Investigations on the Nervous System of Caenorhabditis elegans

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Introduction – Understanding the working principle of nervous systems of living species has long been a huge source of inspiration in the artificial intelligence (AI) community. In particular, the interpretation of reflexive behavior employing neural circuits. Reflex is considered to be the fundamental reason of many physiological behaviors in physical organs of creatures. High-level synchronization of the neural activities as well as having an understanding of particular physical action, is essential to represent such behavior in the brain. Providing an artificial platform that resembles the brain under which one is able to identify the corresponding working principles of such orchestrating neural activities is an extremely helpful step towards decoding the brainś perception of behavior.

Accordingly, the nervous system of the nematode *Caenorhabditis elegans* (*C. elegans*) is a suitable system to be modeled due to its simplicity as it only has 302 identifiable neurons and a total of approximately 5,000 synapses. *C. elegans* has been in the focus of research for decades investigating its nervous system connectome [1], anatomy and physiology of individual neurons including gene expressions [2]. However, before having the ability of imaging the entire brain, studies on the distributed dynamics of the neural circuits in *C. elegans* has not been fully explored [3]. Moreover, a comprehensive machine learning approach to build up an artificial nervous system together with researching its dynamics is still an open topic to be investigated.

In the present study, we create a platform for precisely looking at the nervous system of the *C. elegans* from a computer science point of view. We divide our research into four subgroups as follows:

Mathematical Model of a Neuron – Dynamics of the membrane potential of a neuron V_m, is defined by the kinetics of the ionic conductance channels together with sum of the input currents stimulating the neuron as follows:

$$\frac{dV_m}{dt} = -\frac{1}{C_m}(I_{Ca} + I_K + I_{SK} + I_{Leak}) + \frac{1}{C_m}\sum(I_{input}),$$

where C_m is the membrane capacitance, I_{Ca}, I_K, I_{SK} and I_{Leak} represent the calcium current, potassium current, calcium-gated potassium channel current and the leakage current, respectively. We design a novel conductance-based neuron model, where dynamics of ion channels are precisely modeled and therefore the model explicitly reproduce the behavior of a biological neuron [4].

Neural circuit implementation – Preliminary, we implement the *Tap Withdrawal* (TW) neural circuit, which controls the reflexive motion of the worm when a mechanical tap is applied to the petri dish in which it swims[5]. Recently, in [6], we performed a novel probabilistic model checking approach in order to estimate the unknown and known parameter-space within the TW circuit. Accordingly, our target is to equip neuroscientists with novel state of the art AI tools which simplify the process of decoding the brain of the worm.

Learning in C. elegans – Kinetics of ionic channels as well as the mechanism of transmission of information among neurons through synapses are proved to be the fundamentals of learning in the *C. elegans* [7, 8]. By utilizing our detailed model, we aim to extract learning algorithms and principles existing within the *C. elegans* nervous system.

Applications for neural circuits – We envision various applications for our neural circuits such as autonomous driving. We utilize a simple neural circuit imitating the TW behavior of *C.elegans* for an autonomous parking algorithm. Eight neurons are used to steer a self-driving vehicle in a given parking spot. Furthermore, we employ a simple artificial neural circuit to control a Pan-Tilt-Zoom camera in order to keep track of a designated object. The circuit takes the distance to the object as an input and keeps the object in the center. We aim to extend the circuits to incorporate feedback information allowing it to adapt its own synaptic connections similar to mechanisms used in equivalent biological neural networks.

References

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