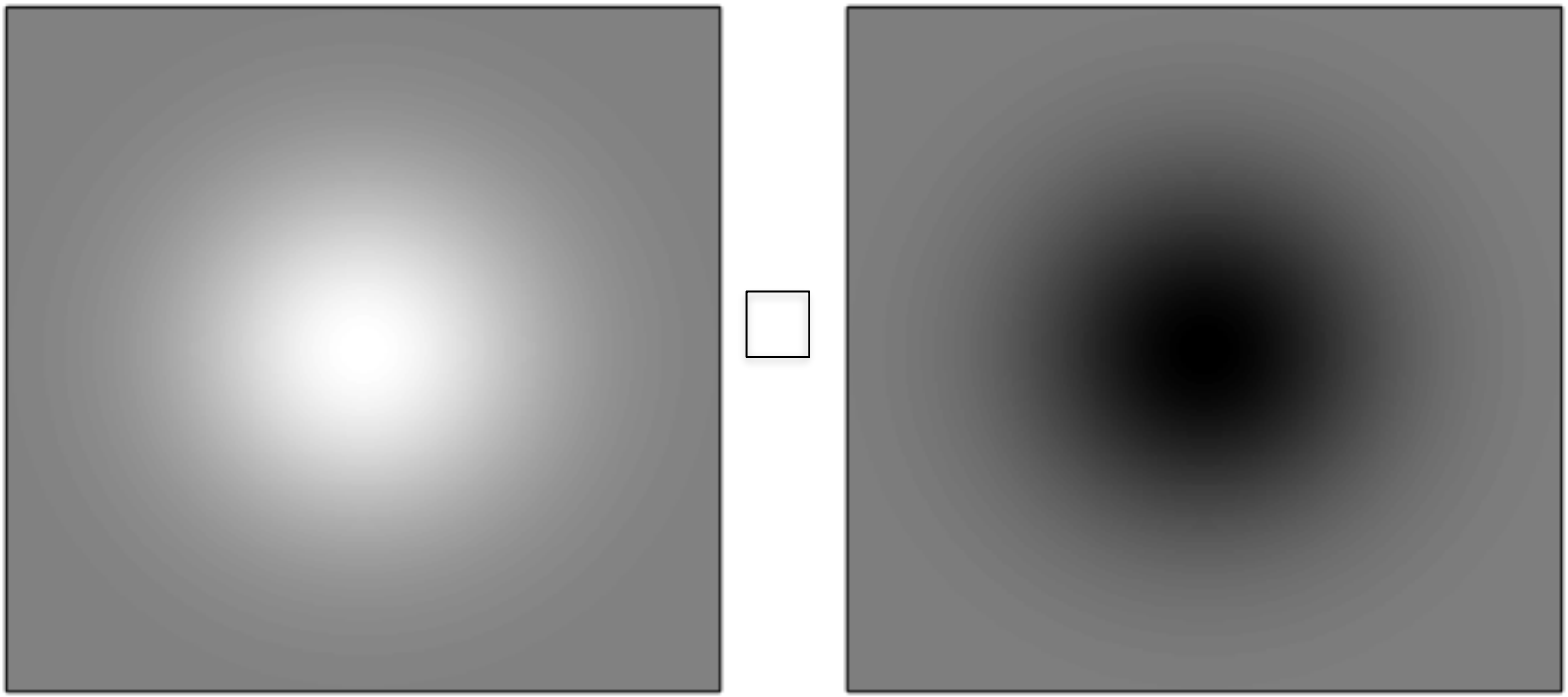
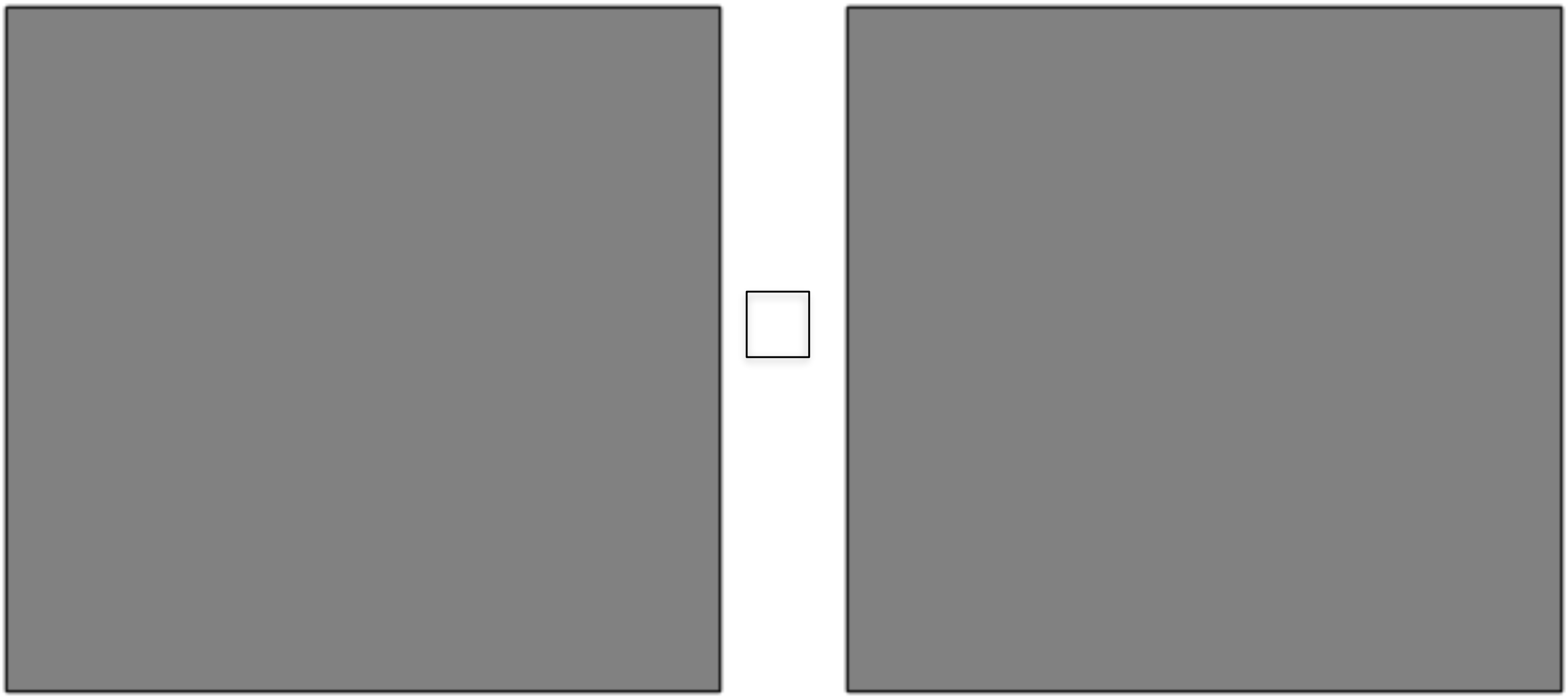
# NEPR208 Synapses, plasticity and learning

