Anti-Hebbian learning with Hebbian spike timing dependent plasticity.

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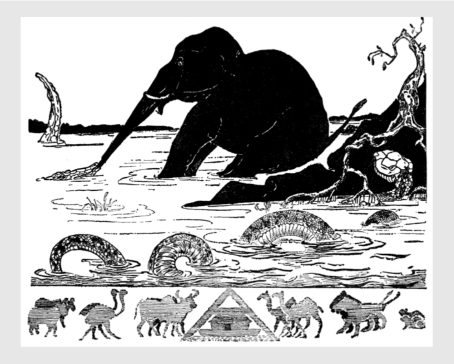
CS, U Bristol

Neuroplasticity, July 2018

Just So



How the Elephant Got His Trunk.

https://en.wikipedia.org/wiki/Just_So_Stories

Hebb's rule

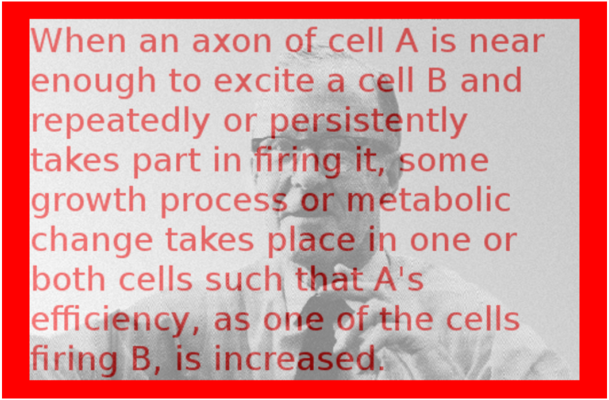
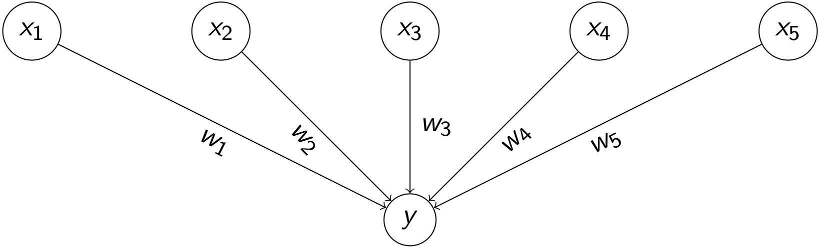


Photo from `http://www.cambridgemedicine.org/node/81`

Plasticity in AI - perceptron

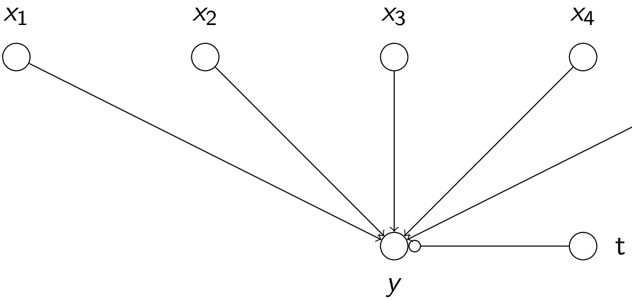
'the embryo of an electronic computer that [the Navy] expects will be able to walk, talk, see, write, reproduce itself and be conscious of its existence.'(*)



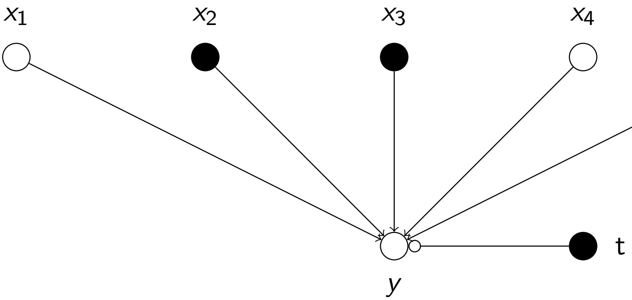
$$\Delta w_i = \eta x_i (t - y)$$

(*) Frank Rosenblatt

Plasticity in AI - perceptron - naïve



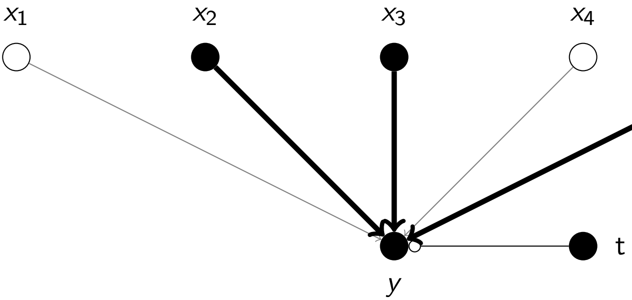
Plasticity in AI - perceptron - training



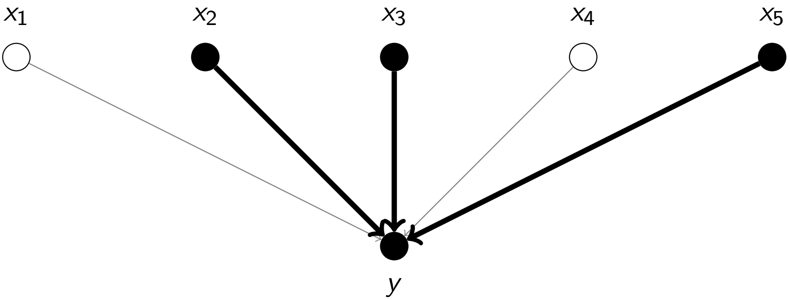
Plasticity in AI - perceptron - training

$$\Delta w_i = \eta x_i (t - y)$$

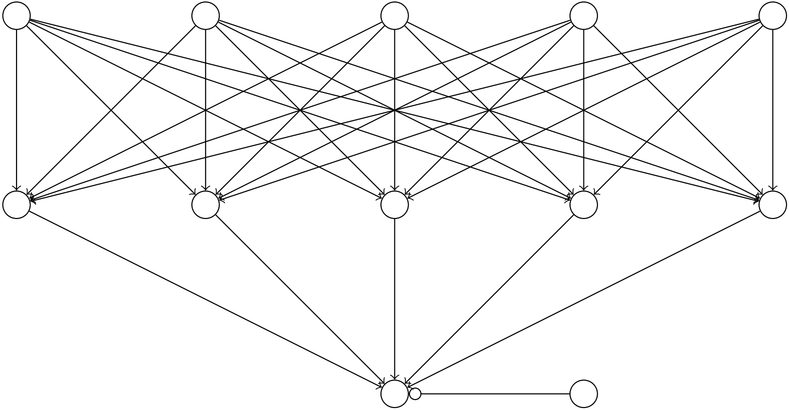
Plasticity in AI - perceptron - trained



Plasticity in AI - perceptron - recognition



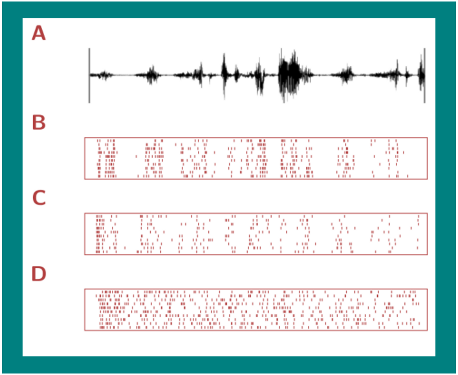
Plasticity in AI - back propagation



This is not Hebbian plasticity!

$$\Delta w_i = \eta x_i (t - y)$$

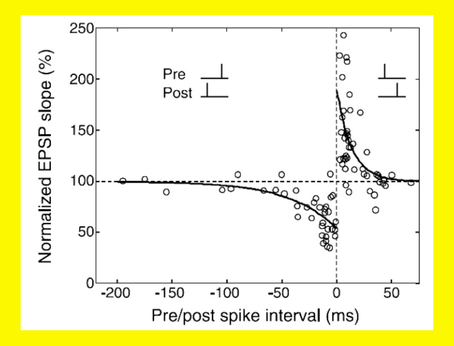
Also neurons have spikes!



