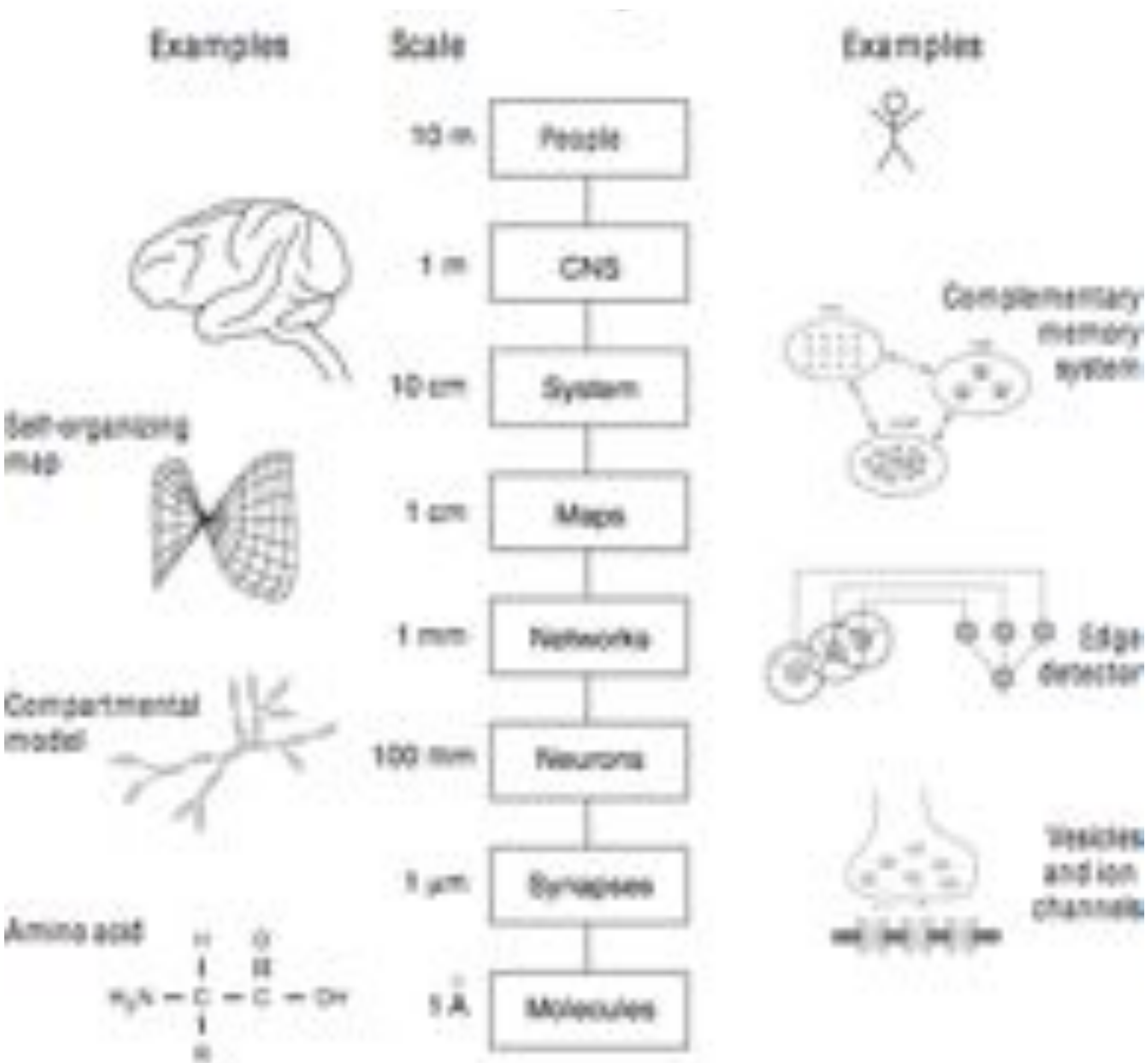
Memory and Learning

Levels of organization in the nervous system



Marr's approach

1. Computational theory: What is the goal of the computation, why is it appropriate, and what is the logic of the strategy by which it can be carried out?

2. Representation and algorithm: How can this computational theory be implemented? In particular, what is the representation for the input and output, and what is the algorithm for the transformation?