- Synaptic depression and adaptation
- Synaptic facilitation and working memory
- Spike time dependent plasticity and long term memory
- Heterosynaptic long term depression and network stability
- Anti-hebbian plasticity and decorrelation

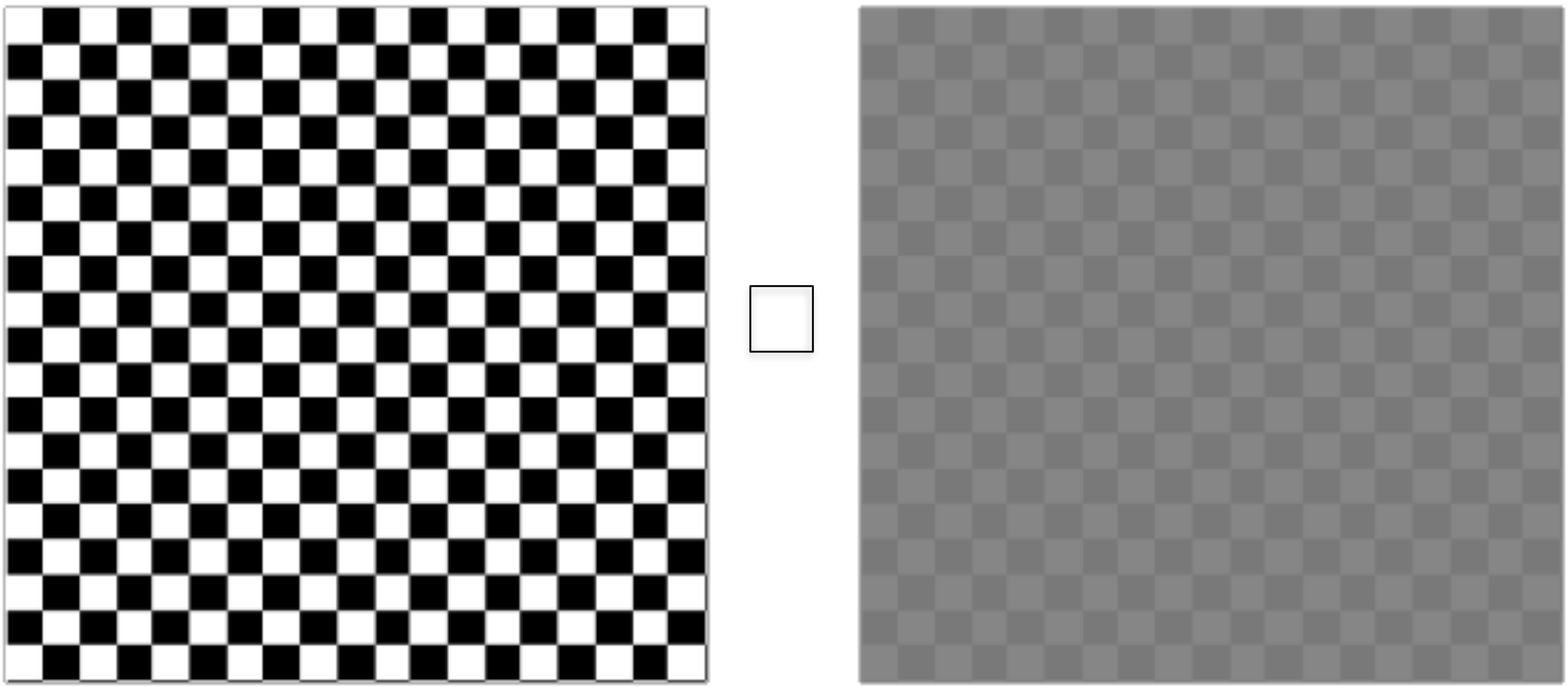
# The visual system adapts to the mean luminance



