniform

Figure 2: Synapse behavior (drawn for two neurons, coef=10)



2.2 Connectivity Schemes

Model parameters are shown in Table 4 and 5.
As previously discussed, there exist multiple approaches for implementing connections between neurons. The first method is full connectivity, which represents the simplest coupling scheme. In this scheme, all connections have the same weight. However, to prevent the changing number of neurons from directly impacting the weights, we can introduce an appropriate scaling law. (Figure 3,4 and 5)

$$w_{ij} = \frac{J_0}{N} \tag{1}$$

In the limit of $N \to \infty$, the fluctuations disappear.
Another approach is to choose $p \times N^2$ connections where p is a probability, In this way for each neuron there would be an average of pN presynaptic neurons with variance $p(1-p)N$.
By increasing the number of neurons, the number of connections increase, so we may decrease the scaling factor which is a representation for connection's power so that the mean input to typical neuron does not change if the number of model neurons in the simulated population increased. The amount of fluctuations in the input decreases with the population size. (Figure 6,7 and 8)

$$w_{ij} = \frac{J_0}{pN} \tag{2}$$

The third approach is to fix the number of presynaptic connections for each neuron. We can construct a random network with a fixed number C of inputs by the following procedure: we pick one neuron after another and choose randomly its C presynaptic partners. No scaling factor is needed. (Figure 9,10 and 11)

Table 4: Neuron group parameters

Model	**Parameters**				
	thresh	**R**	**u rest**	**u reset**	**tau**
LIF (pop1)	-37	5	-67	-75	10
LIF (pop2)	-37	5	-67	-75	10

Table 5: Synapse group parameters

Scheme	**Parameters**			
	J_0	p	C	N
Full	10	-	-	100 and 1000
FixedProb	10	0.2 and 0.8	-	100
FixedPre	-	-	20 and 80	100

Figure 3: Synapse behavior (Full connectivity approach, drawn for one neuron. N=100)

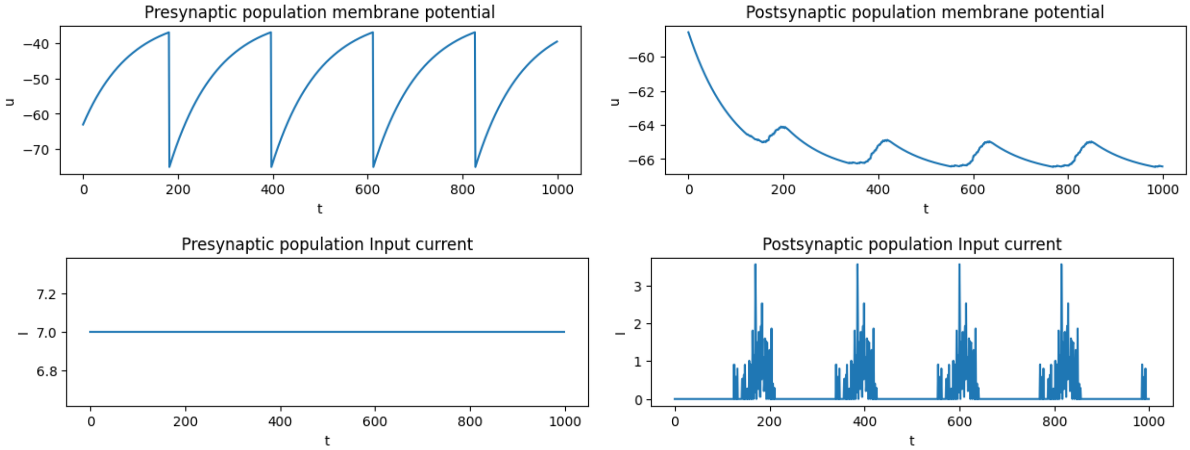


Figure 4: Synapse behavior (Full connectivity approach, drawn for one neuron. N=1000)

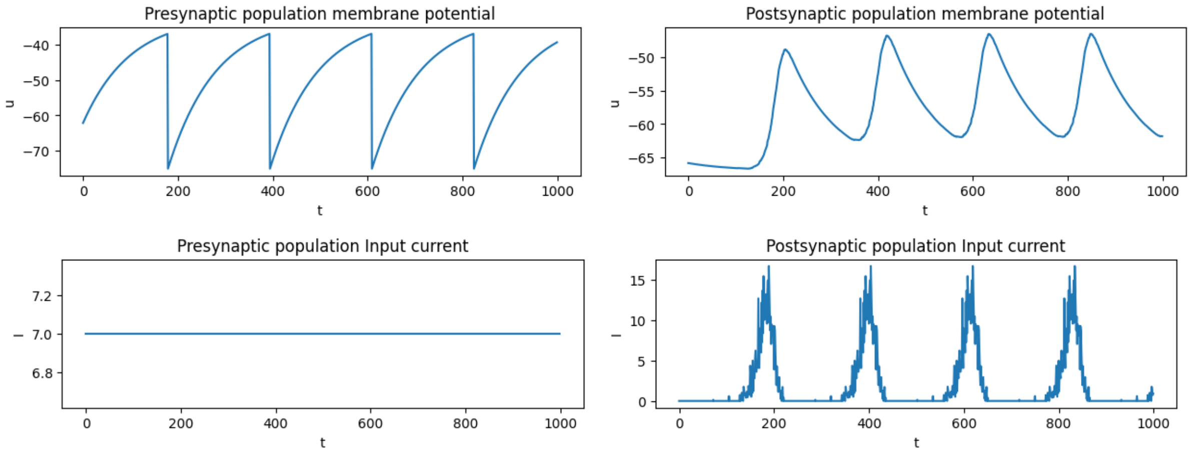


Figure 5: Synapse behavior (Full connectivity approach, drawn for one neuron. N=1000)

