Synaptic plasticity and learning

James Humble

November 7th 2011

Learning outcomes

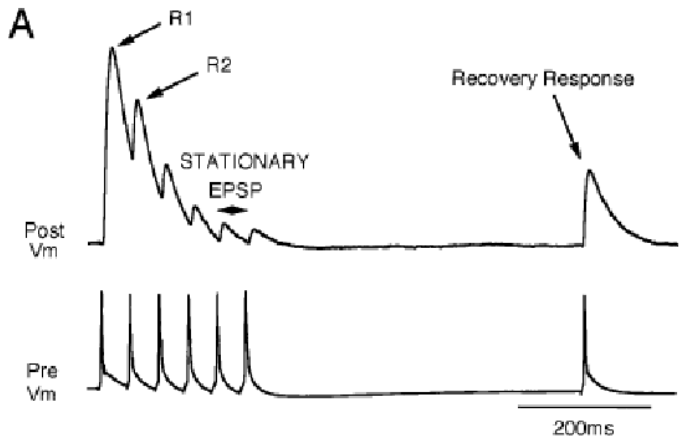
- Identify different types of plasticity.
- Describe current biological knowledge on short and long term plasticity.
- Demonstrate how plasticity can be implemented computationally.

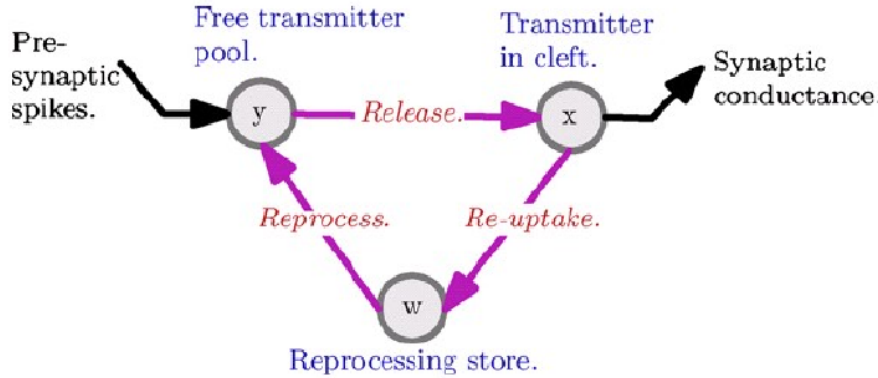
Outline

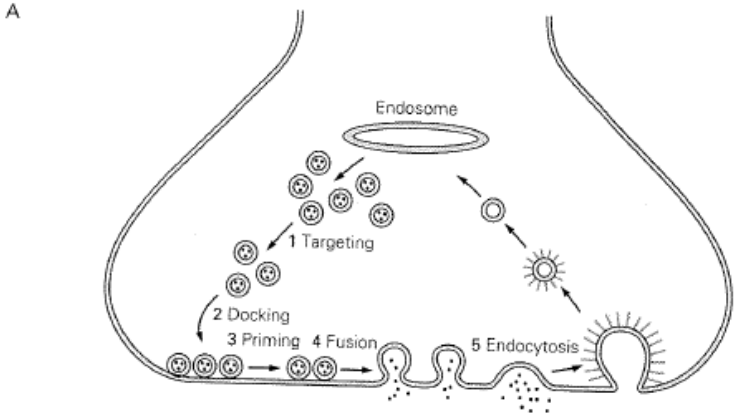
Section 1

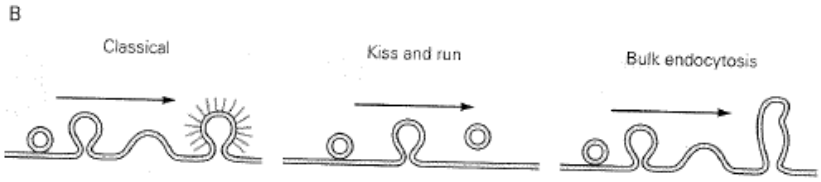
Short term plasticity

Synaptic depression

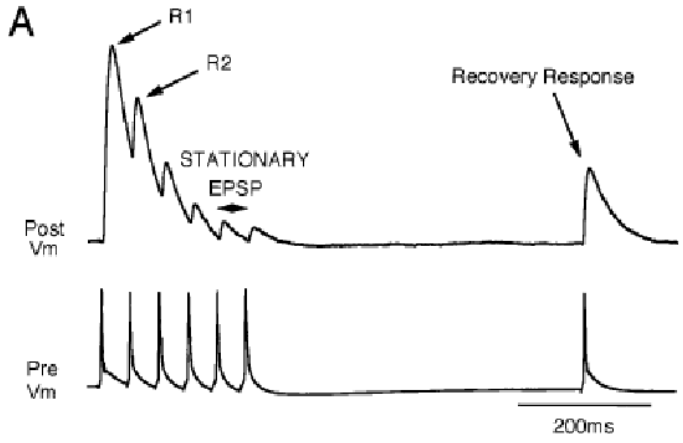


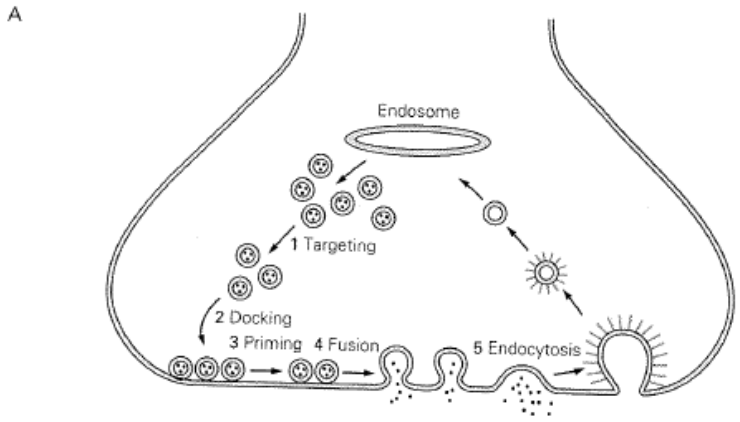


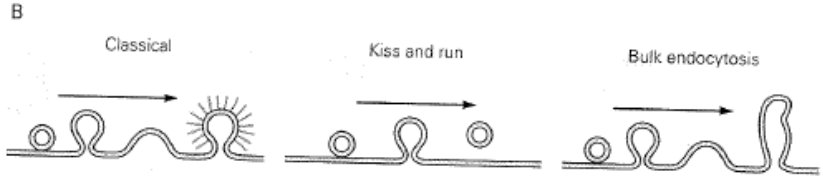


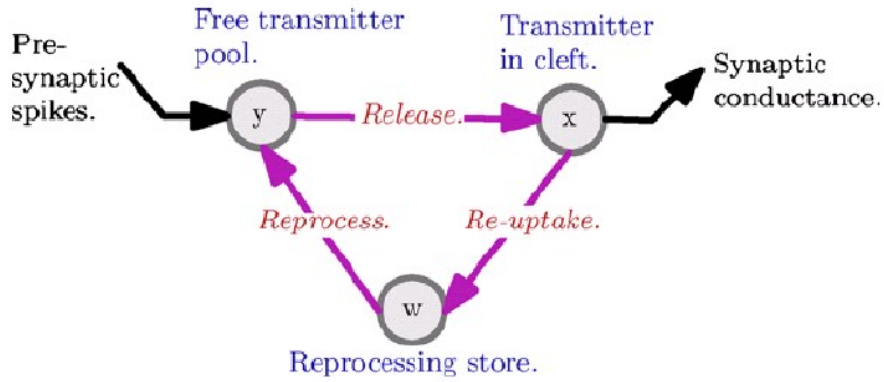


Synaptic depression