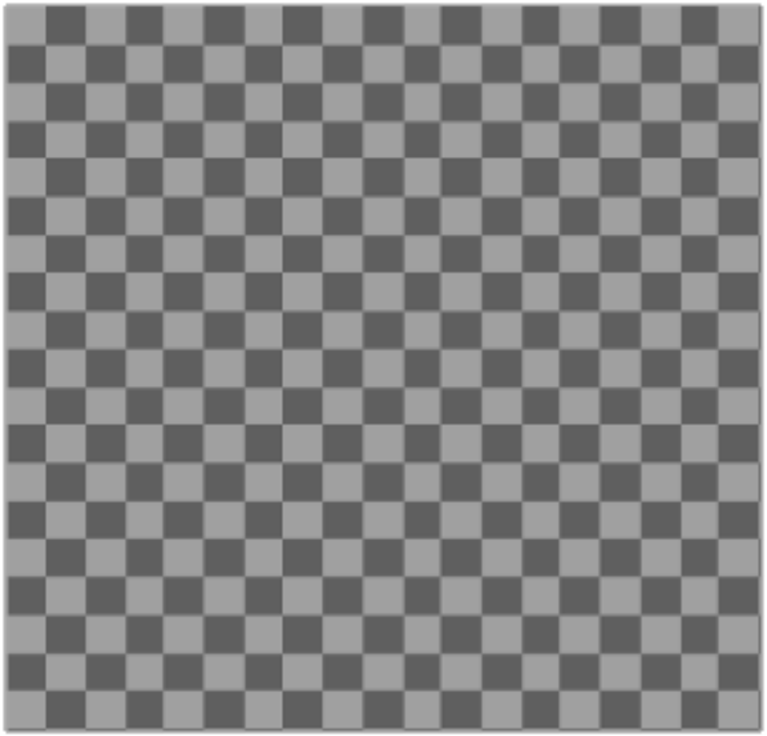
# The visual system adapts to the mean luminance

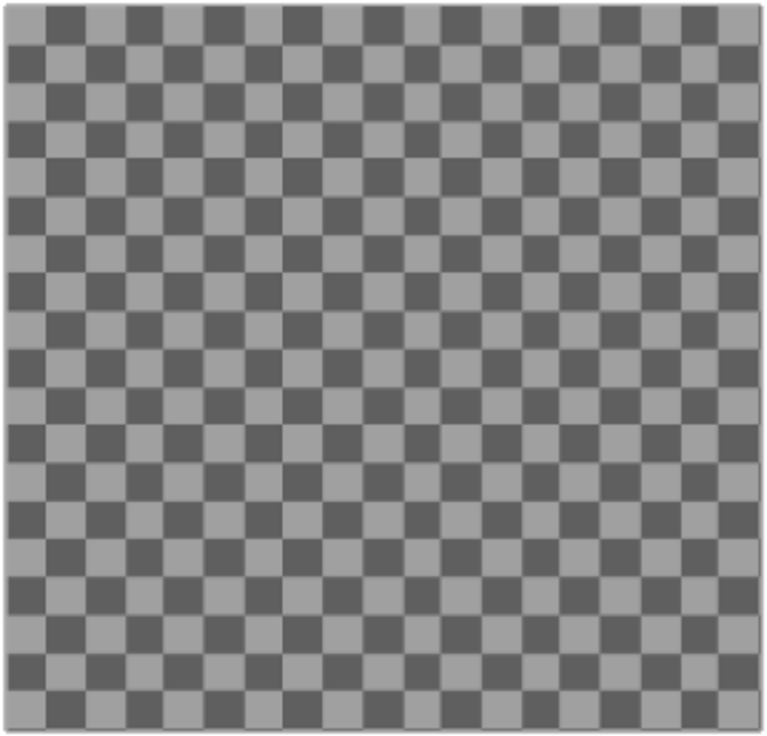


# The visual system adapts to contrast

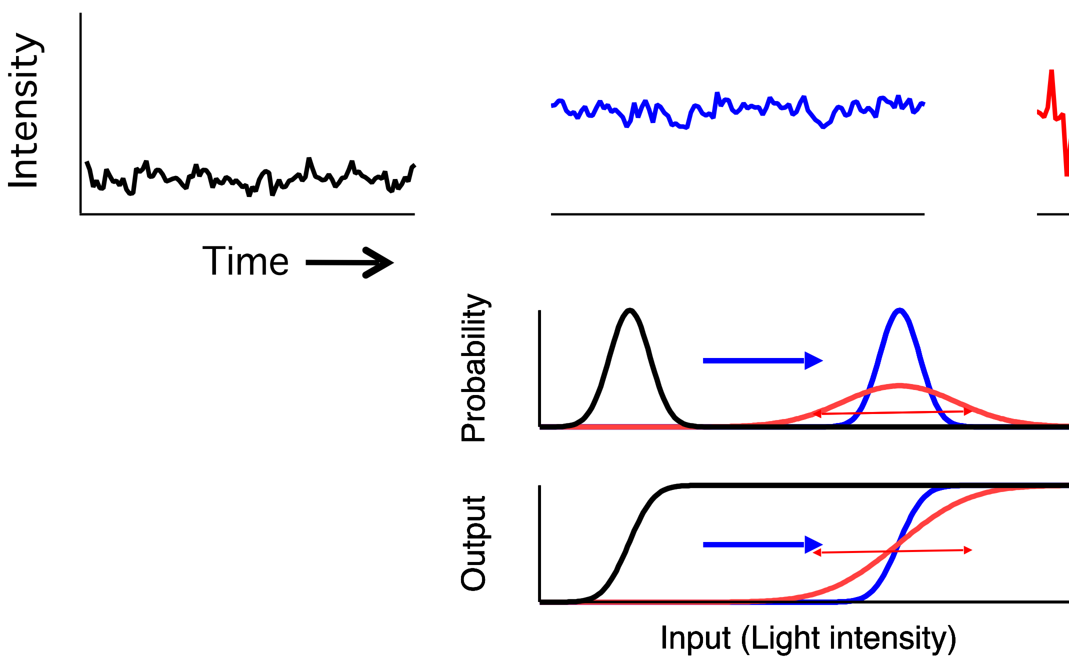


# The visual system adapts to contrast





# Functional importance of adaptation




Luminance adaptation
Contrast adaptation

Blakemore & Campbell, 1969
Shapley & Victor, 1979
Smirnakis et al., 1997

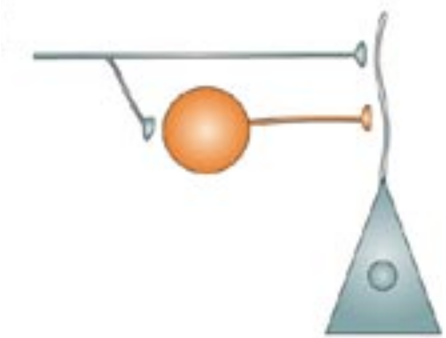
# Common properties of contrast adaptation

| | Avian auditory forebrain | Vertebrate retina | Fly motion sensitive neuron H1 |
|---|---|---|---|
| Kinetics | | Change quickly | |
| Gain | | Changes quickly | |
| Amplitude | | Changes slowly | |


