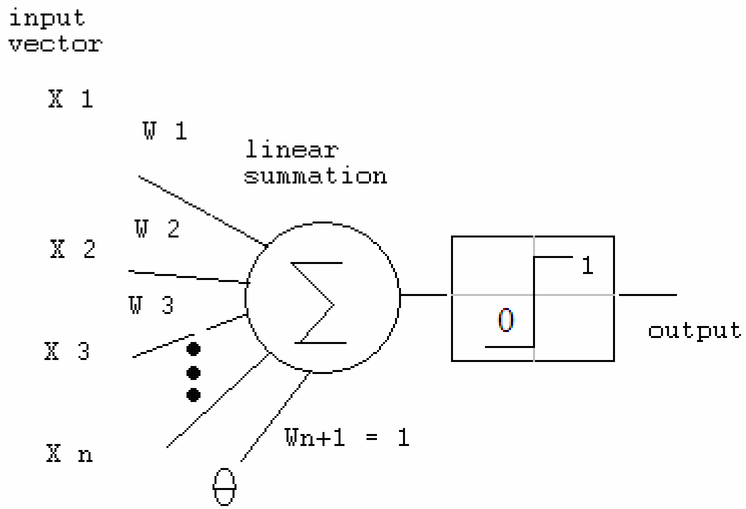
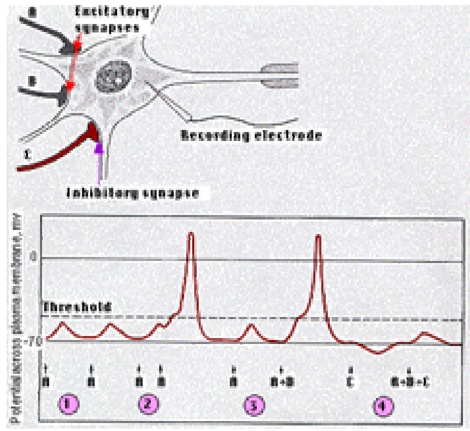
Perceptron vs. the point neuron

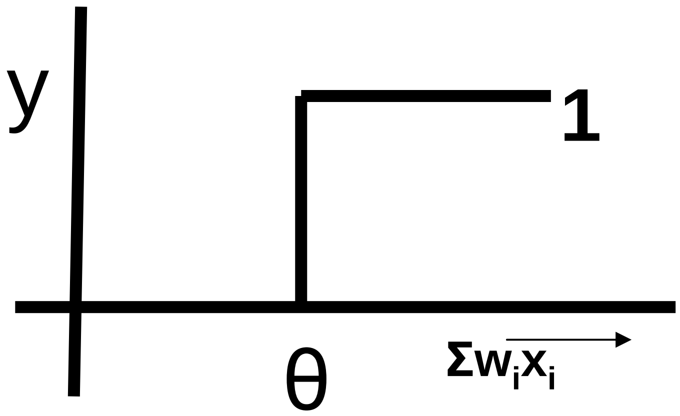
- Incoming signals from synapses are summed up at the soma
- $\sum$, the biological "inner product"
- On crossing a threshold, the cell "fires" generating an action potential in the axon hillock region



The McCulloch and Pitt's neuron



Biological neuron



Step function / Threshold function

y = 1 for $\Sigma w_i x_i > \theta$

=0 otherwise

Features of Perceptron

- Input output behavior is discontinuous and the derivative does not exist at $\boldsymbol{\Sigma w_i x_i = \theta}$

- $\boldsymbol{\Sigma w_i x_i - \theta}$ is the net input denoted as net

- Referred to as a linear threshold element - linearity because of **x** appearing with power **1**

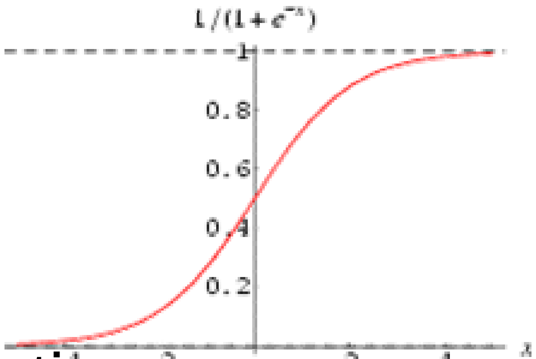
- **y= f(net)**: Relation between y and net is non-linear

Sigmoid neurons

- Gradient Descent needs a derivative computation

  - not possible in perceptron due to the discontinuous step function used!

  → Sigmoid neurons with easy-to-compute derivatives used!



$$y \to 1 \text{ as } x \to \infty$$

$$y \to 0 \text{ as } x \to -\infty$$

- Computing power comes from non-linearity of sigmoid function.

