

Axonal Delay Learning: from biology to computational neuroscience

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Computational neuroscience aims to model the biological reality of brain behaviour using computer science tools. In particular, one branch of this research field has specialised towards bio-inspired artificial intelligence, which comprises Spiking Neural Network (SNN). A spiking neuron mimics the dynamics of biological neuronal circuits by receiving, processing and sending information in the form of spike trains [1]. A SNN is constructed using populations of neurons linked together with connections, with respect to a certain architecture and certain rules allowing it to learn a behaviour. These rules often concern the evolution of the synaptic weight between two pre- and post-synaptic neurons, i.e. the amount of neurotransmitters released in the synapse following the pre-synaptic neuron's excitation.

Delay learning is another of those learning rules which, instead of changing the synaptic weight, changes the delay of the electrical spike journey in the pre-synaptic neuron's axon [2].

First biological observations

The first evidence of any neuronal delay in the information propagation within the animal brain came from the interaural time difference, allowing for the azimuthal localization of sound by barn owls. According to Gerstner in 1996, there is a true paradox in auditory neural systems since “neural networks encode behaviourally relevant signals in the range of a few μs with neurons that are at least one order of magnitude slower” [3]. Various biological experiments have thus revealed the existence of a biological axonal delay precisely adjusted according to variations of parameters in the brainstem.

The importance of myelination

Over and over, myelin has been identified as one of the parameters mentioned above. Indeed, this multilaminar coating formed by the glial cells in the Vertebrates' nervous system facilitates both the neural circuit function and the behavioural performance [4]. Experiments on mammals show that myelination is directly related to learning and memory consolidation, both at an early age and in older animals, due to its involvement in coupling the activity of distant neuron populations.

Some computational approaches

Delay learning is a striking example of a computer science concept effectively reinforced by ongoing neuroscience work. Indeed, more and more SNN models are being developed with an impetus to learn by updating delays, not just synaptic weights. One convincing instance among many is given by [1], which combines delay adaptation and polychronization for reservoir computing; or more recently by [5], which proposes an STDP extended to the delay learning repeating spatio-temporal patterns. We likewise aim to implement such a delay learning applied to motion detection, notably by drawing on neurological knowledge in order to approach biological efficiency.

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