Mind of a Nematode Caenorhabditis Elegan

Project in Cognitive Science
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Abstract

Nematode. C. Elegans are the only animal, till date, whose nervous system connections are known by human beings. It has only 302 neurons, which can be grouped based on their function as sensory receptors, interneurons and motoneurons. In this project, detailed neuron structure of a hermaphrodite worm has been studied, and a simpler neuron circuitry have been created which is demonstrated using an animation that shows how a worm behaves in different conditions, like touching its head or placing food near it. The animation is developed using NEURON softwate, Matplot library and Python.

Part I
Introduction

1 What is a Nematode. C. Elegan?

Latin : Nemat means 'thread' + odes means "like, of nature of".

Greek: Caeno means "new, fresh" + Rhabditis means "rod, wand".

C. Elegan is a small, free-living, soil nematode worm. It grows to length of $1.3mm$ and a diameter of $80\mu m$, if there is a plenty supply of food.

It responds in a regulated manner to a number of sensory stimuli. It will chemotax up a gradient of chemical attractant or down a gradient of repellan, avoid regions of high osmolarity, actively maintain itself at an optimum temperature in a temperature gradient, respond to light touch by moving away from the point of stimulation, use its mechanosensory system to navigate through the interstices between soil particles in its natural habitat.

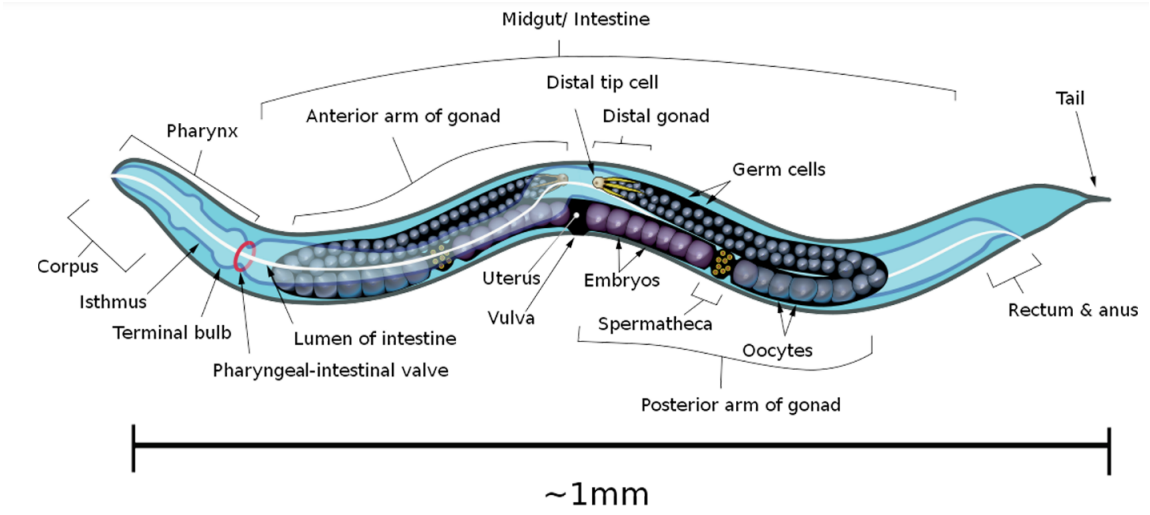


Figure 1 (A C. Elegan through microscope)

2 Why are Nematode. C. Elegans important for research?

C. Elegans have a nervous system and a brain (nerve ring). They exhibit phenomena like embryogenesis, morphogenesis, development, nerve function, behavior and aging, determined by genes, and yet are only 1 mm long. It is usually grown (in laboratory, for research) on petri plates seeded with bacteria. All somatic cells of its transparent body are visible with a microscope, and its average life span is a only 2-3 weeks. Thus C. Elegans provides the researchers with the ideal compromise between complexity and tractability.