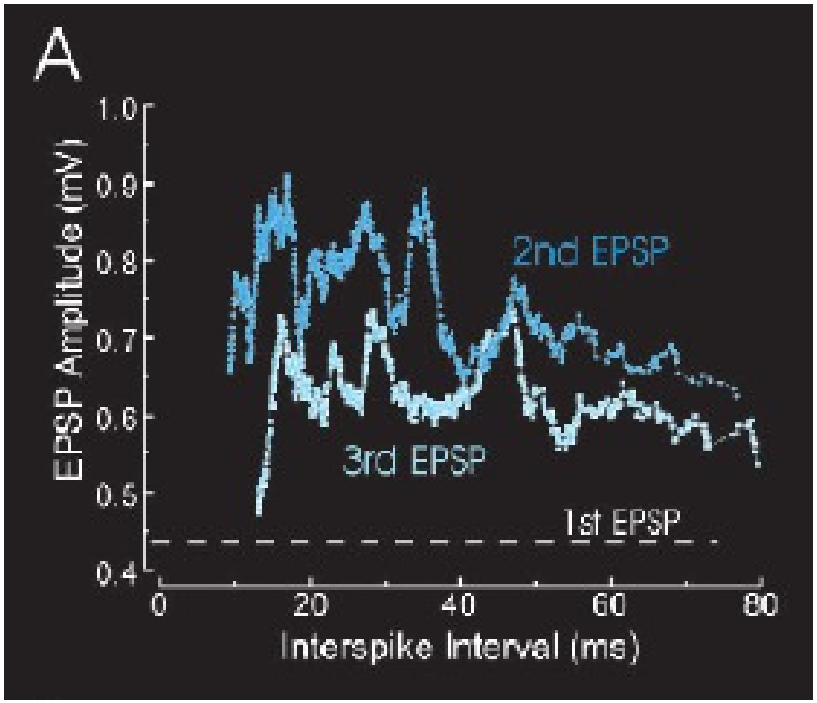


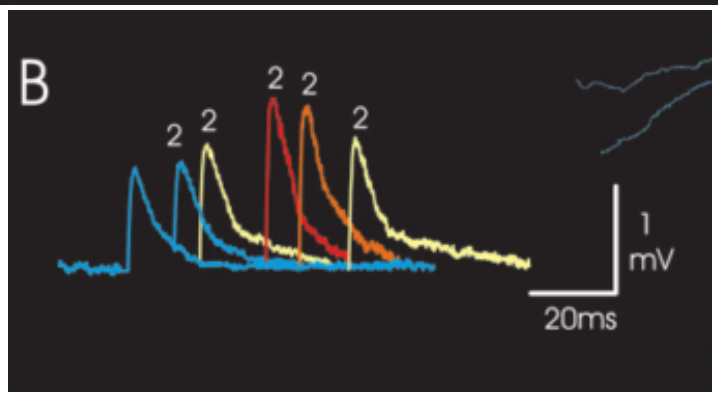




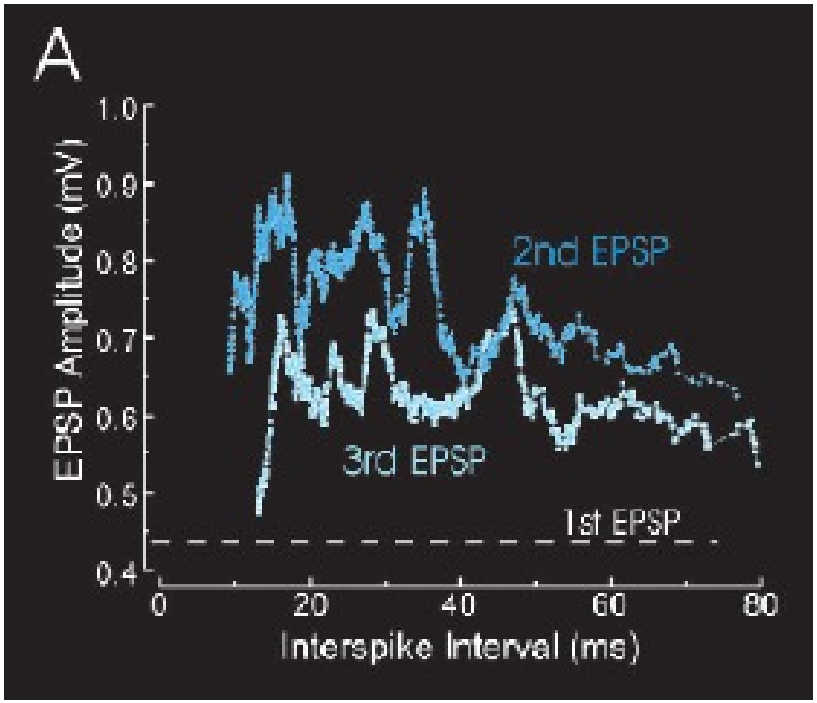
- Depletion of the readily releasable pool
- Inactivation of release sites
- Reducation in calcium influx

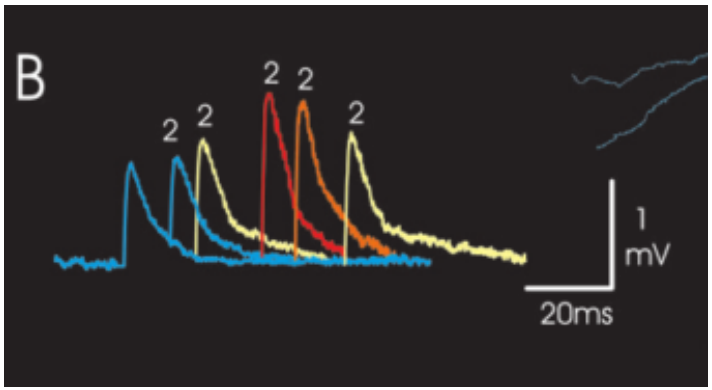
Synaptic facilitation





Synaptic facilitation



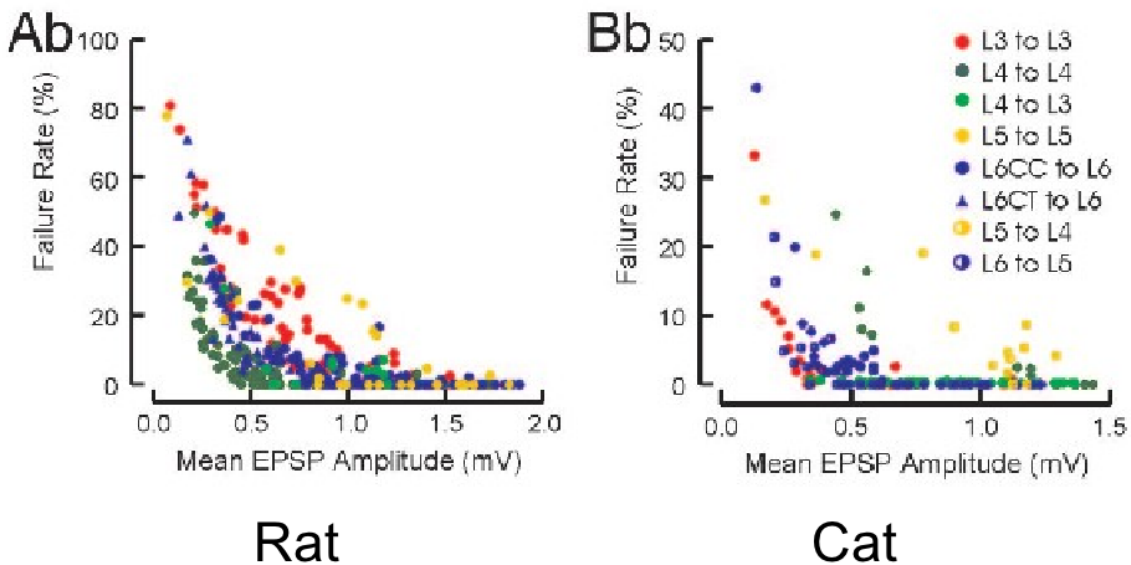


West et al., 2006

- Residual calcium may increase release probability
- Saturation of calcium buffers
- Increase of calcium currents

Synaptic failure

- Release of transmitter vesicles is stochastic
- Typical synapses release 4 to 15 vesicles
- Complete transmission failure is possible
- Some synapses are indeed very unreliable

