Mini-Project 1: Report
CSE486: Introduction to Neural and Cognitive Modeling

Just Another Cog in the Wheel
Ujwal Narayan, 20171170
Sayar Ghosh Roy, 20171047
Shelly Jain, 20171008

This is the report for the selected mini-project 1 for the course. The report consists of a brief introduction of the topic chosen, a simple description of the task to be completed, and a compilation of the results of the task (including procedure and observation).

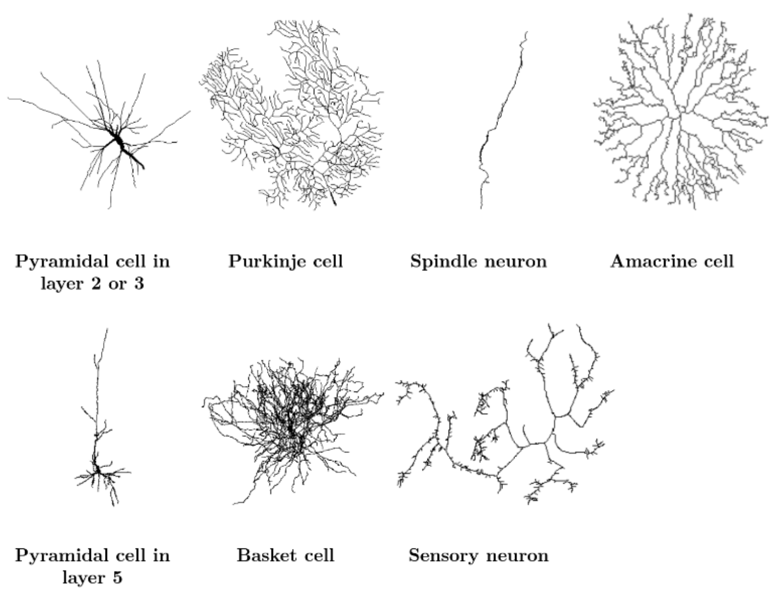
1 Types of Cells

1.1 Introduction

There are many types of cells in each organism. These differ by both structure and function. One such cell is the neuron. A neuron (or neurone) is a nerve cell that carries electrical impulses. Neurons are the basic units of the nervous system. The general structure of a neuron consists of a cell body (soma or cyton), dendrites and an axon.

1.2 Classification of Neurons

The nervous system has lots of different types of neurons. They all have different size, structure and function. Due to this, neurons can be classified on the basis of various parameters such as size, bifurcation, size of soma, etc. Different types of neurons exhibit different shapes. The structures of some types of neurons are shown below:



(i) **Pyramidal Cell in Layer 2 or 3 -** Pyramidal cells are a type of multipolar neuron found in areas of the brain including the cerebral cortex, the hippocampus, and the amygdala. Pyramidal neurons are the primary excitation units of the mammalian prefrontal cortex and the corticospinal tract. Cortical layer 2 and 3 input evokes both excitatory and inhibitory currents in layer 5, with net excitatory effect. The input amplifies and modulates the gain of sensory-evoked responses in layer 5.

(ii) **Purkinje Cell -** Purkinje cells are a class of GABAergic neurons found within the Purkinje layer in the cerebellum. They are named after their discoverer, Czech anatomist Jan Evangelista Purkyně. These are some of the largest neurons in the human brain, with an intricately elaborate dendritic arbor, characterised by a large number of dendritic spines. They are aligned like dominoes stacked one in front of the other. Their large dendritic arbors form nearly two-dimensional layers through which parallel fibers from the deeper-layers pass. Purkinje cells send inhibitory projections to the deep cerebellar nuclei, and constitute the sole output of all motor coordination in the cerebellar cortex.

(iii) **Spindle Neuron -** Spindle neurons, also called von Economo neurons (VENs), are a specific class of mammalian cortical neurons characterised by a large spindle-shaped soma (or body) gradually tapering into a single apical axon in one direction, with only a single dendrite facing opposite. Spindle neurons are found in two very restricted regions in the brains of hominids: the anterior cingulate cortex (ACC) and the fronto-insular cortex (FI), but recently they have been discovered in the dorsolateral prefrontal cortex of humans. Spindle neurons are relatively large cells that may allow rapid communication across the relatively large brains.

