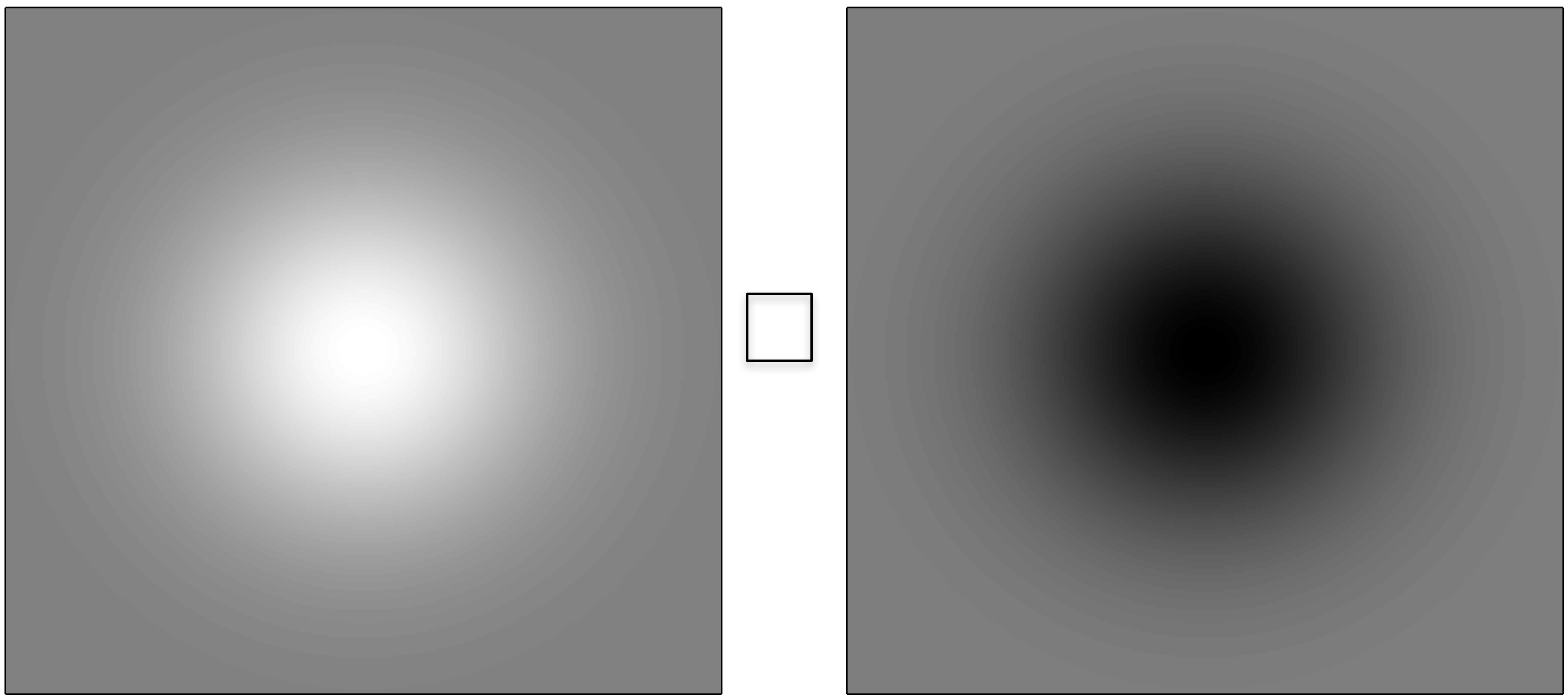
NEPR208 Synapses, plasticity and learning

- Synaptic depression and adaptation
- Synaptic facilitation and working memory
- Spike time dependent plasticity and long term memory
- Heterosynaptic long term depression and network stability
- Network learning of motor patterns in birdsong – Hannah Payne

