Dynamical Complexity Coursework

README

Introduction

We built a small world modular network made up of 1,000 Izhikevich neurons. It consists of 8 modules, each one with 100 excitatory neurons, and one module with 200 inhibitory neurons. The network is initially built with 1,000 random edges between excitatory neurons belonging to the same module. These edges are then rewired with probability, p, to other communities. There is also a focal connection between excitatory neurons of the same module to inhibitory neurons, with a ratio of 4:1, and inhibitory neurons are diffused to the whole network. Each connection has a weight and scaling factor as described by the lecture topic 9, dynamical complexity. For each rewiring probability between 0 and 0.5, the experiment builds a network and generates background firing from a Poisson process to show dynamical behaviour.

Project Structure

The project contains a Python file called neurodynamics_CW1.py that executes the experiment.
The file is divided into 5 sections:

1. **Definition of network parameters**. These global parameters are used for the defining the network and can be changed.
2. **Functions to build the network**. This contains the following helper functions:
   - build_basic_connectivity_matrix
   - rewire_excitatory_neurons
   - build_weights_matrix
   - build_delay_matrix
   - set_heterogeneous_params

   The function build_network uses the helper functions to build a network, as described in the introduction.
3. **Function to run the experiment** called run_experiment.
4. **Helper functions to plot the experiment components**.
5. **Main function** called main. This function runs the experiment for each rewiring probability p between 0 and 0.5. This is the function that is called when the Python script is executed.

Installation

This Python project requires iznetwork.py file from Exercise 2, as well as the following packages:

- Matplotlib
- NumPy

Usage

Run from the project directory: `python neurodynamics_CW1.py`
A directory with the name "outputs" will be created in your project directory. This will contain the outputs of the experiment.

Report

This PDF contains the results of the experiment described for each rewiring probability.

Rewiring probability 0.0

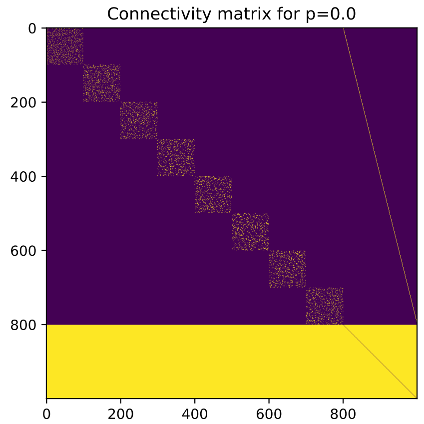

Figure 1: Connectivity matrix for p = 0.0

Description for Figure 1: Yellow points in the connectivity matrix represent connections between neurons while purple points indicate the absence of a connection. We can see that the excitatory neurons are divided into separate modules. Inhibitory neurons, in the last 200 rows, are connected to all neurons but themselves, explaining the thin purple diagonal line. Also, every 4 excitatory neurons in same module are connected to a single inhibitory neuron.

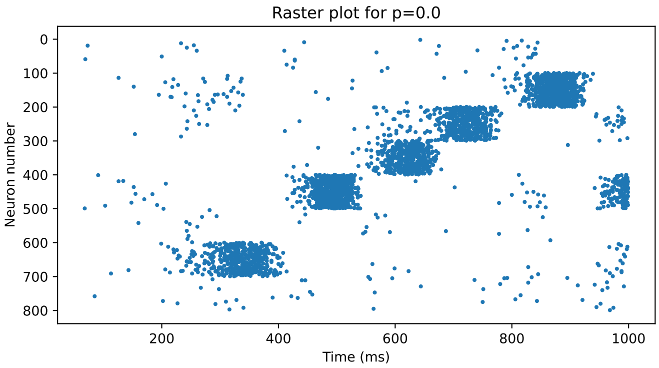

Figure 2: Raster plot for p = 0.0

Description for Figure 2: As expected, the modules compete with the common inhibitory pool. There is a "winner-takes-all" situation, and a different module is the winner at each point in time.

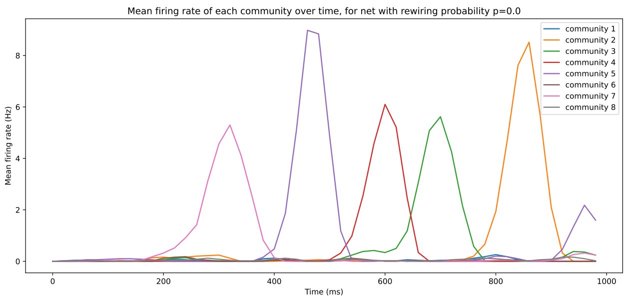

Figure 3: Graph of mean firing rate for p = 0.0

Description for Figure 3: The mean firing rate corresponds with the raster plot, with mostly independent firing activity for each module.