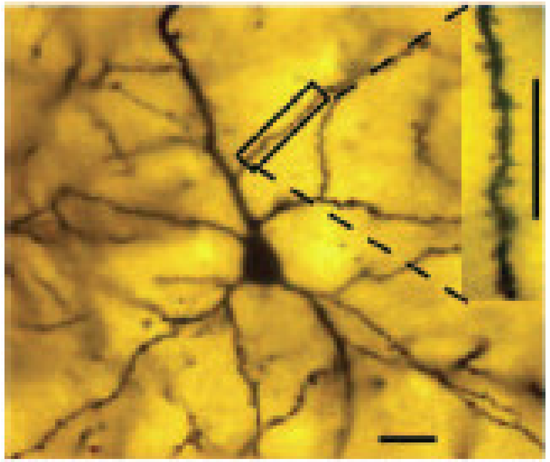
Derivative of Sigmoid function

$$y = \frac{1}{1+e^{-x}}$$

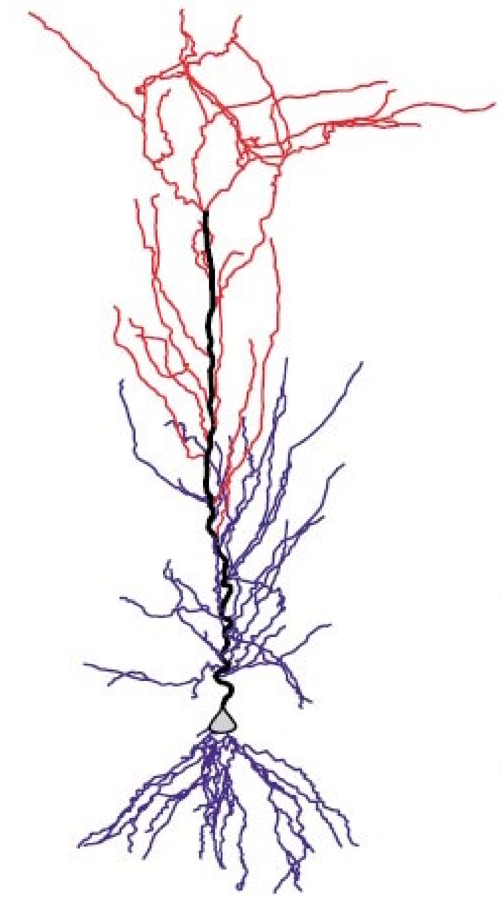
$$\frac{dy}{dx} = -\frac{1}{(1+e^{-x})^2}(-e^{-x}) = \frac{e^{-x}}{(1+e^{-x})^2}$$

$$= \frac{1}{1+e^{-x}}\left(1 - \frac{1}{1+e^{-x}}\right) = y(1-y)$$

The biological neuron



Pyramidal neuron, from the amygdala (Rupshi *et al.* 2005)



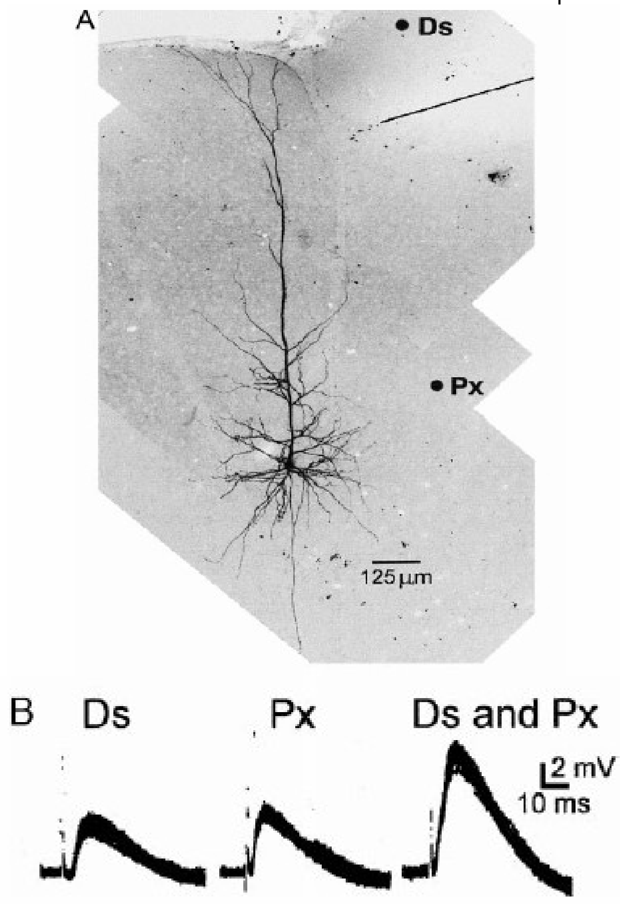
A CA1 pyramidal neuron (Mel *et al*. 2004)

What makes neuronal computation special ?

- Electrical activity in neurons
- Traveling action potentials
- Leaky, conducting membrane
- Highly branched structures
- A variety of electrical connections between neurons
- A varied range of possibilities in neural coding of information