(iv) **Amacrine Cell -** Amacrine cells are interneurons in the retina, named as such because of their short neuritic processes. Amacrine cells are inhibitory neurons, and they project their dendritic arbors onto the inner plexiform layer (IPL), they interact with retinal ganglion cells and/or bipolar cells. There are at least 33 different subtypes of amacrine cells based just on their dendrite morphology and stratification.

(v) **Pyramidal Cell in Layer 5 -** Pyramidal neurons in layer 5 of the motor cortex send their axons down the spinal cord to drive muscles. They might thus be thought of as the 'movers and shakers' of the brain. Layer 5 pyramidal neurons are thought to benefit from their large size, partitioning off parts of themselves into semi-autonomous processing units.

(vi) **Basket Cell -** Basket cells are multipolar inhibitory GABAergic interneurons of the brain, found throughout different regions of the cortex and cerebellum. Their dendrites are free branching, contain smooth spines, and extend from 3 to 9 mm. Axons are highly branched, ranging from 20 to 50mm. The branched axonal arborisations give them their name as they look like baskets surrounding the soma of the target cell. Basket cells form axo-somatic synapses (their synapses target somas of other cells). By controlling the somas of other neurons, they directly control the action potential discharge rate of target cells

(vii) **Sensory Neuron -** Sensory neurons, or afferent neurons, are neurons in the central nervous system, that convert a specific type of stimulus, via their receptors, into action potentials or graded potentials via a process called sensory transduction. The cell bodies of the sensory neurons are located in the dorsal ganglia of the spinal cord. Different types of sensory neurons have different sensory receptors that respond to different kinds of stimuli. Sensory neurons may be classified on the basis of adequate stimulus, location, morphology or rate of adaptation.

2 Task of the Mini-Project

For the purpose of this mini-project, refer to the directory in the git repository given here. The task is to plot the neurons from the data files and determine which of the aforementioned types it should be classified as.

(i) **Data Files -** Have a look inside an `.swc` file. Each line describes a small piece of the neuron (*compartment*). The space-separated values are:
- ID of the compartment
- Type of the compartment
  - 0 - undefined
  - 1 - soma
  - 2 - axon
  - 3 - basal dendrite
  - 4 - apical dendrite
- X coordinate (in µm)
- Y coordinate
- Z coordinate
- Radius of the compartment
- ID of parent compartment

(ii) **Importing Data -** Import the coordinate data into your program (or `Matlab`, `R` environment).

(iii) **Plotting Data -** Plot the data in three dimensional (for example using `scatter3` in `Matlab`).

(iv) **Classifying Data -** Look at the resulting three dimensional images and try to classify the type of neuron.

3 Results

3.1 Procedure

The neurons were simulated using their compartment characteristics from the provided data files. Several libraries were attempted in order to generate three dimensional models from the input data, such as `swc2vtk`. There were several issues as most of these libraries were not documented properly. Finally, the library 'NeuroM' (available here) was used. NeuroM is a Python toolkit for the analysis and processing of neuron morphologies. To install NeuroM, run the following command: `pip install neurom`

However, due to the constraints from the `neurom` library we could not visualise Neuron 1 as it had invalid soma points. In addition, Neuron 3 gave *infinity* or `NaN` as values and therefore that too could not be visualised. As a result, we switched to a more robust library, `nat`, which did not enforce such rigid constraints. This library stands for 'NeuroAnatomy Toolbox' and is found in the `R` environment. To install the package, run the following command in your `R` shell: `install.packages("nat")`