The visual system adapts to the mean luminance



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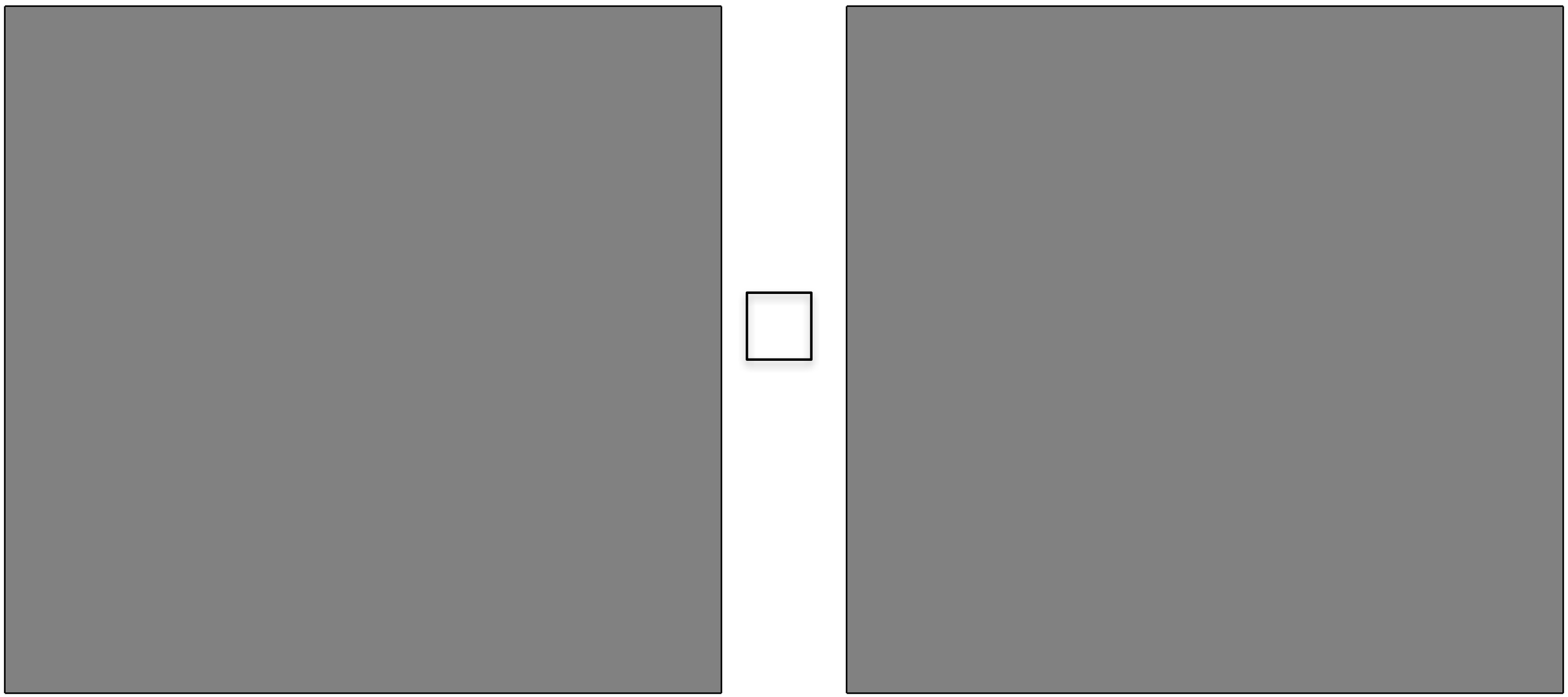
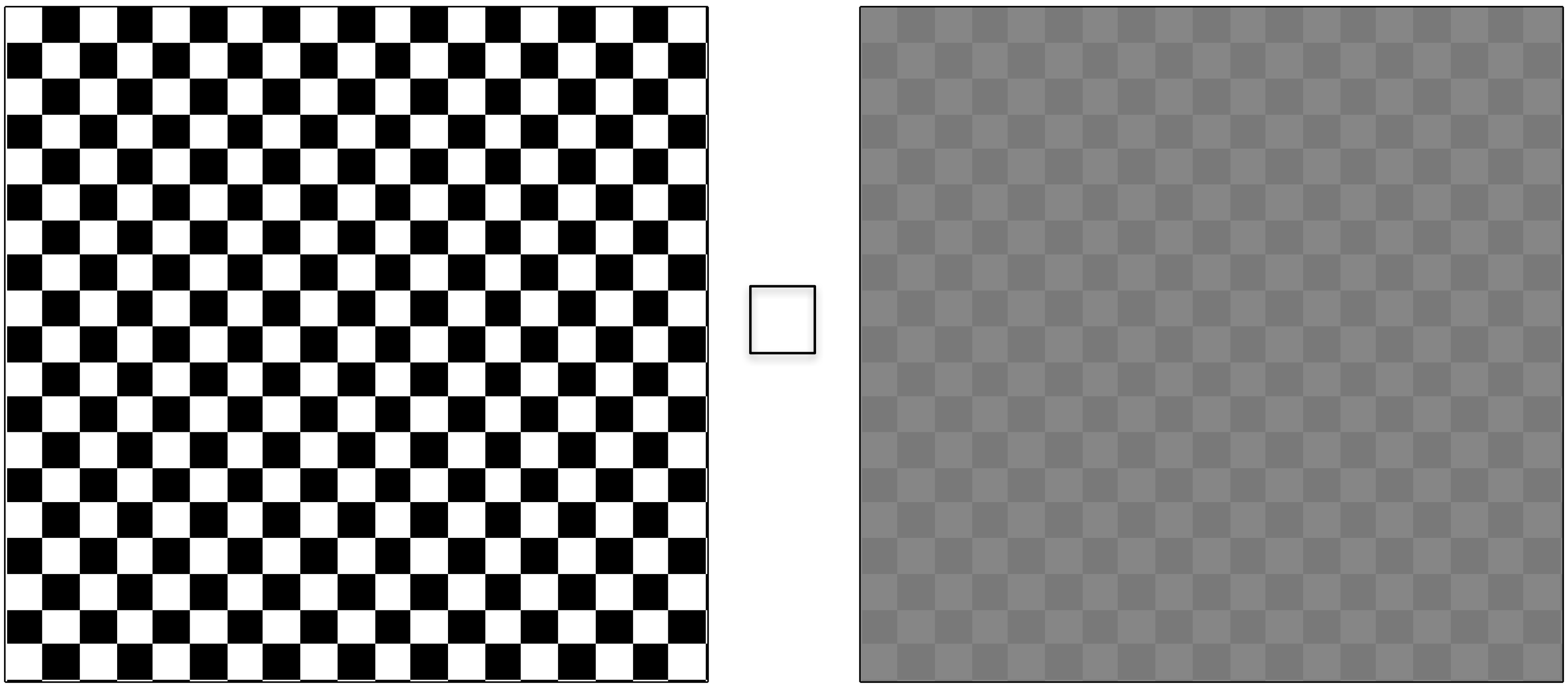
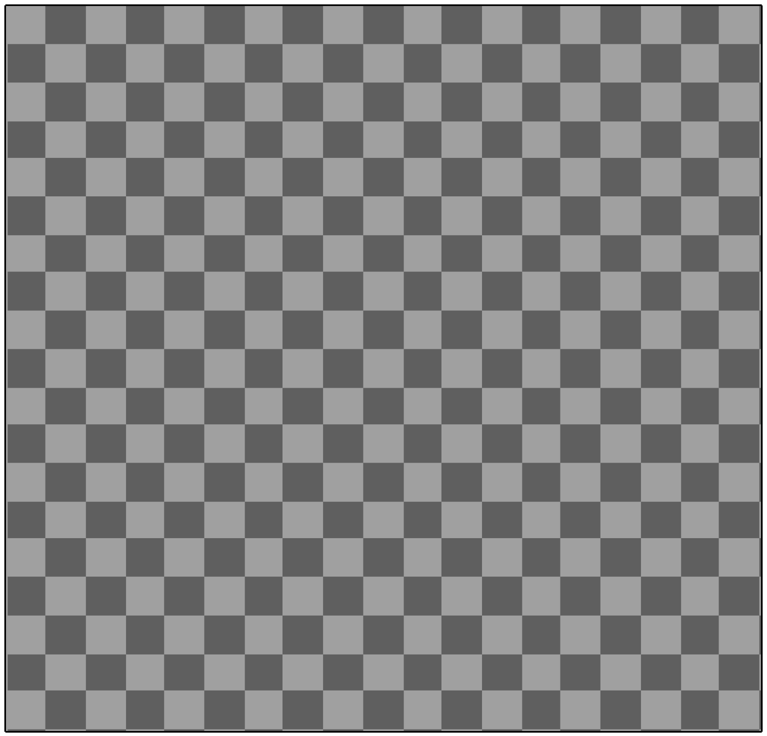
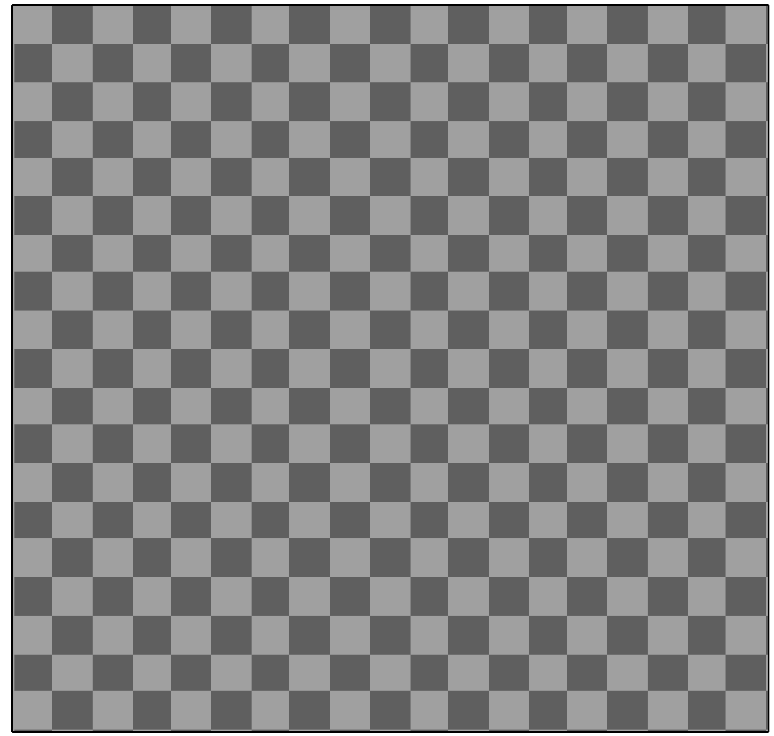