Nagel & Doupe, 2006
Fairhall et al., 2001

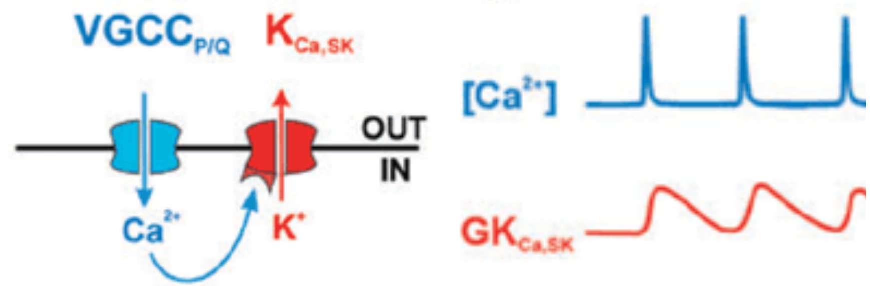
# Change in sensitivity by *modulation*

Feedforward inhibition



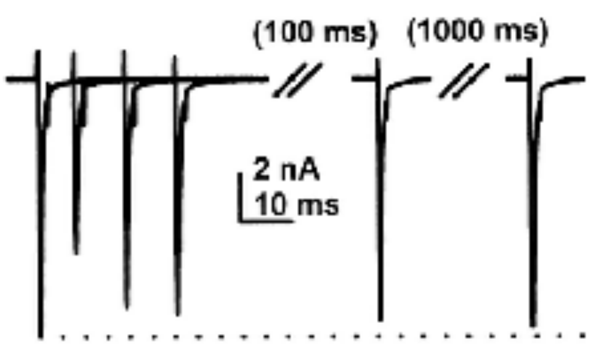
Feedback inhibition

Spike dependent conductances

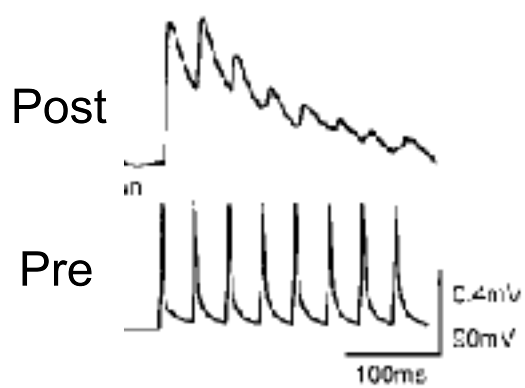



# Change in sensitivity by *depletion*

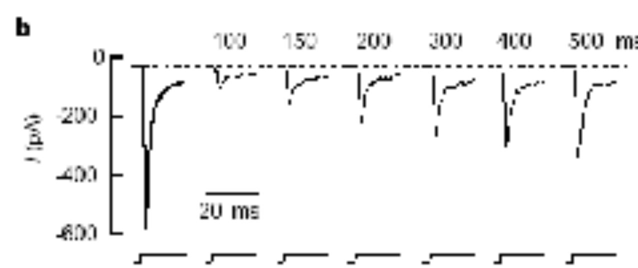
Ion channel inactivation




Short-term synaptic plasticity
synaptic depression



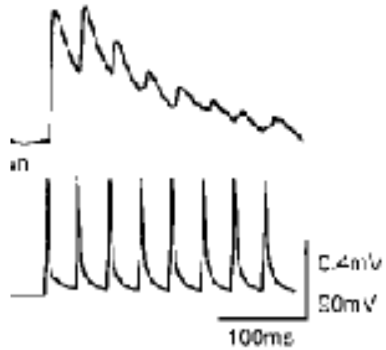

Receptor desensitization

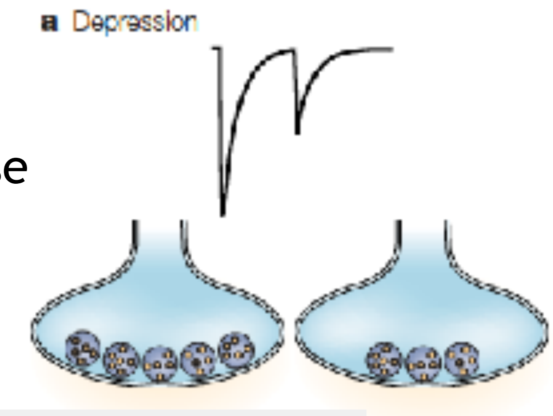


# Short-term synaptic plasticity – synaptic depression

Post

Pre




Depletion of available vesicles as a mechanism for depression

n: Number of vesicle
p: Probability of vesicle release

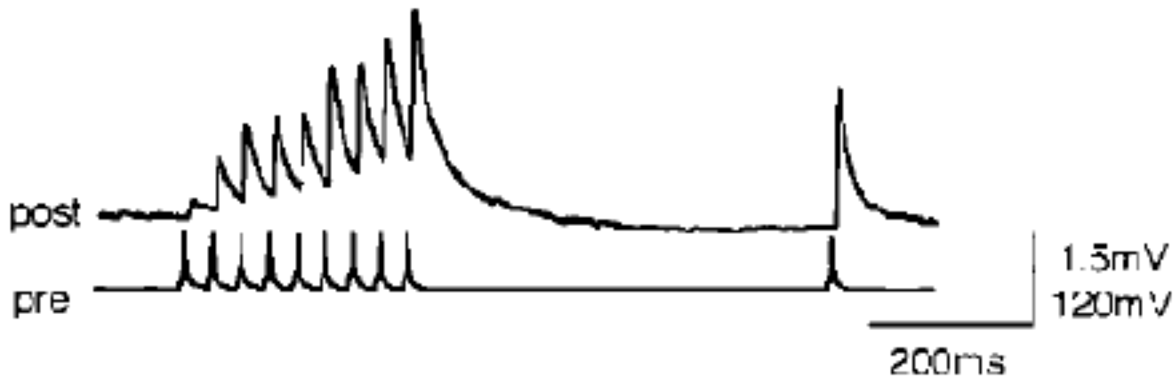
Release = n x p

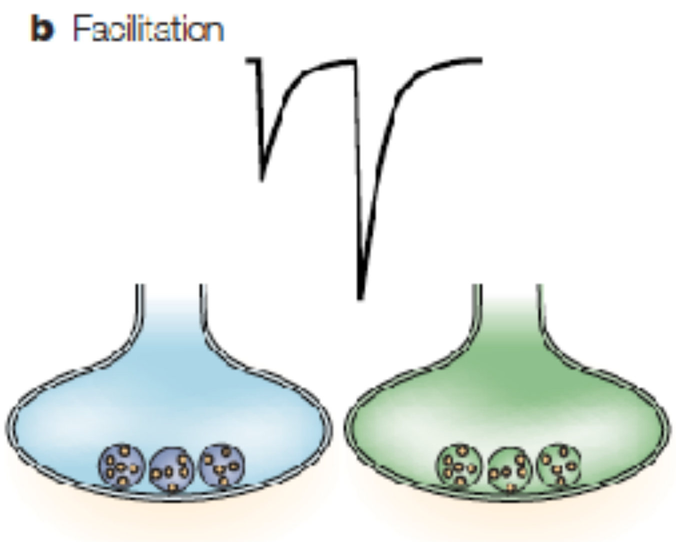