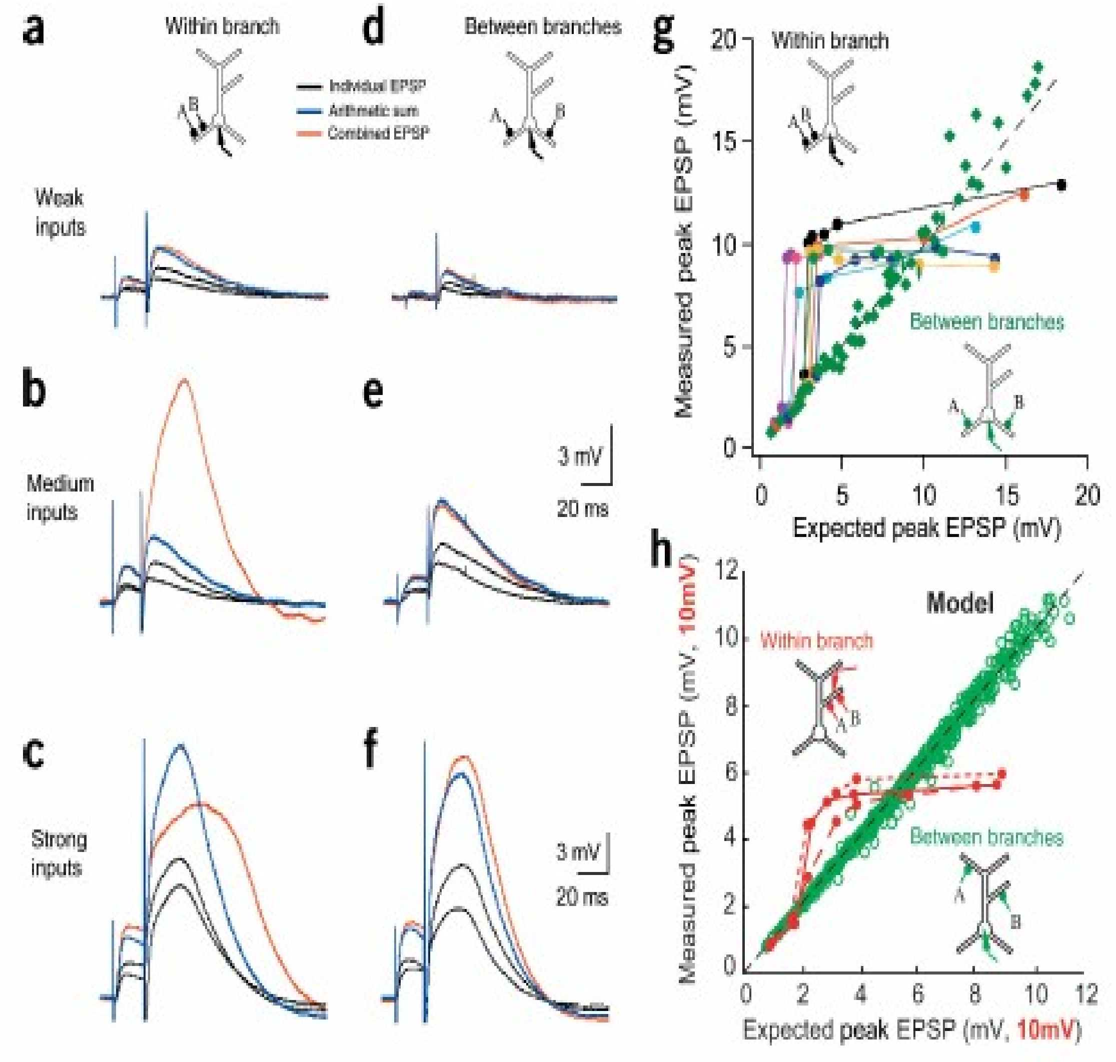
Dendritic computation

- Time delay
- Attenuation, duration increase
- Spatial and temporal summation
- Non linear intra branch summation
- Multiple layer configuration
- Retrograde propagation of signals into the dendritic arbor
    - Backprogating action potentials



Spatial and temporal summation of proximal and distal inputs (Nettleton *et al.* 2000)

Dendritic computation



(Mel *et al.* 2003, 2004)

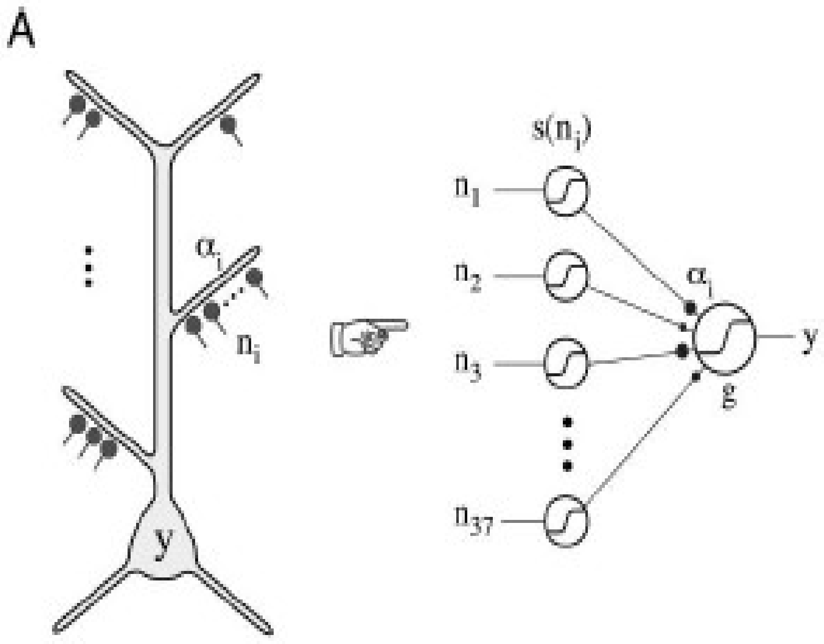
Comparison of within-branch & between-branch summation.

(**a-f**)
Black: individually Activated
Red: simultaneously activated
Blue: arithmetic sum of individual responses.