The visual system adapts to contrast

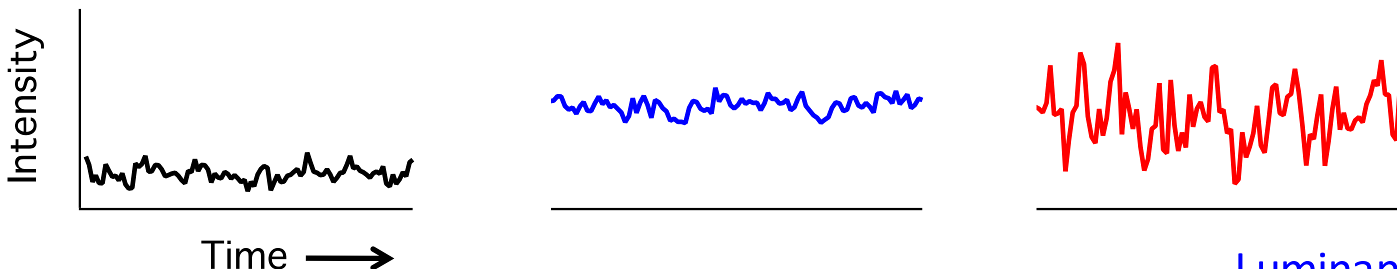


The visual system adapts to contrast

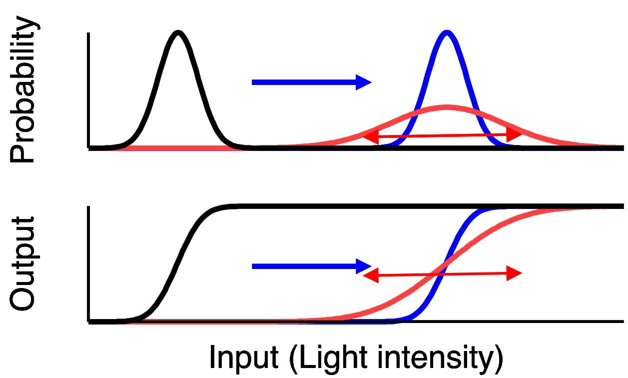




Functional importance of adaptation



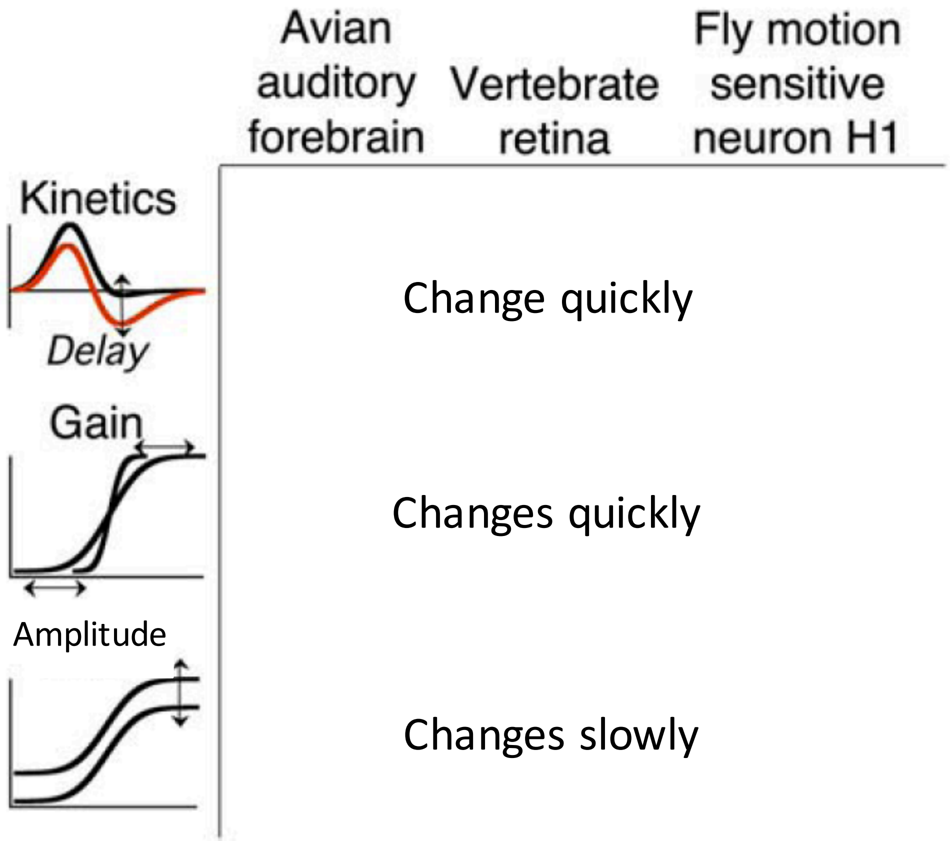
Luminance adaptation
Contrast adaptation



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

How can a neural circuit compute a higher-order statistic, and how can it change response properties?

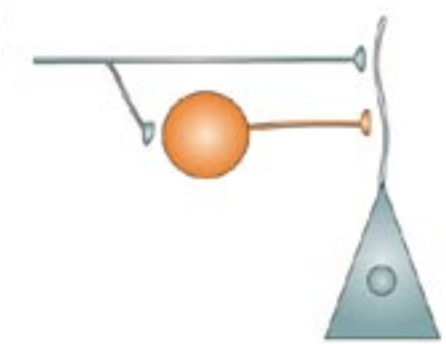
Common properties of contrast adaptation



Nagel & Doupe, 2006
Fairhall et al., 2001

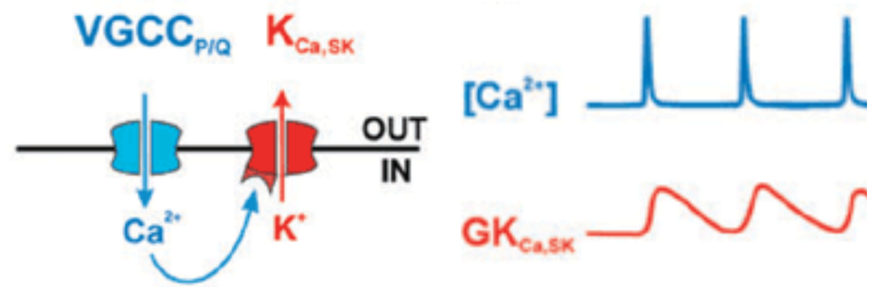
Change in sensitivity by *modulation*

Feedforward inhibition



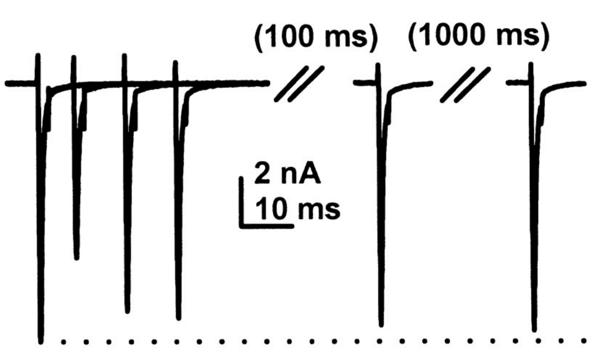
Feedback inhibition

Spike dependent conductances

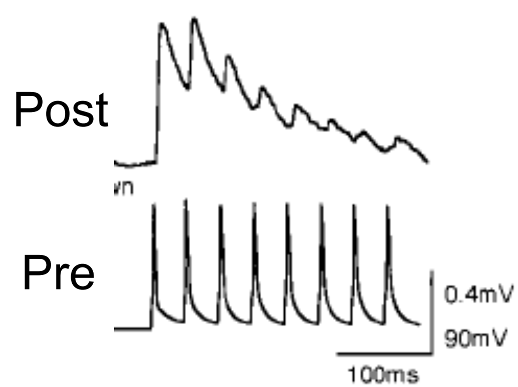


Change in sensitivity by *depletion*

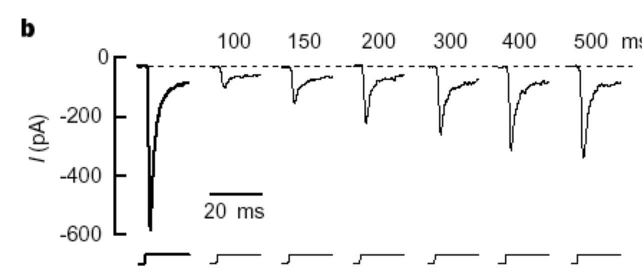
Ion channel inactivation



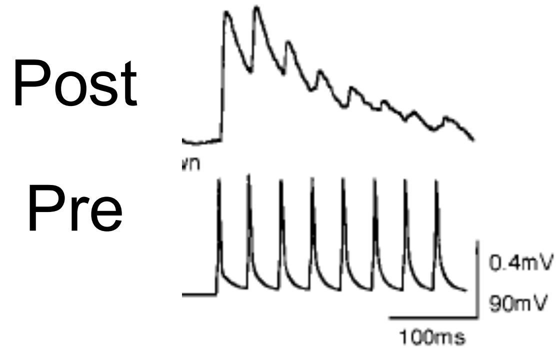
Short-term synaptic plasticity
synaptic depression

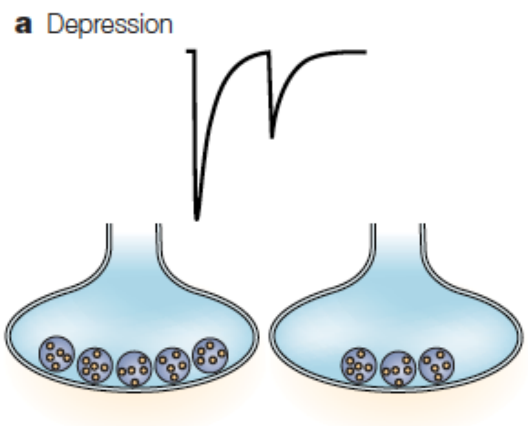


Receptor desensitization



Short-term synaptic plasticity – synaptic depression





Depletion of available vesicles as a mechanism for depression

n: Number of vesicle
p: Probability of vesicle release

Release = n x p

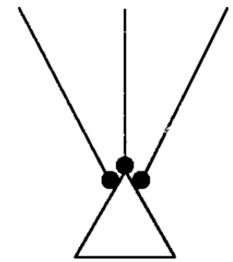
$$\frac{dn(t)}{dt} = \underbrace{\frac{1-n(t)}{\tau_r}}_{\text{replenishment}} \underbrace{- \sum_j \delta(t-t_j) \cdot p \cdot n(t)}_{\text{release}}$$

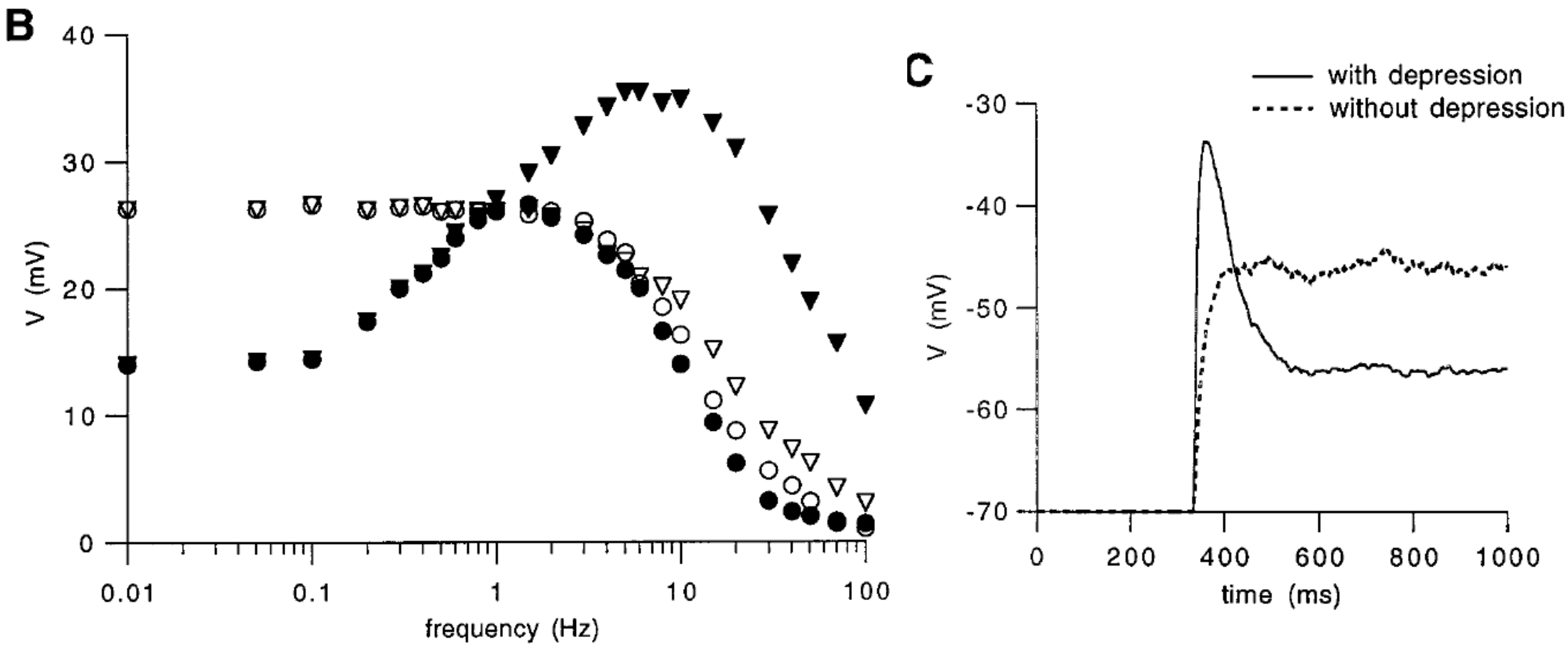
Hennig, 2013. Theoretical models of synaptic short term plasticity

