Metaplasticity – Integral Part of Plasticity?

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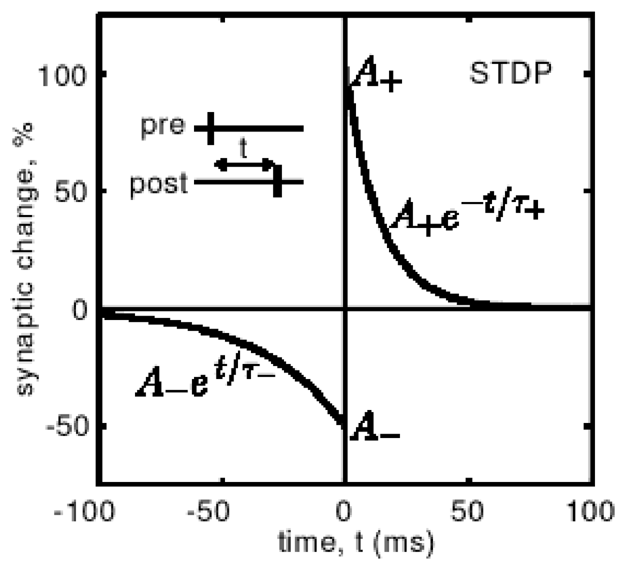
Background

Original STDP rule:

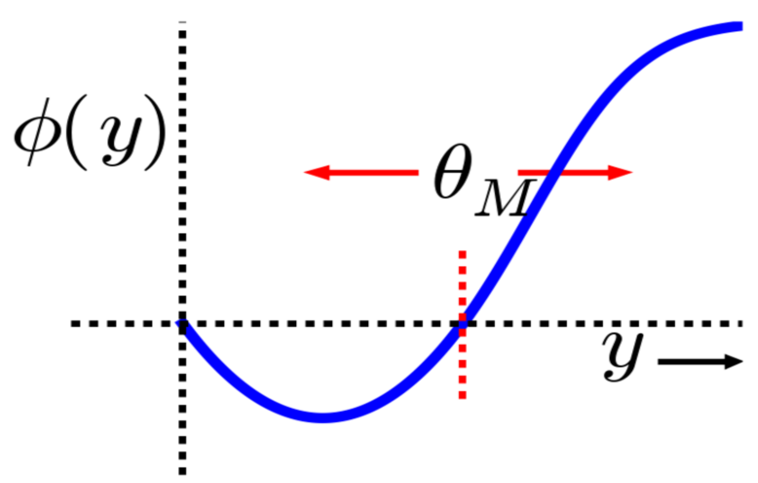
$\Delta w_+(\Delta t) = A_+ \exp(-\Delta t / \tau_+)$ if $\Delta t > 0$
$\Delta w_-(\Delta t) = A_- \exp(\Delta t / \tau_-)$ if $\Delta t < 0$



STDP alone may not be sufficient to describe all forms of synaptic plasticity. Some form of metaplasticity may result in a more accurate description.

Original metaplasticity rule introduced by Bienenstock, Cooper and Munro (the BCM theory):

$y = \sum_i w_i x_i$
$dw_i/dt = \eta\, y(y - \theta_M)x_i - \varepsilon w_i$
$\theta_M = \theta_0\, E^P[(y)]$



The goal

In this simulation, various implementations of STDP and BCM are tested using the Izhikevich spiking neuron model:

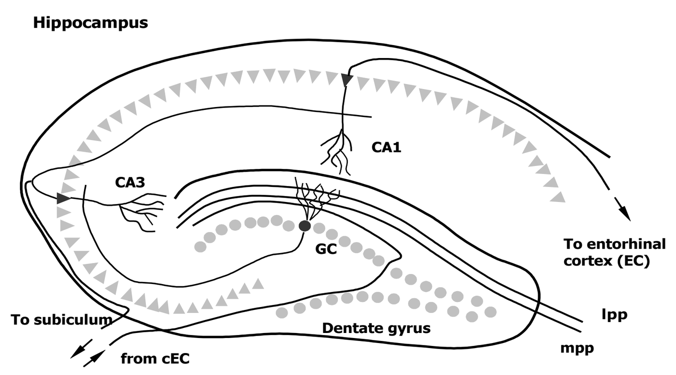
$v' = 0.04v^2 + 5v + 140 - u + I$
$u' = a(bv - u)$

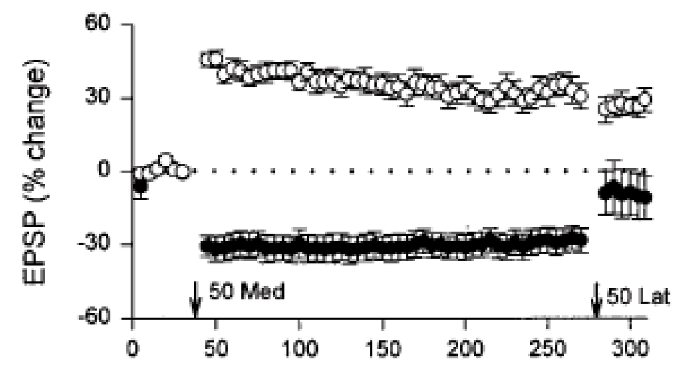
If $v \geq 55$mV then $v \leftarrow c$ and $u \leftarrow u + d$

a, b, c, d are parameters that are set based on cell type.

