Assignment 2

Principle of Brain Computation, SS2017

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Principle of Brain Computation - 02

Dynamic Synapses

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06.04.2017

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Introduction

In this simulation, we have a neural network of 500 spiking neurons following the poisson distribution(input) and 1000 spiking neurons(output neurons) connected with the input neurons, more specific every output neuron is connected randomly to 100 input neurons. Also, in this model the synapses are modelled as tsodyks synapses, i.e. they follow the equation (1).

$$A_k = u_k \cdot R_k \cdot w(1)$$

Where A_k is the post synaptic potential(PSP) of the synapses at every iteration, u_k is the coefficient relevant to the facilitation of PSP and R_k the coefficient concerning the depression.The equations that define the coefficients are:

$$u_k = U - u_{k-1}(1-U)e^{-\frac{\Delta_{k-1}}{F}}(2)$$

$$R_k = 1 - (1 - R_{k-1}(1-u_{k-1}))e^{-\frac{\Delta_{k-1}}{D}}(3)$$

So, when a train of spikes with the same presynaptic potential comes to a synapse the output of the synapse is going to be different, depending of the parameters U,F,D(parameters of equations (2,3)) and the time intervals between spikes, in other words the frequency of the incoming spikes (Rin).

In other words we could say that the equation (1) doesn't only represents the PSP of the synapses, but,in a way, also the weight of the synapses. For example, if the synapse is facilitating the weight is growing and if it is depressing the weight is dropping. In general is difficult to determine exactly the perform of the network with an arbitrary set of parameters, but we can say easy enough, which the steady state of the network is going to be, as we are going to discuss in the question 3.

Question 1

This question is answered in/with the code file.

Question 2

In this question, we are called to simulate our network with the following sets of parameters [1] U=0.16, F = 0.376, D = 0.045 and [2] U=0.16, F = 0.1, D = 0.045, in both cases the input spikes, that are going to the output neurons, are created from a poisson process with average spiking rate 20 Hz. Also, we are asked to plot the average firing rate of population and commend their performance with aspect to the previous parameters.

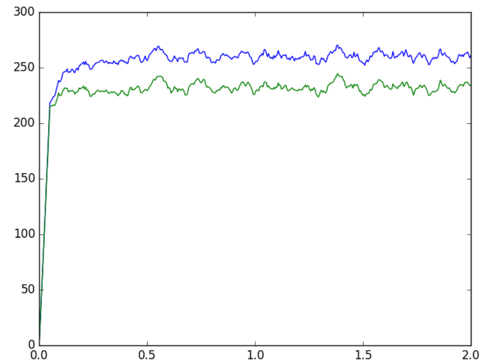


Figure 1: The blue curve is for F = 0.376 and the green one for F = 0.1
Average firing rate

As we can see the results from both simulations are quite similar. Firstly, both networks are facilitating and the form of the curve near the starting point and after it stabilizes are quite similar. The main differences between these two simulations are the value after stabilization and the time which each curve facilitates till stabilization. But these two differences are strongly connected, because the more the network facilitates the bigger the final steady state is going to be.
Note: This is explained better in question 3, in terms of why bigger PSP of synapse creates bigger average firing rate of the network.
In that essence, our results are completely logical, because the facilitation time of the first case(blue curve) is bigger from the one of the second case(green curve).

Question 3

For $t \to \infty$ and firing rate R_{in} of input neurons the equations (2-3) becomes:

$$u_k = U - u_k(1-U)e^{-\frac{1}{R_{in}F}} \quad (4)$$

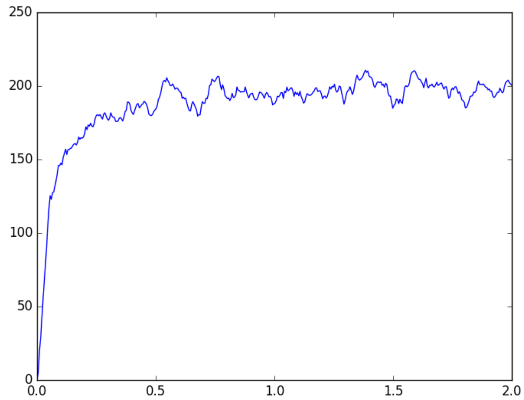
$$R_k = 1 - (1 - R_k(1-u_k))e^{-\frac{1}{R_{in}D}} \quad (5)$$

If we solve them for u_k and R_k respectively we end up to the following results:

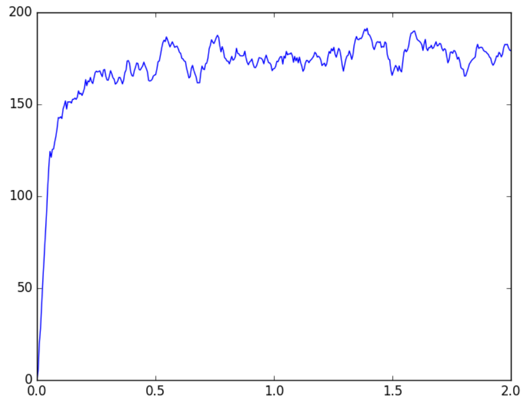
$$u_k = \frac{U}{1-(1-U)e^{-\frac{1}{R_{in}F}}} \quad (6)$$

$$R_k = \frac{1-e^{-\frac{1}{R_{in}D}}}{1-(1-u_k)e^{-\frac{1}{R_{in}D}}} \quad (7)$$

