School of Computing
FACULTY OF ENGINEERING AND
PHYSICAL SCIENCES

UNIVERSITY OF LEEDS

# Final Report

## Affects of Neural Network Parameters on Population Firing Rates

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**Submitted in accordance with the requirements for the degree of MEng, BSc Computer Science**

2021/22

COMP3931 Individual Project

The candidate confirms that the following have been submitted.

| Items | Format | Recipient(s) and Date |
|---|---|---|
| Final Report | PDF file | Uploaded to Minerva (DD/MM/YY) |
| Experiment Code Repository and Raw Data | `https://github.com/C41Underscore/MIIND-NEST-Analysis` | Uploaded to Minerva (DD/MM/YY) |

The candidate confirms that the work submitted is their own and the appropriate credit has been given where reference has been made to the work of others.

I understand that failure to attribute material which is obtained from another source may be considered as plagiarism.

(Signature of Student) ____________________

**Summary**

<Concise statement of the problem you intended to solve and main achievements (no more than one A4 page)>

## Acknowledgements

<The page should contain any acknowledgements to those who have assisted with your work. Where you have worked as part of a team, you should, where appropriate, reference to any contribution made by other to the project.>

Note that it is not acceptable to solicit assistance on ‘proof reading’ which is defined as the “the systematic checking and identification of errors in spelling, punctuation, grammar and sentence construction, formatting and layout in the test”; see
`https://www.leeds.ac.uk/secretariat/documents/proof_reading_policy.pdf`

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# Chapter 1

# Key Biological Foundations

## 1.1 Basics of Neurons

Here we shall discuss some basic anatomy of neurons and the biology that underpins them. It should be noted that here we shall specifically be talking a type of neuron called a Multipolar neuron, which is the most common neuron in mammalian nervous systems [1], and even more specifically we shall be referring to spiking neurons.

### 1.1.1 What are Neurons

Neurons are considered to be the basic building blocks of our brain and the nervous system [2] which are responsible for signalling information throughout our body [1]. The human brain itself consists of an incredible amount of these units, roughly 86 billion [1], and are the cells responsible for receiving external sensory input, relying messages to our muscles, and our behaviour [2].

Neurons operate together by constantly communicating with one another [3] and sending messages to build complex behaviour [1], and these messages consist of small electrical pulses know as action potentials. Action Potentials are the signals that neurons receive, integrate, and send information with, and generally tend to be on the order of 100mV within the neuron [1]. These action potentials are then transmitted to other neurons along small gaps called synapses [1], and when an action potential reaches the synapse, it causes the release of chemical neurotransmitters, which is what allows neurons to communicate with each other [2]. The process of a neuron sending an action potential to another neuron is called firing.

### 1.1.2 Structure of Neurons

Neurons have a "tree-like" [2] structure, and consists of four defined regions [1]. Firstly, there is the Soma, also known as the cell body [2], and this contains the cell's nucleus, which itself contains the DNA of the cell [1]. It is also the responsibility of the Soma to perform processing of the incoming signals from other neurons, we can treat it as the 'central processing unit' [4] of a neuron. Furthermore, in relation to the action potential, it connects two key elements of a neuron: Dendrites and the Axon.

Dendrites are considered to be the main way that a neuron will receive signals from other neurons [1], and contain the receiving sites for the chemical neurotransmitters released by the sending neuron in the synapse [2]. It can be said that the summation of dendritic inputs is a key factor in what causes a neuron to fire [2].

The axon of the neuron is the medium of transmission used by a neuron to get an action potential from the dendrites across to other neurons [1]. They are a thin membrane, with a

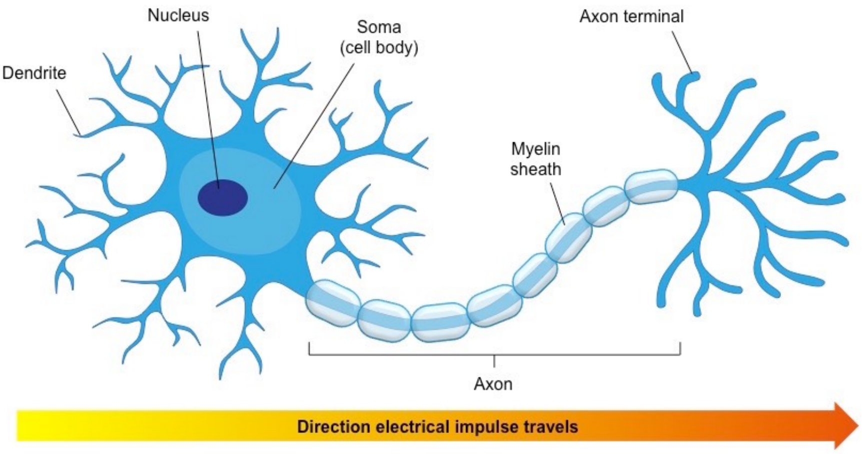


Figure 1.1: The Anatomy of a Neuron [6]