3. Hardware implementation: How can the representation and algorithm be realized physically?

Marr puts great importance to the first level:
"To phrase the matter in another way, an algorithm is likely to be understood more readily by understanding the nature of the problem being solved than by examining the mechanism (and hardware) in which it is embodied."

Non-associative learning:

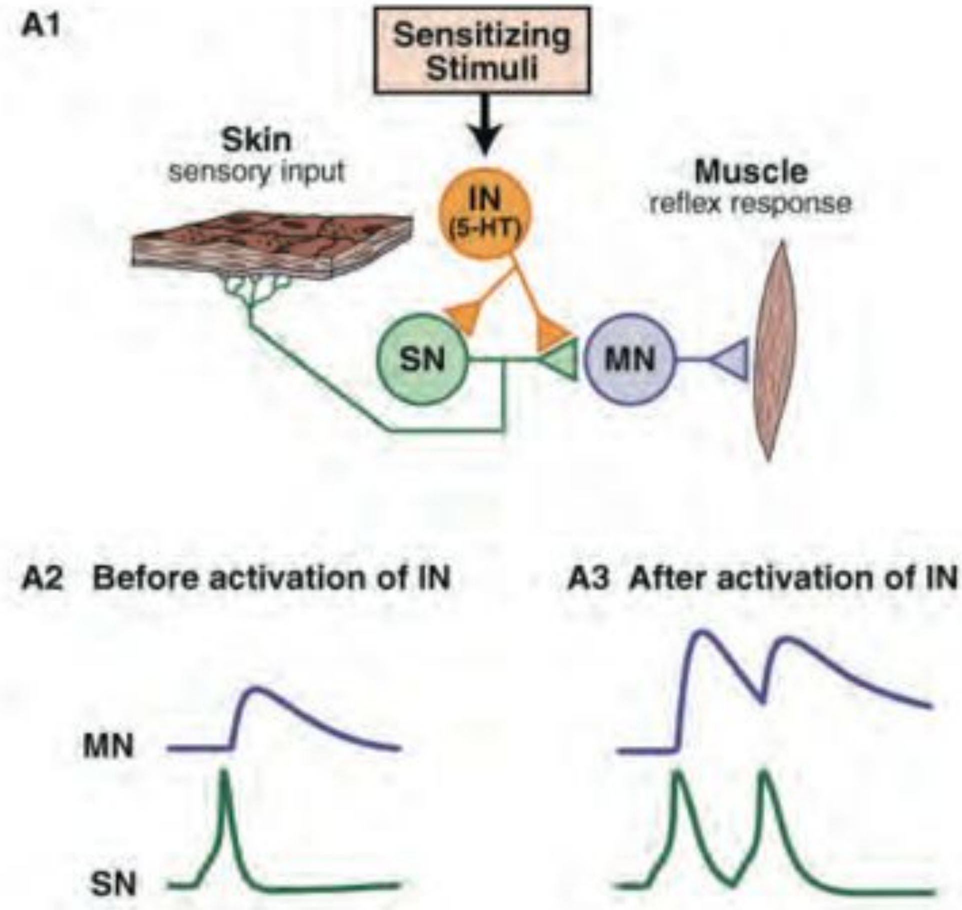
- Habituation
- Dishabituation
- Sensitization

Associative learning:

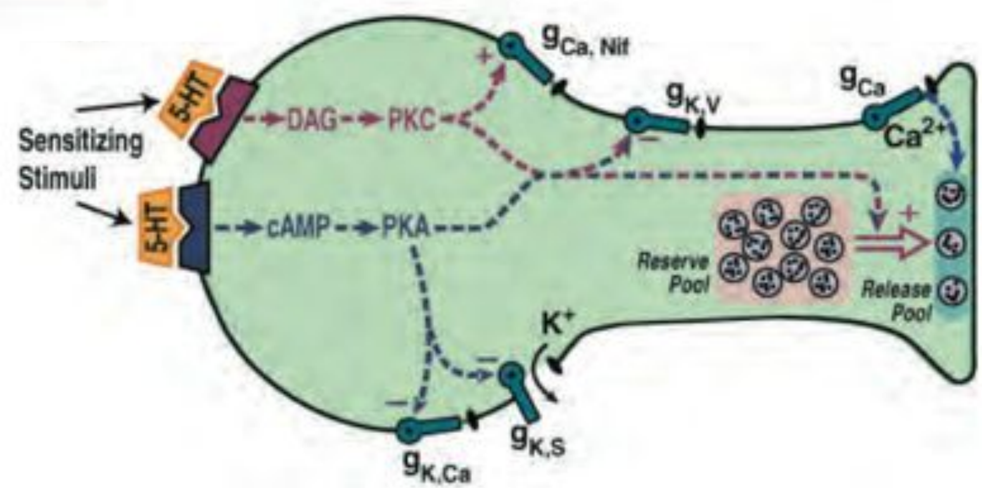
- Classical conditioning
- Instrumental (operant) conditioning
- Recognition Memory