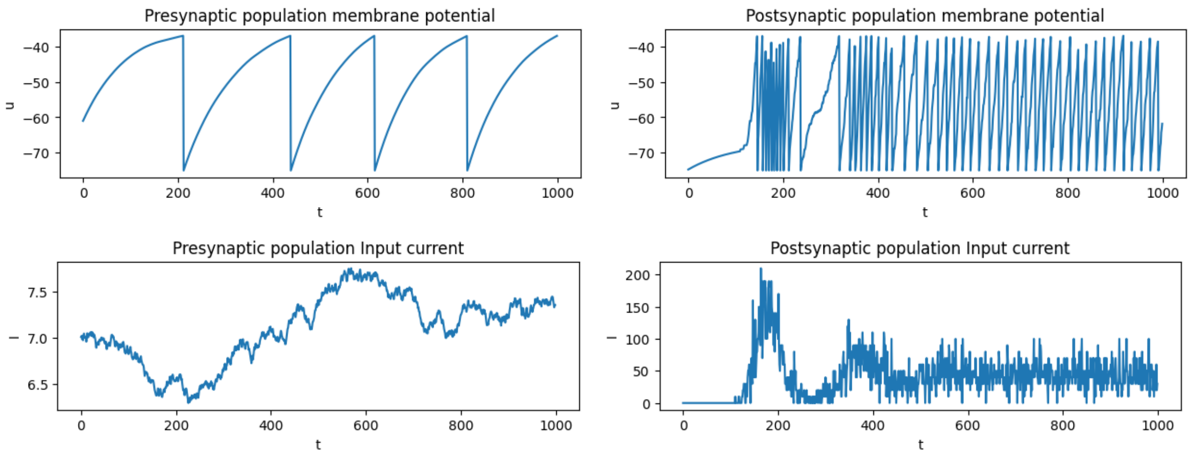


Figure 6: Synapse behavior (Fixed probability approach, drawn for one neuron. p=0.2)

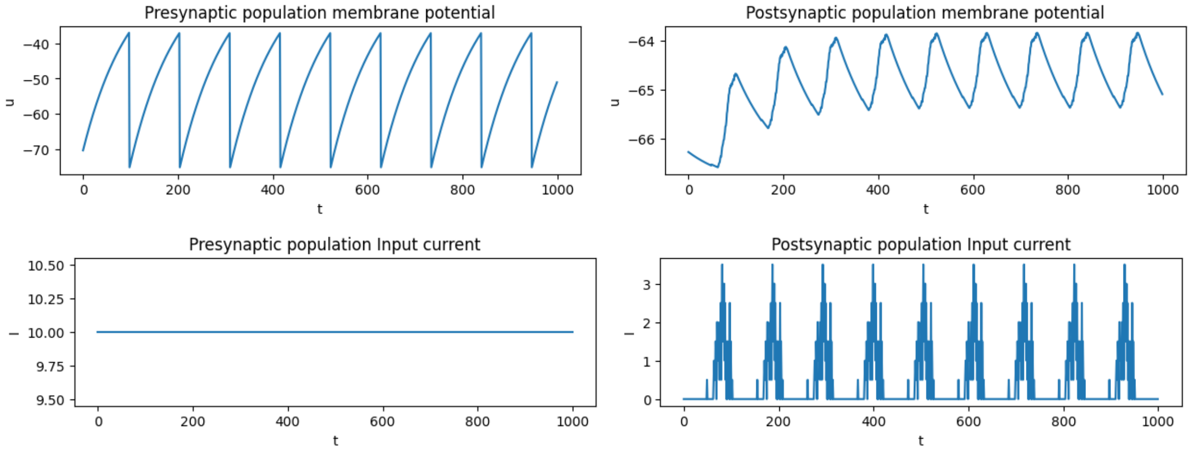


Figure 7: Synapse behavior (Fixed probability approach, drawn for one neuron. p=0.8)

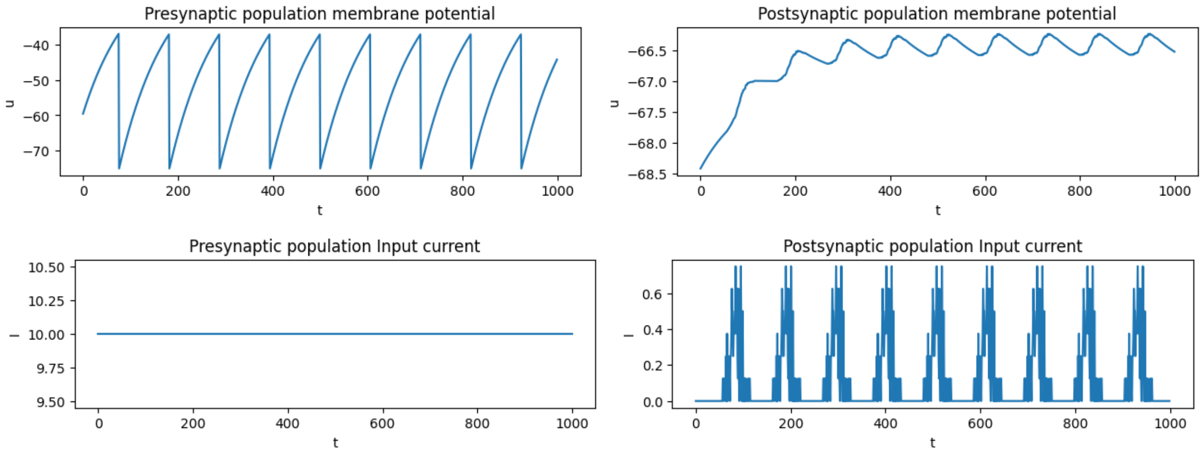


Figure 8: Synapse behavior (Fixed probability approach, drawn for three neurons. N=1000)