Contrast adaptation and a model of synaptic depression

Single spike ● depressing
○ not depressing

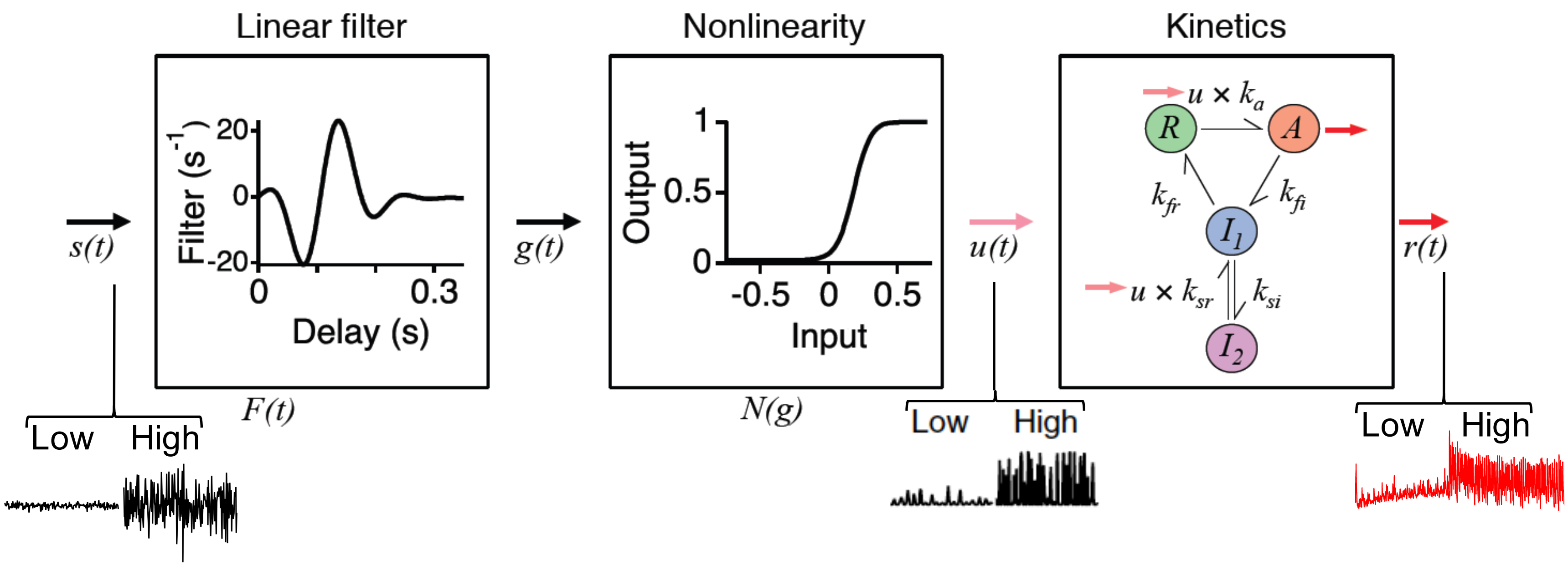
Spike trains ▼ depressing
▽ not depressing





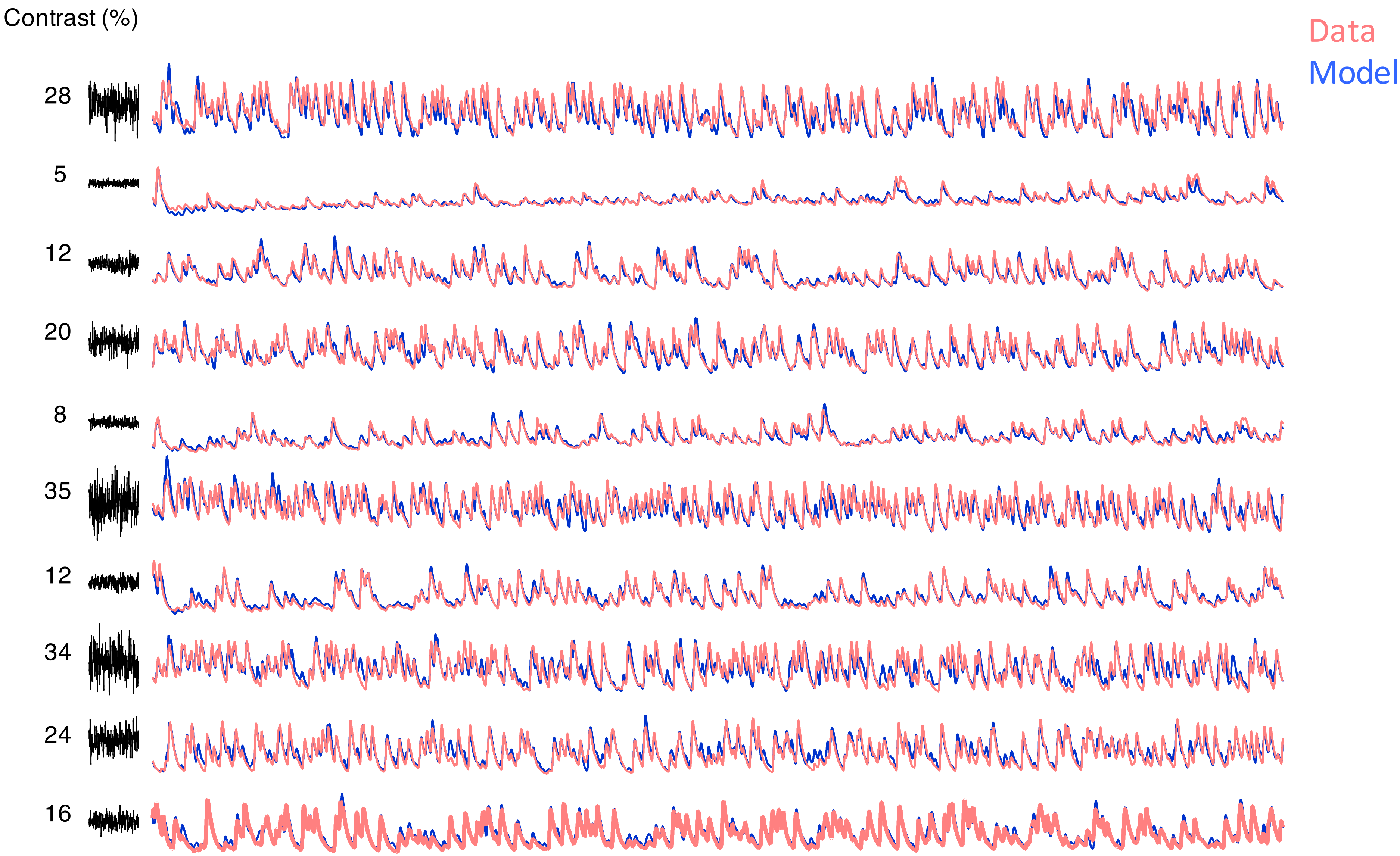
Synaptic depression and the temporal response characteristics of V1 cells.
Chance FS, Nelson SB, Abbott LF. (1998)

Biophysical model of contrast adaptation



Ozuysal & Baccus (2012)