$$\frac{dn(t)}{dt} = \underbrace{\frac{1-n(t)}{\tau_r}}_{\text{replenishment}} - \underbrace{\sum_j \delta(t-t_j)\cdot p\cdot n(t)}_{\text{release}}$$

Hennig, 2013. Theoretical models of synaptic short term plasticity

Chance FS, Nelson SB, Abbott LF. (1998)
Ozuysal & Baccus (2012)

# Short-term synaptic plasticity – synaptic facilitation

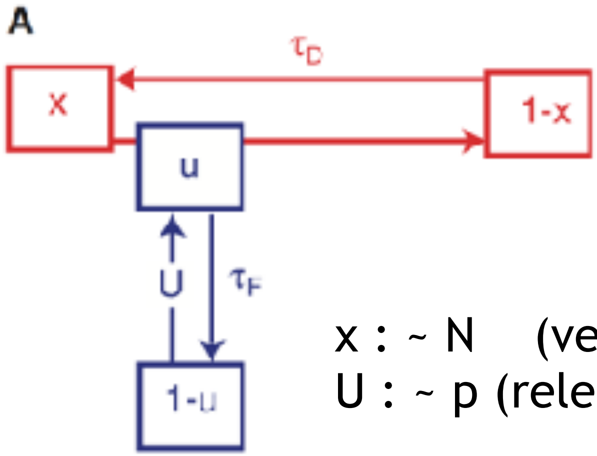


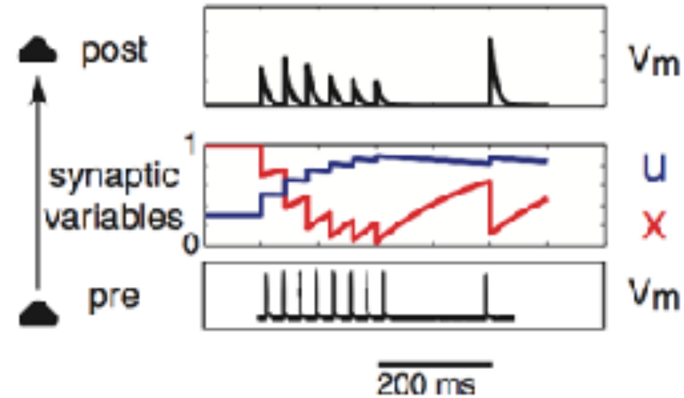

Residual calcium as a mechanism for increased release

$$\frac{dp(t)}{dt} = \frac{p_0 - p(t)}{\tau_f} + \sum_j \delta(t - t_j) \cdot a_f \cdot (1 - p(t))$$

# Proposal for synaptic facilitation in short-term memory




x : ~ N (vesicles)
U : ~ p (release probability




## Release & Replenishment

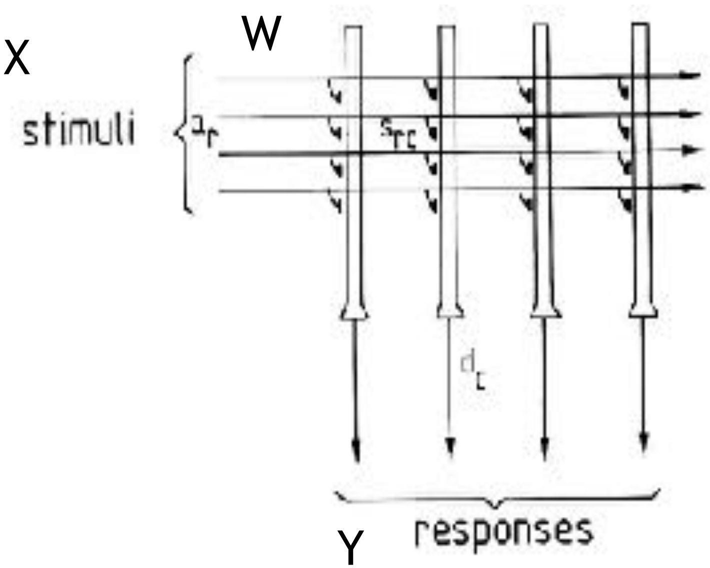
$$\frac{dx}{dt} = \frac{1-x}{\tau_D} - u\, x\, \delta(t-t_{sp})$$