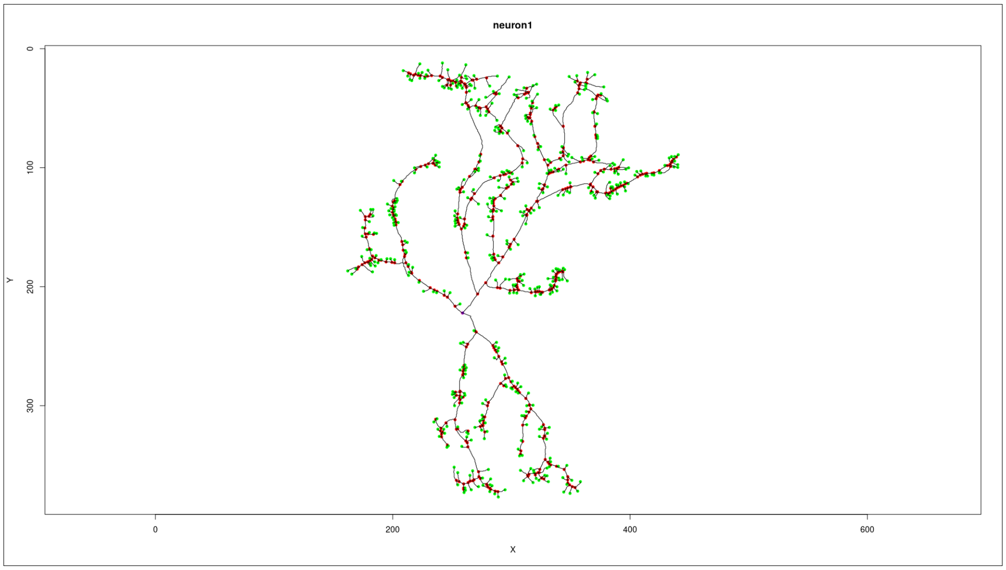
The given neurons were then visualised in both three dimensions and two dimensions. These simulations were compared with the given example neurons and classified accordingly. All simulations can be found at the link here

3.2 Observations

The two dimensional projections of the imagery generated using R are displayed below:

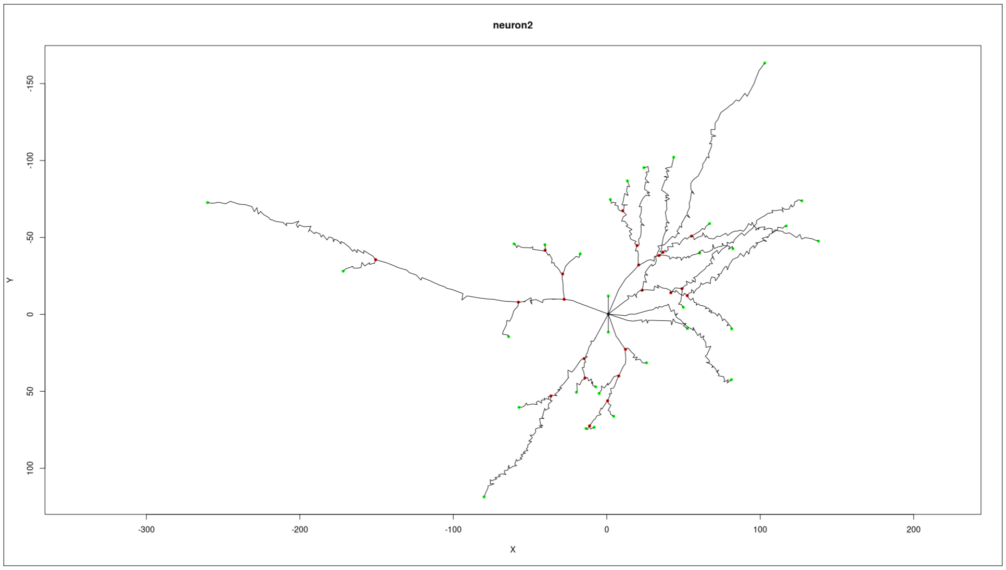
3.2.1 Neuron 1

The first simulated appeared to be a sensory neuron. The diagram is given below:



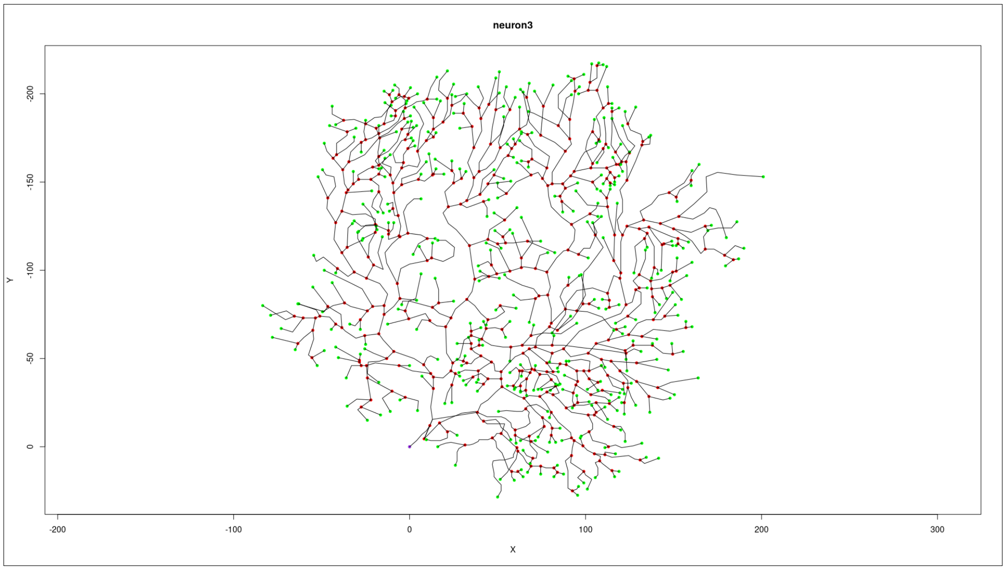
3.2.2 Neuron 2

The first simulated appeared to be a pyramidal cell in layer 2 or 3. The diagram is given below:



3.2.3 Neuron 3

The first simulated appeared to be a Purkinje cell. The diagram is given below:



4 Conclusions

The methodology used to execute this mini-project allows us to visualise the cell in a three dimensional format such that minor differences in structure can be both isolated and identified with great ease. A pathologist can effectively use these structures to pinpoint cell anomalies which would not be apparent simply on analysing given feature sets of the neurons.

Due to its simple and yet effective procedure, as well as its easy-to-interpret results, this methodology is undeniably useful to gain quick and accurate insights into into problems that may occur in the morphology of neurons. Thus, it may be said that three dimensional visualisation of the neuron is an essential technique for cell structure analysis even beyond classification tasks.

5 References

(i) https://github.com/kuz/Computational-Neuroscience-Course/tree/master/2014/Practices/Practice1-StructureoftheBrain
(ii) https://github.com/BlueBrain/NeuroM
(iii) https://github.com/ujwal-narayan/Cognitive-Modeling
(iv) https://en.wikipedia.org/wiki/Neuron
(v) https://faculty.washington.edu/chudler/cells.html
(vi) https://qbi.uq.edu.au/brain/brain-anatomy/types-neurons
(vii) https://explorable.com/types-of-neurons
(viii) https://blogs.scientificamerican.com/brainwaves/know-your-neurons-classifying-the-many-types-of-cells-in-the-neuron-fores

(ix) https://en.wikipedia.org/wiki/Pyramidal_cell

(x) https://www.cell.com/cell-reports/pdfExtended/S2211-1247(18)31309-3 https://www.cell.com/current-biology/pdf/S0960-9822(11)01198-5.pdf

(xi) https://en.wikipedia.org/wiki/Purkinje_cell

(xii) https://en.wikipedia.org/wiki/Spindle_neuron

(xiii) https://en.wikipedia.org/wiki/Amacrine_cell

(xiv) https://en.wikipedia.org/wiki/Basket_cell

(xv) https://en.wikipedia.org/wiki/Sensory_neuron