The LNK captures membrane potential responses



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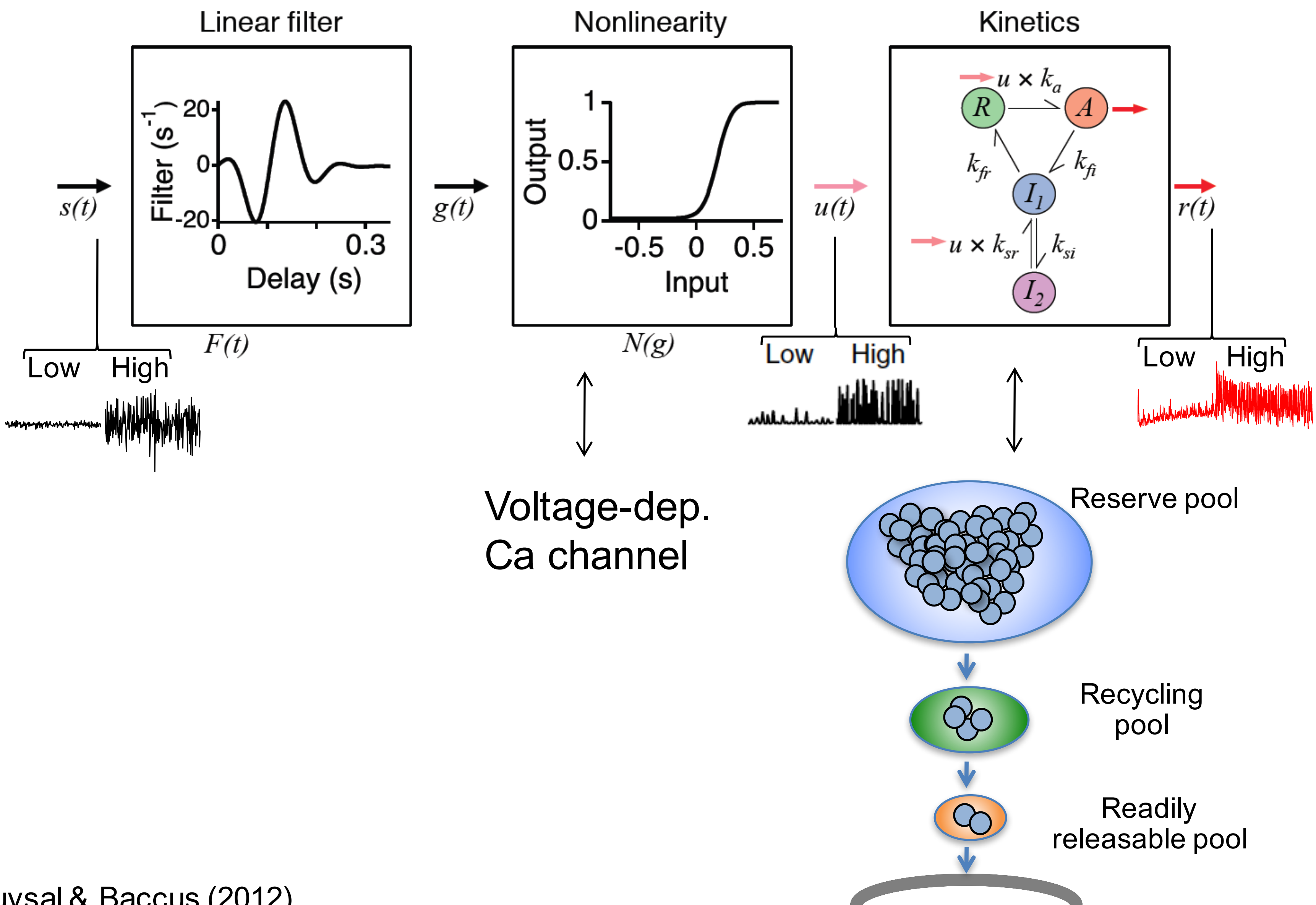
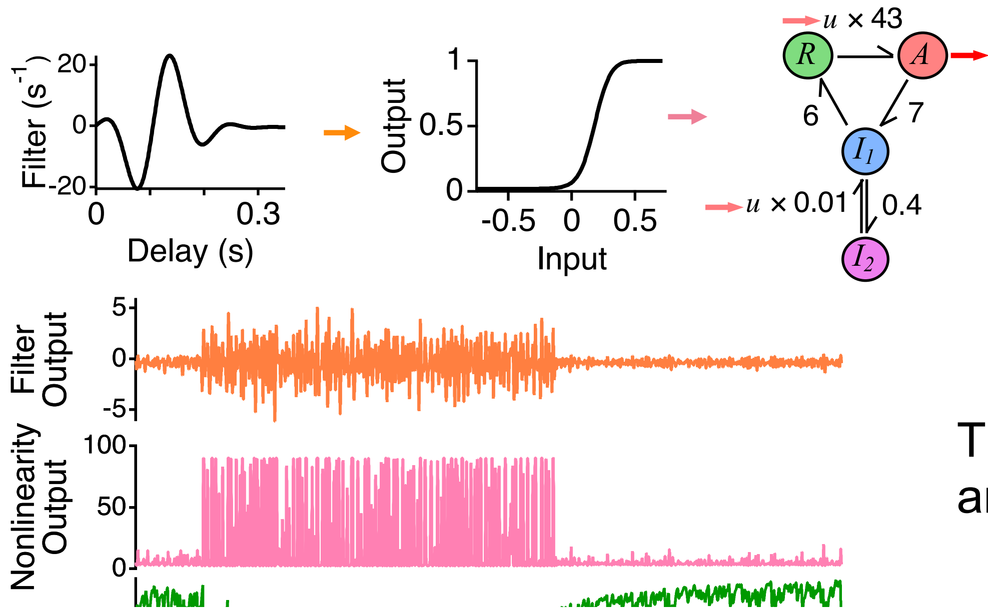


Ozuysal & Baccus (2012)



Threshold converts amplitude to mean

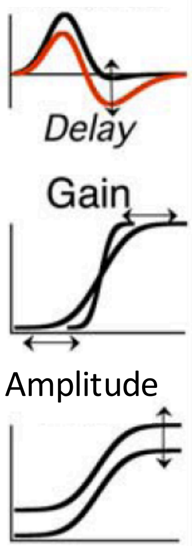
Change in rate constants change kinetics

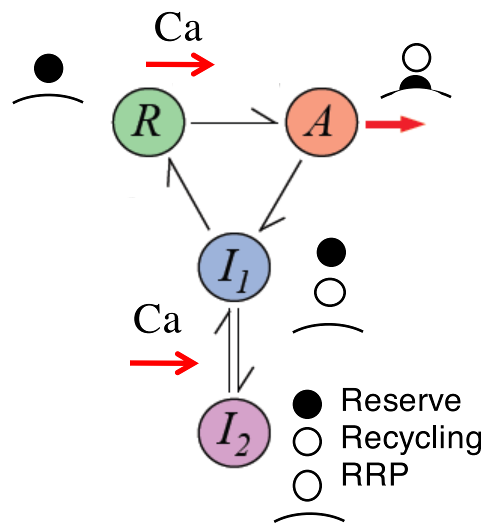
Depletion of resting state changes sensitivity

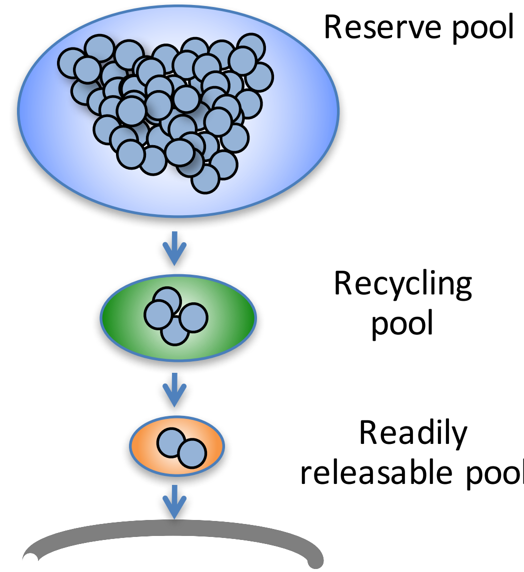
Inactivated states act as buffers

Theoretical explanations for biophysical properties

Temporal filtering







Why does the readily releasable pool deplete?

To produce large changes in gain.

Why have a recycling pool?

To give distinct dynamics for fast and slow adaptation.

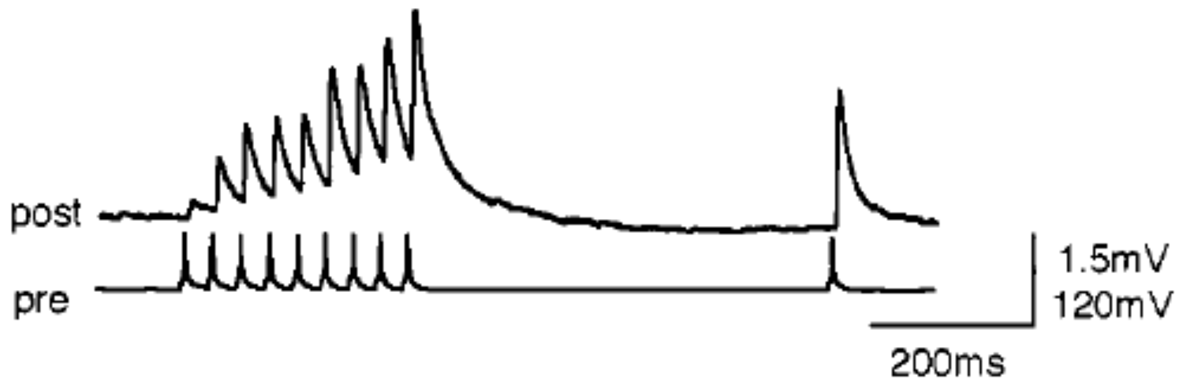
Why is the reserve pool so large?