3 Structure

There are four longitudinal ridges running down the inside of the body cavity: two medial and two lateral. These ridges consist of a ridge of hypodermis adjacent to a bundle of nerve processes, the whole structure being bounded by a basal lamina. Body movements are mediated by four strips of muscle cells running in four quadrants between these longitudinal ridges.

Part II
The nervous system of Nematode. C. Elegans

There are 302 neurons in the nervous system of C. elegans; this number is invariant between animals. Each neuron has a unique combination of properties, such as morphology, connectivity and position, so that every neuron may be given a unique label.

The simplest functional groupings of neurons that are usually made are their categorizations as either receptor neurons, interneurons or motoneurons. Assignment of a particular class to a group is, however, not straightforward; several neuronal classes have to be assigned to more than one group, because they appear to combine two or more of these basic functions.

4 Sensory receptors

The bulk of the nervous system of C. elegans is situated in the head, which is richly endowed with sensory receptors. These are arranged in groups of sense organs, known as sensilla. Each sensillum contains one or a number of ciliated nerve endings and two non-neuronal cells: a sheath cell and a socket cell. A socket cell is effectively an interfacial hypodermal cell acting to join the sensillum to the hypodermis. A sheath cell is a glial-like cell that envelops the endings of neurons.

There are arround 39 neurons, which, on the basis of morphology and connectivity, are likely to function as sensory receptors. There are two general types of sensillum: those that have channels that open to the outside, exposing some or all of the neurons to the external chemical environment, and those that have no such channel. The former class is generally considered to be chemosensory and the latter, mechanosensory in function. The component neurons of sensilla are all ciliated and some of the presumed mechanoreceptors also have ciliary rootlets,