## Facilitation

$$\frac{du}{dt} = \frac{U-u}{\tau_F} + U\,(1-u)\,\delta(t-t_{sp})$$


Synaptic theory of working memory
Mongillo, Barak & Tsodyks, 2008

# Synaptic transmission as a matrix multiplication




Input X, column vector

n × 1

Output Y, column vector

m × 1

Matrix of synapses W

m × n

$$WX = Y \qquad \sum_i w_{ji} x_i = y_j$$

W: m × n

X: n × 1

=

Y: m × 1

## The Hebb rule for synaptic plasticity

$$A \xrightarrow{w_{BA}} B$$

When an axon of cell A is near enough to excite cell B or repeatedly or 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, is increased.

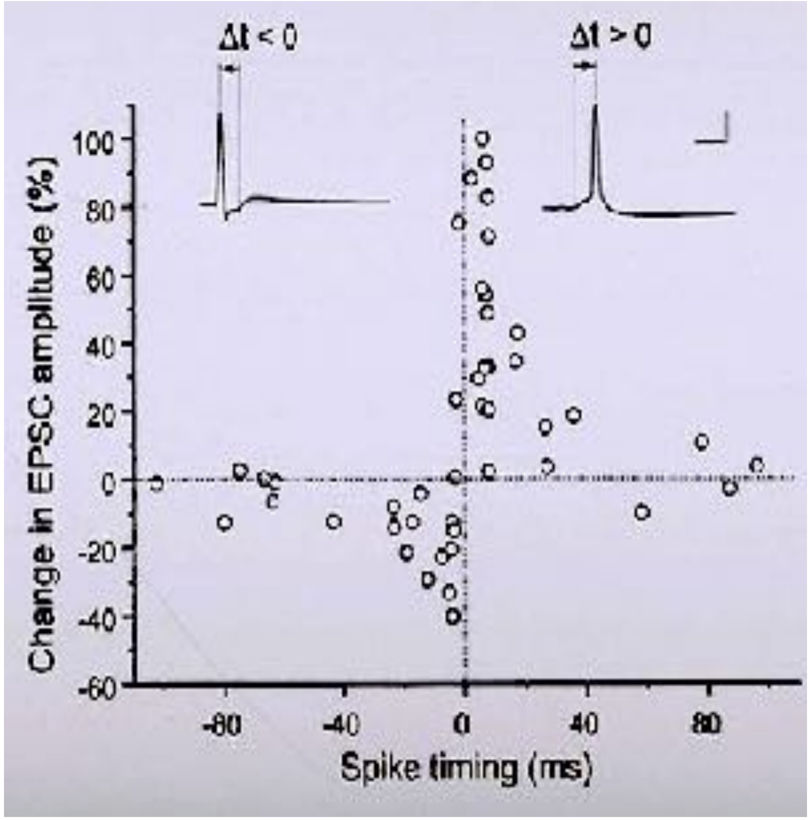
Hebbian plasticity

A excites B: Coincidence leads to greater release

$$\frac{dw_{BA}}{dt} = \langle AB \rangle$$

# Hebbian spike timing plasticity (STDP)

hippocampal neurons



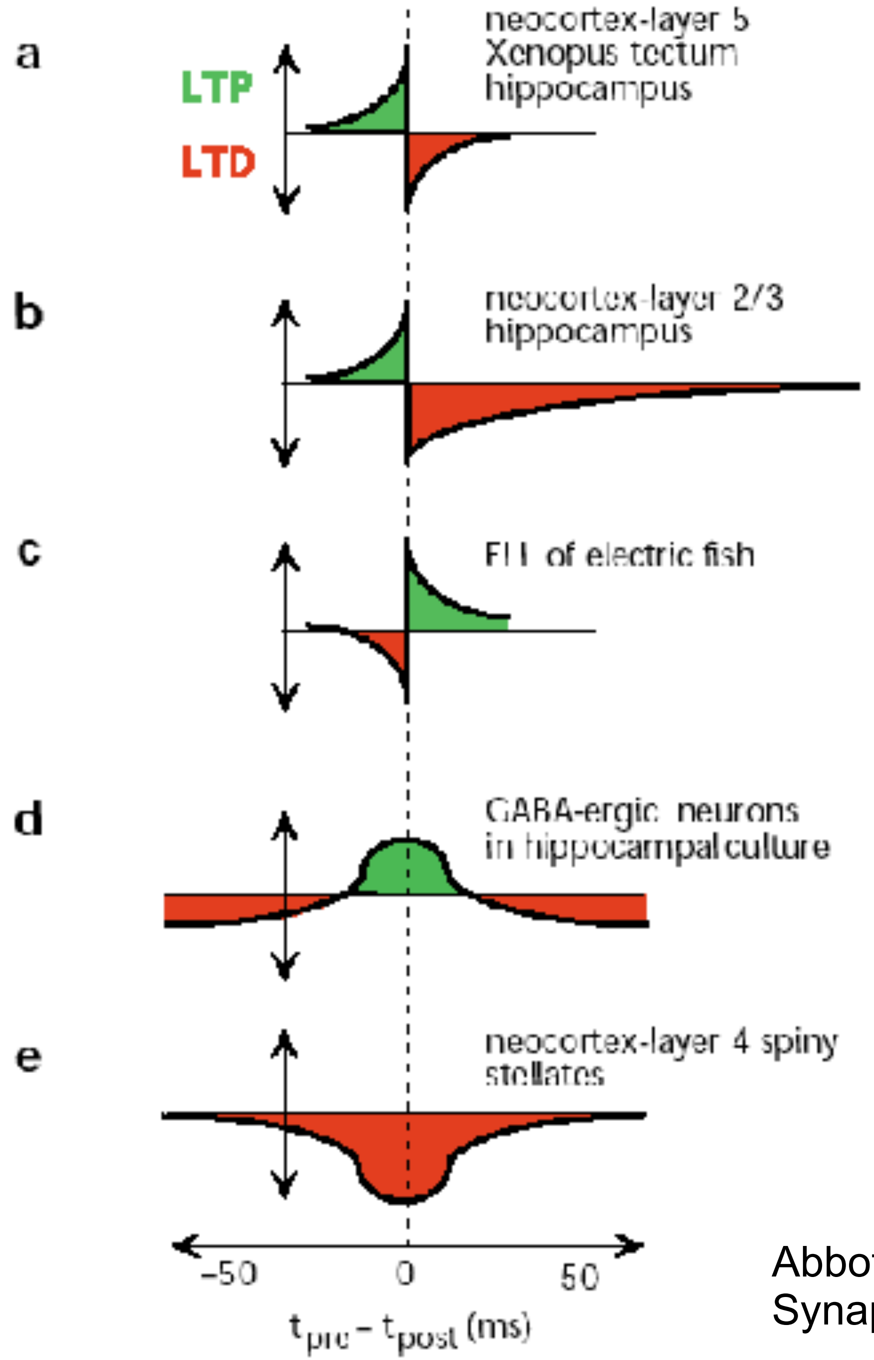

Pre before Post

$$\frac{dw_{ba}}{dt}(t) = f(\tau)a(t)b(t-\tau)$$

Bi & Poo (1998)

Simplified: $$\frac{dw_{ba}}{dt}(t) = a(t)b(t-1) - a(t-1)b(t)$$

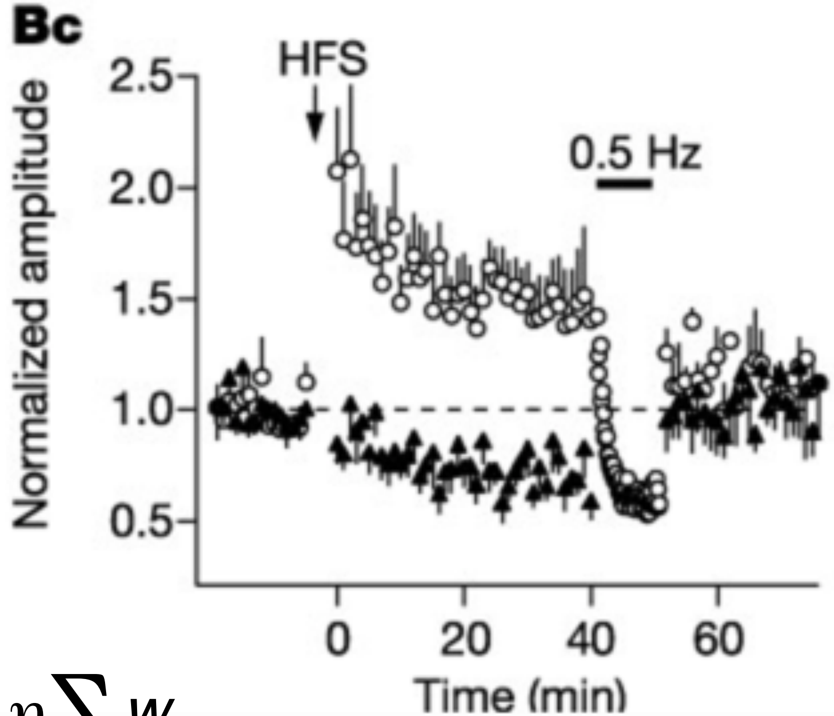
# Different varieties of Spike-timing dependent plasticity




Abbott L. and Nelson S.
Synaptic plasticity: taming the beast (2000)