Benchmark: Benuskova & Abraham (2007)

As a benchmark rule, we use the STDP rule endowed with metaplasticity from Benuskova & Abraham (2007) – this properly reproduces behaviours shown in rat dentate gyrus granule cells. Experimental data shows both homosynaptic LTP and heterosynaptic LTD when HFS is applied to one of the inputs, i.e. MPP.

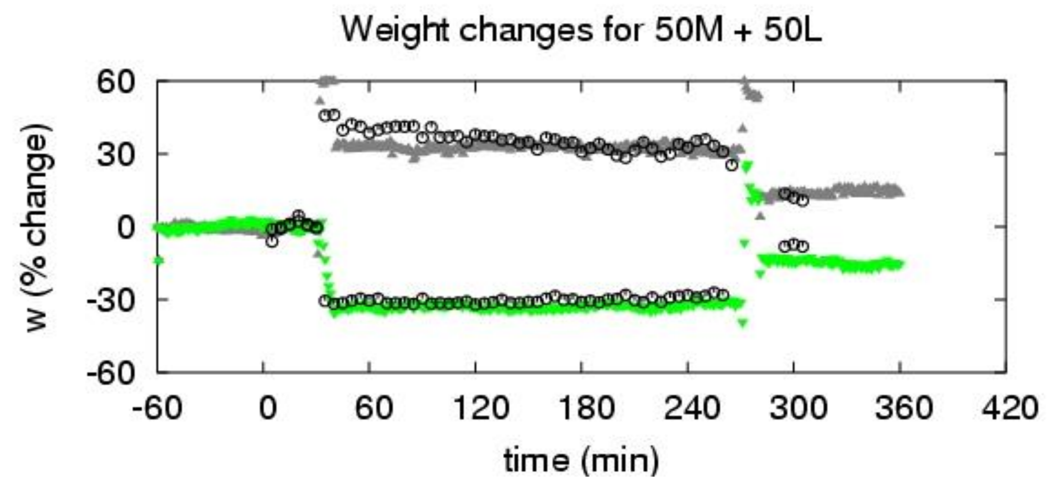




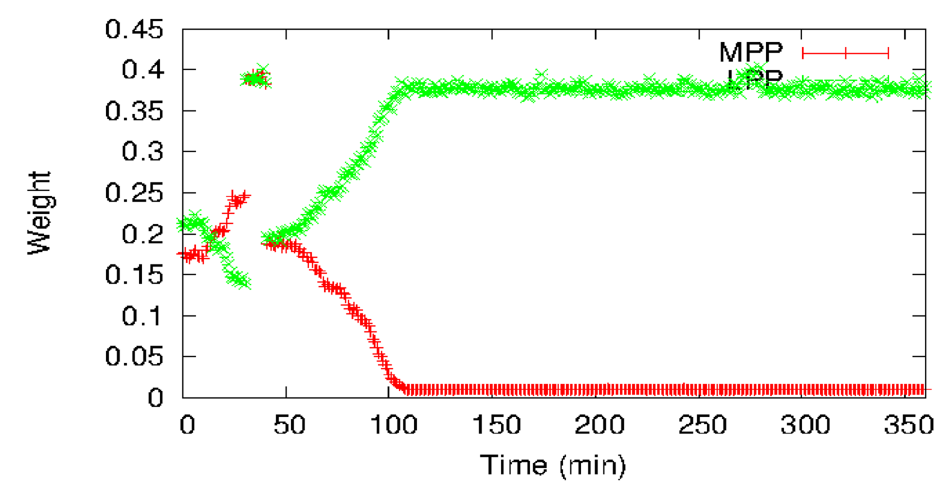
The Benuskova & Abraham STDP rule with BCM-like metaplasticity, i.e.