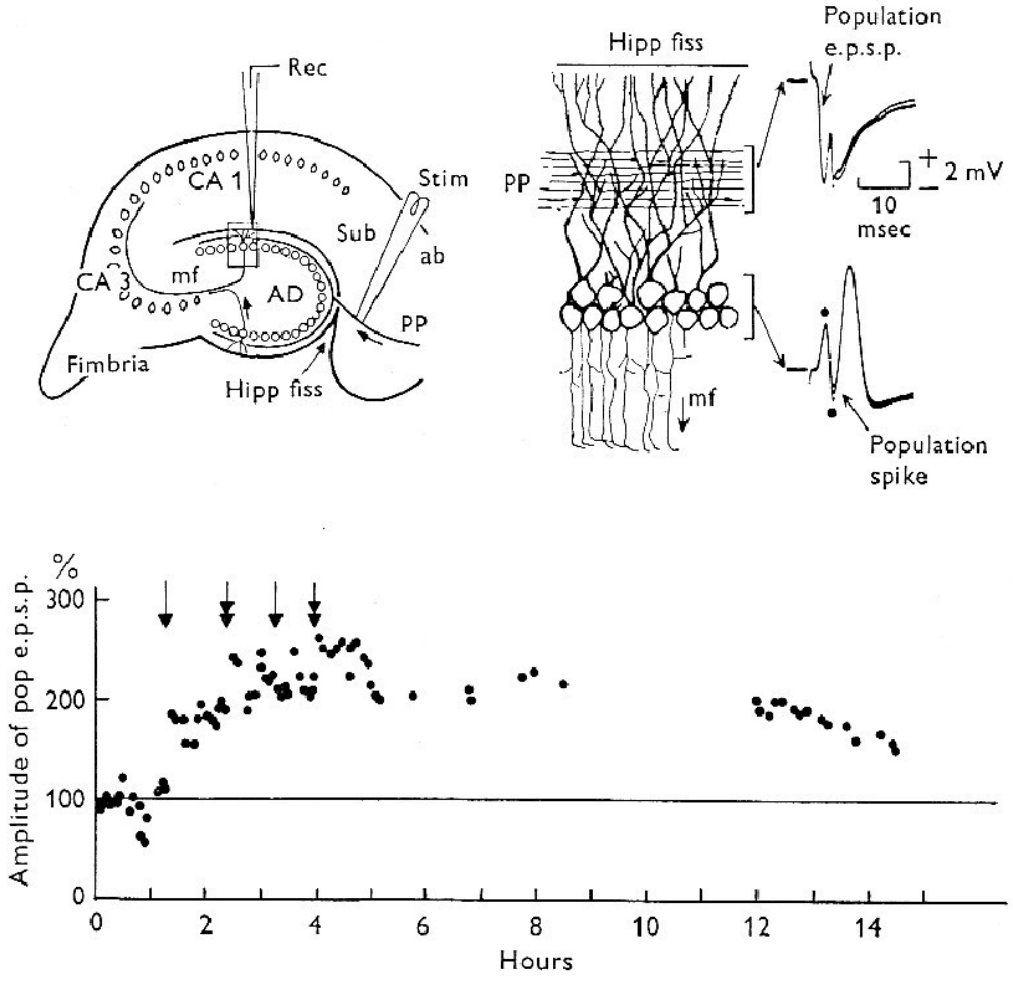


Rat Cat

Section 2

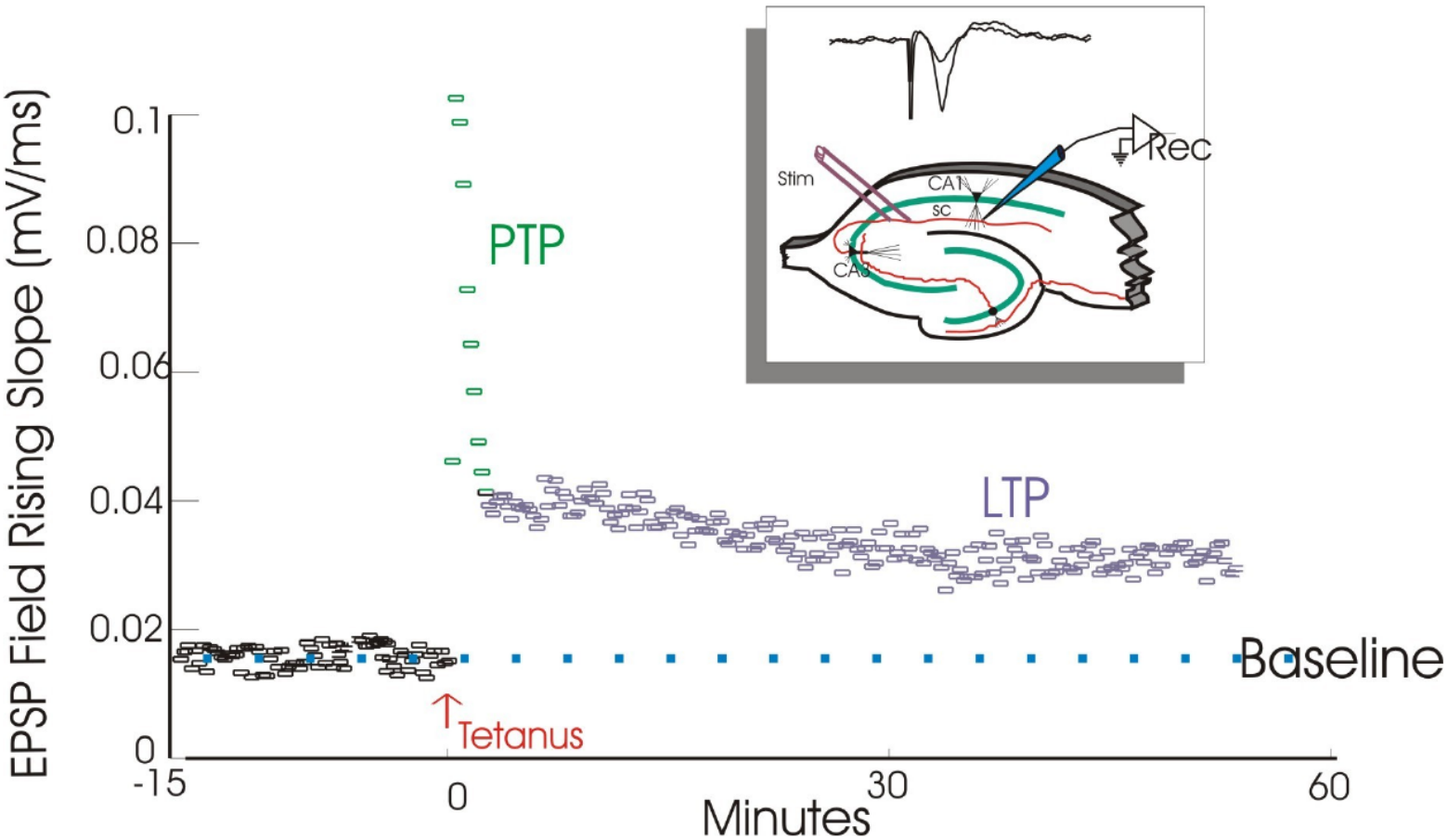
Long term plasticity

LTP



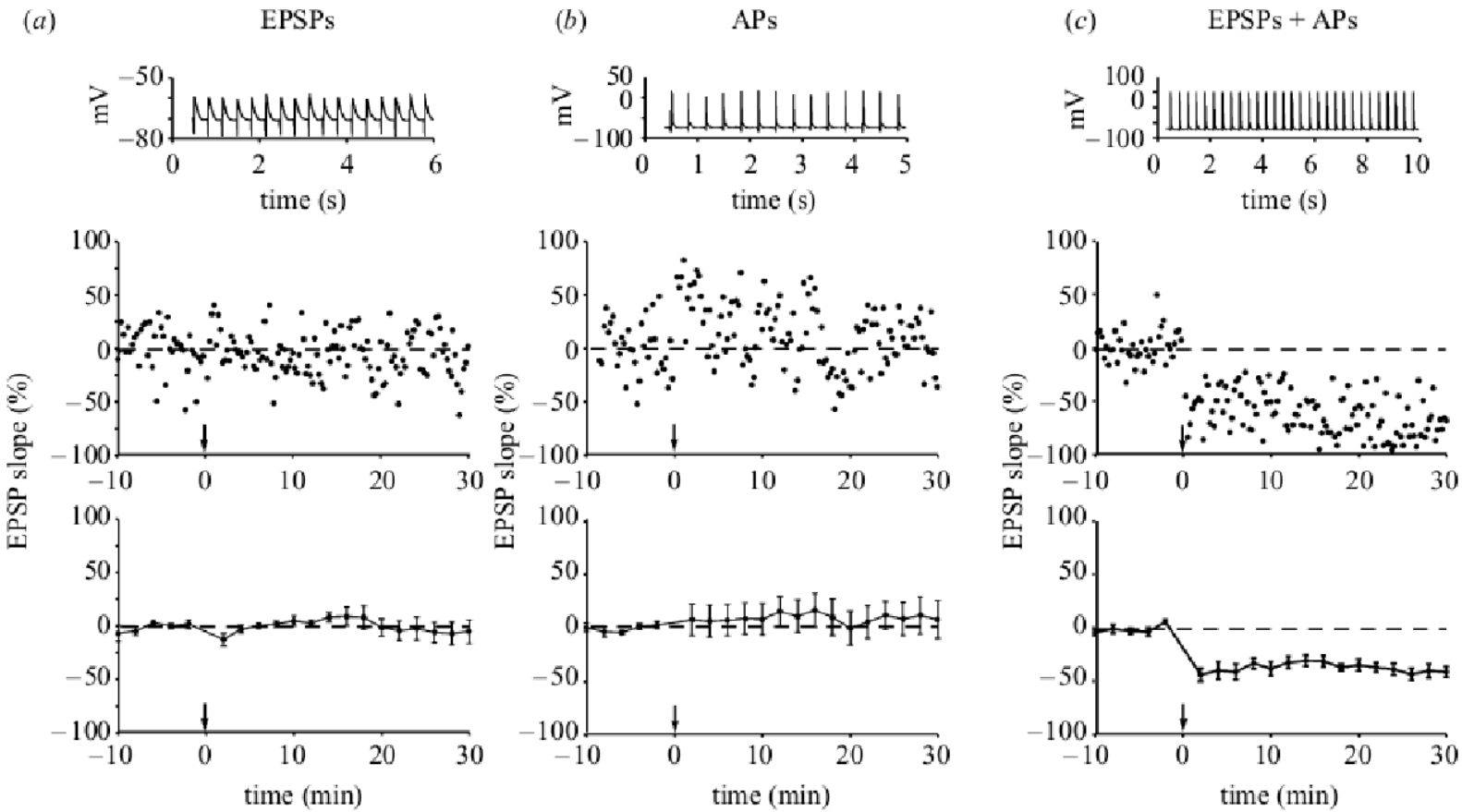
Bliss&Lomo, 1973

LTP continued

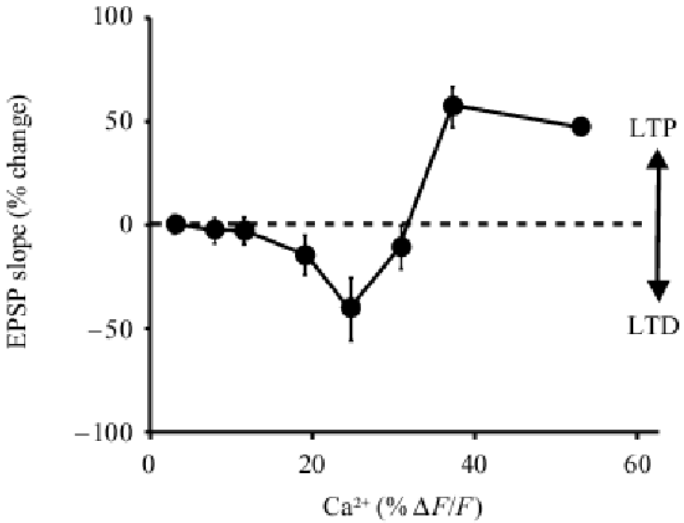


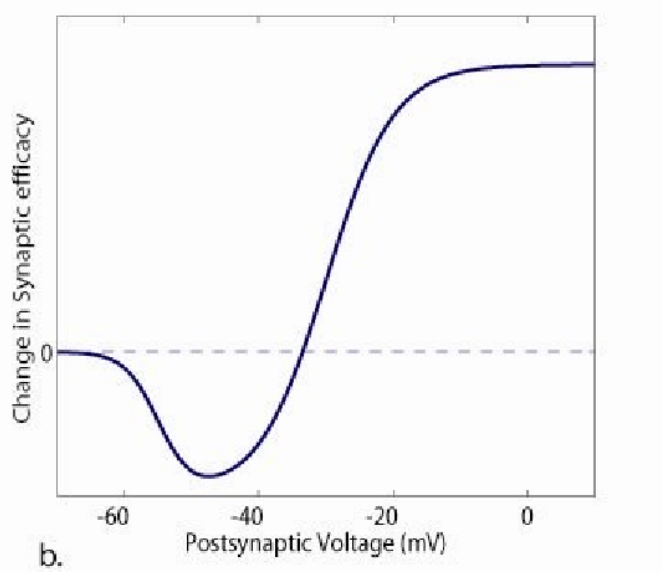
Paradiso et al, 2007

LTD


(a)
EPSPs
mV
−50
−80
0
2
4
6
time (s)
(b)
APs
mV
50
0
−100
0
1
2
3
4
5
time (s)
(c)
EPSPs + APs
mV
100
0
−100
0
2
4
6
8
10
time (s)
EPSP slope (%)
100
50
0
−50
−100
−10
0
10
20
30
time (min)

Voltage and calcium dependency





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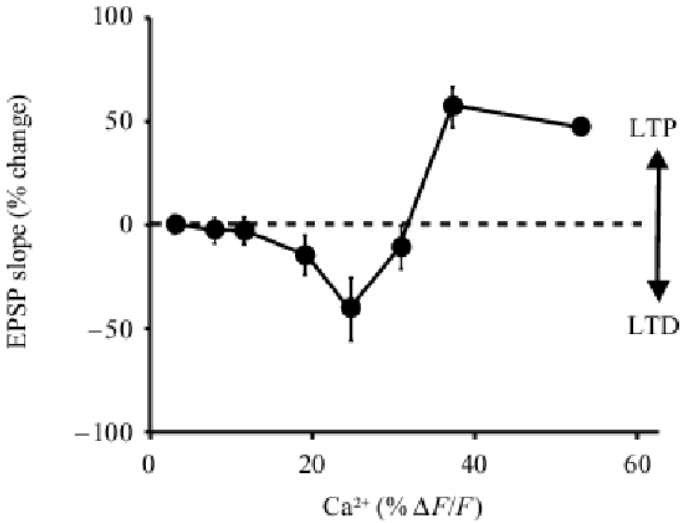
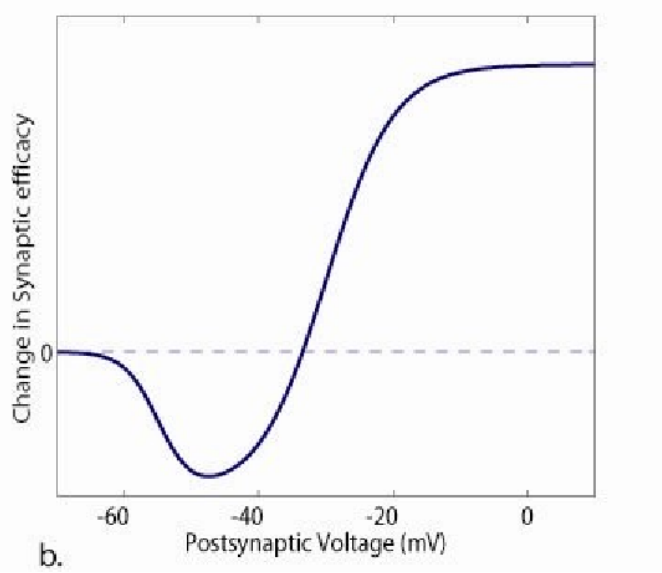
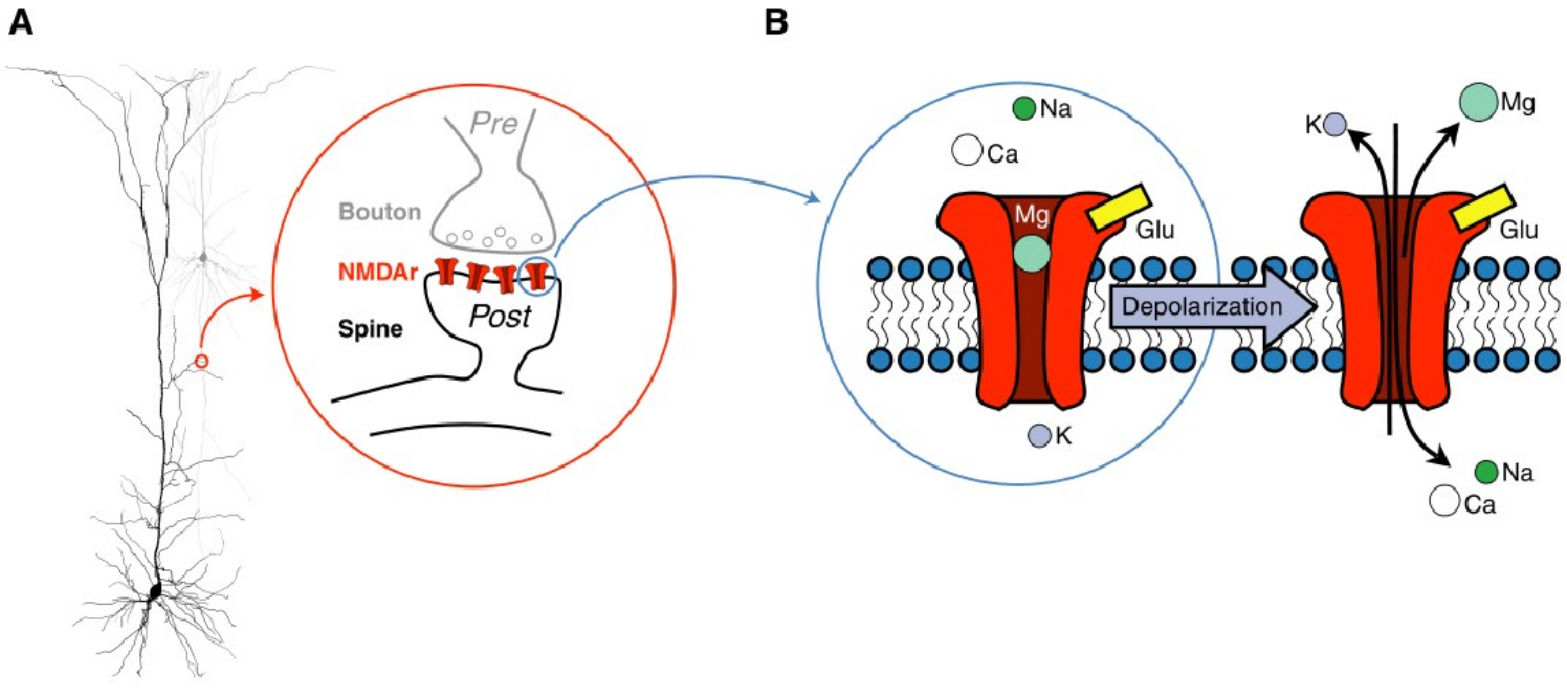




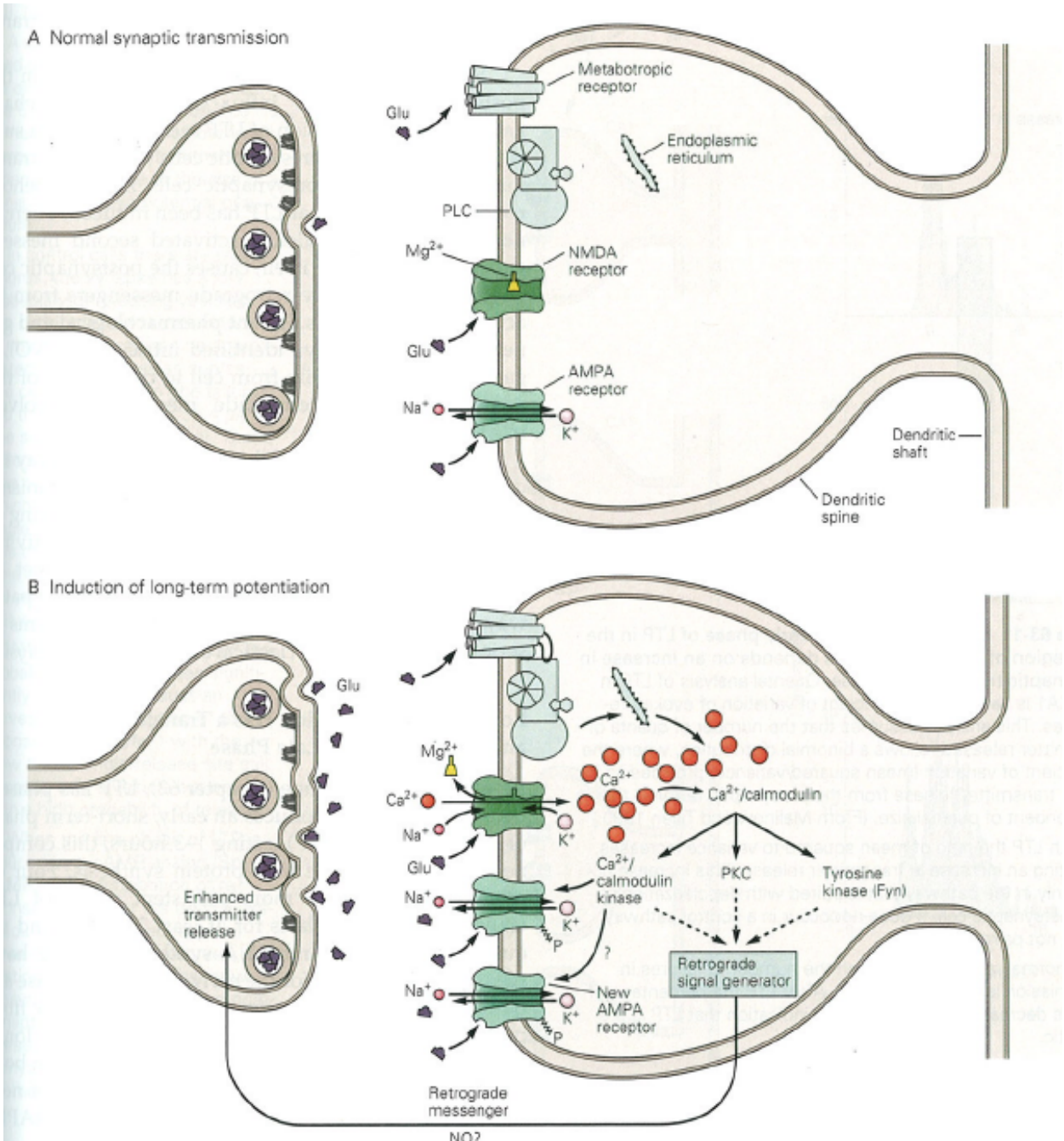
- LTP and LTD seem to be dependent on:
  - calcium levels
  - membrane voltage
- Calcium levels are usualy high when membrane potential is also high.
- High levels are associated with LTP.

What happens at the synapse?

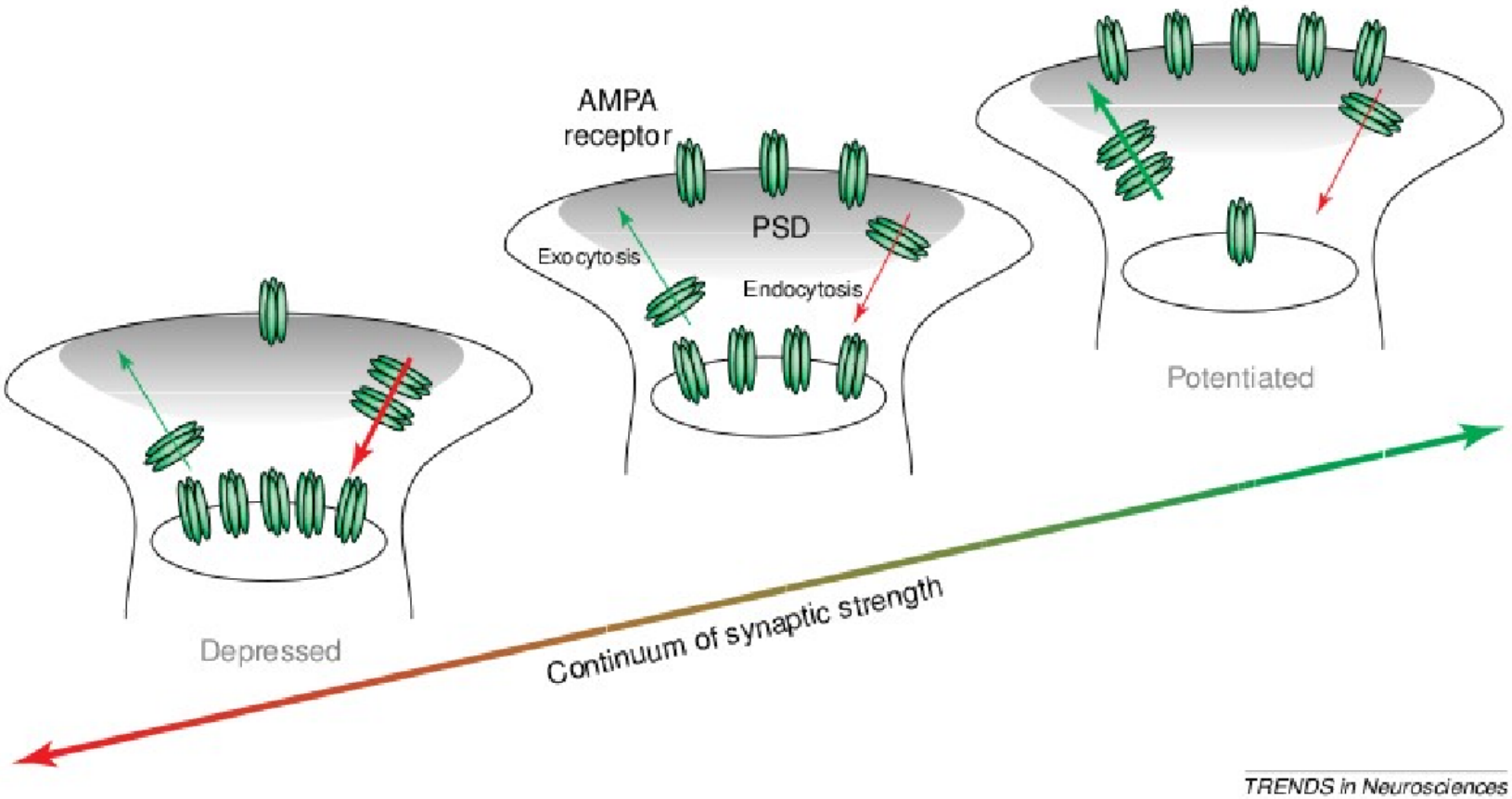


A magnesium block is removed from NMDA receptors at high voltages. Sodium, potassium and calcium can then then flow.

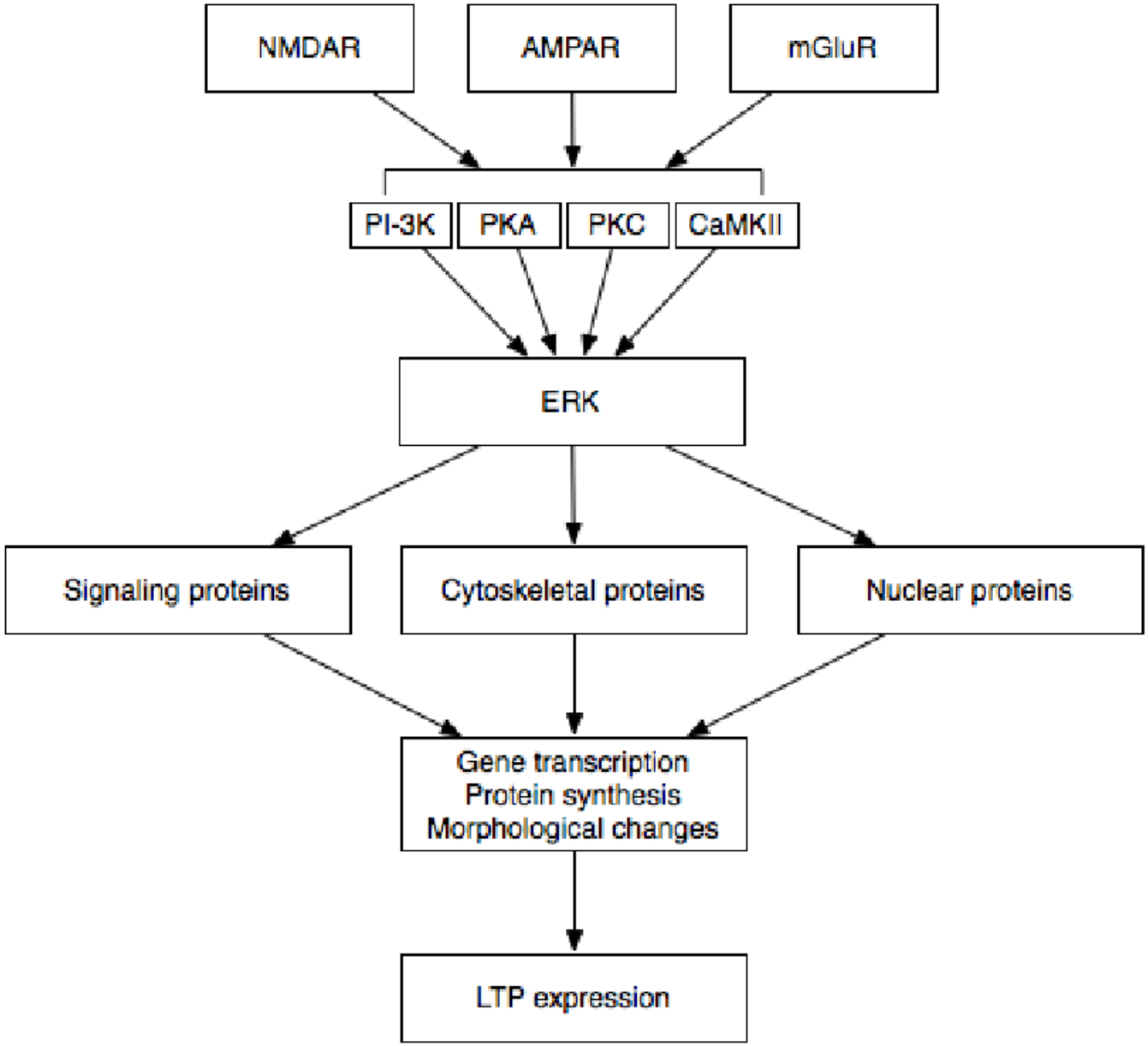
What happens at the synapse? cntd.



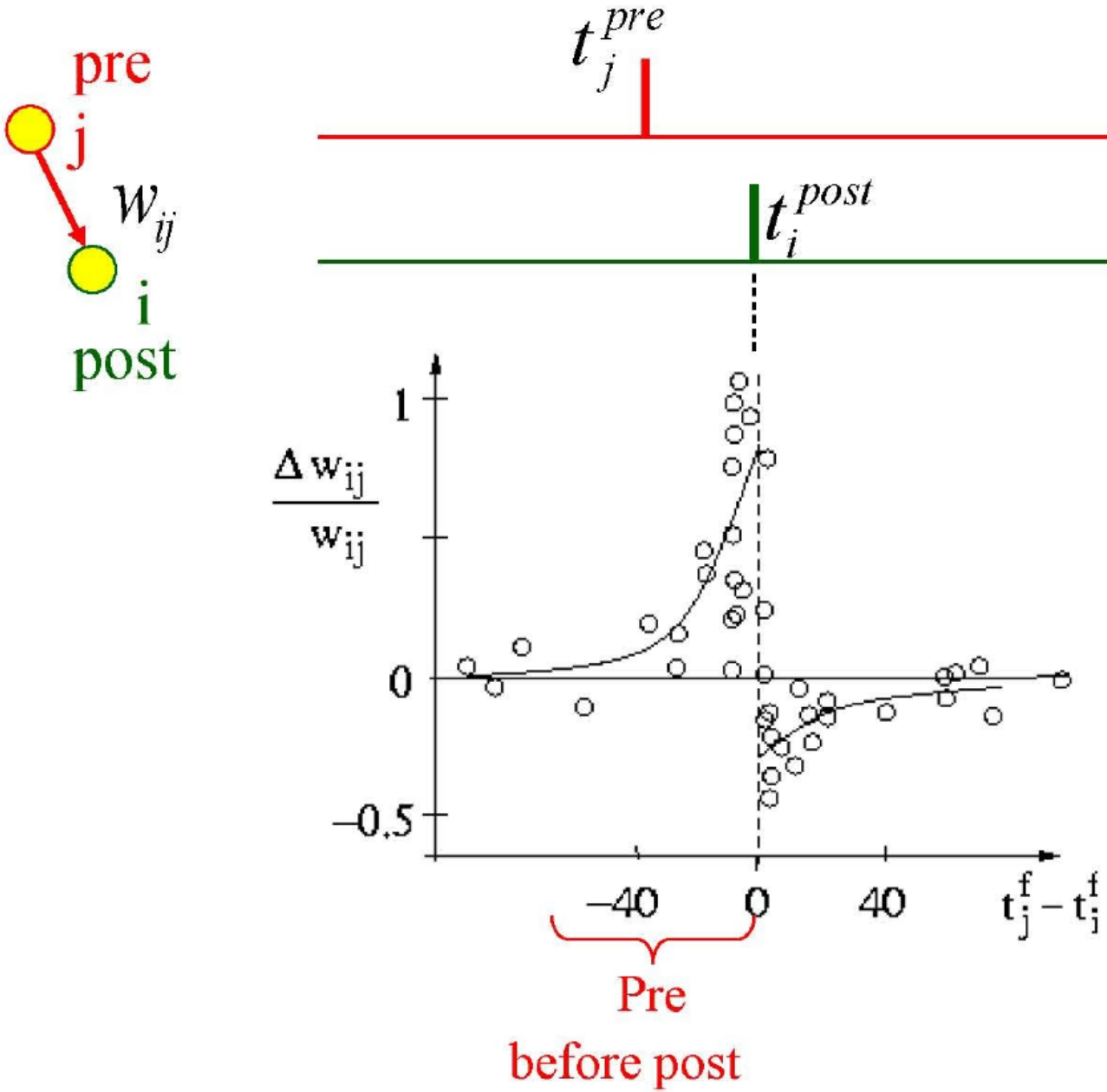
AMPA receptors



Late LTP


NMDAR
AMPAR
mGluR
PI-3K
PKA
PKC
CaMKII
ERK
Signaling proteins
Cytoskeletal proteins
Nuclear proteins
Gene transcription
Protein synthesis
Morphological changes
LTP expression

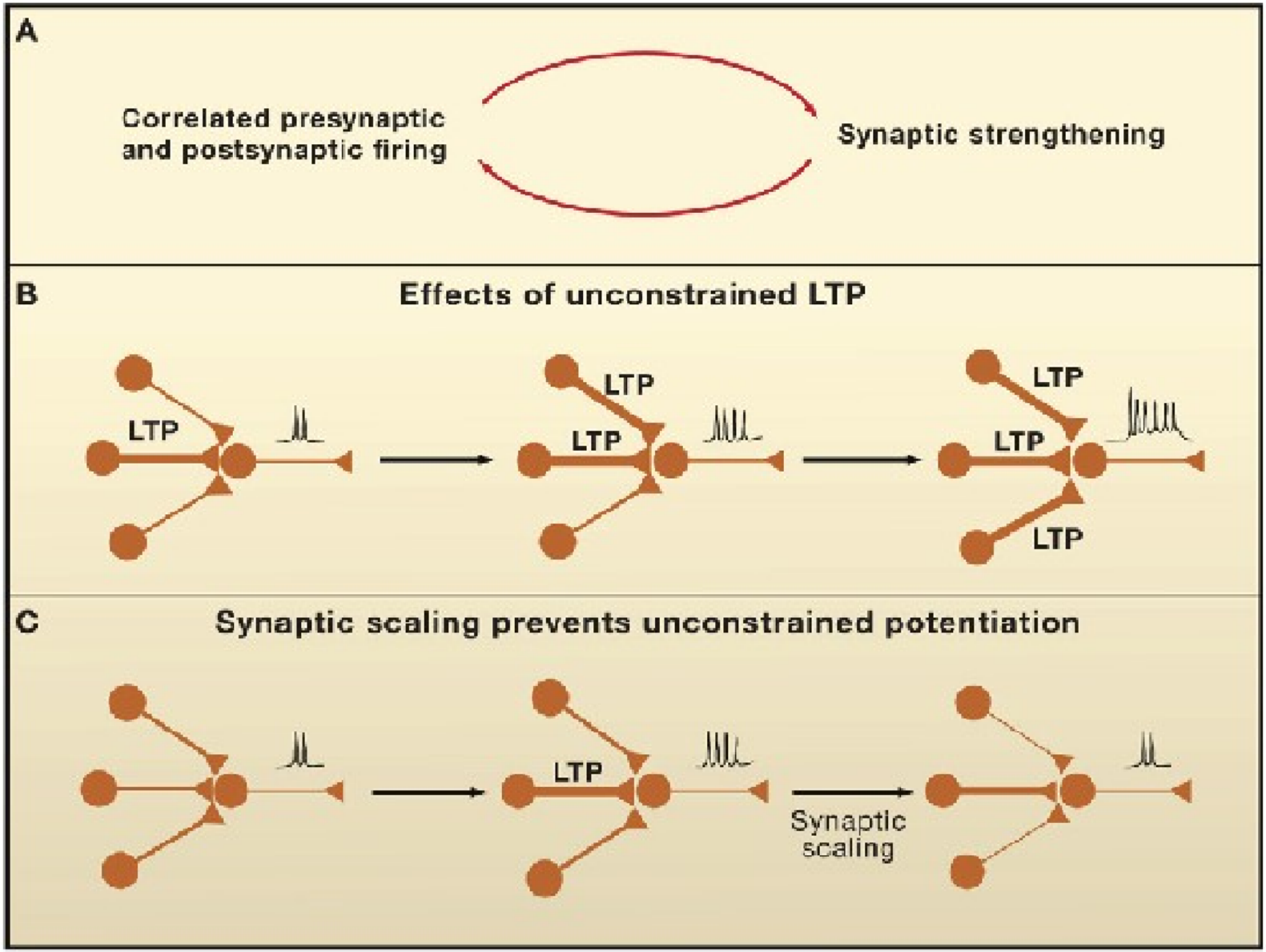
STDP


pre
j
w_{ij}
i
post
t_j^{pre}
t_i^{post}
$\frac{\Delta w_{ij}}{w_{ij}}$
1
0
–0.5
–40
0
40
$t_j^f - t_i^f$
Pre
before post

Heterosynaptic plasticity

- LTP/LTD on one pathway can be associated with a reversal, respectively, on another.
- Previous LTP can lead to easier LTD
- Can be both pre- and postsyanptic.
- Might be linked to calcium diffusion.