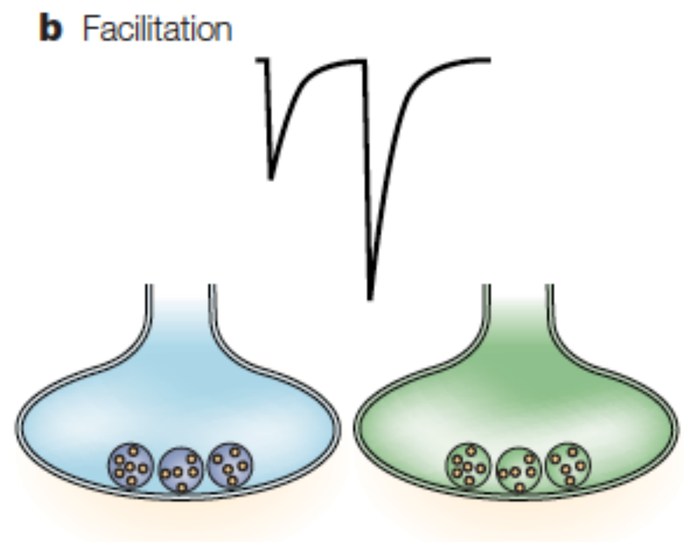
This may be a natural consequence of slow adaptation.

Why is slow vesicle movement calcium dependent?

This may set the slow adaptive timescale.

Short-term synaptic plasticity – synaptic facilitation

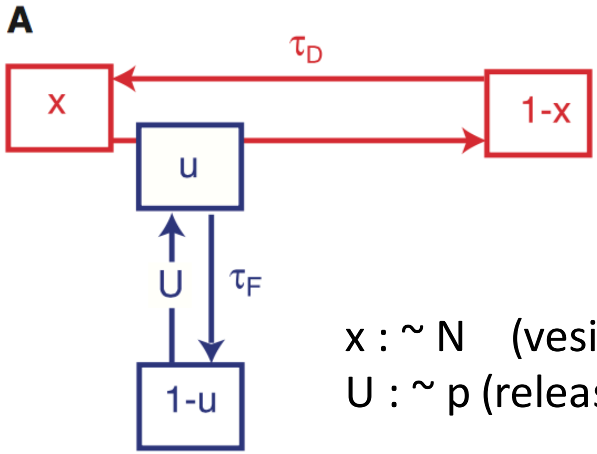




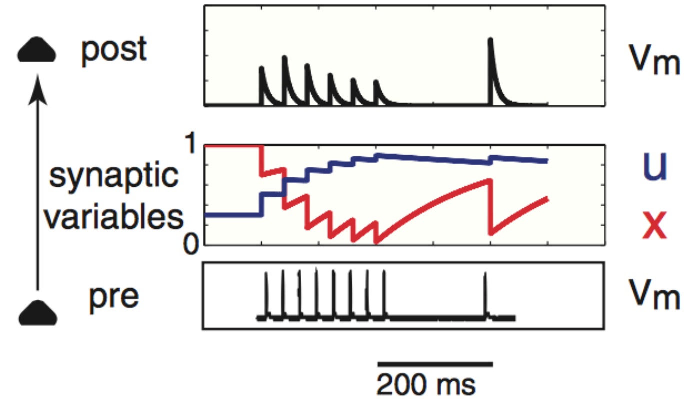
Residual calcium as a mechanism for increased release

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

Proposal for synaptic facilitation in short-term memory



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

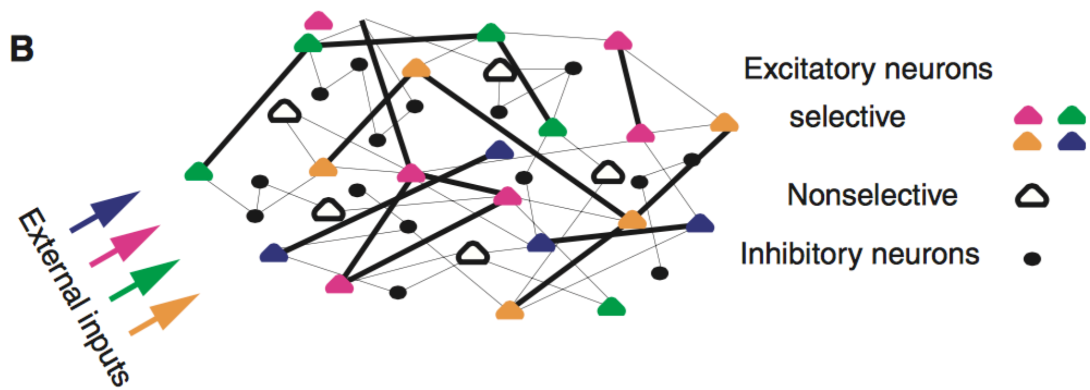


Release & Replenishment

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

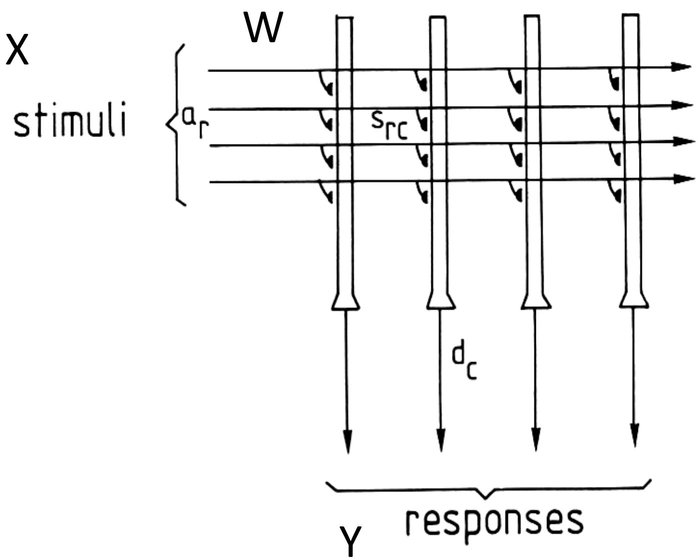
Facilitation

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



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	X		Y
m × n	n × 1	=	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.