$A_+(t) = A_+(0)\,(1 / \langle c(t)\rangle_\tau)$
$A_-(t) = A_-(0)\,\langle c(t)\rangle_\tau$

(where <c(t)> is the average of the past postsynaptic activity) is in concordance with data:

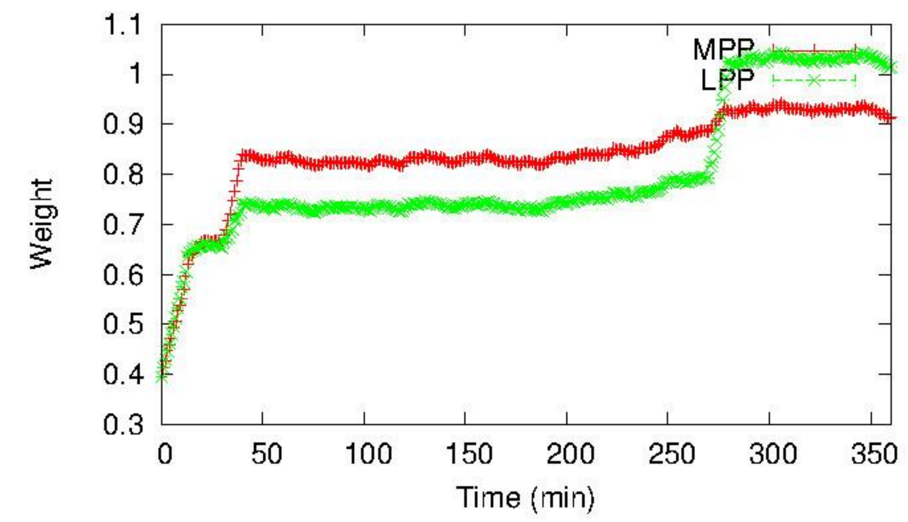


Naive STDP on its own without the BCM-like metaplasticity implementation was tried, but completely failed at reproducing the experimental data for any parameter choice, instead the weights always tend towards "stable" min and max values:

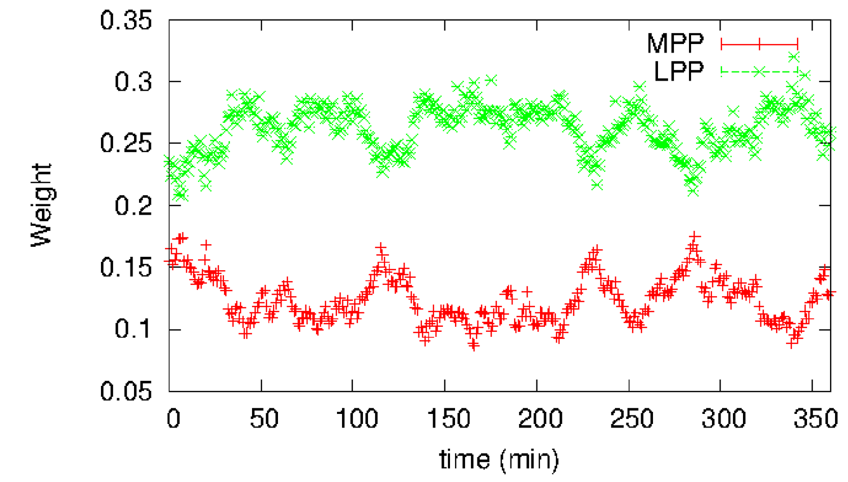


Only rules with metaplasticity properly repoduce experiment

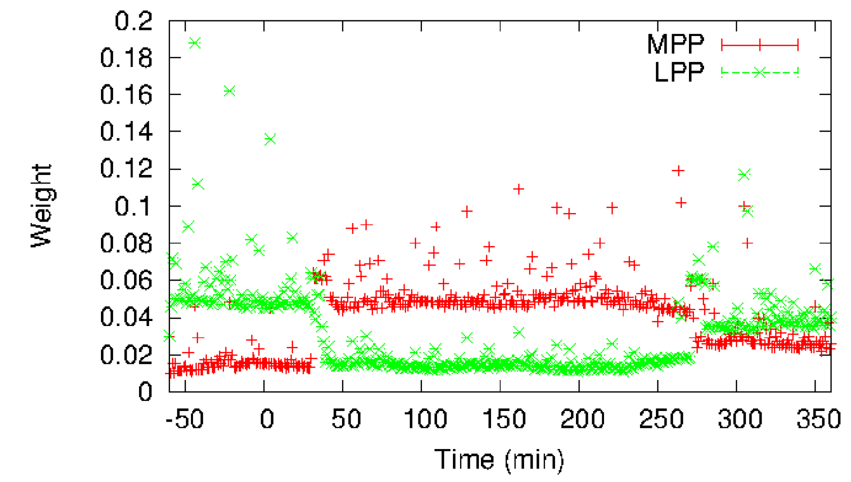
Froemke rule [Froemke et al., 2006] has metaplasticity of sorts in its "suppression" mechanism. However, it doesn't reproduce the data properly, only showing LTP:



Pfister rule [Pfister & Gerstner, 2006] deals with triplets rather than pairs of spikes, but has no metaplasticity built in. This rule failed to match the data:



Modified Pfister rule using the sliding window BCM from Benuskova & Abraham is in much closer agreement with data:



Clopath rule [Clopath et al., 2010] has built-in metaplasticity, so no modification was needed to get concordance with data: