

# Learning and Plasticity

Plasticity in neuronal circuits means the ability for connections to change and remain changed.

## Hebbian Plasticity

Hebb's Postulate (from the "Organization of Behaviour", 1949):

*When an axon of cell A is near enough to excite cell B or repeatedly or consistently takes part in firing it, some growth or metabolic change takes place in one or both cells such that A's efficiency, as one of the cells in firing B, is increased.*

Sometimes summarized as "cells that fire together wire together."

Rate-based models: change in synaptic strength,  $W_{ij}$  from neuron  $i$  to  $j$  is dependent on the correlation between the two rates  $\langle r_i r_j \rangle$ .

Note this can be an unstable rule (synaptic strengths could strengthen endlessly, so normalization of some sort is required to maintain competition.)

For example a covariance based rule:

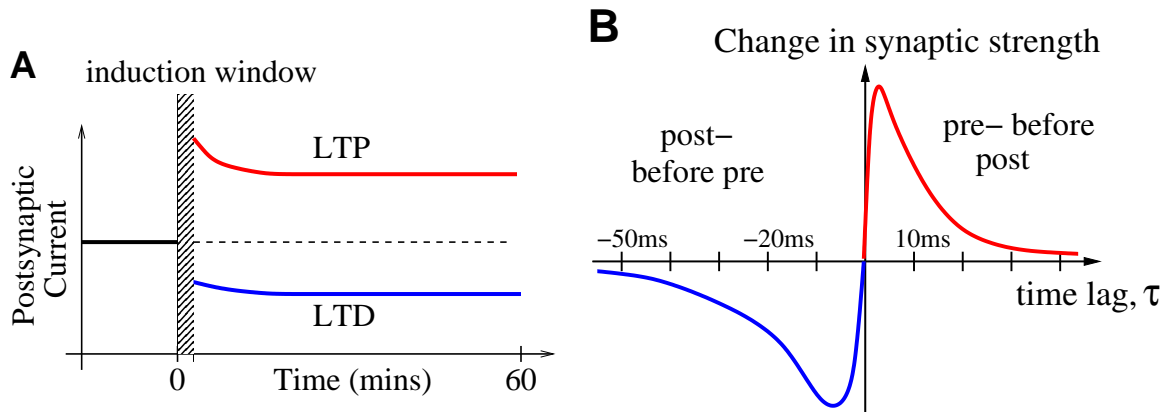
$$\frac{dW_{ij}}{dt} = \epsilon r_i(t) [r_j(t) - \langle r_j \rangle] \quad (1)$$

where  $\epsilon$  is a small quantity that determines how rapidly synaptic strengths can change, allows depression as well as potentiation of the synapse. If the postsynaptic neuron ( $j$ ) has a low firing rate compared to its long-term average, while the presynaptic neuron ( $i$ ) fires a lot, this rule decreases  $W_{ij}$ . Conversely if the rates are high together, the rule increases  $W_{ij}$ .

Limits should be enforced, so that  $0 \leq W_{ij} \leq W_{max}$ .

Note that these rate-based rules are symmetric, since the correlation is between the rate of the two neurons at the same time. In this sense these rules do not distinguish between causality of firing ( $i$  causes  $j$  to fire or  $j$  causes  $i$  to fire).

## Temporally Asymmetric Plasticity and Spike-Timing Dependent Plasticity (STDP)



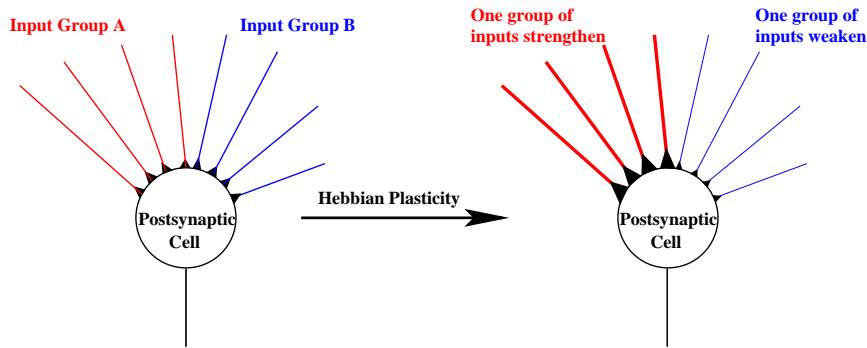
**A** Depending on the protocol, an increase in synaptic strength (long-term potentiation = LTP) or a decrease in synaptic strength (long-term depression = LTD) can be induced. In general a large increase in postsynaptic calcium leads to LTP. A small increase in postsynaptic calcium leads to LTD.

**B** By experimentally inducing pairs of spikes in individual, connected cells, the relative timing of pre- versus post-synaptic spikes can cause depression or potentiation (see review by Bi and Poo). Note that Hebb's hypothesis suggests a causality, so pre before post leads to potentiation in accordance with neuron  $i$  helping cause a spike in neuron  $j$ .

### Segregation of Inputs (cf Ocular Dominance).

Inputs that have correlations between their spikes are more likely to induce a postsynaptic spike than uncorrelated inputs.

Similarly, as some connections strengthen, other connections that have correlated spike times are more likely to strengthen, and connections with less correlation are more likely to weaken. Over time this leads to a strengthening of inputs that correspond to a particular correlated group. The group that "wins" will typically be a mixture of chance and initial bias.



### Sequence Learning (cf Blum and Abbott 1996)

If one cell regularly gets inputs before another cell, such as occurs for place cells on a regular route, then connections from the first cell to the second cell will strengthen. Eventually, firing of the first cell can lead to firing of the second cell. If this occurs for a number of cells in a sequence, the firing of the first cell can eventually lead to a replay of the complete sequence.