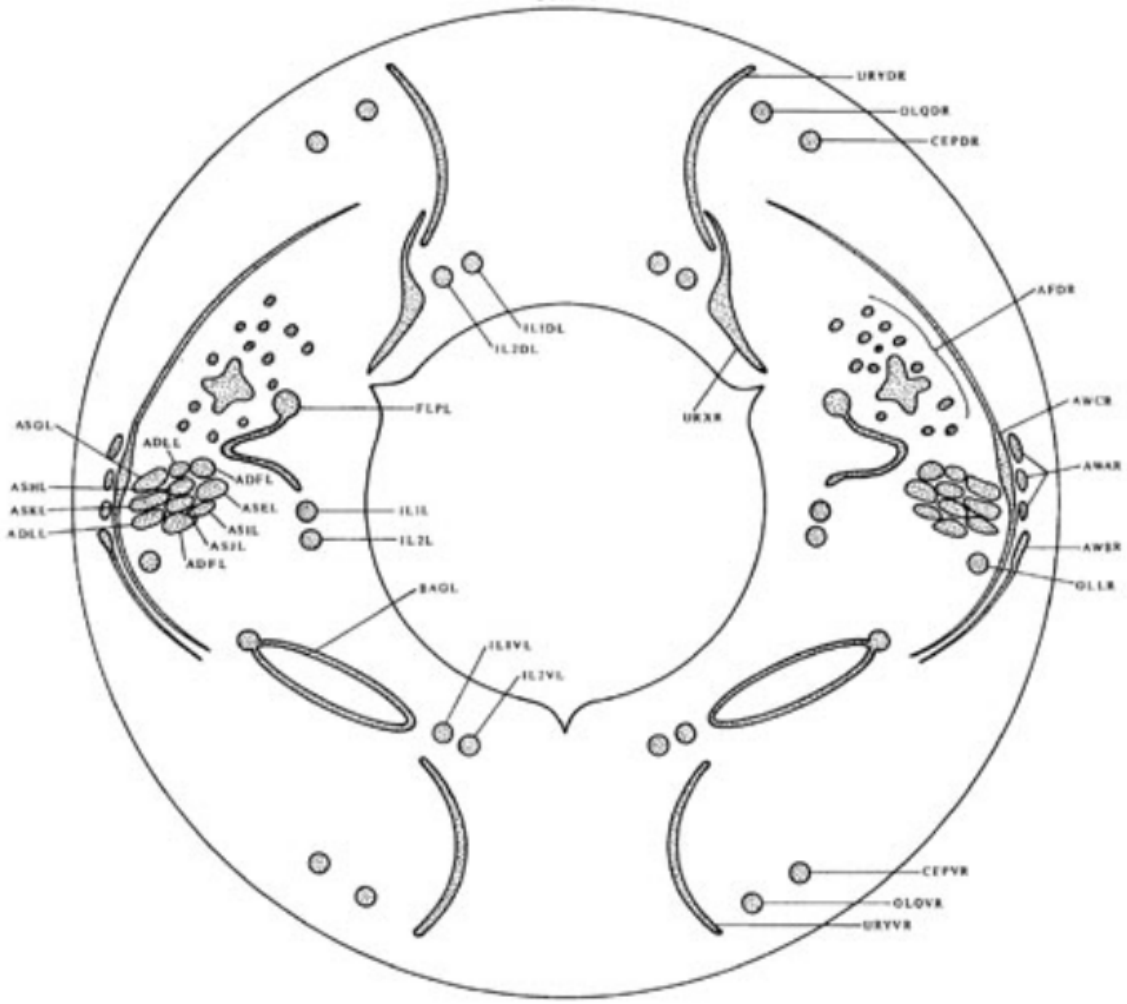


Figure 2: Sensory receptors in a section near the tip of the head.

5 Interneurons

The interneurons in C. elegans are fairly diverse in their general organization, but some classes can be formed based on the neuron with which they interact. Some of the interneurons receive synaptic input predominantly from the neurons of the amphid sensilla, whereas some receives its synaptic input from putative mechanoreceptors. Other interneurons do not show such a restriction in sensory modalities and receive synaptic input from many sources.

The only other striking grouping that is seen in interneurones is of the classes whose synaptic outputs are directed primarily to motoneurons (in the ventral/dorsal cords, or nerve ring). These interneuron classes are among the most prominent neurons in the whole nervous system. They generally have larger-diameter processes than other neurons and have many synaptic connections.

6 Motoneurons

Each of the motoneurons in C. elegans innervates a specific group of muscle cells. This is particularly noticeable in the head region, where there is a fairly precise mapping of motoneurons onto their target muscles. The body-wall muscles can be logically divided into three regions according to the source of innervation: the head region, which receives innervation from motoneurons in the nerve ring, the neck region, which is innervated by motoneurons of the nerve ring and ventral / dorsal cords, and the rest of the body region, which is innervated by motoneurons of the ventral/deorsal cords.

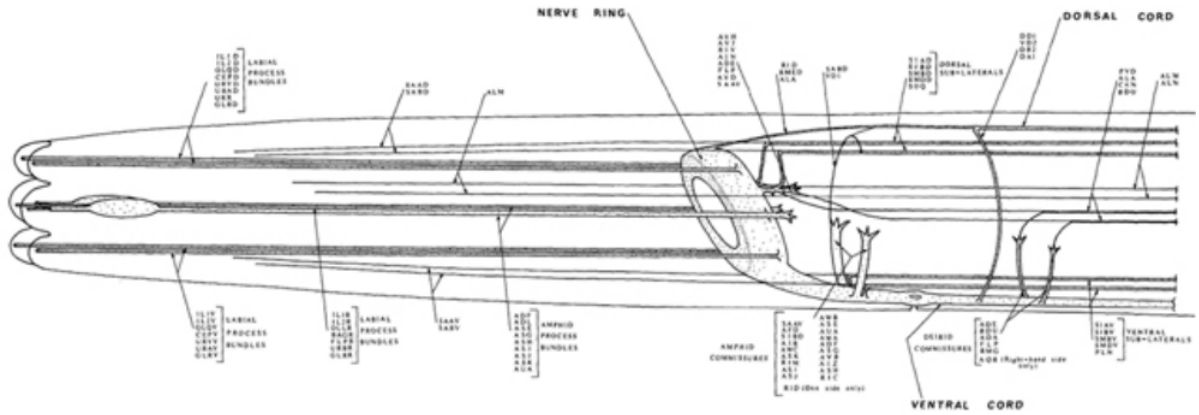


Figure 3: Process tracks in the head.