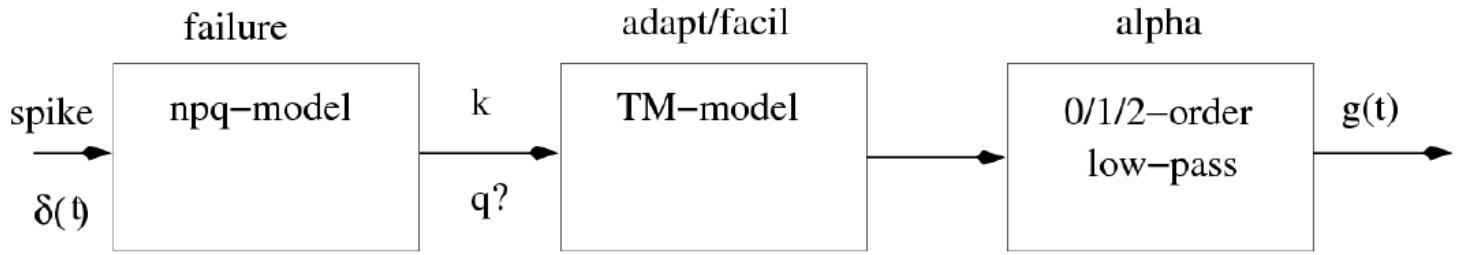
Homeostasis



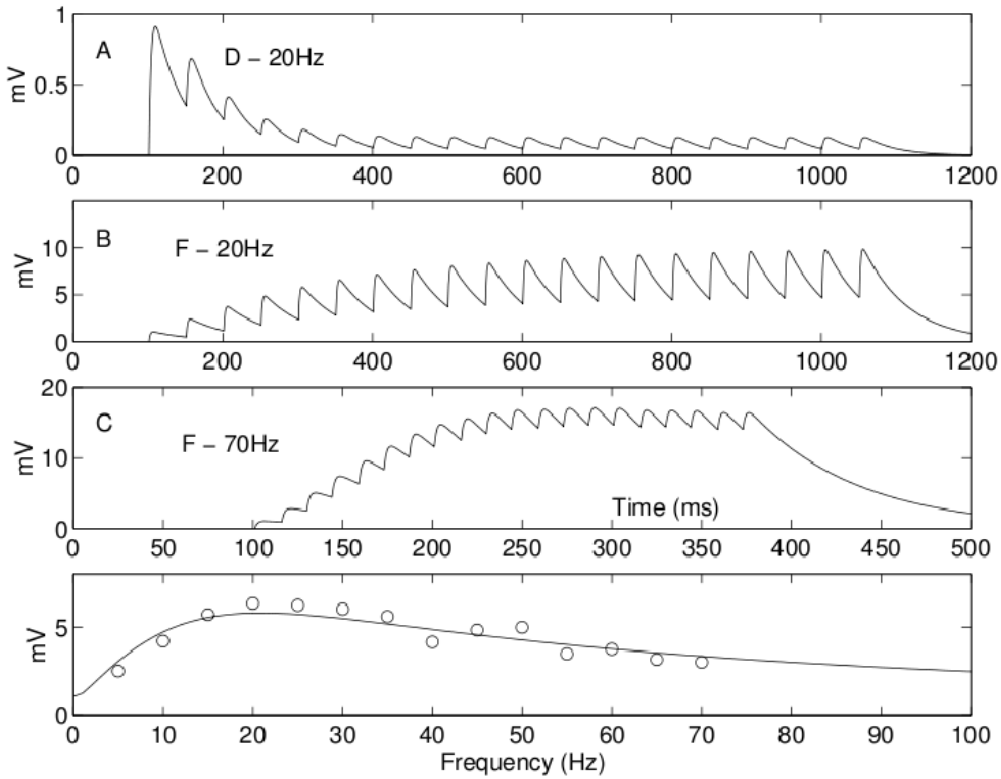
Section 3

Computational modelling

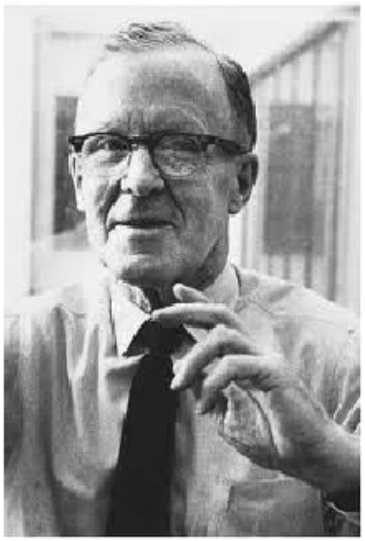
Dynamic synapses model



$$\frac{dx}{dt} = \frac{z}{\tau_{rec}} - U_{SE}x(t_{sp} - 0)\delta(t - t_{sp})$$
$$\frac{dy}{dt} = -\frac{y}{\tau_{in}} + U_{SE}x(t_{sp} - 0)\delta(t - t_{sp})$$
$$\frac{dz}{dt} = \frac{y}{\tau_{in}} - \frac{z}{\tau_{rec}},$$



Hebbian learning



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- Book: “The Organization of Behavior” (1946).

Hebbian learning

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- Synapses should strengthen if connected neurons often fire together; A "causes" B to fire.
- Extend this to include the opposite (LTD).

STDP learning

STDP learning

- Weight dependence: hard or soft bounds.
- Additive exponential STDP rule. $w(t) = w(t - \Delta) + A_{\pm} f(w)$
- Multiplicative exponential STDP rule.
  $w(t) = (w^{max} - w(t - \Delta))A_{\pm} f(w)$

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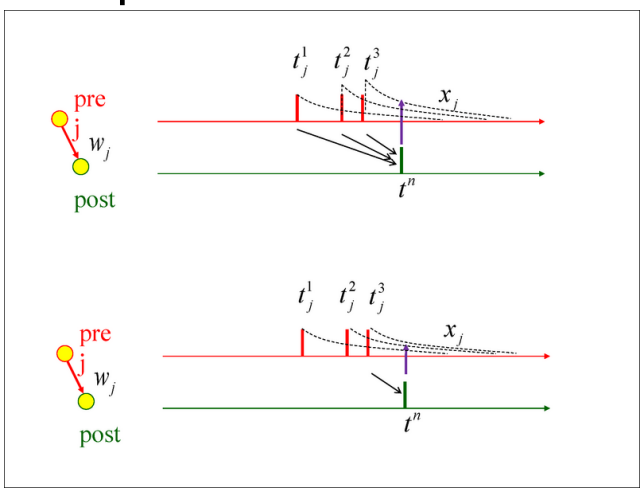
- Temporal all-to-all versus nearest-neighbour spike-interaction.



- Homeostasis?

Summary

- There are different types of short- and long-term plasticity including:
  - Depression
  - Facilitation
  - Failure
  - LTP & LTD
  - STDP
  - Heterosynaptic plasticity and homeostasis

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  - Pre-synaptic: vesicle use, nature of synapse and calcium
  - Post-synaptic: increase/decrease in number of receptors, signalling cascades and neuron/dendritic wide homeostatic changes.

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- Different plasticity types use difference mechanisms:
  - Pre-synaptic: vesicle use, nature of synapse and calcium
  - Post-synaptic: increase/decrease in number of receptors, signalling cascades and neuron/dendritic wide homeostatic changes.
- These biological phenomena can be described/modelled to a certain extent computationally.

Learning outcomes

- Identify different types of plasticity.
- Describe current biological knowledge on short and long term plasticity.
- Demonstrate how plasticity can be implemented computationally.