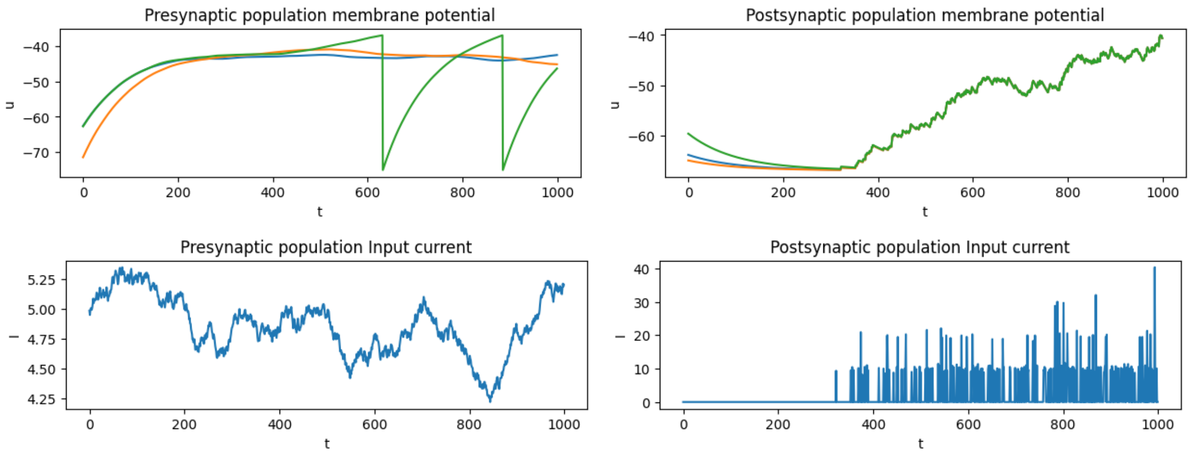


Figure 9: Synapse behavior (Fixed presynaptic partners approach, drawn for three neurons. C=20)

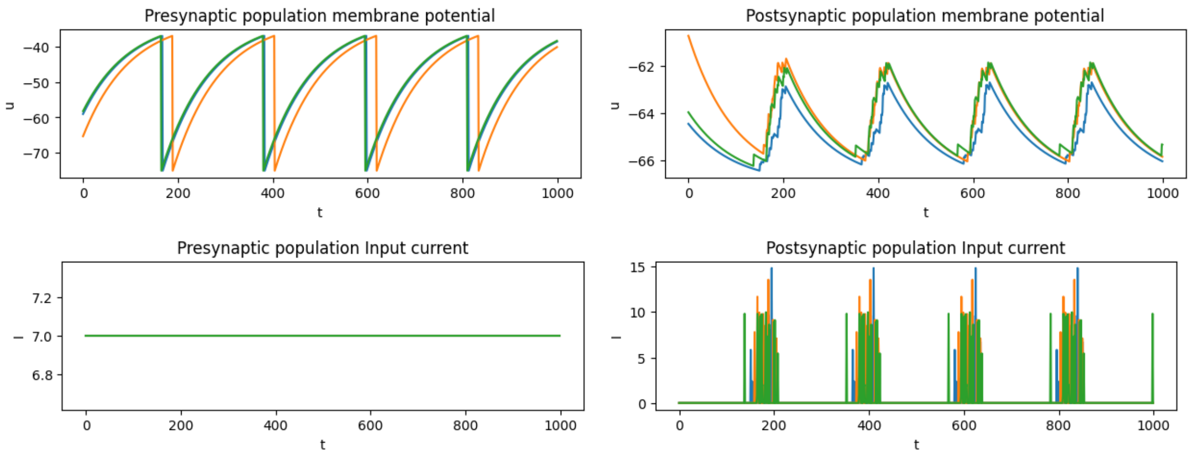


Figure 10: Synapse behavior (Fixed presynaptic partners approach, drawn for three neurons. C=60)