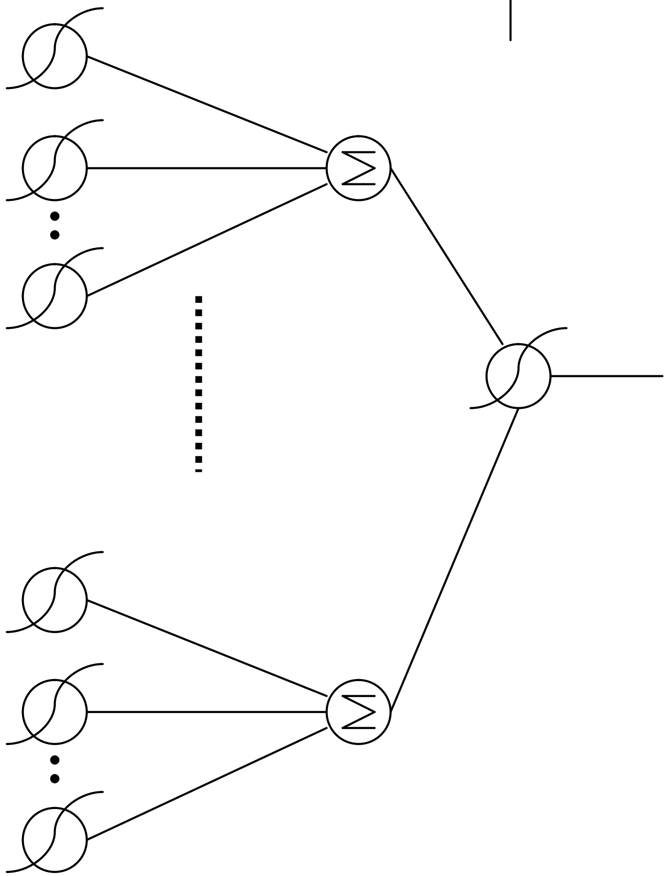
(**g**) Summary plot of predicted versus actual combined responses.
Coloured circles: within-branch summation
Dashed line: linear summation.
Green diamonds: between-branch summation

(**h**) Modeling data: summation of EPSPs
Red circles: within-branch summation
Open green circles: between-branch summation

Dendritic computation: Single neuron as a neural network



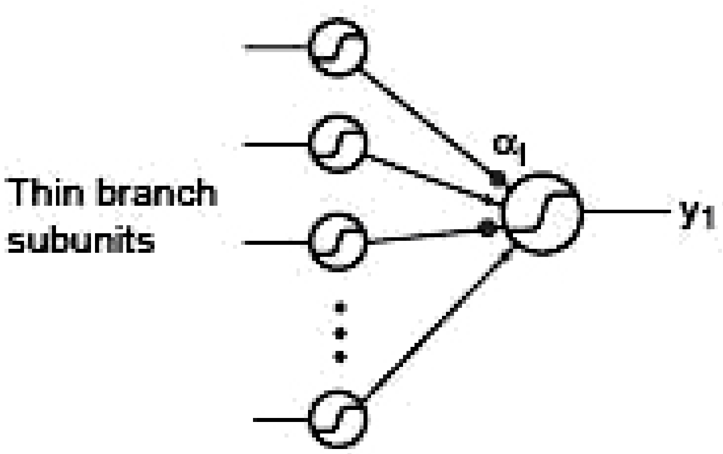
Possible computational consequences of non-linear summation in dendritic sub-trees (Mel *et al.* 2003)



