Problem Set 9:
Random Neuronal Networks

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In this sheet, we will look at NEST simulations of neuronal networks. An obvious starting point are random networks, where the connections of neurons are left to some statistical laws. We will consider some different rules, as well as different network/neuron parameters and different types of neurons, networks with just excitatory, just inhibitory and a mixture.

Problem 1: Networks of excitatory neurons 6 points

The most numerous cell type in the neocortex are pyramidal neurons (approximately 80%), and therefore excitatory. Also, though the exact structure of networks in the brain are hard to determine, and differ between different regions and physical scales, most local networks are known to be highly recurrent. We will thus first consider recurrent networks of only excitatory neurons. We will investigate whether different random networks can produce similar activity found in the brain and how these activities differ.

Problem 1.1: Different randomness with DC input 3 points

A typical value for the connection probability (directed connection between any two neurons) in local cortical networks is 10%. Set up a network of 100 excitatory LIF neurons (e.g. iaf_psc_alpha) and DC current input common to all neurons (so that there is no randomness in the input). Create random synapses between neurons with **(a)** fixed indegree, **(b)** fixed outdegree, **(c)** pairwise Bernoulli probability for each possible connection, **(d)** a fixed total number of synapses. Find a meaningful way to monitor neuronal activity in the network and characterise the type of activity that you observe. What happens if you increase the weight of recurrent connections in the network?

Problem 1.2: Different randomness with Poisson input 3 points

Let us now explore how *stochastic* input impacts the dynamics of the network. A Poisson input best models external input from other neurons, with each neuron receiving a different realisation of the same Poisson process. Redo the last problem for the different random types of network wiring but with this Poisson input. What happens if you change the strength of recurrent connections? What about the rate of the Poisson input?

Problem 2: Networks of inhibitory neurons 4 points

We now turn to networks of purely inhibitory neurons, seen in the basal ganglia for example. Obviously, such networks require excitatory external input to obtain activity.

Problem 2.1: Different randomness with DC and Poisson input — 3 points

Use a similar set up as for Problems 1.1 and 1.2 but for inhibitory neurons. What is the main difference with the excitatory networks? Briefly explain the main difference between DC and Poisson input and what happens when you change the strength of recurrence?

Problem 2.2: Other parameters — 1 points

Other neuron parameters have a great influence on activity dynamics too. What is the impact of the synaptic transmission delay on the network dynamics, for example? Do this for both DC input and Poisson input, both with fixed indegree neurons. Note, you might need to set the recurrence weights quite large to see the effect of synaptic delay.

Problem 3: E-I networks — 6 points

Let us now look at networks with both excitatory and inhibitory neurons. We can do this by creating two networks, an excitatory and an inhibitory network, and connect them together accordingly. This means that we have four connectivity parameters, for the connections $E \to E$, $E \to I$, $I \to E$, and $I \to I$. Let us just keep them all at connection probability $p = 0.1$ and with strength $J_{II} = J_{IE} = -gJ_{EE} = -gJ_{EI}$. That is, all excitatory neurons produce post-synaptic potentials (PSPs) of the same height, regardless of the type of the receiving neuron, and so do inhibitory neurons. The value $g > 0$ allows us to scale the strengths of inhibitory neurons with relation to excitatory ones in the network. We will also just use Poisson input and wire the networks using pairwise Bernoulli probability $p = 0.1$.

Problem 3.1: Obtaining a stable low-firing regime — 2 points

Set $g = 5$ and $N_E = 4N_I$ (4 times more excitatory neurons). Choose parameters to obtain a stable and low but somewhat regular firing network. Observe briefly what occurs when you increase the input rate.

Problem 3.2: Synchrony — 2 points

Decrease the strength of your input in relation to your recurrence and try to obtain slight synchrony while still having relatively low firing rates. Check the extent of E-I balance in your network.

Problem 3.3: Inhibitory strength — 2 points

Change the strength of inhibition g and document what you observe. What happens to firing rates? What can you say about synchrony and E-I balance?