Spikes from neurons in the auditory forebrain of zebra finch

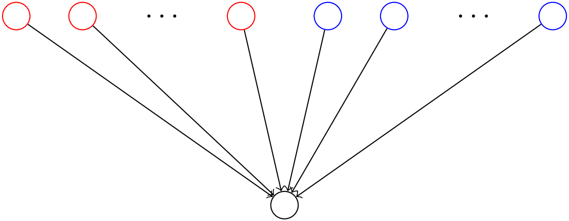
Data from Kamal Sen, picture from Houghton and Victor (2012)

Spike timing dependent plasticity



Bi and Poo 1998

STDP - learning correlations



Song and Abbott (2000)

STDP - correlations

$$x_i = 10(1 + 0.3\xi_i + 0.3\zeta)$$

with ξ_i and ζ both from $\mathcal{N}(0,1)$ with inputs constant on intervals drawn from an exponential distribution with mean 20 ms.

Song and Abbott (2000)

STDP - details

$$\tau_+ \frac{dx_i}{dt} = -x_i + \sum \delta(t - t_i^f)$$

and

$$\tau_- \frac{dy}{dt} = -y + \sum \delta(t - t^n)$$

with

$$\frac{dw_i}{dt} = \eta_+ x_i(t) \sum_n \delta(t - t^n) - \eta_- y(t) \sum_f \delta(t - t_i^f)$$

and hard lower and upper bounds on w_i:

$$0 \leq w_i \leq w^{max}$$

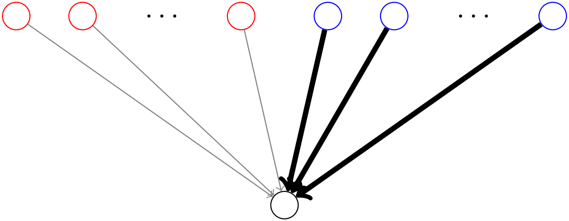
Song and Abbott (2000)

STDP - more down than up

$$B = \frac{\eta_- \tau_-}{\eta_+ \tau_+} = 1.05$$

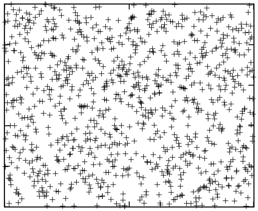
Song and Abbott (2000)

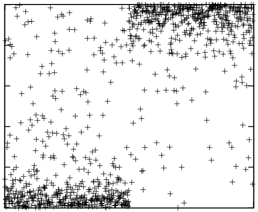
STDP - correlations learned 1



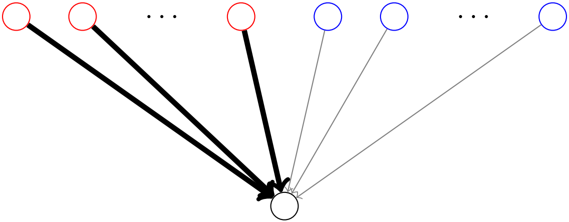
Song and Abbott (2000)

STDP - correlations and synapses





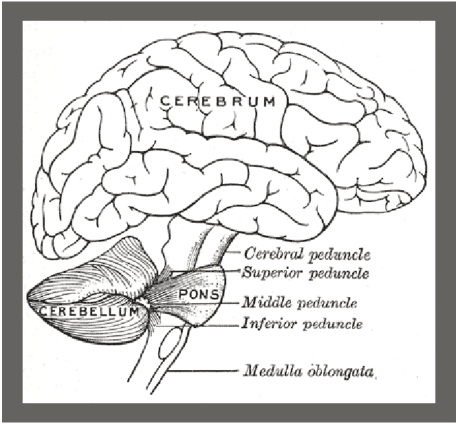
STDP - correlations learned 2



Song and Abbott (2000)

ALWAYS
THE
CORTEX

Cerebellum



Gray's *Anatomy* (1918)

Cerebellum - function - historical view

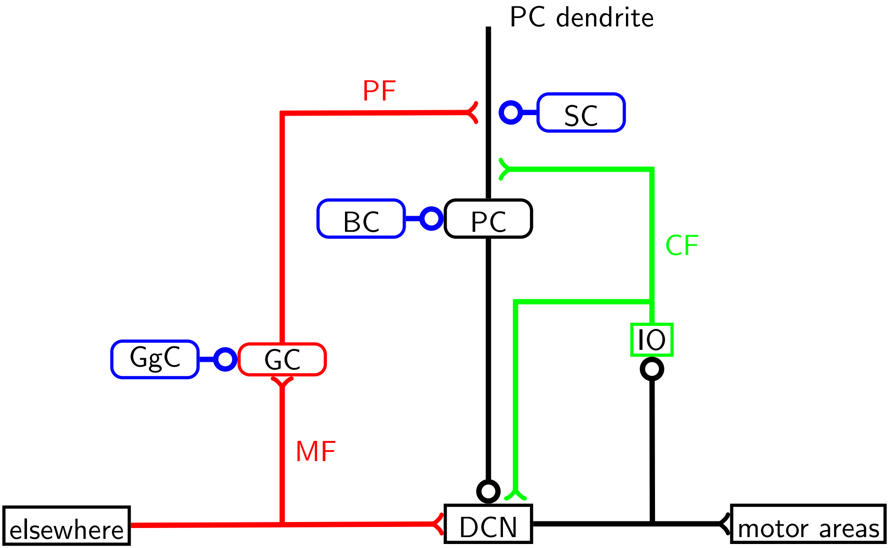
‘Dr Gall was led to the discovery of the function of this organ in the following manner. He was physician to a widow of irreproachable character, who was seized with nervous affections, to which succeeded severe nymphomania. In the violence of a paroxysm, he supported her head, and was struck with the great size and heat of the neck. She stated, that heat and tension of these parts always preceded a paroxysm. He followed out, by numerous observations, the idea, suggested by this occurrence, of connexion between the amative propensity and the cerebellum, and he soon established the point to his own satisfaction.’

George Combe's *A System of Phrenology* (1853)

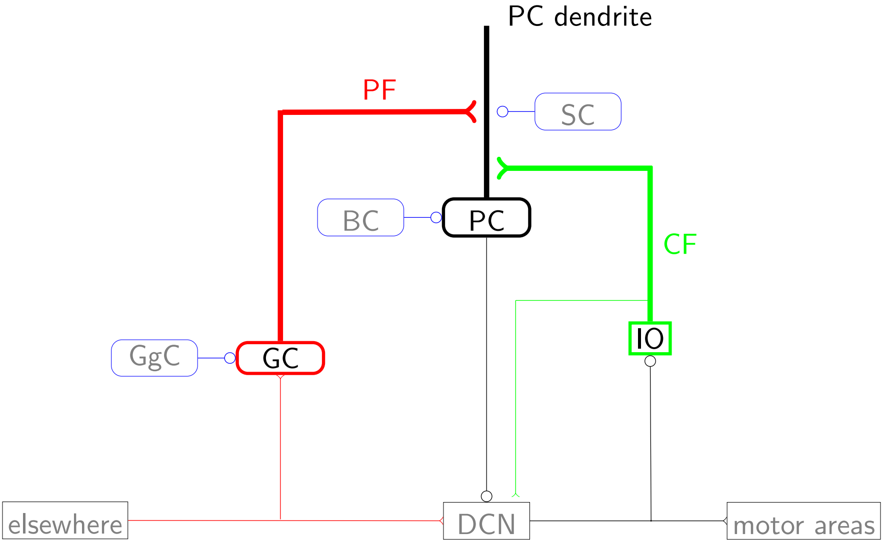
Cerebellum - function

Cerebellar Functions by André Thomas (1912)