Rewiring probability 0.1

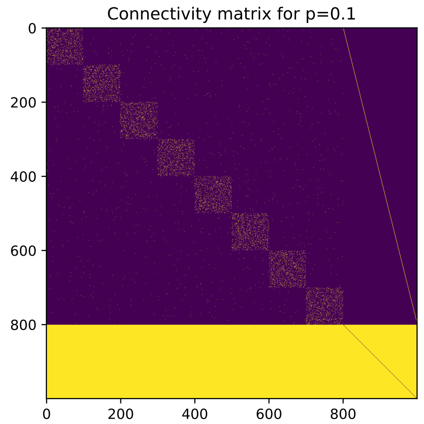

Figure 4: Connectivity matrix for p = 0.1

Description for Figure 4: The connectivity matrix is similar to when p = 0, however, due to some rewiring, we some excitatory neurons reconnecting to other modules.

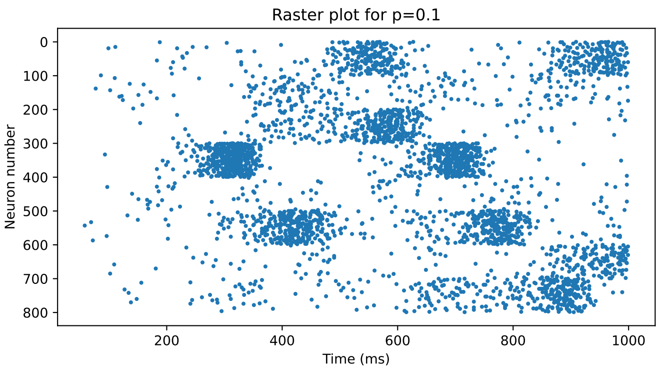

Figure 5: Raster plot for p = 0.1

Description for Figure 5: The raster plots show some of the modules starting to influence the firing activity of other modules. However, we still see mostly distinct independent modular activity.

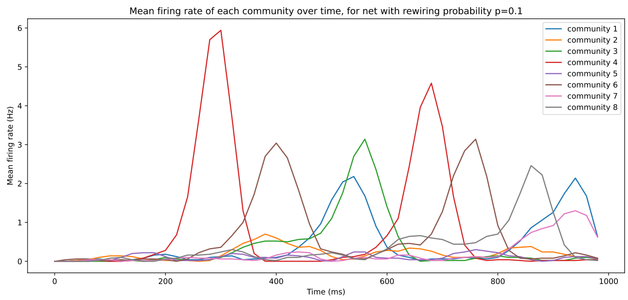

Figure 6: Graph of mean firing rate for p = 0.1

Description for Figure 6: Again, the mean firing rate shows independent modular activity, but we begin to see some overlap.

Rewiring probability 0.2

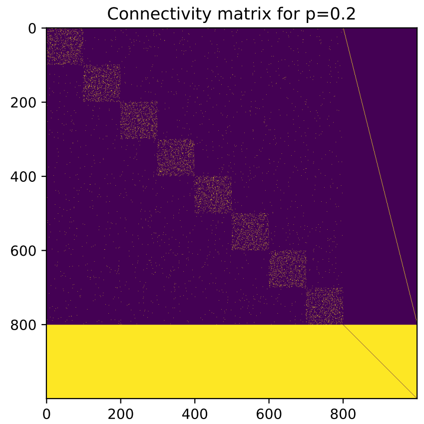

Figure 7: Connectivity matrix for p = 0.2

Description for Figure 7: We see more connections appearing between different excitatory modules.

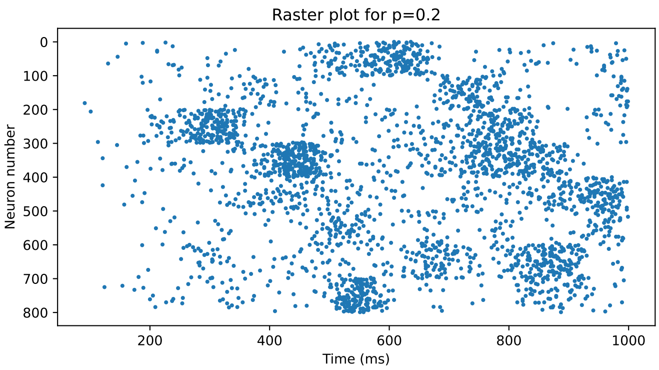

Figure 8: Raster plot for p = 0.2

Description for Figure 8: There is more overlap between modules, and less distinct modular activity.