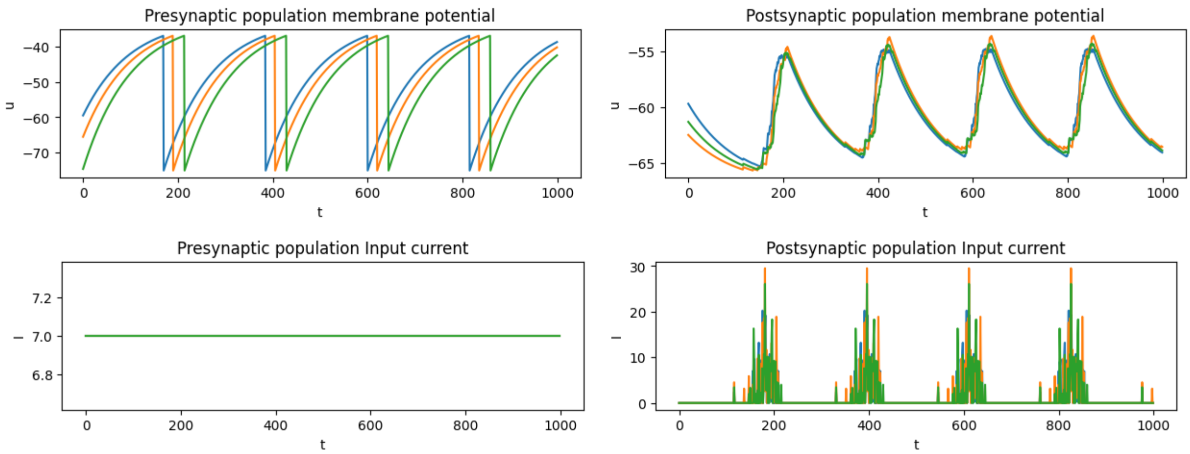
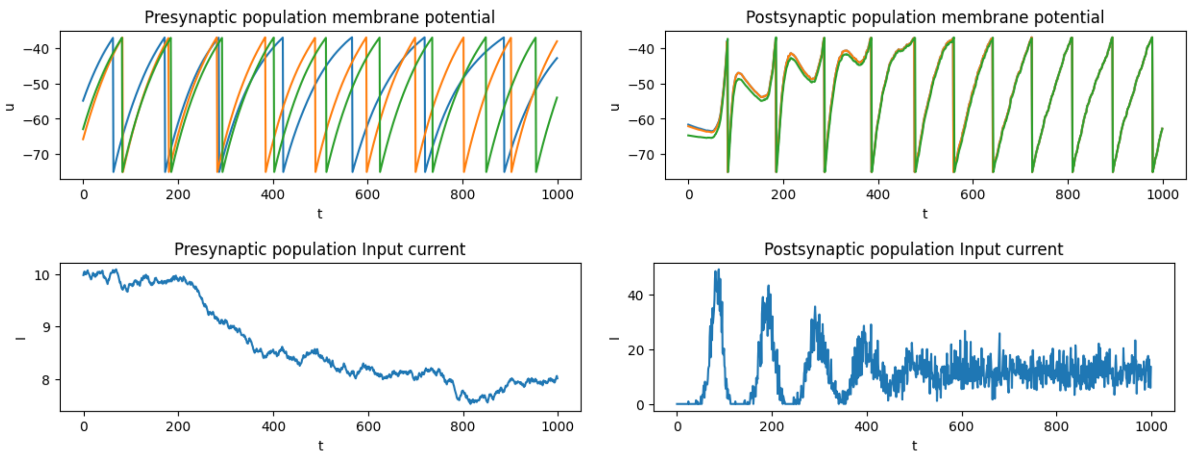


Figure 11: Synapse behavior (Fixed presynaptic partners approach, drawn for three neurons. C=60)



2.3 Homogeneous Populations

Model parameters are shown in Table 6, 7 and 8. By homogeneous we mean that all neurons are identical and they receive the same external input and the interaction strength is statistically uniform. We assume that presynaptic current only affects at the moment of spikes (i.e. α is δ function. in equation below)

$$I_i = \sum_{j=1}^{N} \sum_{f} w_{ij} \alpha(t - t_j^{(f)}) + I^{ext}(t) \tag{3}$$

Four types of interactions have been tested on two inhibitory and excitatory populations: Full (Figure 12 and 13), Fixed probability(Figure 14, 15), Fixed presynaptic partners (Figure 16) and balanced connctivity (Figure 17). Since all neurons are alike, we've chosen their thresholds from a normal distribution. This deliberate choice results in more scattered spikes, making it easier to observe the behavior and activity of the neuron group. In balanced networks, we can configure parameters such that inhibition and excitation are balanced. To regulate fluctuations, we introduce a scaling factor that adjusts the weights. This ensures that the weights exhibit the following relationship:

$$w_{ij} = \frac{J_0}{\sqrt{pN}} \tag{4}$$

In Figures 12 and 13, we observe that when the external current to inhibitory population becomes zero, the activity of these inhibitory neurons decreases. Simultaneously, the excitatory population becomes more active. In Figure 14 we can see that since inhibitory synapse has more weight than before ($J_0 = 3$) excitatory population has less activity and a sparse raster plot. In fixed presynaptic partners approach, the populations have less impact on eachother due to the fixed number of connection (which is 10).

Table 6: Neuron group parameters

Model	**Parameters**				
	thresh	**R**	**u rest**	**u reset**	**tau**
LIF (exc)	normal(-40,4)	5	-67	-75	10
LIF (inh)	normal(-40,4)	5	-67	-75	10

Table 7: Excitatory synapse group parameters

Scheme	**Parameters**			
	J_0	p	C	N
Full	2	-	-	800
FixedProb	2	0.2	-	800
FixedPre	-	-	10	800
Balanced	1	0.2	-	800

Table 8: Inhibitory synapse group parameters

Scheme	**Parameters**			
	J_0	p	C	N
Full	2	-	-	200
FixedProb	3	0.2	-	200
FixedPre	-	-	10	200
Balanced	0.1	0.2	-	200

Figure 12: INH and EXC populations behavior (Full connctivity approach. Both populations have external currents.)