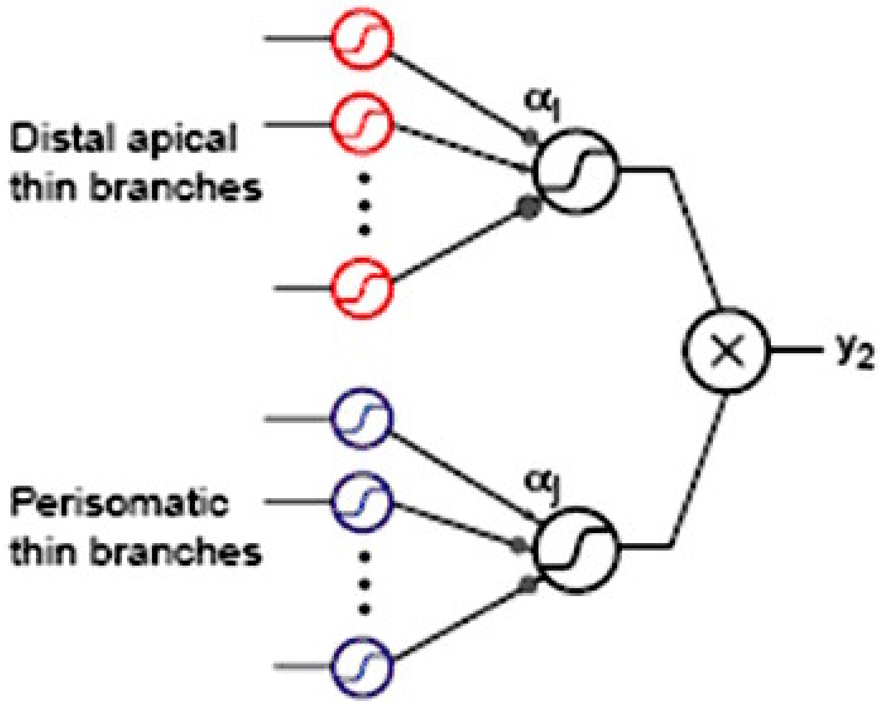
Another possibility

Single neuron as a neural network

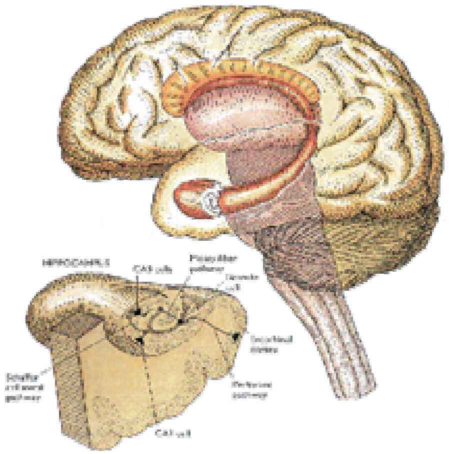
2 Layered Neural Network

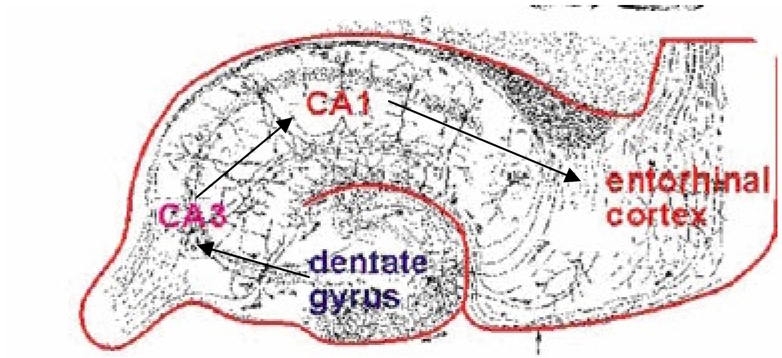


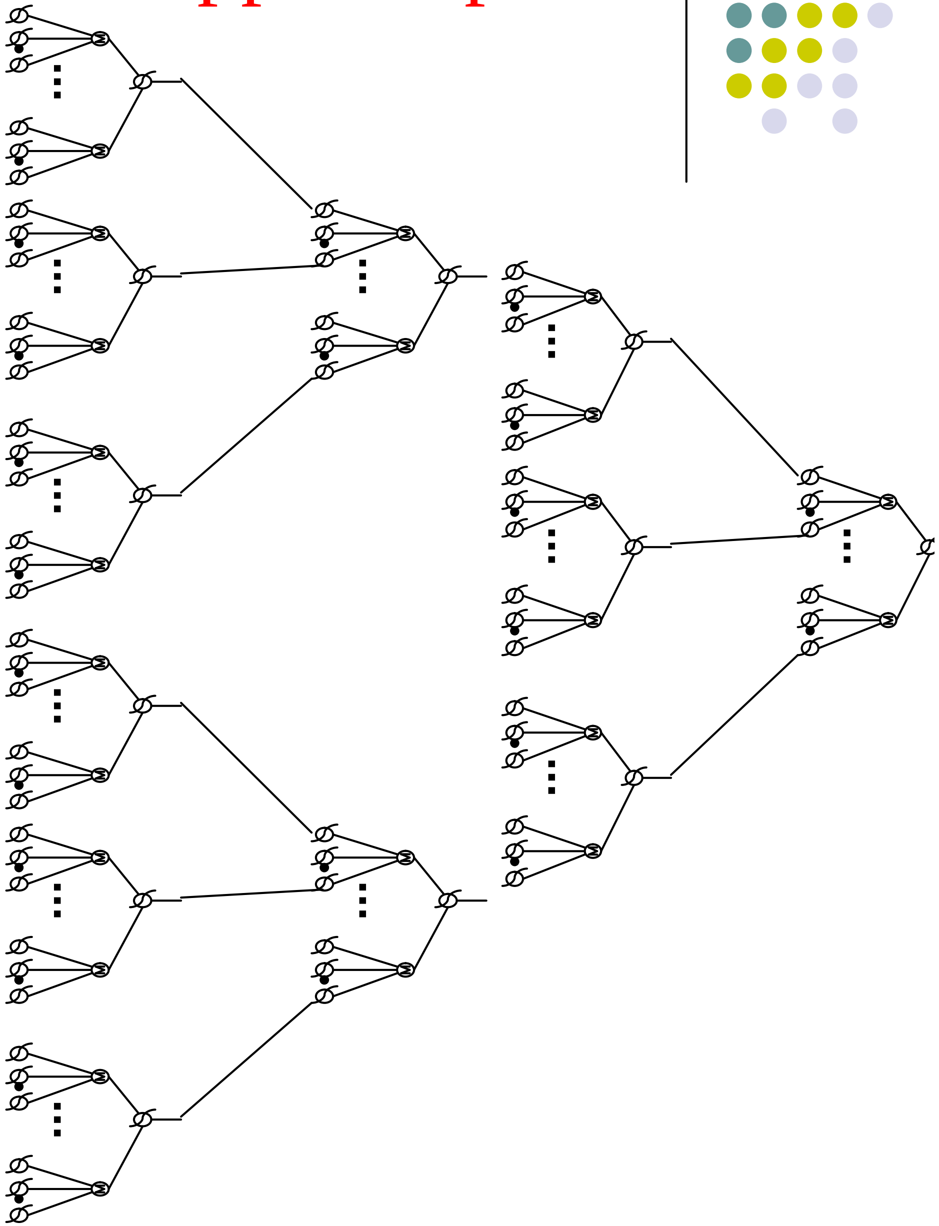
3 Layered Neural Network



A multi neuron pathway in the hippocampus



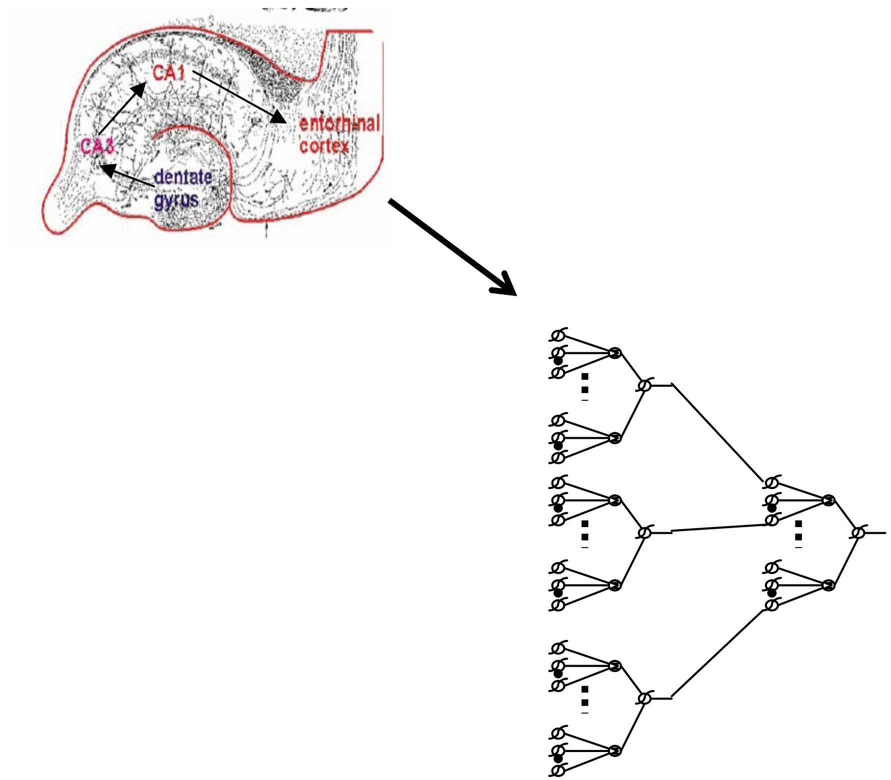