# How can Hebbian networks be stable?

Heterosynaptic Long Term Depression



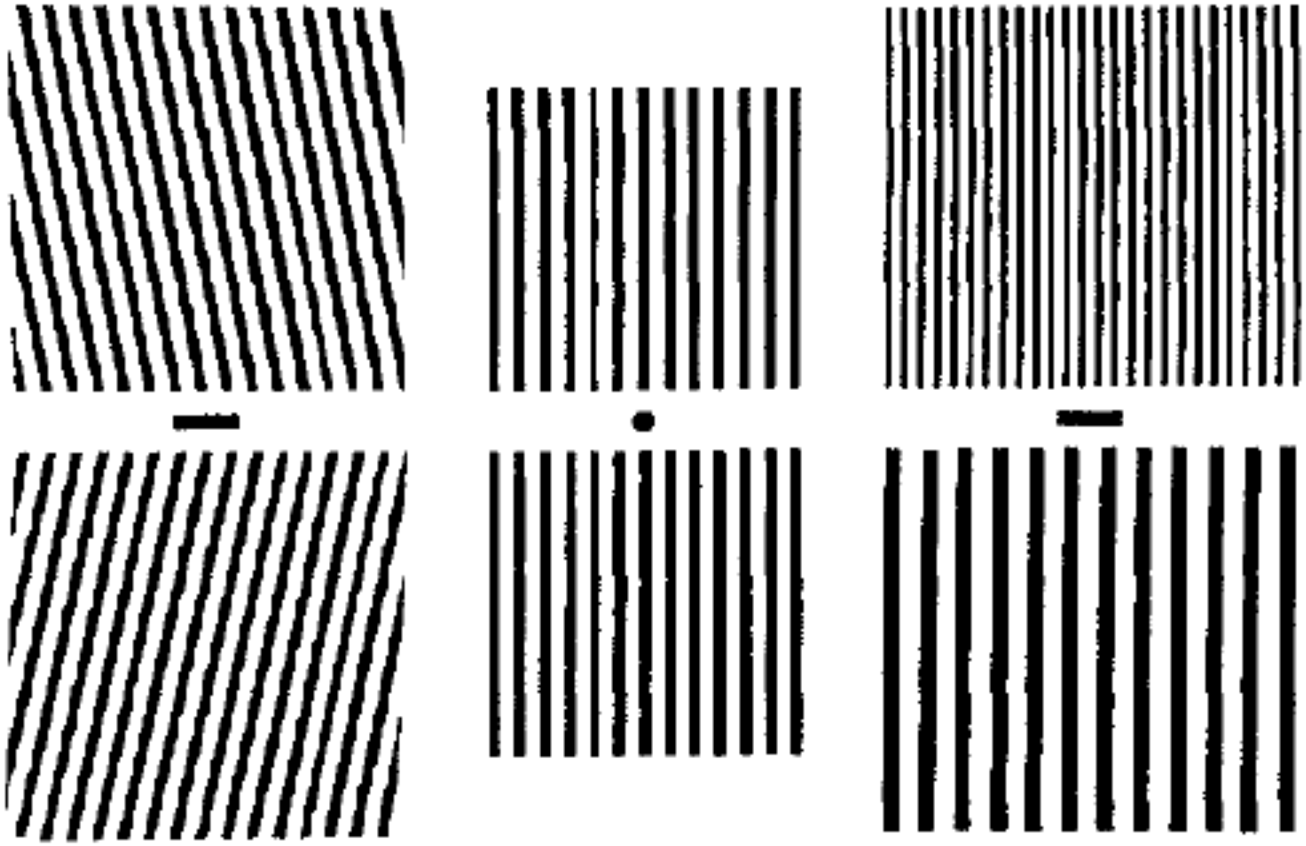

Royer & Pare, 2003

Decrease each $w_{ij}$ by $\eta \sum_k w_{ik}$

Another stability rule, Oja's rule $$\frac{dw_{ji}}{dt} \propto x_i y_j - y_j^2 w_{ji}$$

# Predictive coding: removing predictable signals from the brain

various aftereffects including tilt and motion

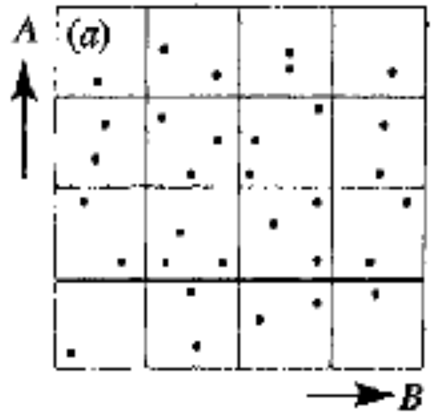


Barlow HB, The knowledge used in vision and where it comes from (1997)

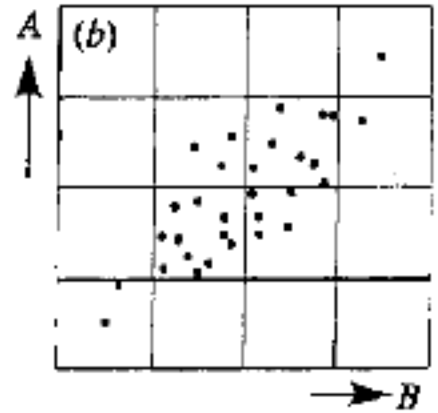
Hosoya et al., Dynamic predictive coding in the retina (2005)

# “Decorrelation” – increasing the difference between inputs

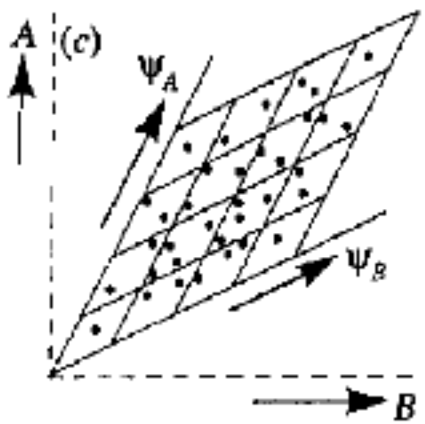
Two uncorrelated inputs



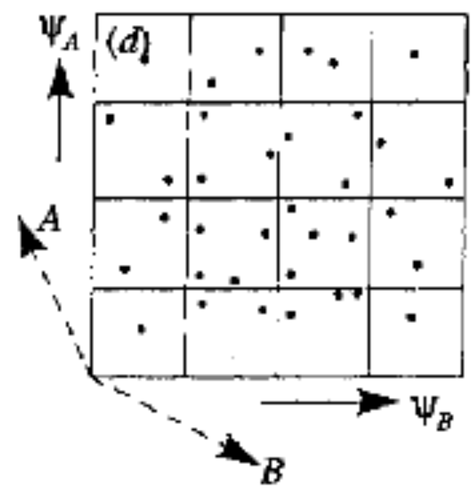

Two correlated inputs



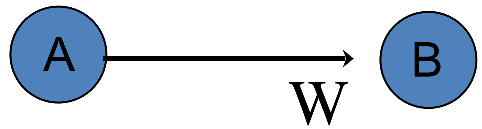

A new representation




Decorrelated in the new representation




Barlow HB, The knowledge used in vision and where it comes from (1997)




Hebbian plasticity $$\frac{dw}{dt} = \langle AB \rangle$$

A excites B: Coincidence leads to greater release

A *inhibits* B: Coincidence leads to less release

"Anti-Hebbian" plasticity $$\frac{dw}{dt} = -\langle AB \rangle$$

A excites B: Coincidence leads to less release

A *inhibits* B: Coincidence leads to greater release