Synaptic Plasticity

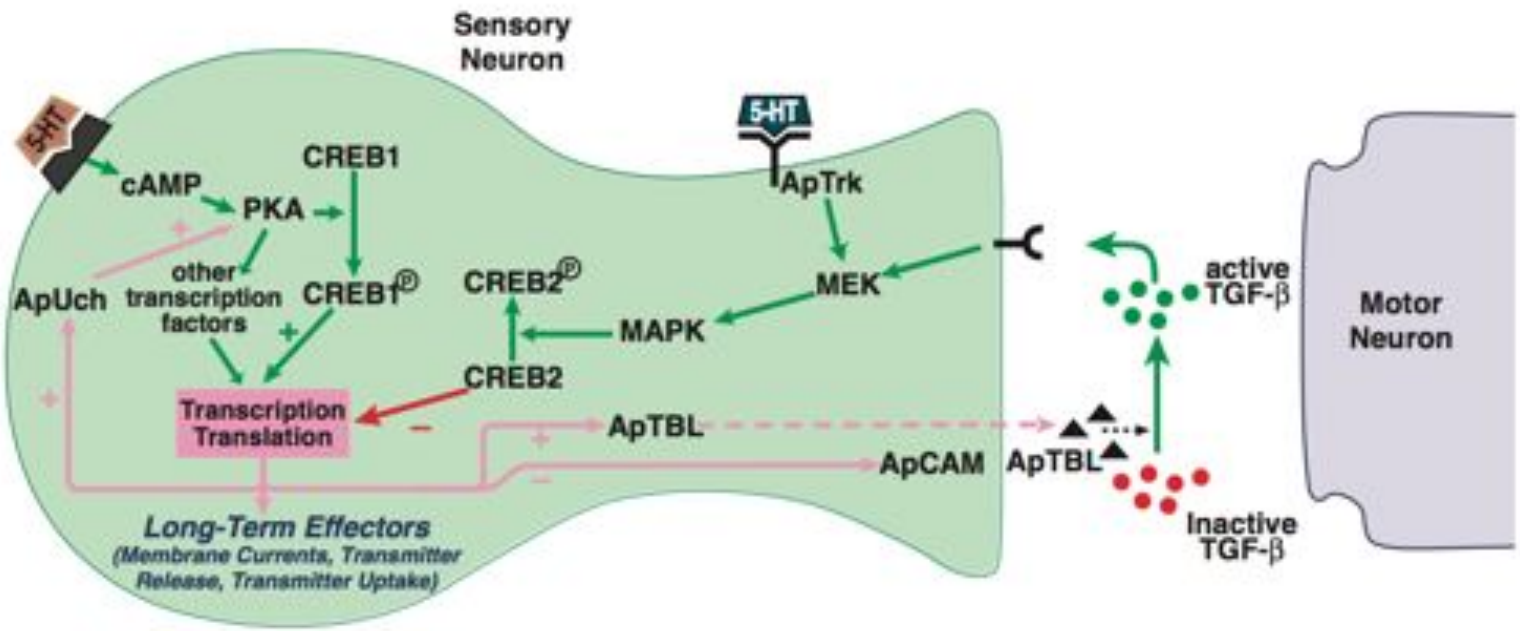
Induction, Expression, Maintenance


A1
Sensitizing Stimuli
Skin
sensory input
IN
(5-HT)
Muscle
reflex response
SN
MN
A2 Before activation of IN
A3 After activation of IN
MN
SN

