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Mathematics

**Neural Networks with Python and TensorFlow**

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# Abstract

Artificial Intelligence (AI) still remains as one of the greatest challenges in scientific research to this date, but much progress in the field has been made using artificial neural networks. The design of artificial neural networks is loosely inspired by that of biological brains, and serves as an expansion of an earlier concept called the perceptron (Rosenblatt, 1958). By using multiple layers of these artificial neurons, we can form a highly connected system that is referred to as a neural network, these networks can then be trained on a large data set to predict the output with high accuracy.

The range applications for neural networks is wide: they can be used to classify data, predict future states of chaotic systems, apply stylisations to images, and control physical/physically-based system in real-time.

[TODO: \*Abstract\*.](#)

# Declaration

With the exception of any statement to the contrary, all the material presented in this report is the result of my own efforts. In addition, no parts of this report are copied from other sources. I understand that any evidence of plagiarism and/or the use of unacknowledged third party materials will be dealt with as a serious matter.

Signed



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# Chapter 1

## Introduction to Neural Networks

*TODO: Chapter: Introduction*

### Biological Neurons

Biological neurons are electrically excitable cells that are found in almost all animals. These neurons can transmit and receive electrical signals to one another via synaptic connections, which maybe either excitatory or inhibitory. Any given neuron will be either active or inactive depending on whether or not its input exceeds a threshold.

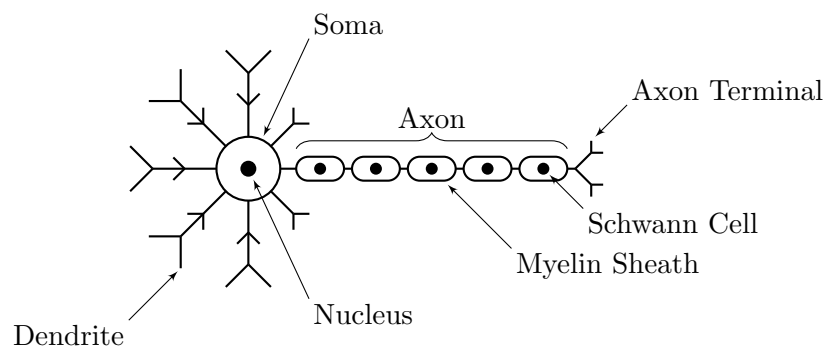


Figure 1.1: Diagram of a biological neuron.

Signals are received by the neuron via connections to dendrites and soma. If the threshold is met, electrical signals are sent along the axon to the terminal, where it is connected to other neurons, or to a controllable cell such as a neuromuscular junction.

*TODO: Section: Biological Neurons*

## Artificial Intelligence

The idea of artificial beings capable of human intelligence can be traced back to mythical stories from ancient Greece. One such story was that of a mythical automaton called Talos, who circled an island's shores to protect it from pirates and other invaders.

By the 19<sup>th</sup> century, other notions of artificial intelligence were explored by fiction in stories such as Mary Shelley's "Frankenstein", and Karel Čapek's "R.U.R.". Some of the fictional writings of the 20<sup>th</sup> century further continued exploring the concept in novels such as Isaac Asimov's "I, Robot".

Academic research into artificial intelligence began around the 1940's, primarily due to findings in neurological research at the time. The first explorations of artificial neural networks was done by McCulloch and Pitts, 1943, who investigated how simple logic functions might be performed by idealised networks. The neurons within these networks operated using some basic logic rules, applied to a discrete time system which, can be summarised using the expression

$$N(t) = (E_1(t-1) \vee E_2(t-1) \vee \dots) \wedge \neg(I_1(t-1) \vee I_2(t-1) \vee \dots),$$

where  $N(t)$  is the state of a neuron at time  $t$ , and  $E_i(t-1)$  and  $I_i(t-1)$  are the states of the excitatory and inhibitory connections from the previous time step respectively. The result is such that the neuron will only be active if at least one excitatory connection is active and all inhibitory connections are inactive. The versatility of this definition is demonstrated in the following examples.

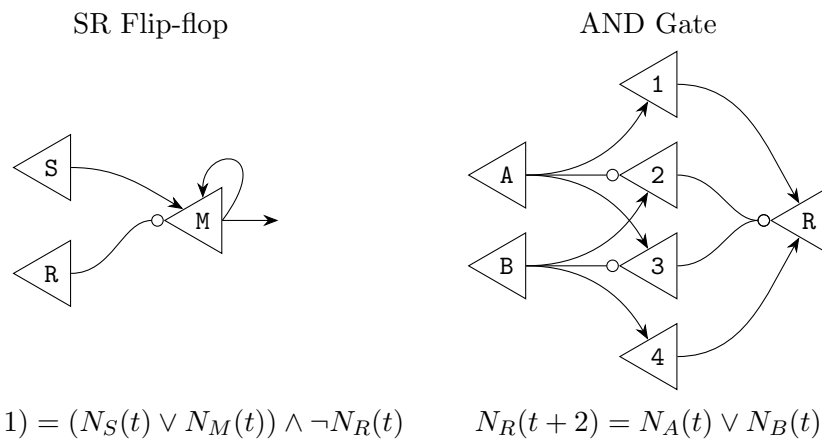


Figure 1.2: Two common logic circuits using McCulloch's neurons where the arrows and circles indicate excitatory and inhibitory connections respectively.

While this model provided insight into the mechanisms by which neurons operate, the structure

was static, and incapable of learning.