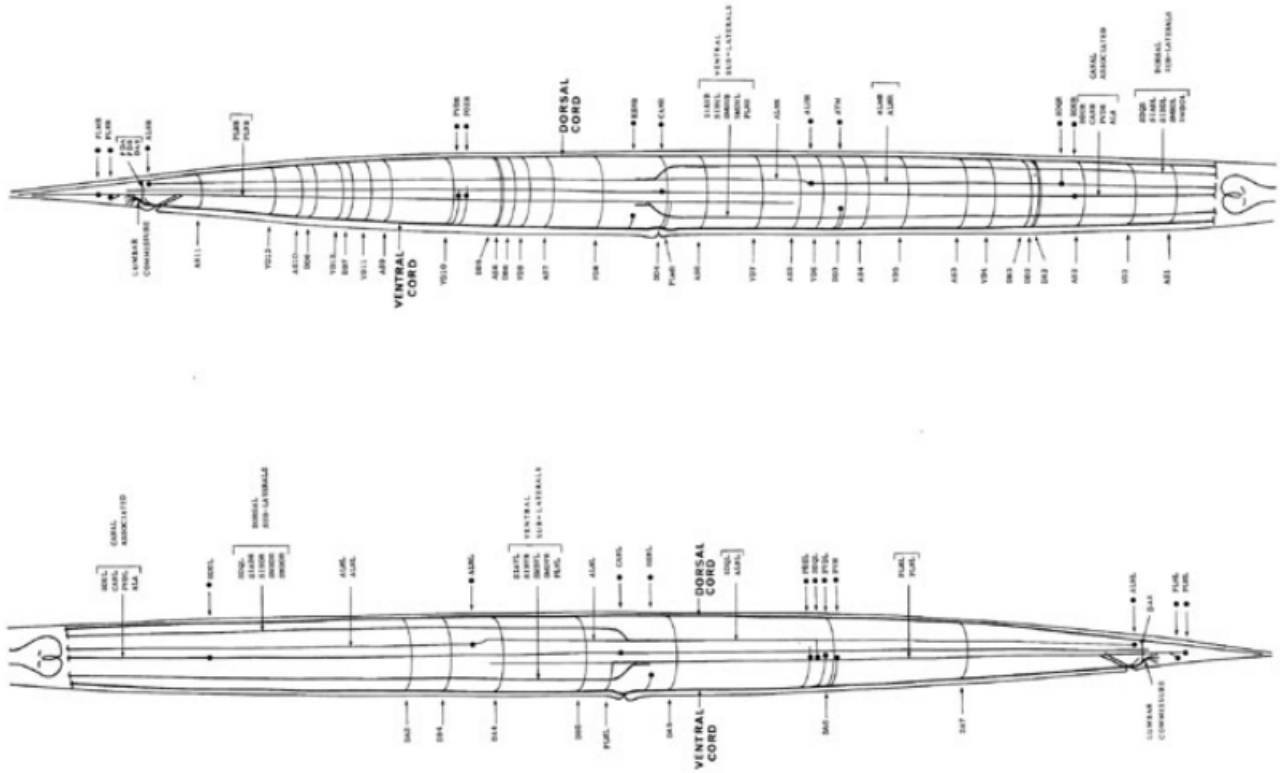


Figure 4: Process tracks in the body. The process bundles in C. elegans are spatially ordered, with processes running in characteristic positions within the bundle and maintaining their locations relative to their immediate neighbours over long distances. This ordering is independent of the size of the process bundle. For example, the four anterior sub-lateral cords, which are made up of only two processes, each have the same relative disposition of processes. On the other hand, the ventral cord near the junction of the nerve ring is made up of about 170 processes;

