CCN Assignment 1 : Hopfield Networks, Schizophrenia and the Izhikevich Neuron Model

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1 Introduction

Deadline is **Friday February 15th at 4 pm**. The report should not exceed **8 pages** (all included, except the code appendix).

Section 2 is independent of Sections 3&4.

Organize your answers according to the questions; don't merge them. Plots should include axis labels and units. Figures should have a caption. Some answers may require units as well. The presentation of graphs and results will count in the final mark - it should look like a scientific publication. You will find that some questions are quite open-ended. In order to receive full marks for those you will need to do more than running a simulation and making a plot. Instead, you should justify your choices, and substantiate your explanations and claims, for instance by doing additional simulations or mathematical analysis. Just writing down all you can think of is discouraged, and incorrect claims can reduce marks. It should not be necessary to consult scientific literature, but if you do use additional literature, cite it. Add your code as an appendix to allow the marker identify problems, but note this can not replace an answer to a question. We will examine code as far as possible, but will be unlikely to trace back every bug. We will not assess the programming style, but we might check the codeif results are unexpected. We will also run plagiarism detectors on them.

For policies on late submissions, see the School Late coursework & extension website:

https://bit.ly/1Jy2YyV

Please note that the University has very strict guidelines on plagiarism, which apply for all marked coursework. You should not copy results, code or text from others. For information, please consult the School Academic misconduct website:

https://bit.ly/2PTUH3A

Submit using the **submit** system: http://computing.help.inf.ed.ac.uk/submit

To facilitate marking, please also hand in hard-copies to ITO (it's the time of submission using the submit command that will count).

2 Hopfield Attractor Network and Schizophrenia (50 points)

Schizophrenia is a major mental illness that affects about 1% of the population. There are three main types of symptoms: cognitive, negative and positive. The cognitive symptoms include distractability, poor attention, working memory deficits and dysexecutive syndrome. The negative symptoms include apathy, poor rapport, motor retardation, blunted affect, and emotional withdrawal and passive behaviour. The positive symptoms of schizophrenia include bizarre trains of thoughts, hallucinations and delusions.

The first computational approach to explain positive symptoms of psychosis has been introduced by Hoffman and Dobsha in 1989[1]. This started a wave of models of schizophrenia [3], corresponding also to the first attempts at modeling in the field of Psychiatry.

It is known that during normal development from childhood to adolescence and onto adulthood, humans gradually loose synaptic connections. The idea of this model is that schizophrenia could be due to abnormal development, corresponding to an over-pruning of connections in young adulthood. Hoffman and Dobsha first used an Hopfield attractor networks in order to model normal behaviour and thoughts. They then hypothesized that schizophrenia could be modelled by a degradation of the network, where some connections are removed (or "pruned").

2.1 Hopfield Network (25 points)

We first aim at recreating the initial 'healthy' attractor network implemented in Hoffman and Dobsha (1989).

We will consider a network of 100 units. Each unit is connected to all the other units of the network. The topography of the network is a 10 by 10 units square. A neuron positioned at (x, y) in the grid, is described by its state S_{xy} and can be either active ($S_{xy} = 1$) or inactive ($S_{xy} = -1$). The synaptic weights between neuron positionned at (x, y) and neuron at (i, j) are denoted $W_{xy\to ij}$ and can be either positive (excitatory) or negative (inhibitory). They are symmetric $W_{xy\to ij} = W_{ij\to xy}$.

The network is used to store memories, which correspond to an activation pattern specifying the state of each neuron in the system, for example $\{1, -1, -1, -1, .., -1\}$. Memories are created randomly.

The state of neuron at (i, j) is given by:

$$S_{ij} = \begin{cases} -1 & if \quad E_{ij} \leq 0 \\ 1 & if \quad E_{ij} > 0 \end{cases} \tag{1}$$

where E_{ij} denotes its total input, which is the sum of all presynaptic activities, weighted by the connection strengths:

$$E_{ij} = \sum_{x,y} w_{x,y \to i,j} \times S_{x,y} \tag{2}$$

Memory storage is done by setting the synaptic weights to

$$W_{x,y \to i,j} = \sum_{m=1}^{M} \mu_{i,j}^{m} \times \mu_{x,y}^{m} \tag{3}$$

where μ_{ij} is the state of neuron (i, j) for memory m, and M is the number of stored memories.

1. Choose 3 memories that you want to encode in the network.
2. Implement the network and show that your network can successfully recover full memories from degraded inputs with each of your three memories.
3. Increase gradually the number of memories that are stored in the network (a.k.a. the memory load). Explore the performance of the network at retrieving those memories from degraded versions. Is there a limit in the capacity of the network? How does it vary with the size of the network? Illustrate and comment. Note: performance of the network can be measured in terms of the Hamming distance between the target memory and the stable pattern.

2.2 Cortical Pruning and the development of Schizophrenia (25 points)

A subsequent version of the Hopfield network assumes that the update of the units is stochastic. In this version, the probability that neuron (i, j) is turned on $(S_{ij} = 1)$ is given by:

$$P_{i,j} = \frac{1}{1 + \exp\left(-E_{i,j}/T\right)}$$

where T is a scaling factor that acts as temperature does in physical systems.

1. Check that the behaviour of the model is satisfactory with $T = 4$

Now we want to experiment the effects of synaptic pruning on the performance of the network. Synaptic pruning is done by applying the following rule:

If

$$W_{x,y \to i,j} < \hat{p} \times \sqrt{(i-x)^2 + (j-y)^2}$$

then prune the synaptic connection $(x, y) \to (i, j)$. Where $\hat{p}$ is the pruning coefficient (i.e. 0.6) and $\sqrt{(i-x)^2 + (j-y)^2}$ is the euclidean distance between the two neurons.

1. Use a network of 100 units and 9 random memories. Plot the performance of the network as a function of pruning level $\hat{p}$. Experiment with different input distances from the memory (i.e. respectively 33 and 20 hamming units away from the original memory). Describe your results and observations.

2. Hoffman and Dobscha argue that the model can account for hallucinations, delusions and Schneiderian symptons (i.e. lack of control in thoughts). Do you think it is a fair claim?

3. Is pruning the only way in which the Hopfield can be modified to lead to degraded performances and spurious attractors? Dopamine neuromodulation and environmental factors (e.g. stress) are known to play a role in Schizophrenia. Do you think these factors could be accounted for in this framework? (how?)

3 Neuron Model of Izhikevich (30 points)

A popular neuron model nowadays is the model of Izhikevich [2]. The Izhikevich model neuron was developed as an efficient, powerful alternative to the integrate and fire model. The model uses two variables, a variable representing voltage potential and another representing membrane recovery (activation of potassium currents and inactivation of sodium currents). It has 4 parameters. According to Izhikivech, “The model can exhibit firing patterns of all known types of cortical neurons with [a suitable] choice of parameters”.

- Using [2], re-implement the model using your own code (one neuron). Illustrate its basic behaviour in response to current injection.

- Can you find all the dynamic modes that he describes in part III? Illustrate.

4 Spikes and Attractors (40 points[1])

- Copy the code describing the population of Izhikevich neurons from [2]. Run it and study how it works. Change the thalamic input and recurrent weights. Can you find new dynamic modes for the population of neurons? (10 points)
- Could you use the model of Izhikevitch to implement more plausible attractor dynamics ? How would you do that ? (10 points)
- How could you model the effect of schizophrenia in this framework? (20 bonus points)

References

[1] R E Hoffman and S K Dobscha. Cortical pruning and the development of schizophrenia: a computer model. *Schizophrenia bulletin*, 15(3):477–90, Jan 1989.

[2] E M Izhikevich. Simple model of spiking neurons. *IEEE Transactions on Neural Networks*, 14:6, 2003.

[3] E T Rolls, M Loh, G Deco, and G Winterer. Computational models of schizophrenia and dopamine modulation in the prefrontal cortex. *Nature Reviews Neuroscience*, 9(9):696–709, Sep 2008.

[1] 20 bonus points