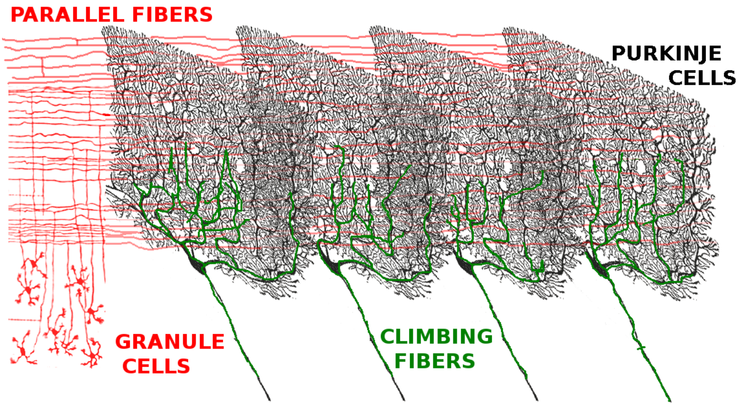
Cerebellar cortex - circuit



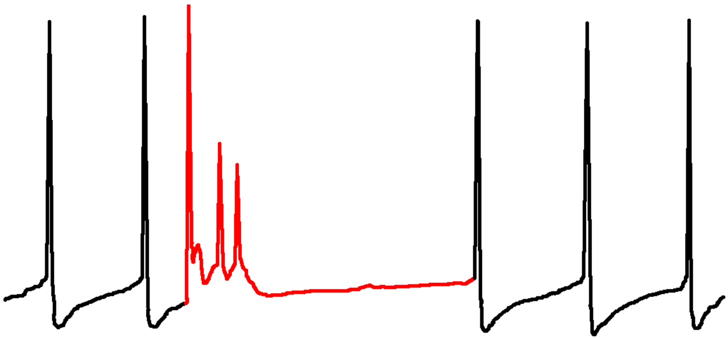
Cerebellar cortex - circuit



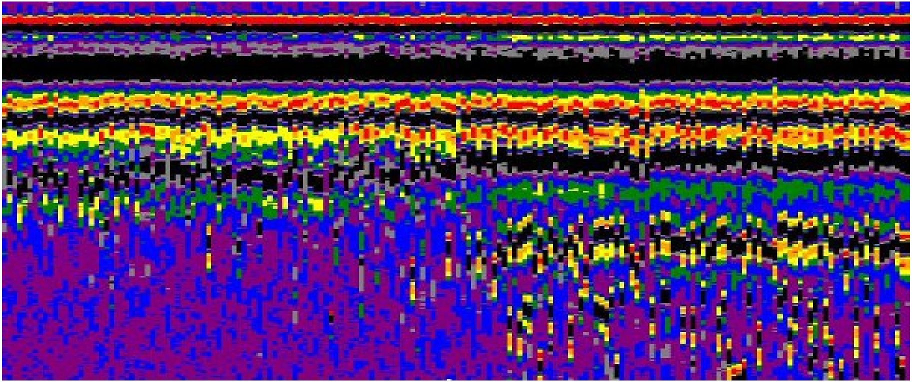
Cerebellar cortex - form



Complex spike



Optogram

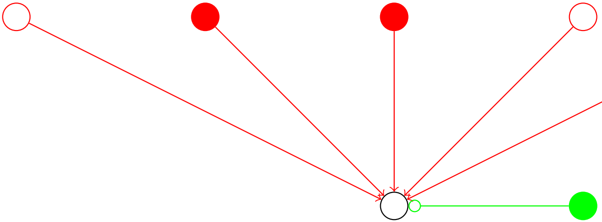


By Amelia Burroughs

http://www.bristol.ac.uk/neural-dynamics/programme-details/gallery

Cerebellar cortex as a perceptron

This viewpoint can be traced back to David Marr.