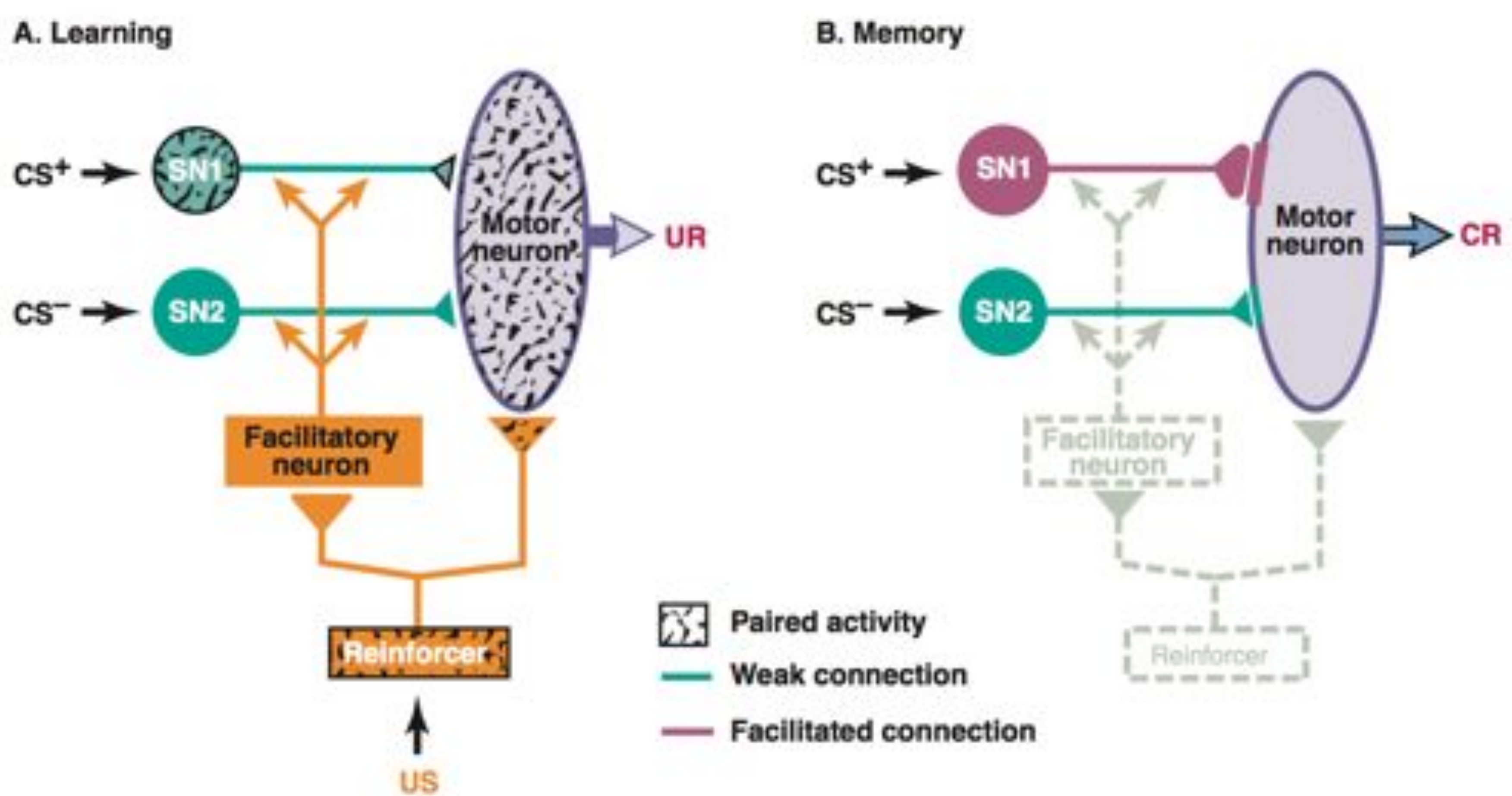
Short Term


Sensitizing Stimuli
5-HT
5-HT
DAG
PKC
cAMP
PKA
$g_{Ca, Nif}$
$g_{K,V}$
g_{Ca}
Ca^{2+}
Reserve Pool
Release Pool
K^+
$g_{K,Ca}$
$g_{K,S}$

