Modeling a Simple Non-Associative Learning Mechanism in the Brain of *Caenorhabditis elegans*

Ramin M. Hasani [1], Magdalena Fuchs [1], Victoria Beneder [2], and Radu Grosu [1]
[1] Institute of Computer Engineering, Vienna University of Technology, Austria
[2] University of Natural Resources and Life Sciences, Vienna, Austria

Abstract

In this study, we computationally discuss biophysical dynamics that induce a simple from of non-associative learning in *Caenorhabditis elegans* (*C. elegans*), when the worm is exposed to periodic touch/tap stimuli. We mathematically model mechanosensory habituation in two paradigms of neuronal habituation and synaptic plasticity and support our hypotheses by comparing our results with real habituated responses.

Learning the Learning Mechanism

The simplest type of non-associative learning exhibited by *C. elegans*, is habituation. It is defined as the decrease of the reflexive response of the worm, in the presence of repetitive exposure to a particular kind of stimulus. Despite its simplicity, habituation involves several identified processes. In the present study, we investigate biophysical mechanisms underlying habituation within the nervous system of *C. elegans*. The worm, at first, seemed to be a hardwired model organism that can simply crawl forward and backward. Later, it proved otherwise by illustrating fascinating behavioral plasticity. Evidence of expressing well-founded non-associative and associative learning behaviors has been observed in *C. elegans* [Ardiel and Rankin, 2010]. It is highly responsive to experience. This indicates that learning can be mediated from every sensory modality.

We perform simulated physiological analysis on neurons and synapses, to explore non-associative learning principles originated from autonomous gene modifications, dynamics of ion channels, and variation of neurotransmitters concentrations. Accordingly, we hypothesize the computational origins of such class of learning within two paradigms of neuronal habituation and synaptic plasticity.

Within the neuronal habituation framework, we model and predict the neurophysiological elements that induce habituation. We simulate the effects of auto-phosphorylation of protein subunits, KHT-1-MPS-1, of a voltage-gated K^+ channel, on the gradual reduction of the calcium concentration, in the sensory neuron, during habituation. Correspondingly, we determine essential biophysical dynamics for imitating habituated response of a touch neuron and compare the modeled response to that of real sensory traces.

Such short-term memory behavior is quantitatively expressed in the sensory neurons. By applying repetitive input stimulus, the state of an input neuron can be modified through some key mechanisms such as K^+ flux reduction, inactivation of Ca^{2+} channel and increase of the Ca^{2+} conductivity. This results in a local short-term memory (habituation).

Habituation is also controlled by changes in the neurophysiological properties of chemical synapses. Within the synaptic plasticity framework, we show that synaptic depression results in a habituated response for an interneuron. A dynamic synapse model can act as a short-term memory initiator (habituation), through control of the amount of available neurotransmitters at the presynaptic terminal. It can also function as a forget gate (dishabituation), by synaptic release recovery.

Overall, we summarize our work into two key statements as follows:

Key finding 1: The state of the activation of a sensory (input) neuron can be modified in the presence of repeatedly induced stimulus, by means of an intrinsic parameter which is dynamically altered, as a function of time, input amplitude and its frequency.

Key finding 2: Synapses with an internal state can autonomously modify the behavior of the system. Synapses can presumably be involved in completion of a habituation process, dishabituation process and propagation of a neuronal habituation to the rest of the neural circuit.

Final Notes

Learning is an essential attribute for survival. *C. elegans* expressed optimal adaptive behavior to numerous environmental circumstances, for survival. Learning how the animal learns and adapts not only is a notable step forward towards decoding the brain's working principles, but can also lead us to the development of better learning algorithms. For the future work, we aim to construct bio-inspired learning algorithms for producing simple behaviors such as habituation, based on our key findings discussed here.

References

[Ardiel and Rankin, 2010] Evan L Ardiel and Catharine H Rankin. An elegant mind: learning and memory in caenorhabditis elegans. *Learning & Memory*, 17(4):191–201, 2010.