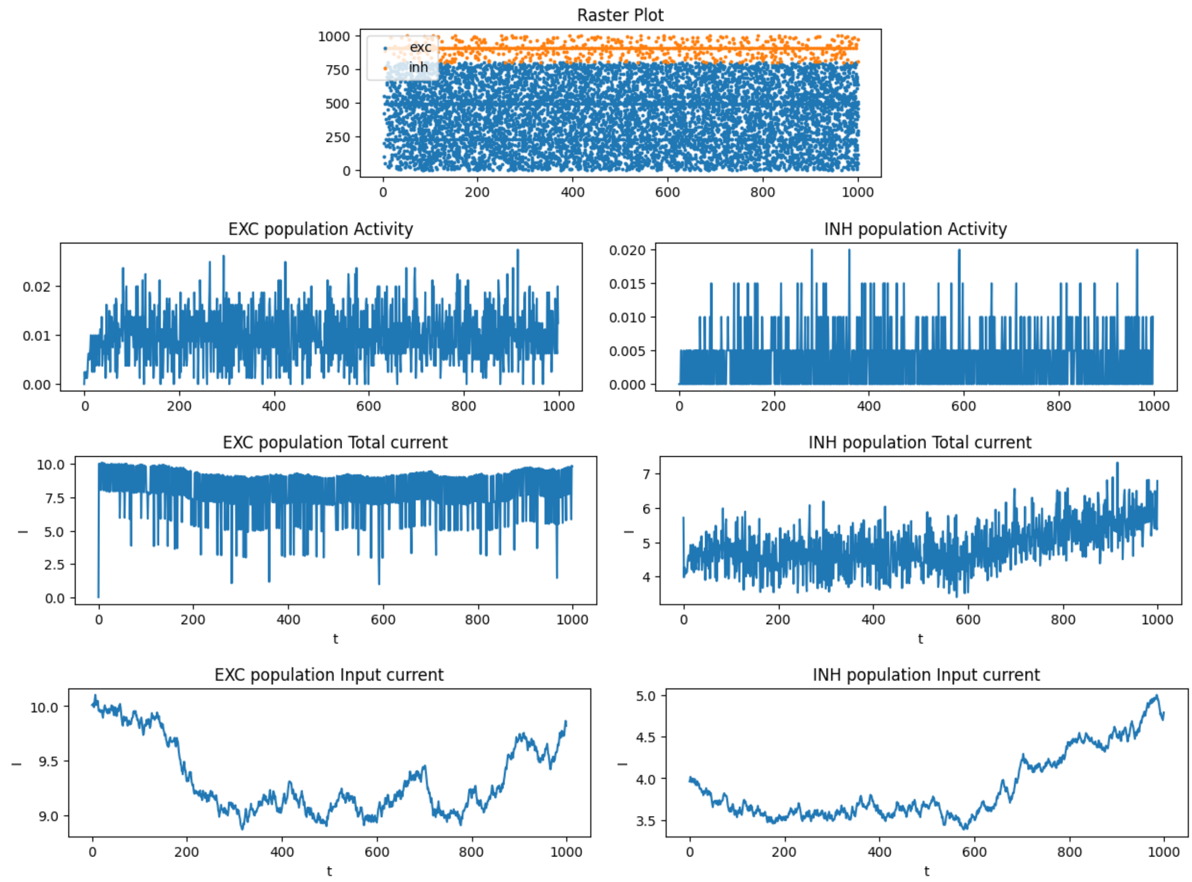


Figure 13: INH and EXC populations behavior (Full connctivity approach. Only EXC population has external current.)

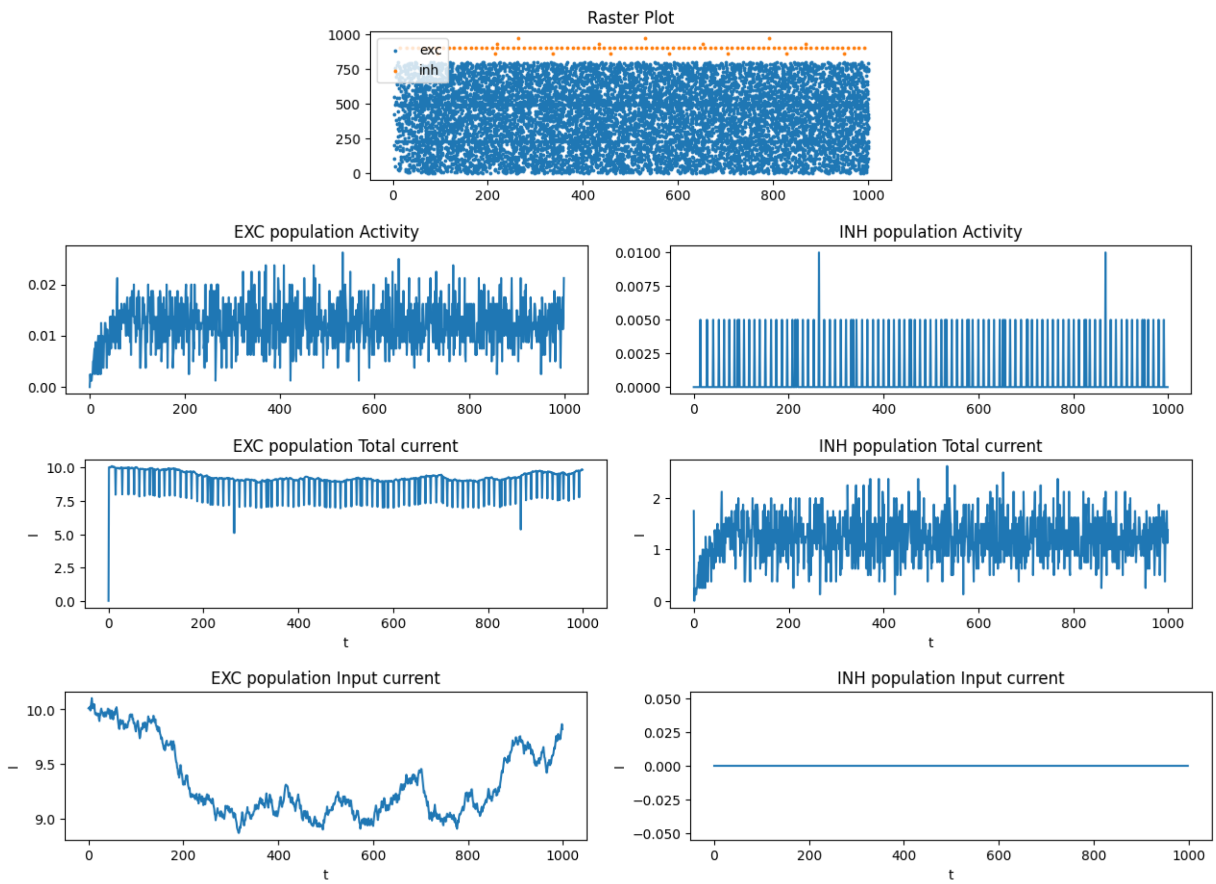


Figure 14: INH and EXC populations behavior (Fixed probability approach. Both populations have external currents.)