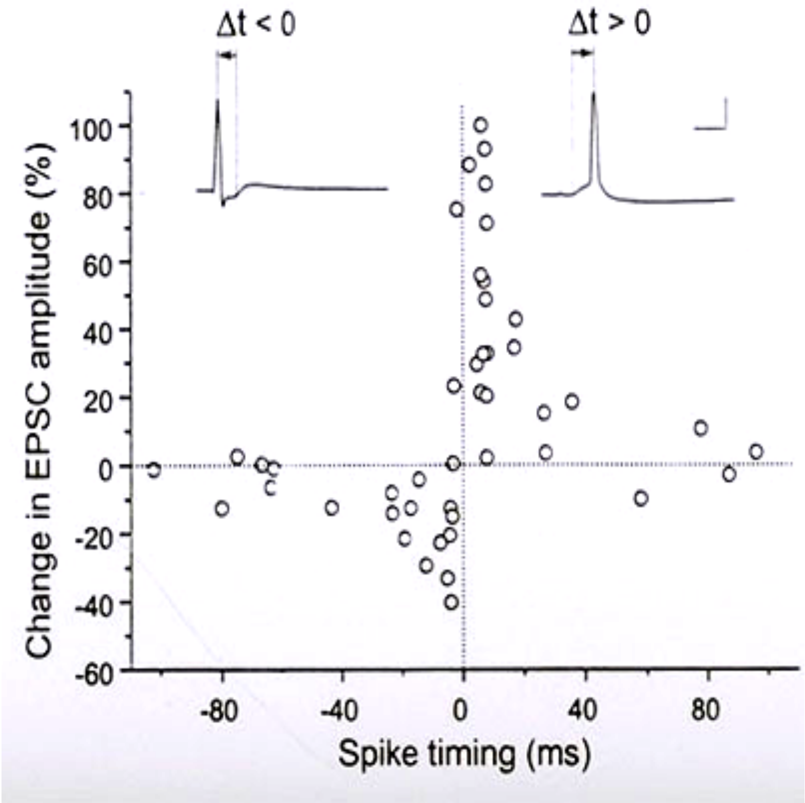
Hebbian plasticity

A excites B: Coincidence leads to greater release

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

Hebbian spike timing plasticity (STDP)

hippocampal neurons



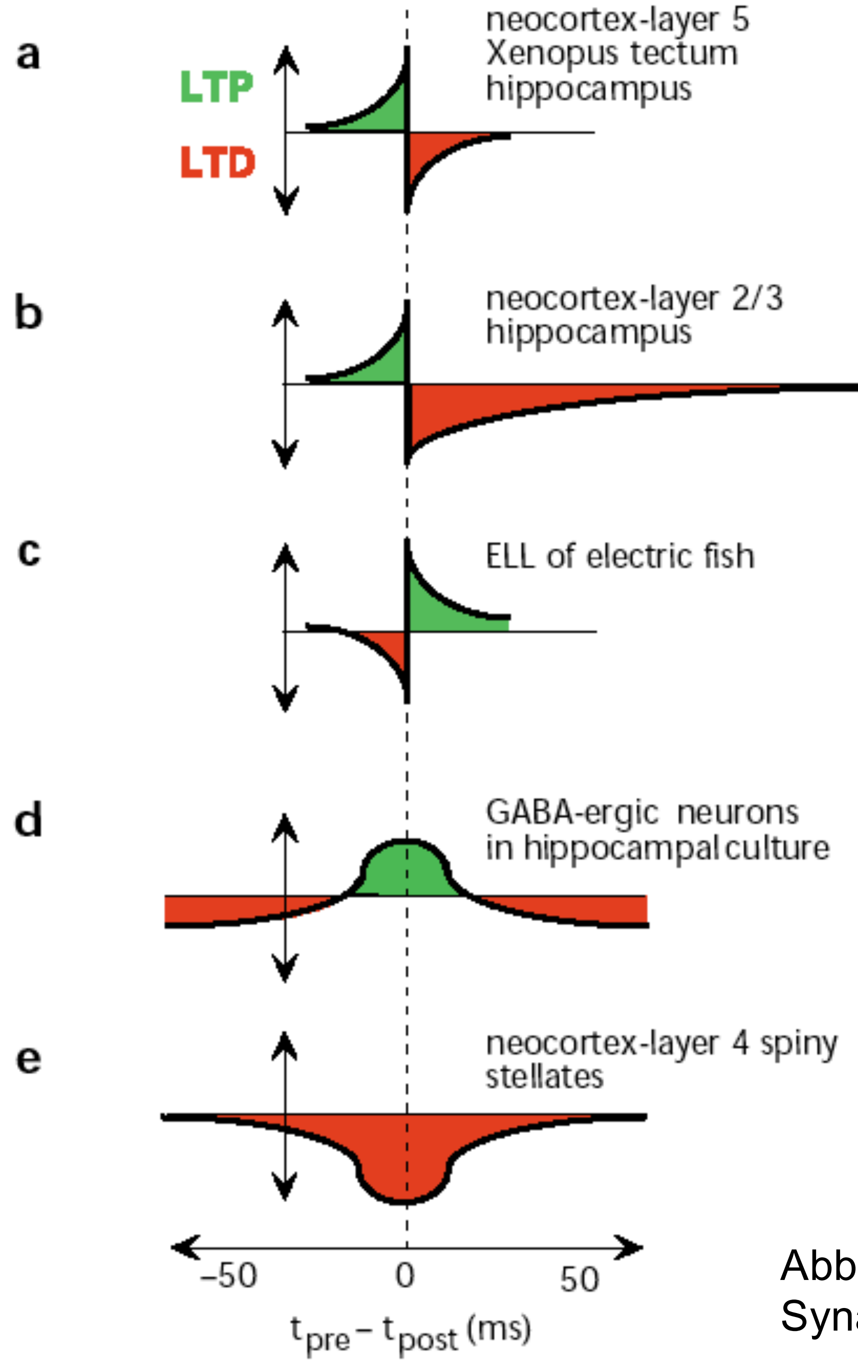
Pre before Post

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

Bi & Poo (1998)

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

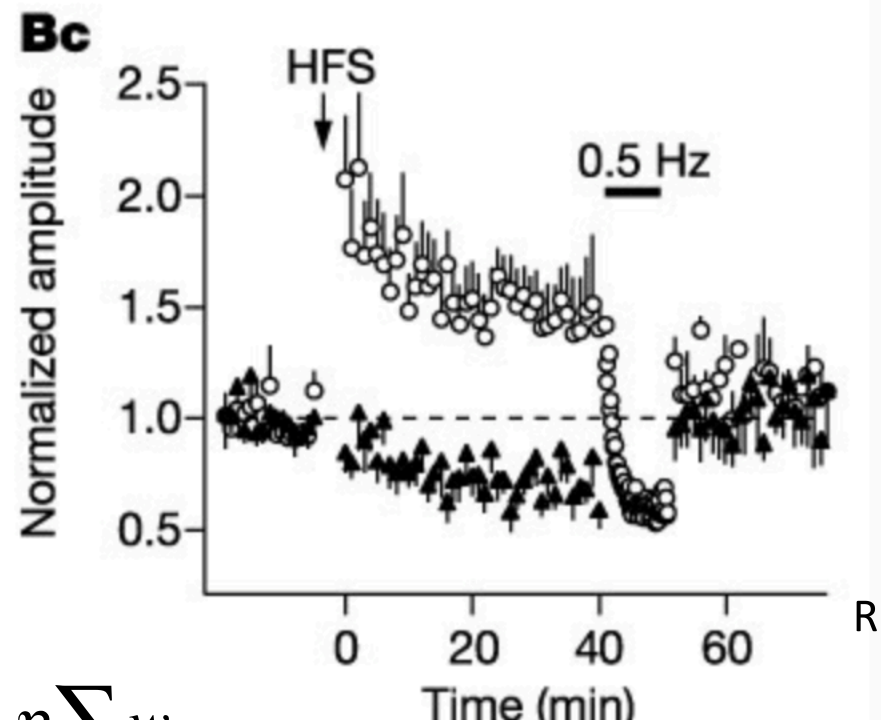
Different varieties of Spike-timing dependent plasticity



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 $$\frac{dw_{ji}}{dt} \propto x_i y_j - y_j^2 w_{ji}$$