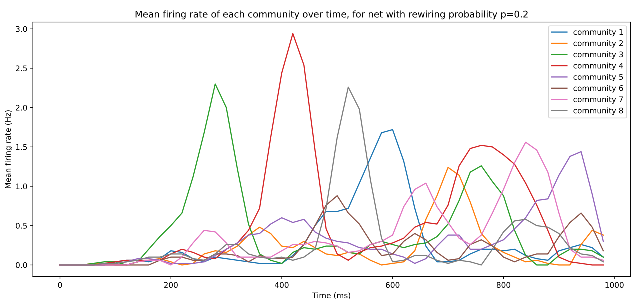

Figure 9: Graph of mean firing rate for p = 0.2

Description for Figure 9: Again, with more overlap between modules, we see that modules are losing their strength to fully inhibit the activity of other modules.

Rewiring probability 0.3

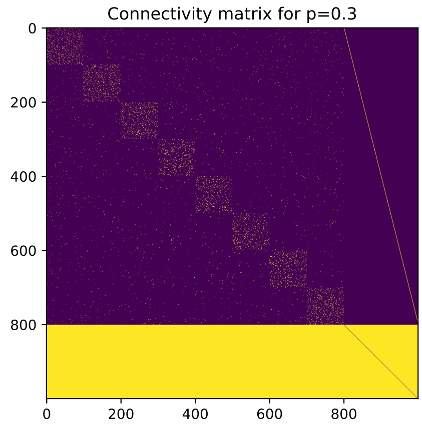

Figure 10: Connectivity matrix for p = 0.3

Description for Figure 10: We see the effect of a higher rewiring probability, with more connections between excitatory neurons of different modules.

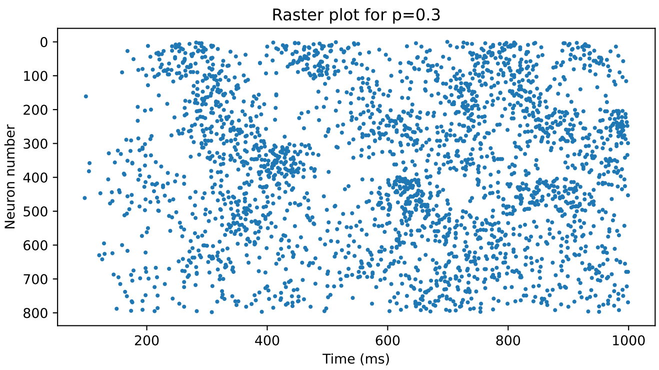

Figure 11: Raster plot for p = 0.3

Description for Figure 11: We start to see lesser independent activity of individual modules.

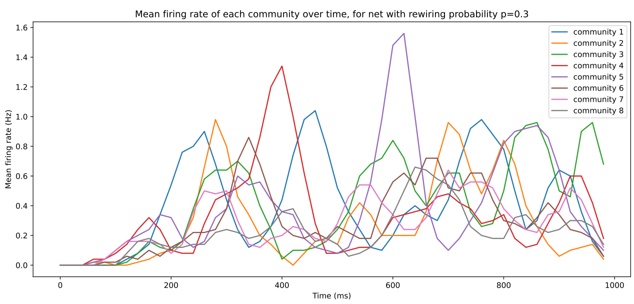

Figure 12: Graph of mean firing rate for p = 0.3

Description for Figure 12: With an increase in p, we start to see it becomes more difficult for each module to achieve a high mean firing rate.

Rewiring probability 0.4

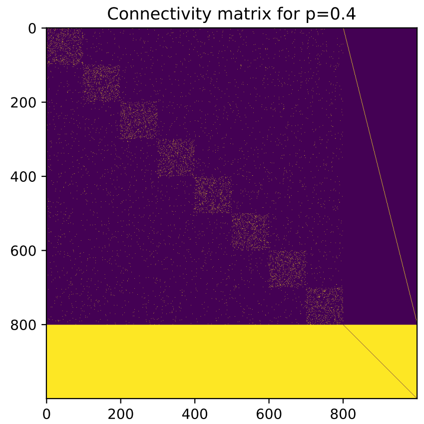

Figure 13: Connectivity matrix for p = 0.4

Description for Figure 13: There are more connections between excitatory neurons of different modules.

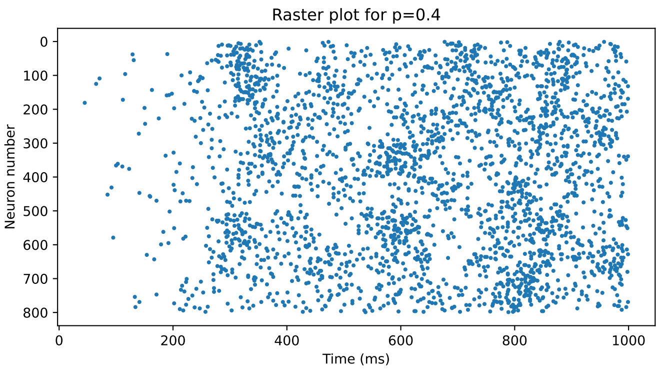

Figure 14: Raster plot for p = 0.4

Description for Figure 14: We can almost no longer see independent modular activity.