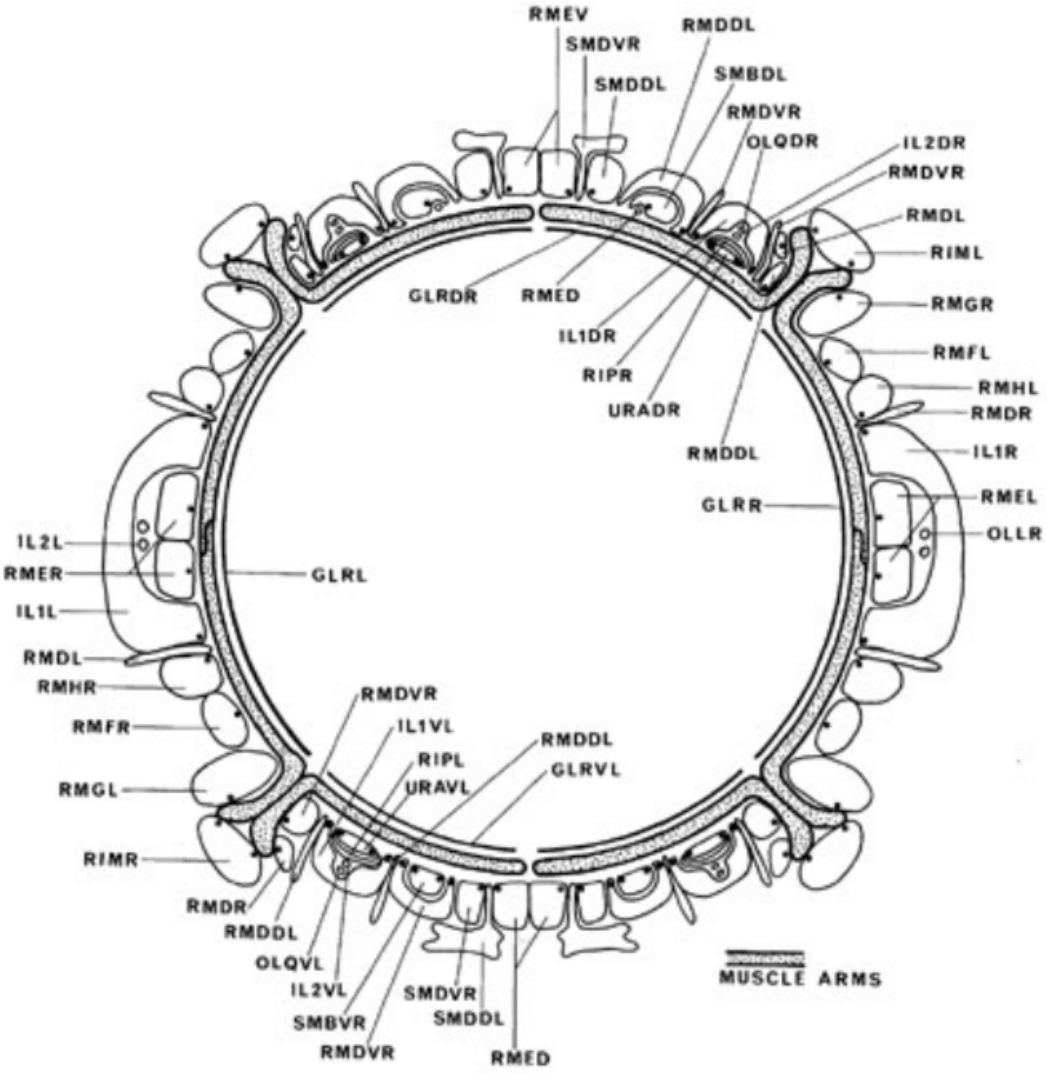


Figure 5: Neuromuscular junction of the nerve ring.

