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Models of plasticity and learning employing adaptive temporal delays

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Abstract:
Temporal precision required in neural system processing can range from the sub-millisecond in sound localization and echolocation, to milliseconds and hundreds of milliseconds in perceptual and motor processing tasks. At a level of signal conduction through axons between individual neurons, the arrival time of action potentials from different neurons requires millisecond precision. It has been proposed that to achieve such precise timing, adaptive regulation of these temporal delays is required. Dynamic modulation of myelination potentially provides one mechanism to control impulse arrival times. However, the focus here is on general consequences of having adaptive time delays, rather than on the precise biological mechanism. We divide “delay plasticity” models into two groups based on the feedback mechanism they utilize. The first is activity-dependent delay plasticity (ADDP), in which the learning rule modifies the time delays based on the locally observed activity level; the second is temporal-mismatch delay plasticity (TMDP). These two learning paradigms were implemented using a framework of delay coupled non-linear oscillators and spiking neural networks with adaptive delays (where TMDP becomes spike-timing-dependent delay plasticity (STDDP)). In both these models we compare and contrast the roles played by synaptic and delay plasticity. We show how a simple local ADDP rule stabilizes a system of coupled oscillators and extend this finding to the case of spiking neural networks. The STDDP is studied in the context of temporal sequence learning. Traditionally, sequence learning has been modeled in terms of specialized neural network architectures implementing tapped delay lines, temporal sequence selection through the mechanisms of spike-timing-dependent plasticity (STDP), or through synaptic triads, and other mechanisms utilizing synaptic plasticity. In this work we introduce a simple feed-forward neural network for sequence learning that utilizes both STDP and STDDP as an effective model for comparing the two plasticity modes. Both detect a mismatch locally at the synapse, but the latter additionally requires retrograde transport, which is inherently slower. We argue that implementing both plasticity mechanisms is needed to provide an optimal trade-off between the speed on one hand, and the efficiency and precision on the other. Our results indicate that the delay plasticity, such as myelin plasticity, is a highly efficient way to make a system stable and learn temporally precise tasks efficiently.
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