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Spike-timing-dependent plasticity and temporal input statistics

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A lot of research has recently focused on possible functional interpretations of the peculiar dependence of synaptic plasticity on the relative timing of pre- and post-synaptic spikes. Here we use a linear Poisson neuron to analytically examine how the temporal statistics of the input signals influence the distribution of the synaptic weights. The analysis shows that the outcome of learning is not determined by the shape of the learning window alone, but rather by the convolution of the learning window with the shape of the excitatory post-synaptic potential (EPSP), subsequently referred to as the effective learning window. This indicates that very different learning windows may have the same functional role depending on the shape of the EPSP. Moreover, it offers a new interpretation of the commonly observed asymmetry of the learning window of spike-timing-dependent plasticity (STDP) as a mechanism for inverting neuronal low-pass filtering as invoked by the EPSP.

For reversible input statistics, the learning rule shows a preference for certain frequency ranges in the input signals. If the symmetric component of the effective learning window has the form of a low-pass filter, STDP focuses on low-frequency components of the input signals, i.e., components that vary slowly relative to intrinsic time scales given by the learning window and the EPSP. This is in line with several learning paradigms that have been proposed as mechanisms for learning invariant sensory representations and for the self-organized formation of visual receptive fields. Moreover, in case the EPSP is short, the effective learning window acts as a band pass filter, leading to the speculation that there could be a connection between cortical rhythms and STDP learning.

Interestingly, it turns out that irreversible input statistics, e.g., causal dependencies between the input signals, tend to destabilize the weight distribution and favor oscillating weights. This observation challenges the interpretation of the asymmetric learning window as a causality detector.