Cerebellar cortex as a perceptron

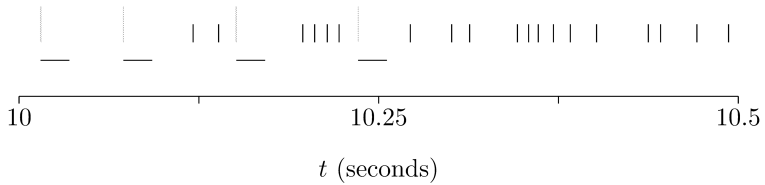
How does the complex spike supervise the learning?

- Special calcium dependent learning rules.

or

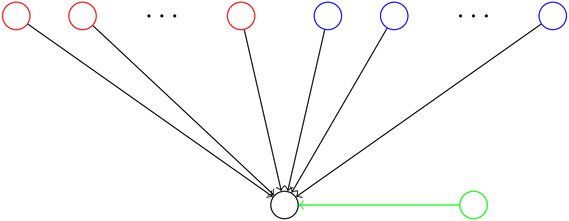
- IDEA: normal STDP but with the pauses causing depression of acausal spikes!

Pauses



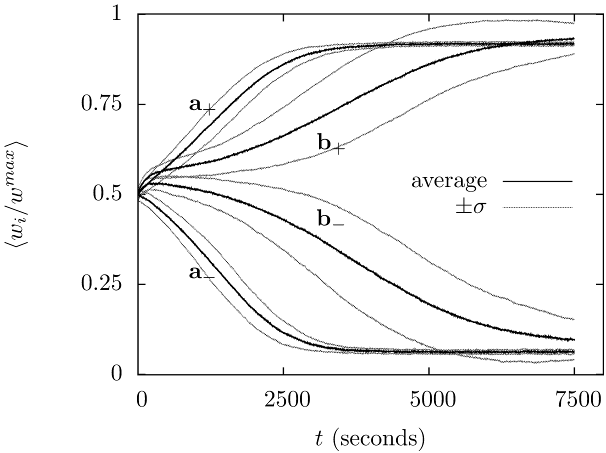
Houghton (PLoS ONE, 2014)

STDP - supervized learning



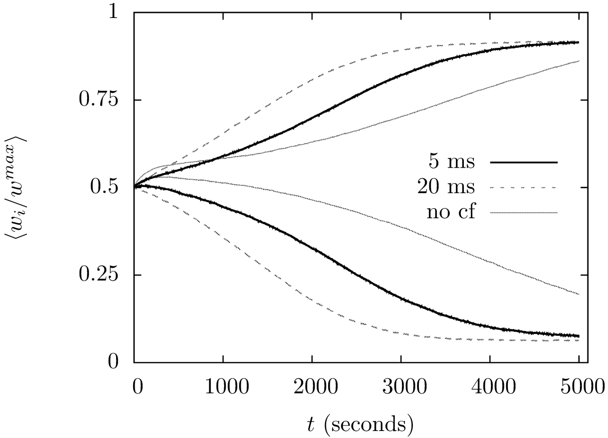
Houghton (PLoS ONE 2014)

It works!



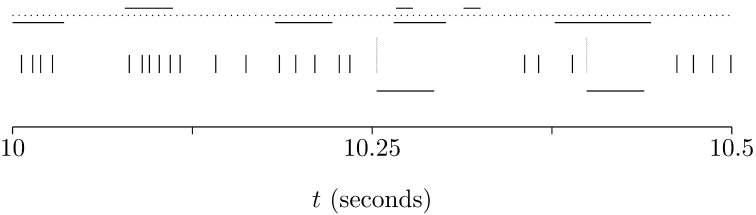
Houghton (PLoS ONE 2014)

It isn't super sensitive to parameters!