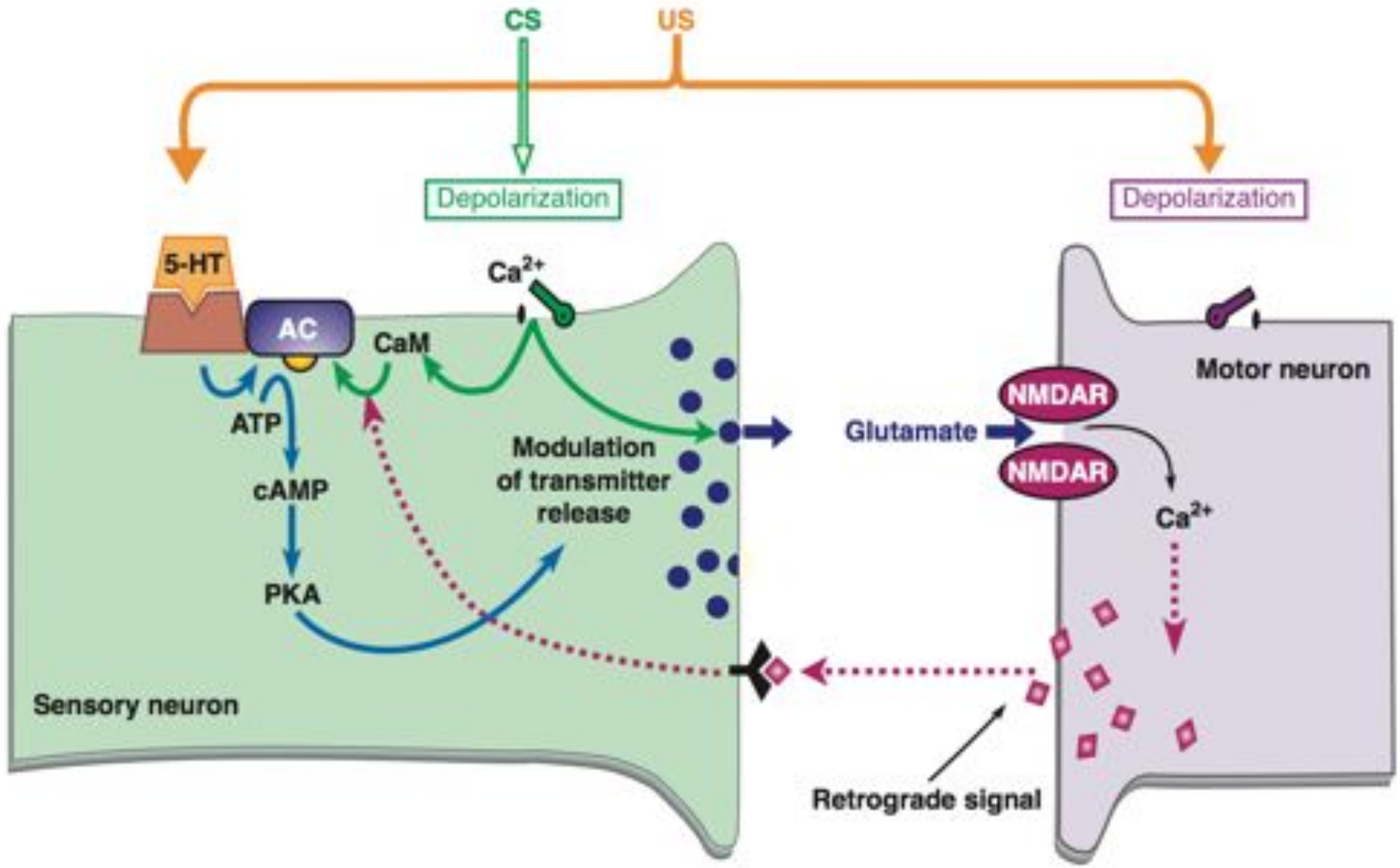
Long Term Sensitization

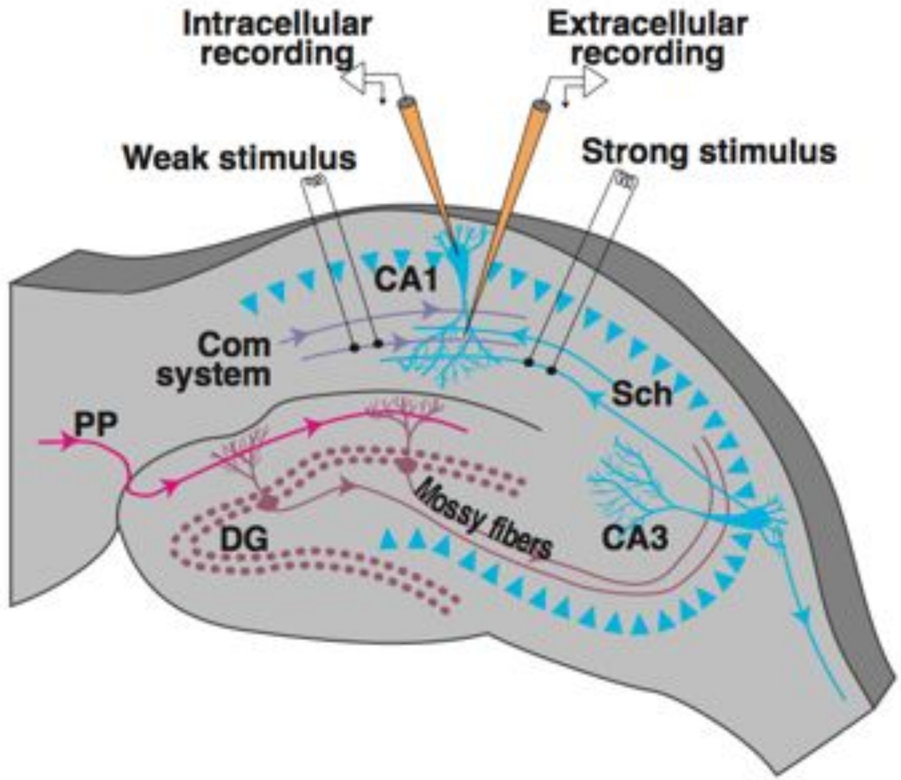


Classical condition of withdraw reflex in Aplysia