Figure 15: INH and EXC populations behavior (Fixed probability approach. Only EXC population has external current.)

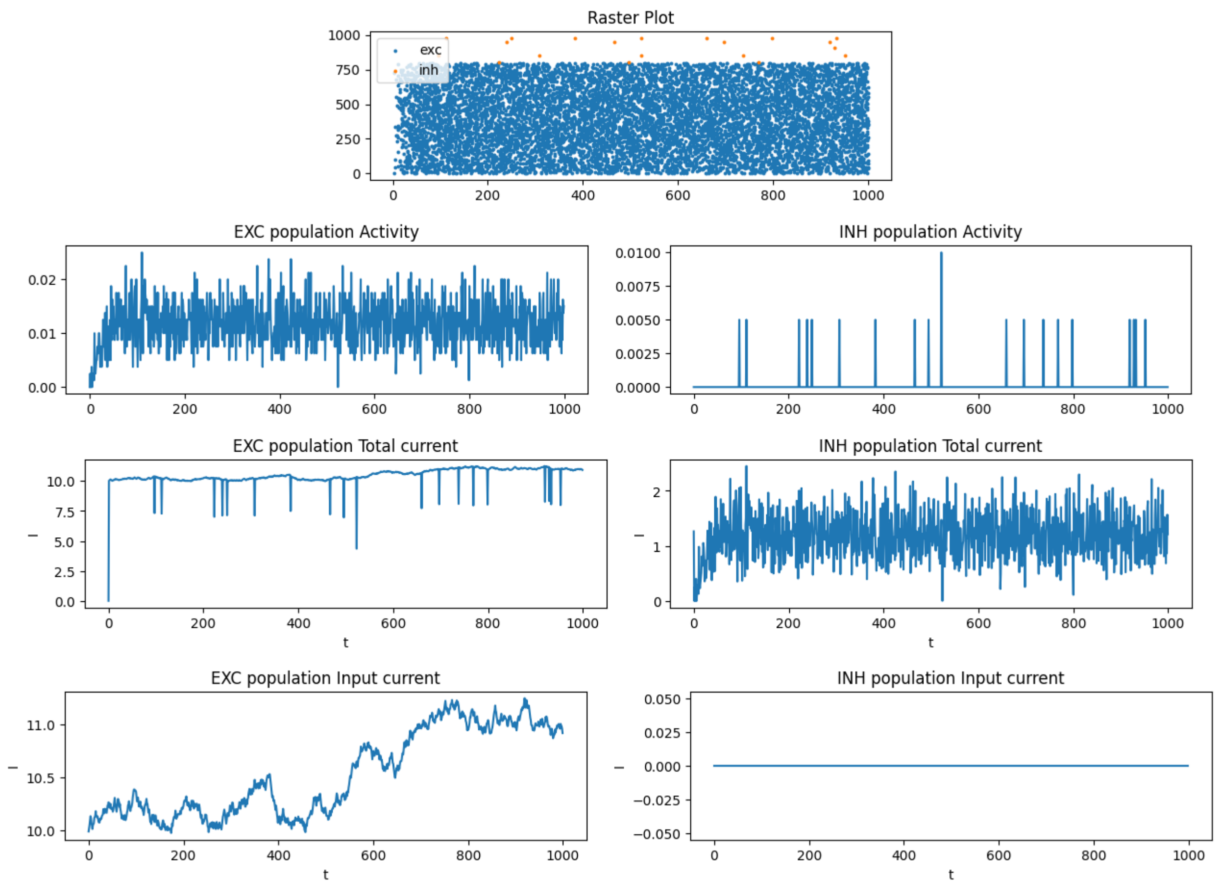


Figure 16: INH and EXC populations behavior (Fixed presynaptic partners approach. Only EXC pop has external current)