Houghton (PLoS ONE 2014)

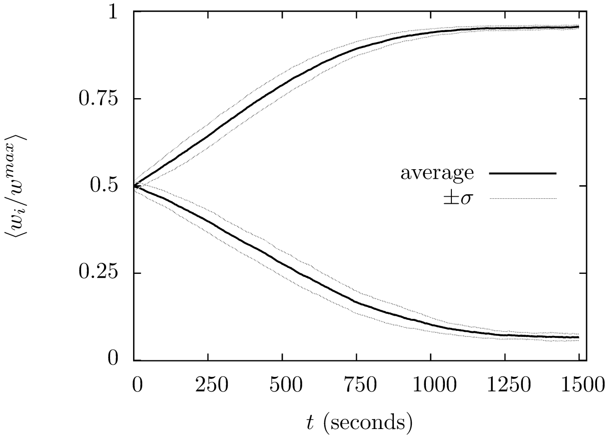
More granule cell like behaviour



$$x_i = \lambda_a + \sigma_a \xi_i$$

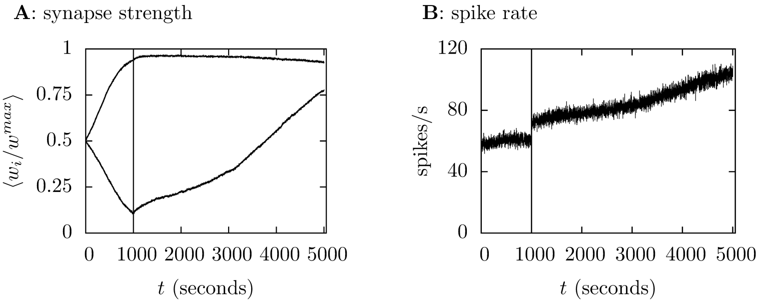
Houghton (PLoS ONE 2014)

It works even better!



Houghton (PLoS ONE 2014)

Switching off the climbing fibre



Houghton (PLoS ONE 2014)

Is it true?

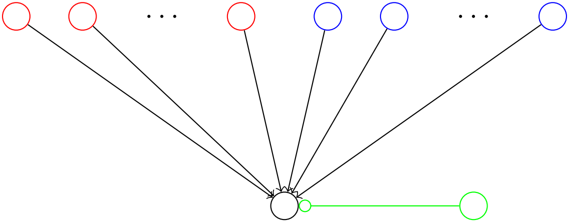
Maybe not! It is unlikely that STDP in Purkinje cells is supported by back-propagation of the somatic spike!

Is it useful?

Perhaps

- Useful in AI?
- Inhibition might allow supervision in other circuits.

Inhibition - supervized learning

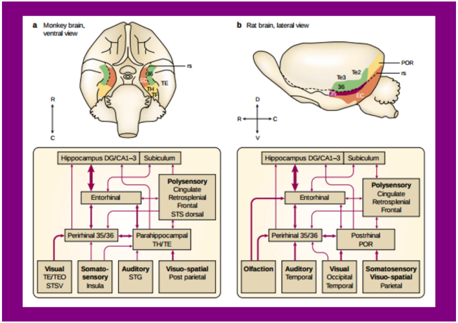


Is it useful?

Perhaps

- Recognition memory

Perirhinal cortex



MW Brown, JP Aggleton (Nature Reviews Neuroscience, 2001)

Recognition memory

TABLE I

Mean errors in recognition test, Experiment I (standard deviations in parentheses).

S	*T*	Material: Vivid pictures			Normal pictures			Words		
20	20	0	(0)	20	0·2	(0·45)	19·6	2·0	(1·2)	16
40	40	0	(0)	40	1·8	(1·1)	36·4	5·6	(1·3)	28·8
100	80	1·6	(0·9)	96	4·0	(2·2)	90	12	(1·9)	70
200	80	2·0	(2·0)	190	6·8	(1·3)	166	16·8	(4·5)	116
400	80	1·9	(3·0)	381	11·4	(5·8)	286	16·6	(7·1)	234
1000	80	4·8	(3·3)	880	9·2	(3·0)	770	15·4	(5·5)	615
4000	160		—		30·2	(16·4)	2490		—	
10000	160		—		27·2	(6·1)	6600		—	

S is the number of stimuli presented in the learning set; *T* is the number of recognition test trials. The third value within each cell is the estimated number of items retained in memory (*M*). Each cell is based on 5 subjects (10 for Vivid pictures)