diameter ranging between 2$\mu$m to 20$\mu$m, but can be as long as 1m [1]. A neuron axon is able to branch, which allows a neuron to connect to multiple other neurons, where the end of an axon branch, known as a terminal [1], will propagate an action potential to the synapse. The action potential is generated at the start of an axon, in an area called the initial segment [1], and are constantly regenerated as they move along the membrane to ensure that it stays at a constant potential [1]. Finally, figure 1.1 shows that the axon is covered in something called Myelin Sheath, which is a plasma membrane wrapped around the axon [5] and is present in order to increase the speed at which an axon transmits it's action potential [3]. Myelination, which is the process given to the coating of nerve axons [3], is considered a key element in ensuring efficient transmission of information in the brain [3]. Finally, there are small gaps in the Myelin Sheath, which are called nodes of Ranvier, which allow the action potential to 'hop' over to the next Myelin membrane, which further increases the speed of potential transmission [5].

### 1.1.3 Spiking Neurons

Signals produced by neurons to other neurons consist of short electrical pulses known as spikes, and these spikes happen as a direct result of an action potential being generated in a neuron, and in reality the terms spike and action potential refer to the same phenomena [4]. Each spike produced will have am amplitude of roughly 100mV and will last for 1-2ms [4], and the spike does not change once it has been generated and moves along the axon [4], in other words, it has no internal variation.

A spike train is defined as a series of spikes emitted by a single neuron that can occur at regular or irregular intervals over a given period of time [4], and importantly, these spikes are stereotyped [4], meaning that each spike is very similar to all other spikes produced. As a consequence of each spike being similar, it's believed that spiking neurons don't encode information in individual spikes, but rather in the timing and number of spikes produced by a neuron [4]. Spikes in spike trains tend to be well separated [4], and this is because after a neuron fires, it enters a refractory state, where it is impossible to generate a second spike; this period is known as the absolute refractory period [4].

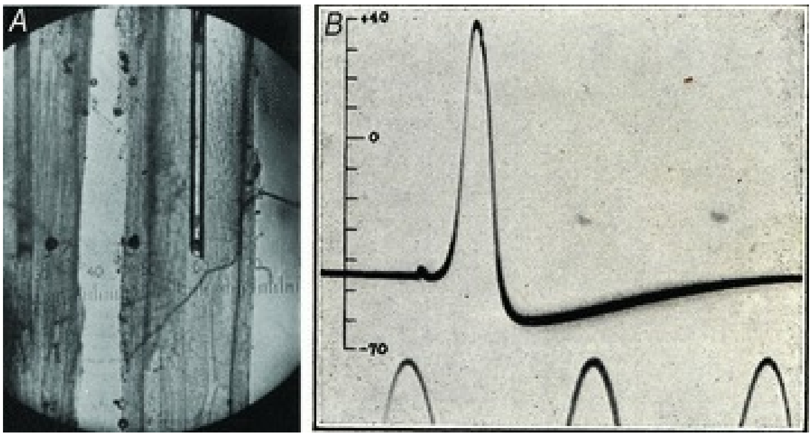


Figure 1.2: Images produced from the famous experiment done by Hodgkin and Huxley in 1939, where they performed the first ever intracellular recording of an action potential in a giant squid axon using an electrode [7]. A) Shows the electrode inserted into the axon membrane, and B) Shows the action potential they recorded, which we would describe as a single spike.