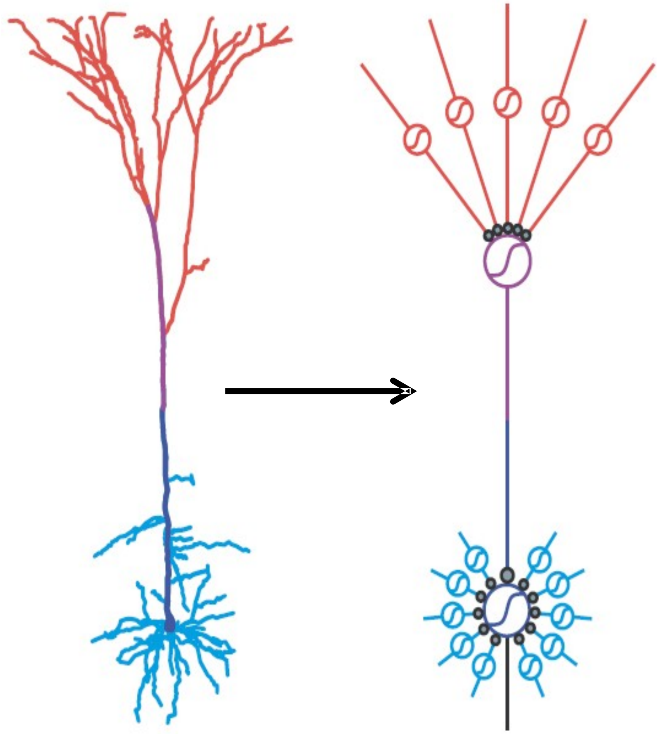


Summary

Classical Picture

Emerging Picture





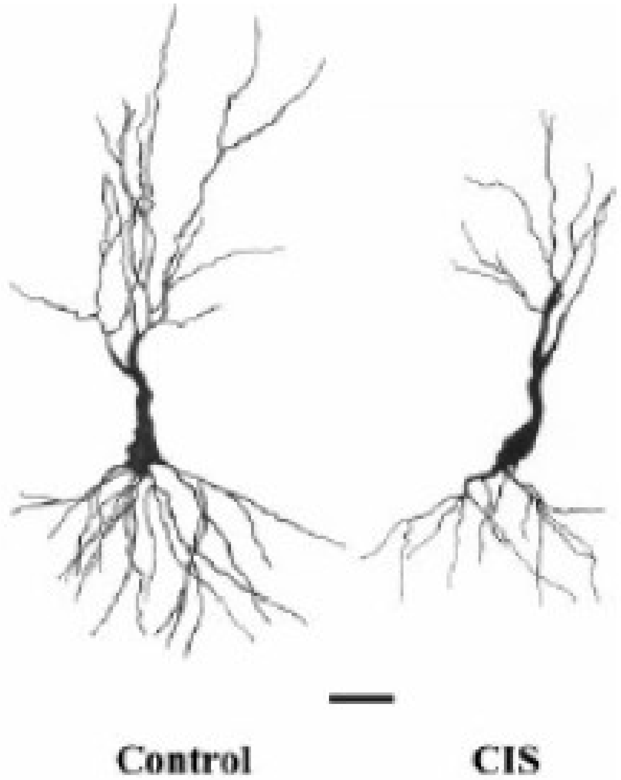
Recent neurobiological discoveries

Changes as a result of stress (CIS)

- Dendritic atrophy

Consequences

- Loss of computational subunits
- Changes in connectivity of the network



Atrophy and de-branching as seen in the CA3 pyramidal cells from (Ajai *et al.* 2002)