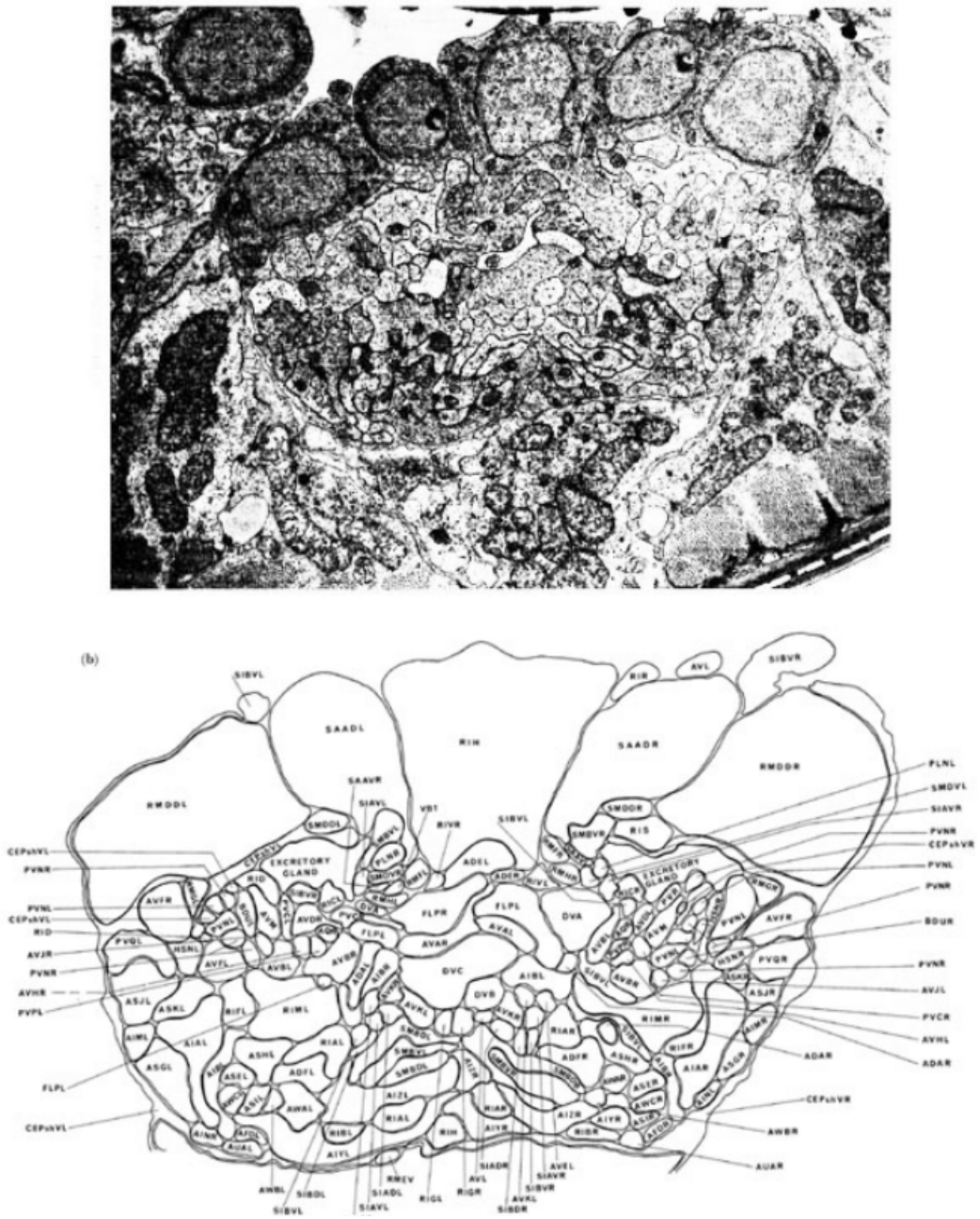
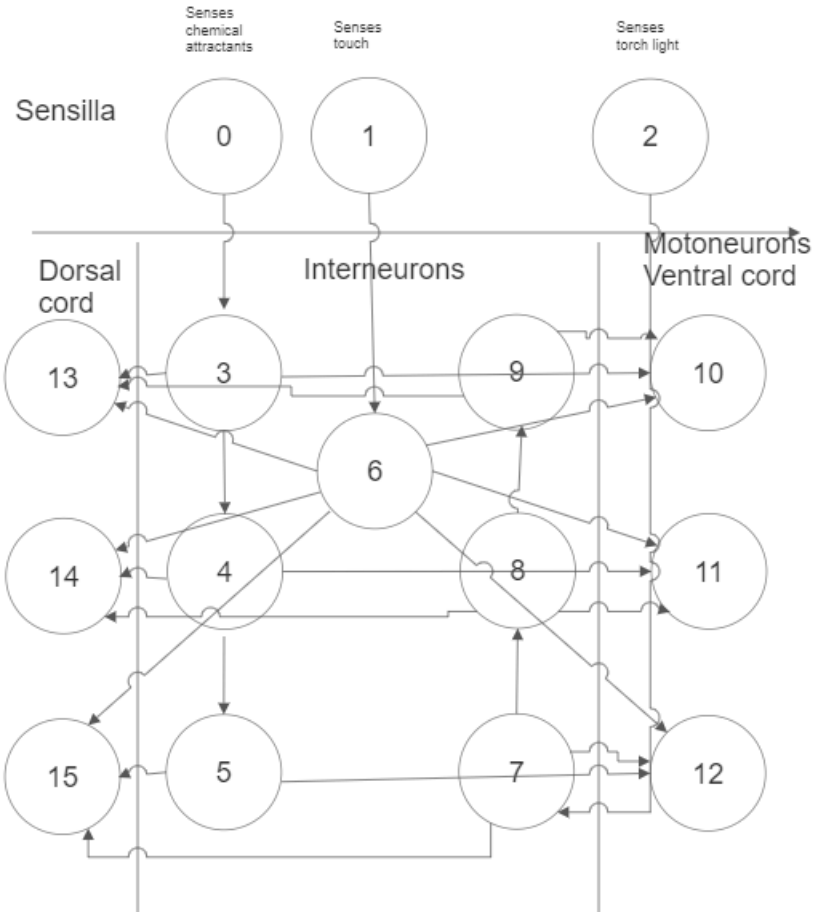