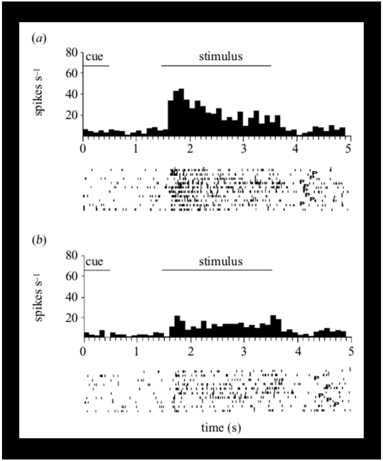
L Standing (The Quarterly journal of experimental psychology, 1973)

Déjà vu

For a few precarious seconds, the chaplain tingled with a weird, occult sensation of having experienced the identical situation before in some prior time or existence. He endeavored to trap and nourish the impression in order to predict, and perhaps even control, what incident would occur next, but the afflatus melted away unproductively, as he had known beforehand it would. *Déjà vu*. The subtle recurring confusion between illusion and reality that was characteristic of paramnesia fascinated the chaplain, and he knew a number of things about it. He knew, for example, that it was called paramnesia

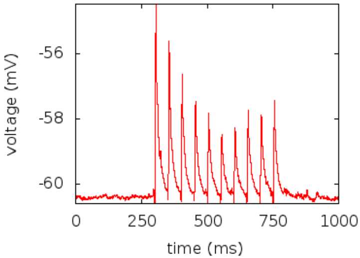
Joseph Heller: *Catch 22*

Recognition neurons



Brown and Bashir 2002

Short term depression



From Ola Bykowska

Short term depression

Synapse strength is $w_i u_i$ with

$$\tau_d \frac{du_i}{dt} = 1 - u_i$$

and

$$u_i \to \lambda_d u_i$$

at spikes.

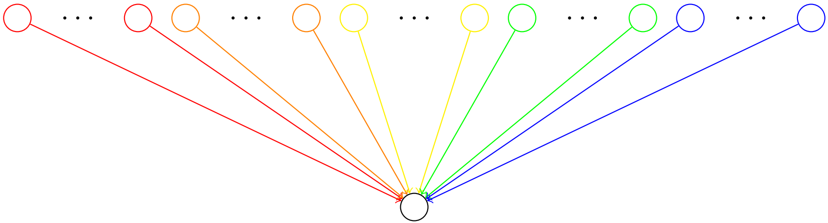
Tsodyks and Markram

STDP / STD - supervised learning

IDEA:

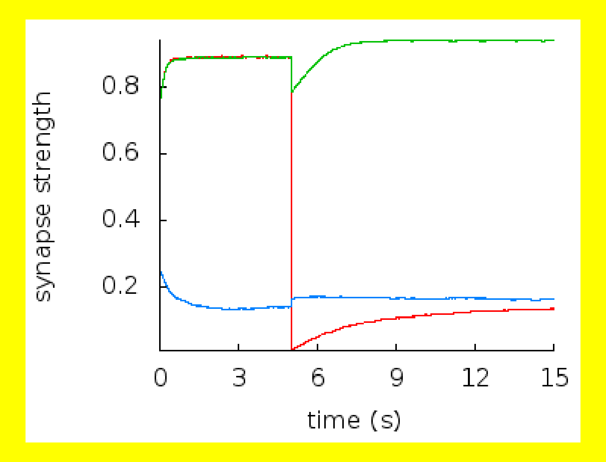
- Lots of potential things to recognize.
- When something is seen the relevant inputs to the recognition neurons fire strongly.
- At first the recognition neuron responds strongly.
- Then STD reduces the input from the synapses.
- However the input continues and this cases depression.
- Next time the same things is seen the recognition neuron doesn't fire.

STDP / STD - model



Houghton with Luke Milton and Andreas Georgiou

It works!



Houghton with Luke Milton and Andreas Georgiou

Thanks!

THE END

Thanks to the James S McDonnell Foundation for support through a scholar award in cognitive science