Principles of Brain Computation, SS17

Robert Legenstein
Institute for Theoretical Computer Science
Graz University of Technology
A-8010 Graz, Austria
robert.legenstein@igi.tugraz.at

March 30, 2017

Last Name	First Name	Matrikelnmr	Team members

Handed out on 30.3.2017
Hand in on 4.5.2017

Task 2: Dynamic synapses (20 Points)

Use this page as the cover sheet of your submission.

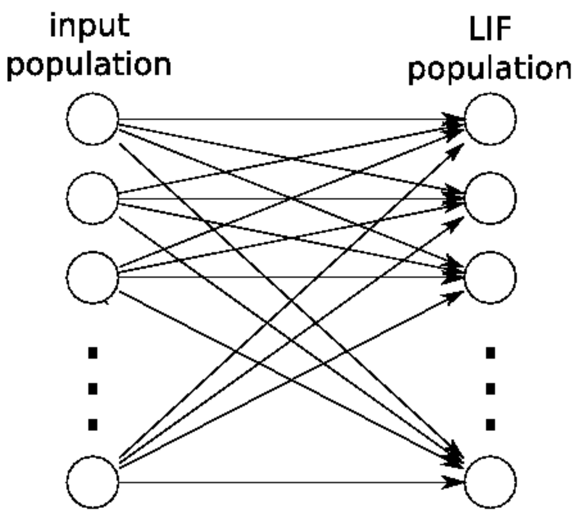

Figure 1: Schematic diagram of the model

In this exercises you will analyse what effect the short-term synaptic dynamics has on the temporal change of the population rate of a population of neurons. You will use the NEST simulator to perform the necessary simulations.

The model

The model that you are going to implement and investigate is composed of two populations of neurons: the input population which contains 500 input neurons and a population of 1000 leaky integrate-and-fire neurons (the LIF population) (see Fig. 1). The population of input neurons is connected to the LIF population with a constant indegree of 100, i.e., each LIF neuron receives input from 100 randomly chosen neurons in the input population. The synapses at the connections exhibit short-term dynamics according to the model described in the lecture (model `tsodyks_synapse`).

The input neurons start to fire at time $t_{start} = 0.1$ s according to a Poisson process with rate r_{input}. The input population can be generated with the function `construct_input_population(Nin, Rin, Tstart)` given in the template script. For the LIF neurons the following values of the parameters should be used: $V_{thresh} = -40$ mV, $V_{resting} = V_{reset} = -60$ mV, $R_m = 2$ MΩ, $C_m = 10$ nF. The refractory time should be 2 ms.

All synapses should have a time constant of $\tau_s = 3$ ms (has to be set in the neuron model as well) and weight set to $w = 1 \cdot 10^6 / r_{input}$ (r_{input} is the firing rate of the input neurons). The values of the U, D and F parameters for the synaptic dynamics are given in the Questions section.

Population rate. The population rate of a population of N neurons over a time period $[t-T, t]$ is defined as

$$A(t) = \frac{1}{T} \frac{n_{act}(t-T;t)}{N} \tag{1}$$

where $n_{act}(t-T;t)$ is the number of spikes (summed over all neurons in the population) that occur between $t-T$ and t. The time period $[t-T, t]$ is also called a bin, and T is the size of the bin.

Template Script

For this exercise you will use the script `ex2_dyn_syn_template.py` available on the web page for the exercises. The script contains the function `perform_simulation(Nnrn,Nin,Rin,U,D,F,Tsim)` where you should implement the model. `Rin` in the input arguments represents the firing rate of the input neurons r_{input}, and U, D and F are the values for the corresponding parameters in the short-term synaptic dynamics model used in the created synapses. You should complete the function by implementing the construction of the model and running the simulation. The return value from the function should be a numpy array containing the recorded spike times of all neurons in the LIF population (spike times in units of [s]; Note: NEST recorders return the spike times in units of [ms]).

To calculate the population firing rate from the spike times, you should use the function `avg_firing_rate(spikes, dt, binsize, Tsim, Nneurons)` available in the script. The array of spike times of the LIF neurons should be given as a first argument, the second argument `dt` is the time step (in seconds) of the points in time for which the rate is calculated and the `binsize` represents the size of the bin used to calculate the firing rate at a particular moment (should be given also in seconds). The `Tsim` argument should be set to the time period during which the spike times were recorded, i.e. the duration of the simulation. `Nneurons` is the number of neurons in the recorded population. The population rate is calculated at equidistant points in time in the range `[0,Tsim]` with a time step `dt`. The function returns a numpy array with the calculated values for the population rate.

Questions

a) **(5 points)** Expand the `perform_simulation(Ri,U,D,F,Tsim)` function to include the construction of the model described above, setup recorders that will record the spiking of the neurons in the LIF population, perform a simulation of the model for $T_{sim} = 2$ s and gather the spike times of the LIF population. The time step of the simulation should be set to $DT = 0.1$ ms.

b) **(5 points)** Perform the simulation by setting $r_{input} = 20$ Hz and the U, D and F parameters to the mean values of the facilitating dynamic synapse type F1 from [1]: U = 0.16, F = 0.376 s and D =0.045 s. Plot how the population rate changes during the simulation. For the calculation of the population rate use the `avg_firing_rate` function with a time step `dt` = 5 ms and `binsize` = 50 ms. `Tsim` should be set to the duration of the simulation (i.e. 2 sec. in this case).

Change the F parameter to $F = 0.1$ s and plot the corresponding population rate in the same plot as the previous case. Describe and explain the results. Explain why the value at which the population rate stabilizes is different for the different values of the facilitation time constant F: 0.376 s and 0.1 s.

c) **(5 points)** Calculate analytically the fixed points of A_k (from the equations for the dynamic synapses) for the previous simulations (use the mean spike interval $\frac{1}{r_{input}}$ in the calculation of the A_k values). These fixed points are reached when the time of the simulation $t \to \infty$. Comment on the obtained values for $A_k(\infty)$ in relation to the stabilized output firing rate from the simulations that you observe in the plots. It is hard to compute the firing rate from the A_k values. Here, it suffices to compare the relative ordering of rates from simulations and $A_k(\infty)$ values.

d) **(5 points)** Expand the function `perform_simulation_d` and perform a simulation where the U, D and F parameters are set to the mean values of the depressing dynamic synapse type F2 from [1]: U = 0.25, F = 0.021 s, D = 0.706 s. Perform the simulation for a total time of 4 seconds. At times 0 s, 1 s, 2 s, and 3 s, set the firing rates of each input neuron (independently from the rates of others) to random values (I) uniformly in the interval $[0, 40]$ Hz, and (II) to 0 Hz or 40 Hz with equal probability. Plot how the population rate changes during the simulation.

Describe the plots and explain your observations, including differences between (I) and (II).

Submit your plots and interpretations on paper, and the code by email to `robert.legenstein@igi.tugraz.at` and `m.mietschnig@student.tugraz.at` (**include "PoBC ex2 submission" in the subject of the email**) until 8am on the day of submission. Write readable code with informative comments. All members of the same team are allowed to submit the same code. Do not send the report by email but hand in a printout.

References

[1] A. Gupta, Y. Wang, and H. Markram. Organizing principles for a diversity of GABAergic interneurons and synapses in the neocortex. *Science*, 287:273–278, 2000.