Figure 6: Transverse sections through the anterior regions of the ventral cord.

Part III
Simulation of a C. Elegan

7 Simplified neuron structure



8 Code for simulation

Above neuron structure, consisting of total 16 neurons is implemented using Python and NEURON software.

A process of forward movement is implemented using circuit, that consists of one sensillum (0), three interneurons $(3, 4, 5)$ and six motoneurons $(10, 11, 12, 13, 14, 15)$. Sensory receptor 0 senses chemical attractants, and fires. The electrical charge then get transferred to the cell bodies of interneurons $3, 4, 5$ serially, which are conneced to the ventral and dorsal cords of head, middle and tail regions, which controls the muscles of corresponding regions of the C. Elegan's body. To move forward, first the front portion's ventral muscles contract and simultaneously dorsal muscles expand, then front portion's muscles relax and middle portion's muscles are contracted and expanded, and then the tail portion muscles. As a result of this serial contraction and expansions, the C. Elegan makes sinusoidal forward movement. The serial neuron firings are plotted using matplot library and displayed by the silumation, alongwith an animation of the animal moving forward.

Similarly another process of backward movement is implemented, with a circuit consisting of sensilum 2, interneurons $7, 8, 9$ and ventral cord $(10, 11, 12)$, dorsal cord $(13, 14, 15)$, that can be triggered by throwing torch light to the C. Elegan.

When the head is touched, the C. Elegan senses it using sensory receptor 1, which passes signal to interneuron 6, that in tern passed signal to all six motoneurons simultaneusly. As a result, the C. Elegan shrinks its body. This animation and plotting of neuron firings are also displayed by the program. The C. Elegan also lays egg intermittantly, using interneuron 5 and motoneurons $12, 15$ in its back portion.

9 Demonstration

Demonstration of the animation and plottings will be done during presentation.

References

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