## 1.2 Relevant Aspects of Neurons

### 1.2.1 Membrane Potential

Throw in the big words - - Threshold - resting state - action potential - depolarisation - repolarisation - hyperpolarisation - refractory period
then, talk about the movement of ions (the things that would've been mentioned under conductance, would better be suited here)
mention typical values in all

### 1.2.2 Synapses

**Synaptic Efficacy**

**Synaptic Delay**

# Chapter 2

# Key Mathematical Foundations

<Everything that comes under the 'Methods' criterion in the mark scheme should be described in one, or possibly more than one, chapter(s).>

## 2.1 What are Neuron Models

## 2.2 Leaky-Integrate-and-Fire

### 2.2.1 Intuition behind the model

### 2.2.2 The LIF Model

### 2.2.3 Conductance-based LIF

## 2.3 Poisson Process

### 2.3.1 Poisson Distribution

### 2.3.2 Poisson Spike Train

## 2.4 Common metrics used for describing Neuron behaviour

### 2.4.1 Rate as a Spike Density and the Peri-Stimulus-Time Histogram

### 2.4.2 Rate as Population Activity

## 2.5 Methods of modelling Neurons

### 2.5.1 Monte Carlo

### 2.5.2 Population Methods

# Chapter 3

# MIIND

<Results, evaluation (including user evaluation) *etc.* should be described in one or more chapters. See the 'Results and Discussion' criterion in the mark scheme for the sorts of material that may be included here.>

## 3.1 Premise and Aims of MIIND

## 3.2 Key Features

## 3.3 The Grid Algorithm

# Chapter 4

# NEST

<Everything that comes under the ‘Results and Discussion’ criterion in the mark scheme that has not been addressed in an earlier chapter should be included in this final chapter. The following section headings are suggestions only.>

## 4.1 Premise and Aims of NEST

## 4.2 Key Features

## 4.3 Core Functioning

# Chapter 5

# Method

## 5.1 Independent Variables

### 5.1.1 Population Size (NEST Only)

### 5.1.2 Number of Connections

### 5.1.3 Input Type

#### Input Strength

### 5.1.4 Network Type

## 5.2 Dependent Variables

### 5.2.1 Firing Rates

### 5.2.2 Simulator Performance

## 5.3 The Experiment Program

### 5.3.1 The NEST Component

### 5.3.2 The MIIND Component

# Chapter 6

# Results

## 6.1 Affect of Size (NEST Only)

## 6.2 Affect of Connections

### 6.2.1 Excitatory

### 6.2.2 Inhibitory

## 6.3 Affect of Input Type

### 6.3.1 Poisson

#### Affect of Rate

### 6.3.2 Cortical

#### Affect of Rate

## 6.4 Affect of Network Structure

### 6.4.1 Balanced E-I

### 6.4.2 Self-Connected Network

## 6.5 Summary of Differences Produced between Simulators

# Chapter 7

# Discussion

## 7.1 Conclusions

## 7.2 A Note on Using the Simulators

## 7.3 Future Work following this

# References


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[5] P. Morell and R. Quarles, "Basic neurochemistry: Molecular, cellular and medical aspects. 6th edition.." https://www.ncbi.nlm.nih.gov/books/NBK27954/, 1999. Accessed: 2022-03-07.

[6] BioNinja, "Neurons." https://ib.bioninja.com.au/standard-level/topic-6-human-physiology/65-neurons-and-synapses/neuron, 2022. Accessed: 2022-03-07.

[7] A. Hodgkin and A. Huxley, "Action potentials recorded from inside a nerve fibre," *Nature*, vol. 144, pp. 710–711, 1939.

# Appendix A

# Self-appraisal

<This appendix should contain everything covered by the 'self-appraisal' criterion in the mark scheme. Although there is no length limit for this section, 2—4 pages will normally be sufficient. The format of this section is not prescribed, but you may like to organise your discussion into the following sections and subsections.>

## A.1 Critical self-evaluation

## A.2 Personal reflection and lessons learned

## A.3 Legal, social, ethical and professional issues

<Refer to each of these issues in turn. If one or more is not relevant to your project, you should still explain *why* you think it was not relevant.>

### A.3.1 Legal issues

### A.3.2 Social issues

### A.3.3 Ethical issues

### A.3.4 Professional issues

# Appendix B

## External Material

<This appendix should provide a brief record of materials used in the solution that are not the student's own work. Such materials might be pieces of codes made available from a research group/company or from the internet, datasets prepared by external users or any preliminary materials/drafts/notes provided by a supervisor. It should be clear what was used as ready-made components and what was developed as part of the project. This appendix should be included even if no external materials were used, in which case a statement to that effect is all that is required.>