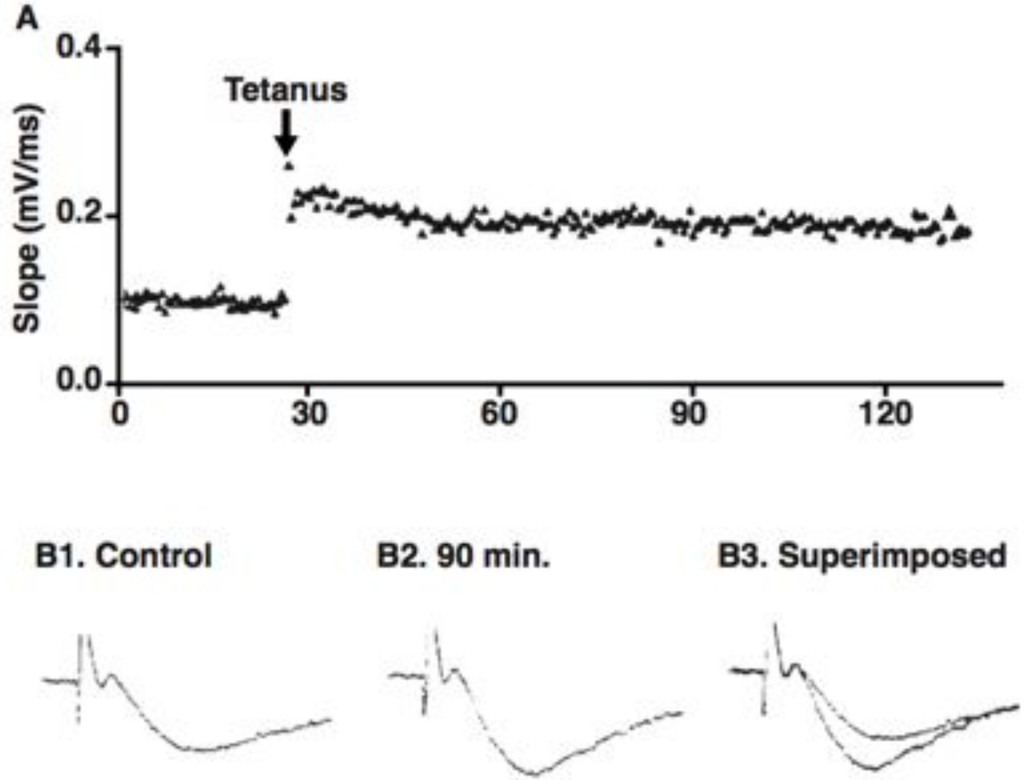


Coincidence detection
and retrograde signaling

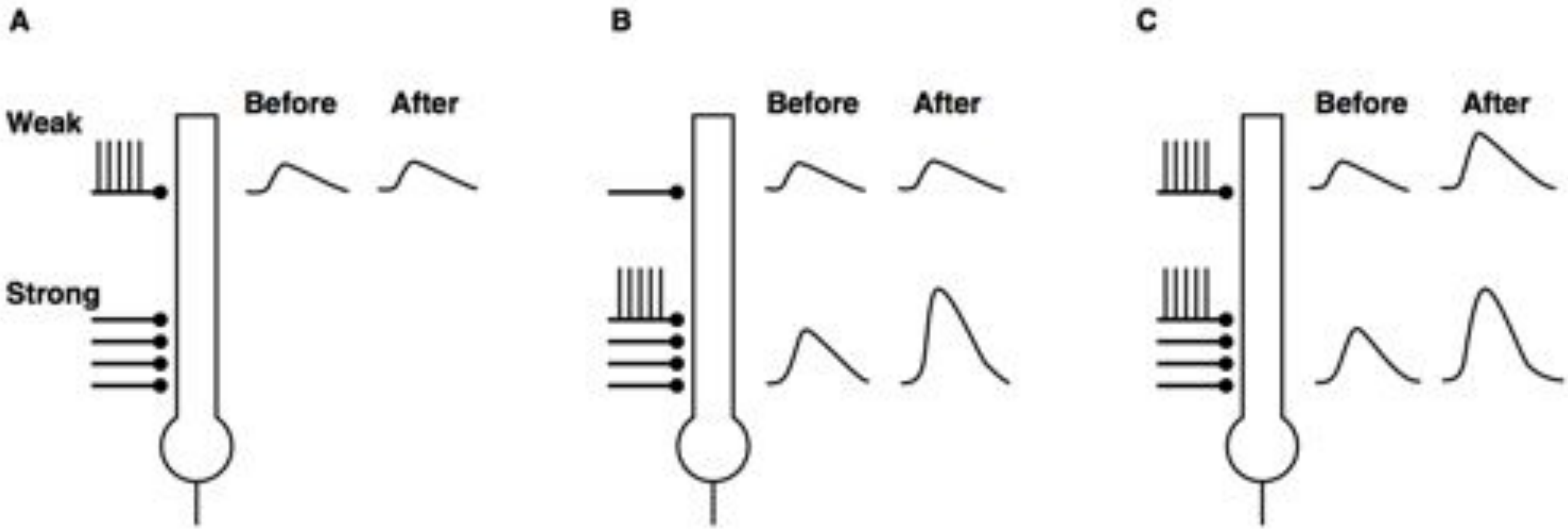


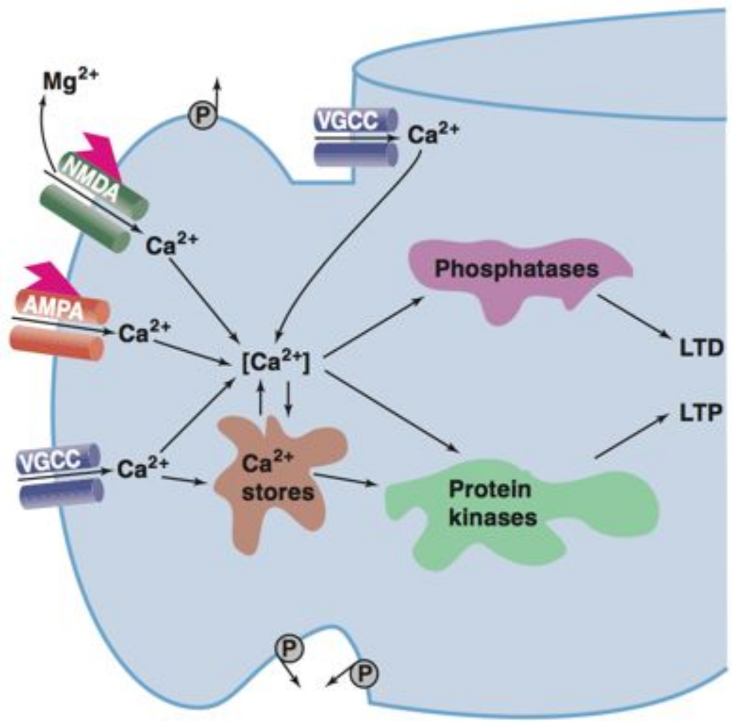