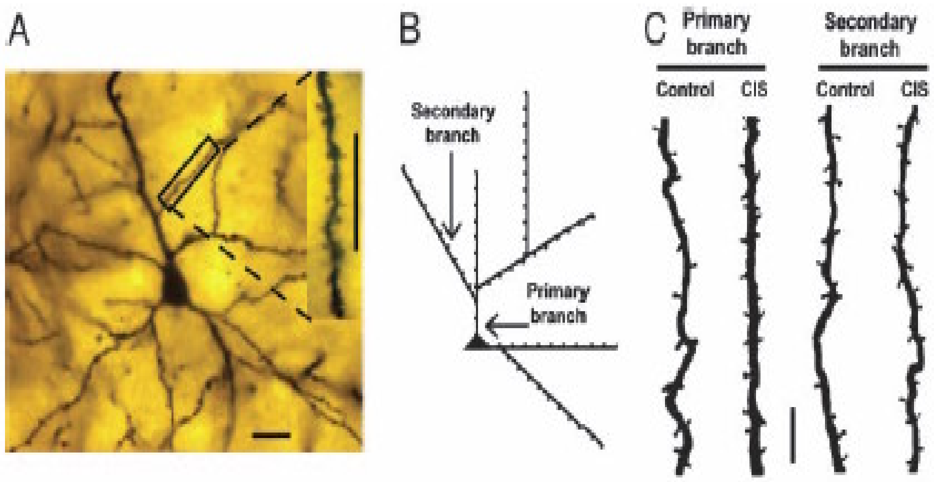
Recent neurobiological discoveries

Changes as a result of stress (CIS)

- **Arbor growth**
- **Increase in spine count**

Consequences

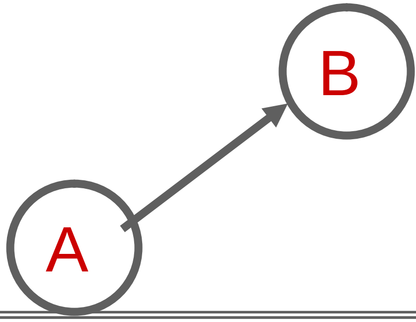
- **Increase in computational subunits**
- **Synaptic site increase**

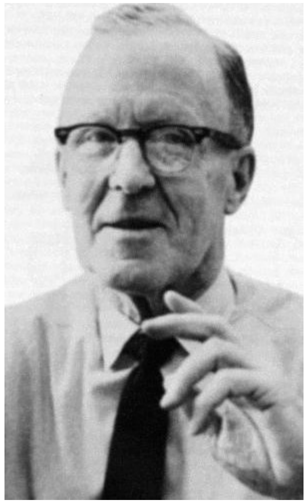


Increase in spine count (Amygdaloid neurons) (Rupshi *et al.* 2005)

Hebb's postulate

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





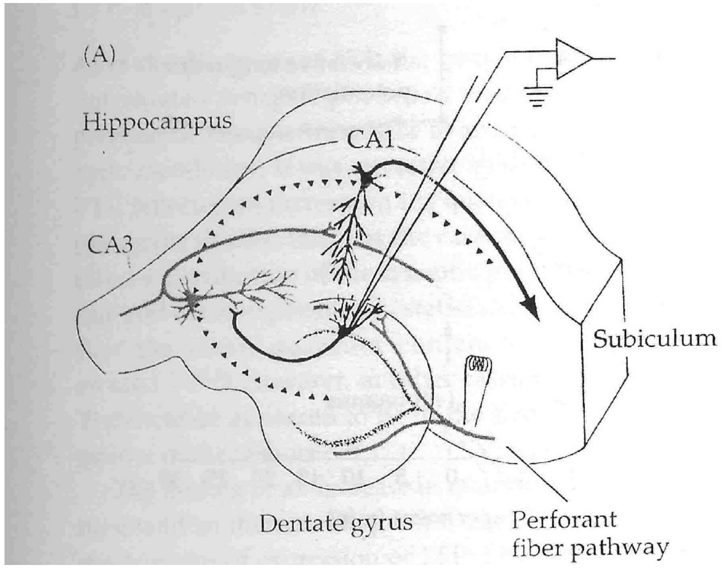
- Repeated simultaneous activation of two cells *strengthens* the synapses that link them

- *"Cells that fire together wire together"*

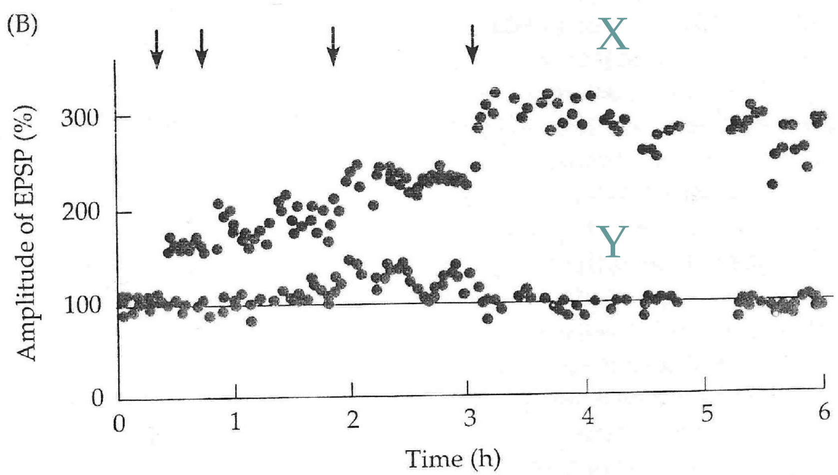
- Practical demonstration of Hebbian theory : "Long term potentiation" (LTP

Hippocampal LTP [Perforant Path – Dentate Gyrus *in vivo*]

Anesthetized rabbit hippocampus



Tetanic stimulation at arrows: 15 Hz, 10 sec



X: Stimulated + Tetanized pathway

Y: Stimulated but not tetanized (control)

Note time scale!