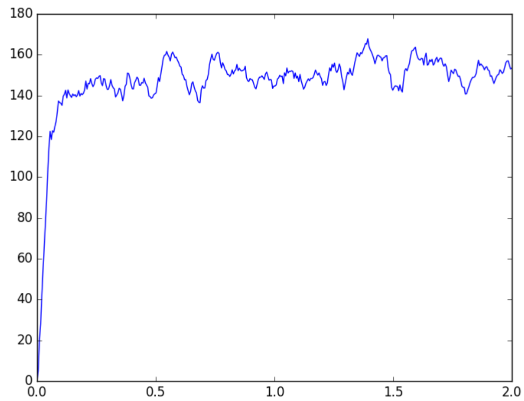
Because deriving a formula that connects the average firing rate and the postsynaptic potential A_k, as described in the previous questions, is quite difficult. We try to find a more practical relation between these two, implementing different set of parameters. The results are the following:



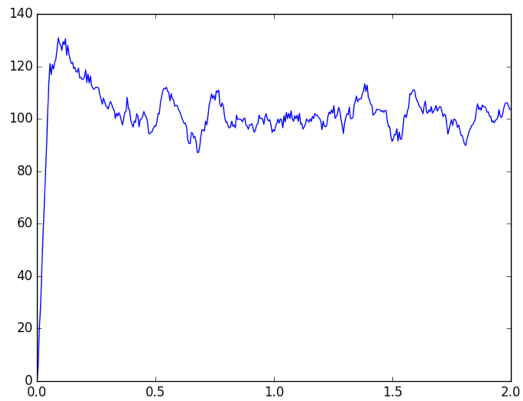
(a) U = 0.16, F = 0.376 D = 0.045



(b) U = 0.16, F = 0.2 D = 0.045



(c) U = 0.16, F = 0.1 D = 0.045



(d) U = 0.16, F = 0.2 D = 0.2

Figure 2: Average firing rate for several cases

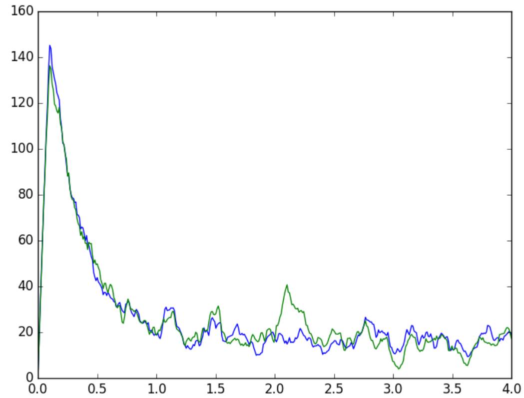
	Value of steady Average Firing Rate	Value of steady postsynaptic potential in synapse
	A(∞)	$A_k(\infty)$
(a)	200	23315.97
(b)	175	18853.42
(c)	150	14058.94
(d)	100	8799.55

Note: The value of the average firing rate of the steady state is calculated by inspection so they are not that much accurate.

Nevertheless, even with not that clear values of the average firing rate we can clearly see that this two values are strongly linear related. This phenomenon is completely logic because, as the potential of the synapses goes up, the same happens to the membrane potential of the neuron and so it fires more frequent. In other words, when the potential of the synapse remains stable the current inserting the neuron is stable and, as we have already see from the last practical the more current goes to the neuron the more frequent it fires.

Question 4

The results of the simulations [1] and [2] are the following

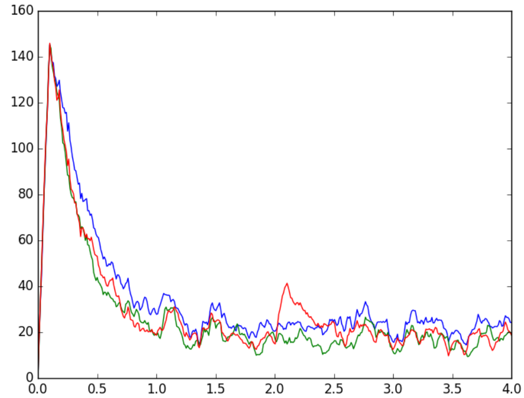


(a) U = 0.25, F = 0.021 D = 0.706

Figure 3: Average firing rate for uniformly distributed firing rate of input neurons (blue) and with equal probability distributed firing rate (green).

In this simulation we see a case of depression, because after the network gained a very big firing rate the firing rate is started to get depressed. The initial burst is caused because the network from being total inactive get a relevant high firing rate, so at the first period, before the depression dynamics take place it facilitates, but after a specific moment the network is depressing till it stabilizes.
Concerning commenting the plots. As we see the results are quite the same, which is normal as the median of input firing rate is the same (20Hz). The biggest difference is observed at 2 secs

when the network with equal distributed probability firing rate has a small facilitation. This probably happens, because at this particular time average firing rate of the input neurons gets somewhat higher, but in the end the depression dynamics are prevail. This phenomenon (somewhat bigger median) can not happen in the [2] case as all the values are uniformly distributed ending each time at the same median.
At this point, is also worth showing the perform of our first network with constant firing rate(20Hz) through the whole simulation.



(a) U = 0.25, F = 0.021 D = 0.706

Figure 4: Average firing rate with constant firing rate of input neurons (blue), with uniformly distributed firing rate (green) and with equal probability distributed firing rate (red).

At this case, we see that, also, all the results are similar, this happens because in every case the median is 20 Hz and each output neuron is connected to 100 input neurons with the same weight value and dynamics. So the summation of all this input have in the end the same result.