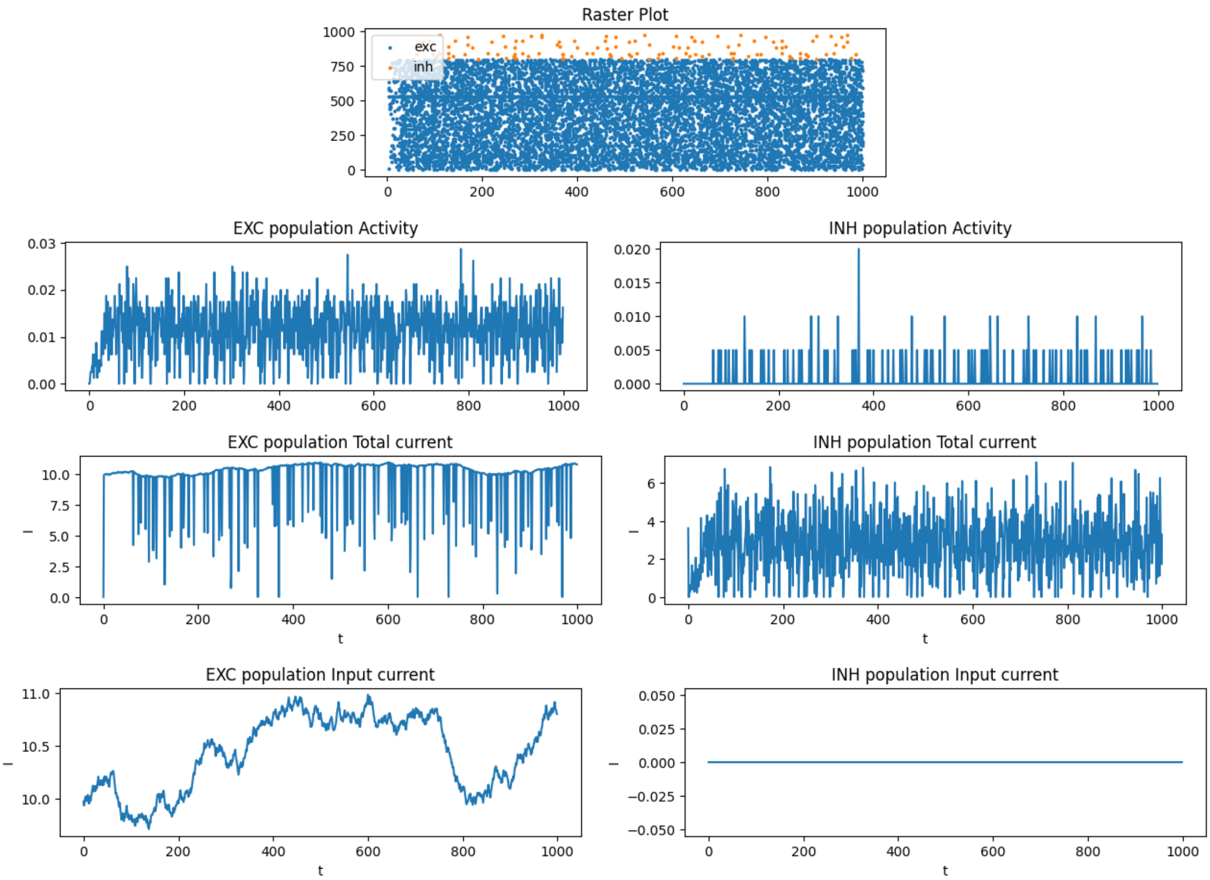
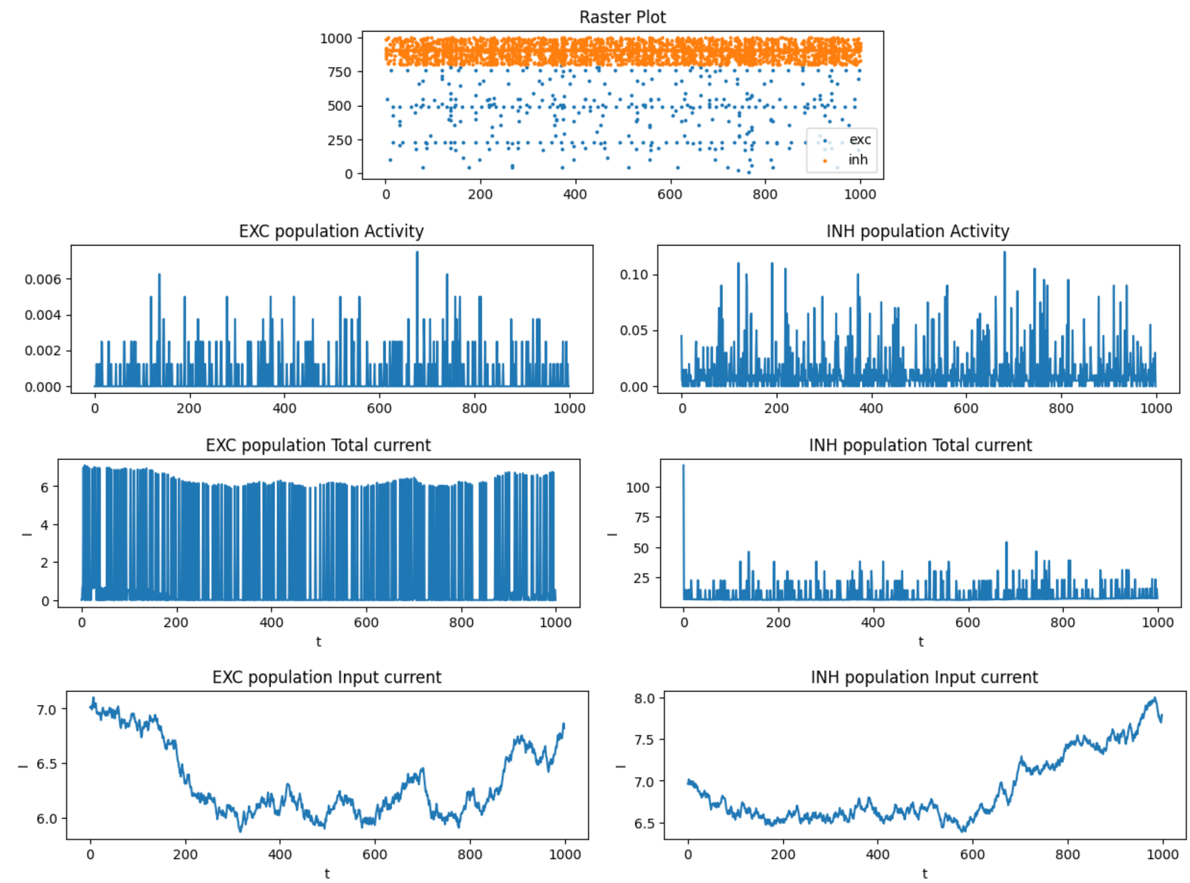


Figure 17: INH and EXC populations behavior (Balanced approach. Both have external currents.)