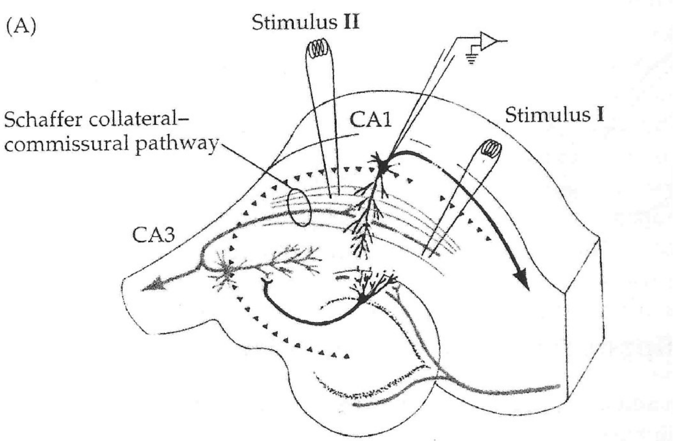
Properties inferenced:

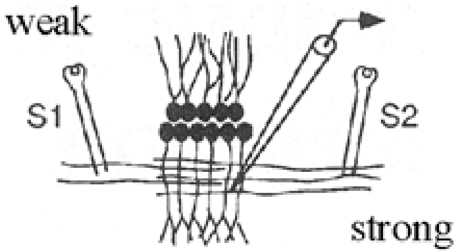
- Co-operativity
- Input specificity

Bliss & Lomo, 1973

Schaffer collateral – CA1 LTP *in vitro*

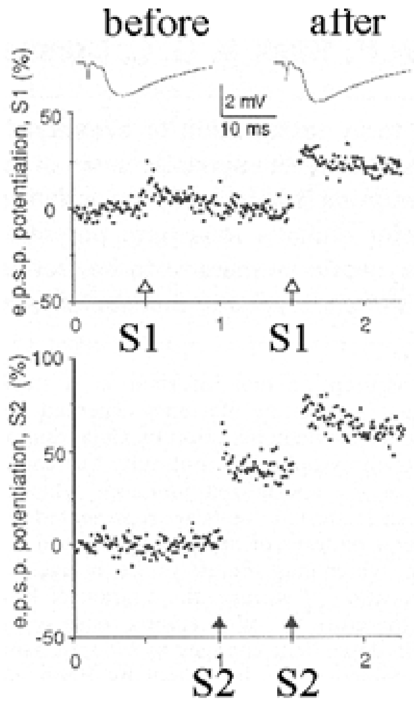
Rat hippocampal slices





alternate at 15 sec intervals

tetanic stimulation
S1: cooperative
S2: input-specific
S1+S2: associative



Note: Excitatory neurotransmitter: Glutamate

Barrionuevo & Brown, 1983

LTP: Cellular Basis of classical conditioning?

Consider the *associativity* property of LTP

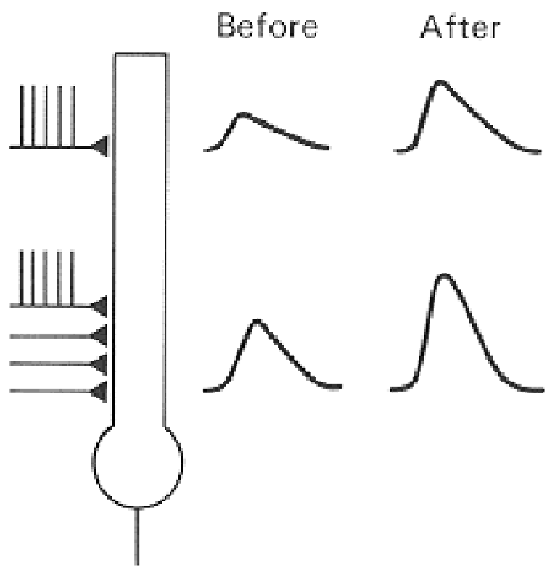
EPSPs

conditioned stimulus

[C-S: Weak]

unconditioned stimulus

[UC-S: Strong]

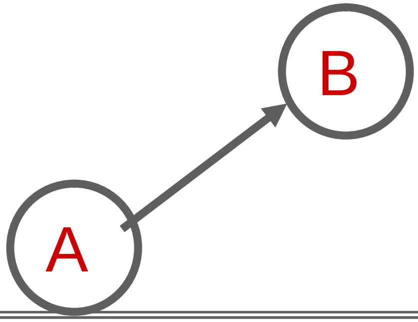


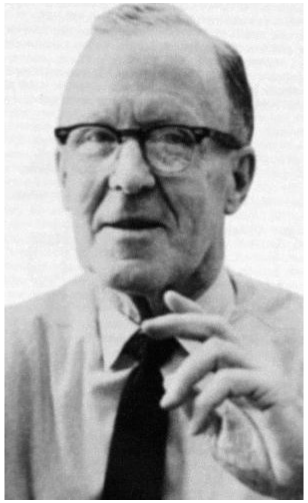
Enhancement
lasts minutes-hrs!

Time to ring in Pavlov's dog…

Hebb's postulate

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





• Repeated simultaneous activation of two cells *strengthens* the synapses that link them

• Long term potentiation : practical demonstration of the Hebbian theory.

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