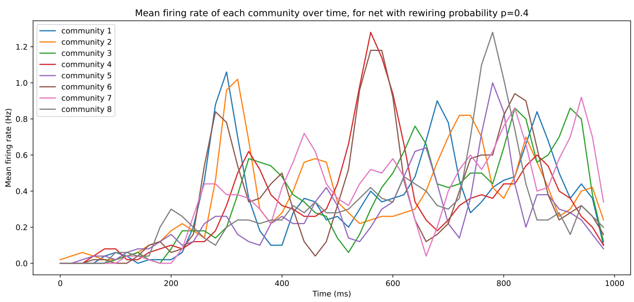

Figure 15: Graph of mean firing rate for p = 0.4

Description for Figure 15: With a low range of mean firing activity for all modules, we see that the network is dynamically suppressed.

Rewiring probability 0.5

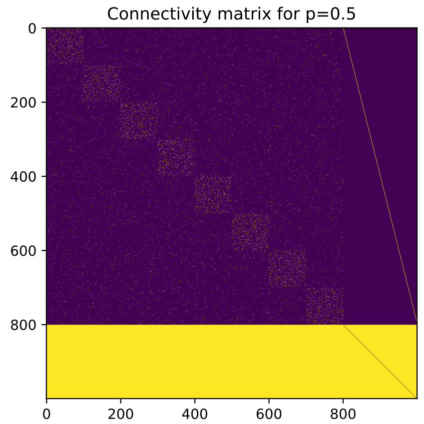

Figure 16: Connectivity matrix for p = 0.5

Description for Figure 16: There is more inter-community connections between excitatory neurons than before.

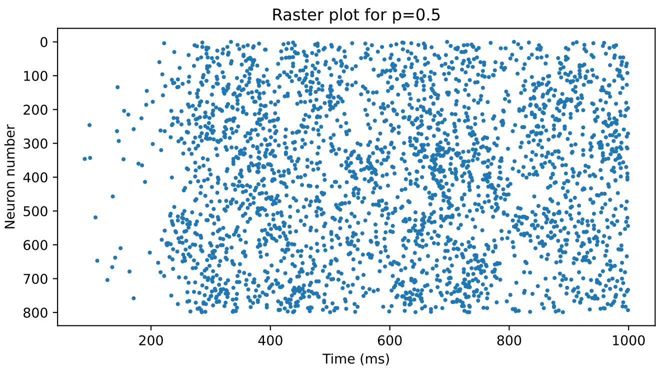

Figure 17: Raster plot for p = 0.5

Description for Figure 17: We can no longer identify distinct modular activity.

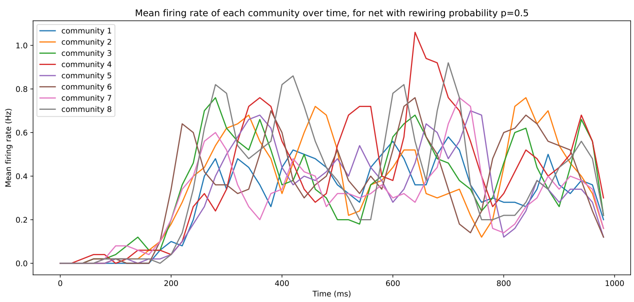

Figure 18: Graph of mean firing rate for p = 0.5

Description for Figure 18: With a low range of mean firing activity for all modules, we see that the network is dynamically suppressed. There is no independent modular activity.

Conclusion

Different network structures significantly affect the network's dynamical properties. By comparing and contrasting the plots for all rewiring probabilities in range 0.0 to 0.5, it is clear that increasing the rewiring probability suppresses individual behaviour of excitatory modules. This is determined by their lower mean firing rates and less distinctive modular activity in plots with higher rewiring probabilities.

- **Higher rewiring probability:** As the rewiring probability p increases, there may still be self-sustained activation; however the connections between the neurons becomes more random and less segregated. Connections become more similar to those of a random network, making it harder to observe separate module behaviour in the raster plots. As the rewiring probability is increased, the system becomes increasingly integrated, causing it to freeze and become incapable of significantly differing responses.
- **Smaller rewiring probability:** It is evident that in the raster plots for smaller p-values, the excitatory neuron spikes appear more modular, demonstrating independent and distinct activity. This reflects competition among excitatory modules, as the inhibitory neurons need to maintain ongoing firing to suppress rival excitatory activity.