2.4 Interacting Populations

Model parameters are shown in Table 9,10 and 11.
We consider a network with three interconnected populations: two excitatory populations and one inhibitory population. Here's how the decision-making process unfolds:

- Background Activity:
  Each neuron group exhibits random background activity. Neurons fire spontaneously due to this intrinsic activity.
- Input Current and Excitatory Neurons:
  Suppose we encounter a stimulus (e.g., we see a dog!). A slightly larger input current is injected into the excitatory neuron group associated with this stimulus. As a result, the activity of this excitatory group increases.
- Inhibitory Neurons Respond:
  The heightened activity in the excitatory group influences the inhibitory neuron group. The inhibitory neurons become more active. Their increased activity leads to inhibition of the second excitatory neuron group, which is associated with a different stimulus (e.g., seeing a cat!). Consequently, the activity of the second excitatory group decreases.

In the fixed presynaptic partners approach(Figure 20), each neuron has only 10 connections. Consequently, the sensitivity of the first excitatory neuron group is lower compared to other approaches.
Figure 18 illustrates the network behavior under full connectivity. At time T=500, when the input current to the first excitatory neuron group is increased, its activity exhibits growth. However, during the same period, the activity of the second neuron group decreases. Figure 19 depicts the network behavior using the Fixed Probability approach.

Table 9: Neuron group parameters

Model	**Parameters**				
	thresh	**R**	**u rest**	**u reset**	**tau**
LIF (exc)	normal(-40,4)	5	-67	-75	10
LIF (inh)	normal(-40,4)	5	-67	-75	10

Table 10: Excitatory synapse group parameters

Scheme	**Parameters**			
	J_0	p	C	N
Full	2	-	-	1000
FixedProb	2	0.2	-	1000
FixedPre	-	-	10	1000

Table 11: Inhibitory synapse group parameters

Scheme	**Parameters**			
	J_0	p	C	N
Full	5	-	-	1000
FixedProb	3	0.2	-	1000
FixedPre	-	-	10	1000

Figure 18: Desicion Network behavior (Full connectivity approach.)

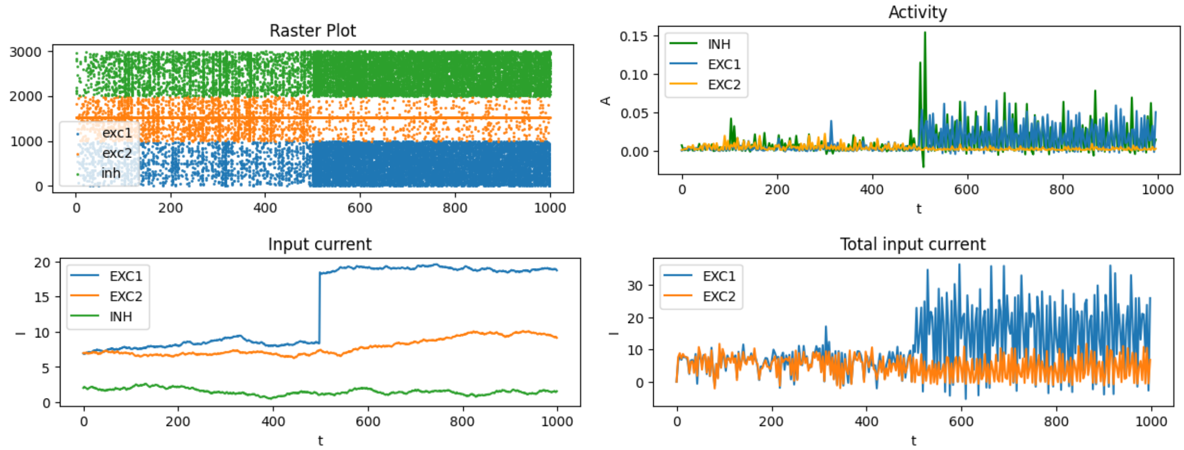


Figure 19: Desicion Network behavior (Fixed probability approach.)

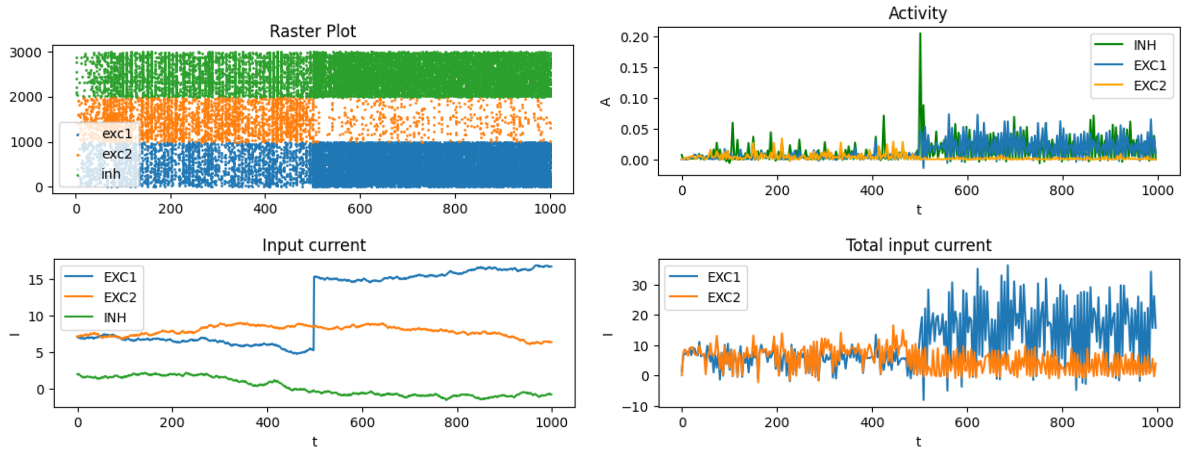


Figure 20: Desicion Network behavior (Fixed presynaptic partners approach.)