McCulloch's work was later cited by psychologist Hebb, 1949, who proposed that the structure of biological neural networks was dynamic, and that frequently repeated stimuli caused gradual development. At the scale of neuron, it was theorised that if one neuron successfully excited another that the connection between them would strengthen, hence increasing the likelihood that the former would be able to excite the latter again in the future. His theory was supported by research conducted by himself and others that showed that intelligence-test performance in mature patients was often unaffected by brain operations that would have prevented development in younger patients, which suggested that learnt stimuli are processed differently to unknown stimuli. This hypothesis became known as Hebbian learning.

Computer simulations applying this theory to a small network were done by Farley and Clark, 1954. The actions of the network were compared to that of a servo system which must counteract any displacements so as to maintain a steady position. The network was trained using a set of input patterns, which were subject to non-linear transformations. Similar to the Hebbian theory, when the network produces the correct responses, the active connections are strengthened. Although the results were of little neurophysiological significance, the results were of great use for demonstrating computational simulations, which were considerably slower at the time.

*TODO: Section: Artificial Intelligence*

## Perceptrons

The idea of the perceptron was originally conceived by Rosenblatt, 1958, to represent a simplified model of intelligent systems free from particularities of biological organisms, whilst maintaining some of their fundamental properties.

The perceptron was built as a dedicated machine that consisted of a number of photovoltaic, analogous to a retina, that feed into an "association area". This association area contains a number of cells that each calculate a weighted sum of the receptor values and output a signal if it exceeds a threshold. Expressed mathematically, the output of a given association cell is



given by

$$A_i = \begin{cases} 1, & \sum_j w_{i,j} I_j \\ 0, & \text{otherwise} \end{cases},$$

where  $I_j$  is the value from the  $j^{\text{th}}$  photovoltaic cell, and  $w_{i,j}$  is the weight there of. These value weights were implemented using variable resistance wires that the perceptron could adjust automatically. The outputs from the association area are then connected to response cells, which operate in a similar fashion to the association cells. The activation of these response cells are the outputs of the perceptron, and indicated the classification of the input.

Similar to Farley and Clark, 1954, the method by which the perceptron adjusted it weights was also based on which cells were active, and whether the correct output was produced; except that the perceptron was also able to “penalise” weights when an incorrect result was outputted.

This machine was initially trained to reliably identify three different shapes: a square, a circle, and a triangle; and did so with a better than chance probability. When attempting to use the perceptron for more complicated tasks, such as character recognition, it failed to produce better than chance results.

*TODO: Subsection: Perceptrons*

## Backpropagation

In order for a neural network to learn, it must undergo some form of optimisation process. For the perceptron, this process was one of positive and negative reinforcement.

In the field of control theory, an optimisation method known as gradient descent was developed by Kelley, 1960, in which a given function of the system is either maximised or minimised. This is achieved by taking partial derivatives of the function with respect to each parameter, which gives an approximation of how the function value will change as the parameter changes. By evaluating the partial derivatives, multiplying them by a constant, and adding them to their respective parameters, the parameter values can be updated. Using these new parameter values, one can expect to improve the function value. This can be written as

$$w'_i = w_i + \eta \frac{\partial f}{\partial w_i}(\mathbf{x}),$$

where  $f(\mathbf{x})$  is the function to be optimised,  $w_i$  is a parameter of  $f$ ,  $w'_i$  is the updated parameter,

and  $\eta$  is ascent/descent parameter. Positive  $\eta$  values will maximise the function value, where as negative values will minimise it. The magnitude of  $\eta$  determines the rate at which the method will attempt change the parameters: if the value is too large, the method will overshoot the optimal values; if the value is too small, the method will be too slow to converge.

*TODO: Subsection: Backpropagation*

## Types of Neurons

*TODO: Section: Types of Neurons*

CNN

RNN

LSTM

## Chapter 2

# Neural Networks in Python

Python is a general-purpose programming language designed by Guido van Rossum, with an emphasis on readability and reusability (Rossum, 1996). It comes with an extensive standard library and is one of the most popular programming languages.

There are multiple options for interacting with Python, these include:

- typing commands into an interpreter,
- writing files and running them with an interpreter,
- using an online service such as Google Colab.

*TODO: Chapter: Neural Networks in Python*

## Single Perceptron Boston Housing Data

*TODO: Section: Single Perceptron Boston Housing Data*

## Multi Layer Perceptron Boston Housing Data

*TODO: Section: Multi Layer Perceptron Boston Housing Data*

## XOR Gate

*TODO: Section: XOR Gate*

## Chapter 3

# Introduction To TensorFlow

TensorFlow *TODO: Chapter: Introduction To TensorFlow*

## Linear Regression

*TODO: Section: Linear Regression*

## XOR

*TODO: Section: XOR*

## Boston Housing with Keras

*TODO: Section: Boston Housing with Keras*

## Chapter 4

# Deep Learning

*TODO: Chapter: Deep Learning*

## Recurrent Neural Networks

*TODO: Section: Recurrent Neural Networks*

## Convolutional Neural Networks

*TODO: Section: Convolutional Neural Networks*

## Image Processing

*TODO: Subsection: Image Processing*

## Supervised Learning

*TODO: Section: Supervised Learning*

## Unsupervised Learning

*TODO: Section: Unsupervised Learning*

## Autoencoding

*TODO: Section: Autoencoding*

## Reinforcement Learning

*TODO: Section: Reinforcement Learning*

## Chapter 5

## Null

*TODO: Decide parent chapter for CNN, RNN, and LSTM sections*

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