Intracellular recording
Extracellular recording
Weak stimulus
Strong stimulus
CA1
Com system
Sch
PP
Mossy fibers
DG
CA3

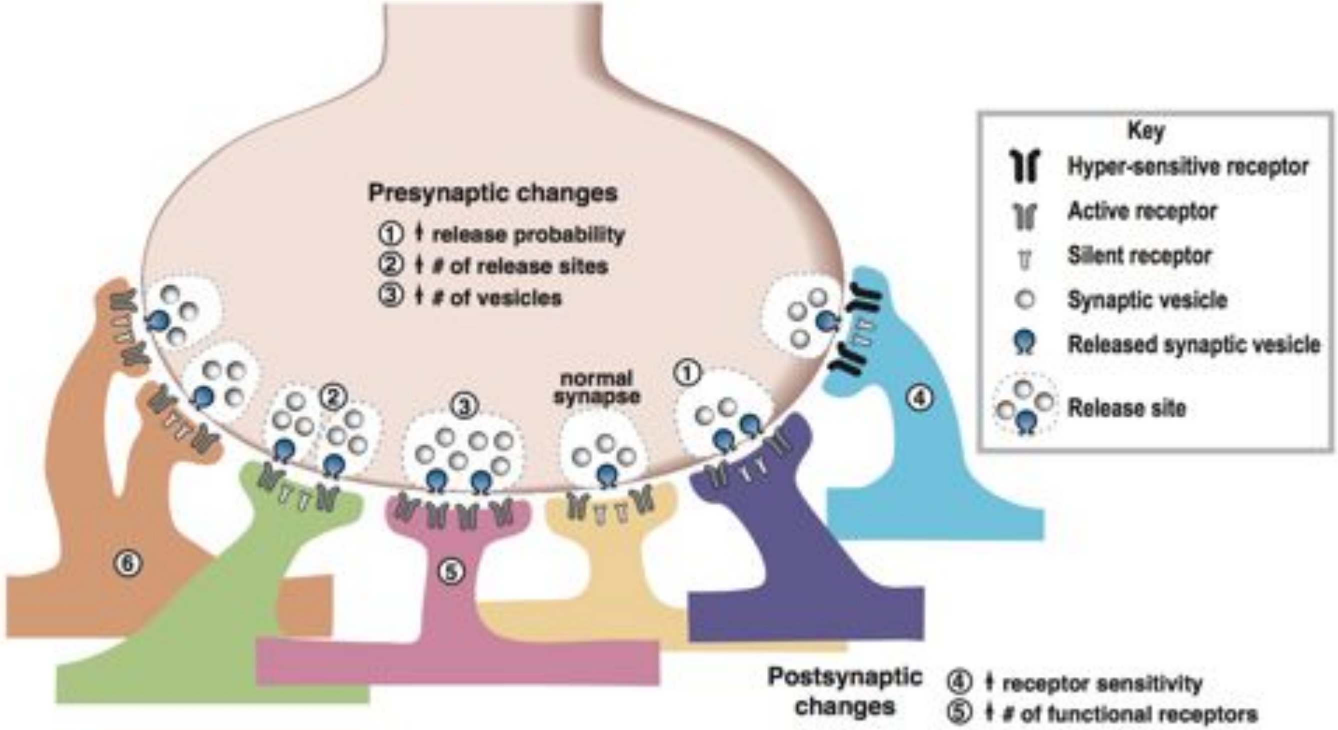


A
0.4
0.2
0.0
Slope (mV/ms)
Tetanus
0
30
60
90
120
B1. Control
B2. 90 min.
B3. Superimposed


A
Weak
Before
After
Strong
B
Before
After
C
Before
After

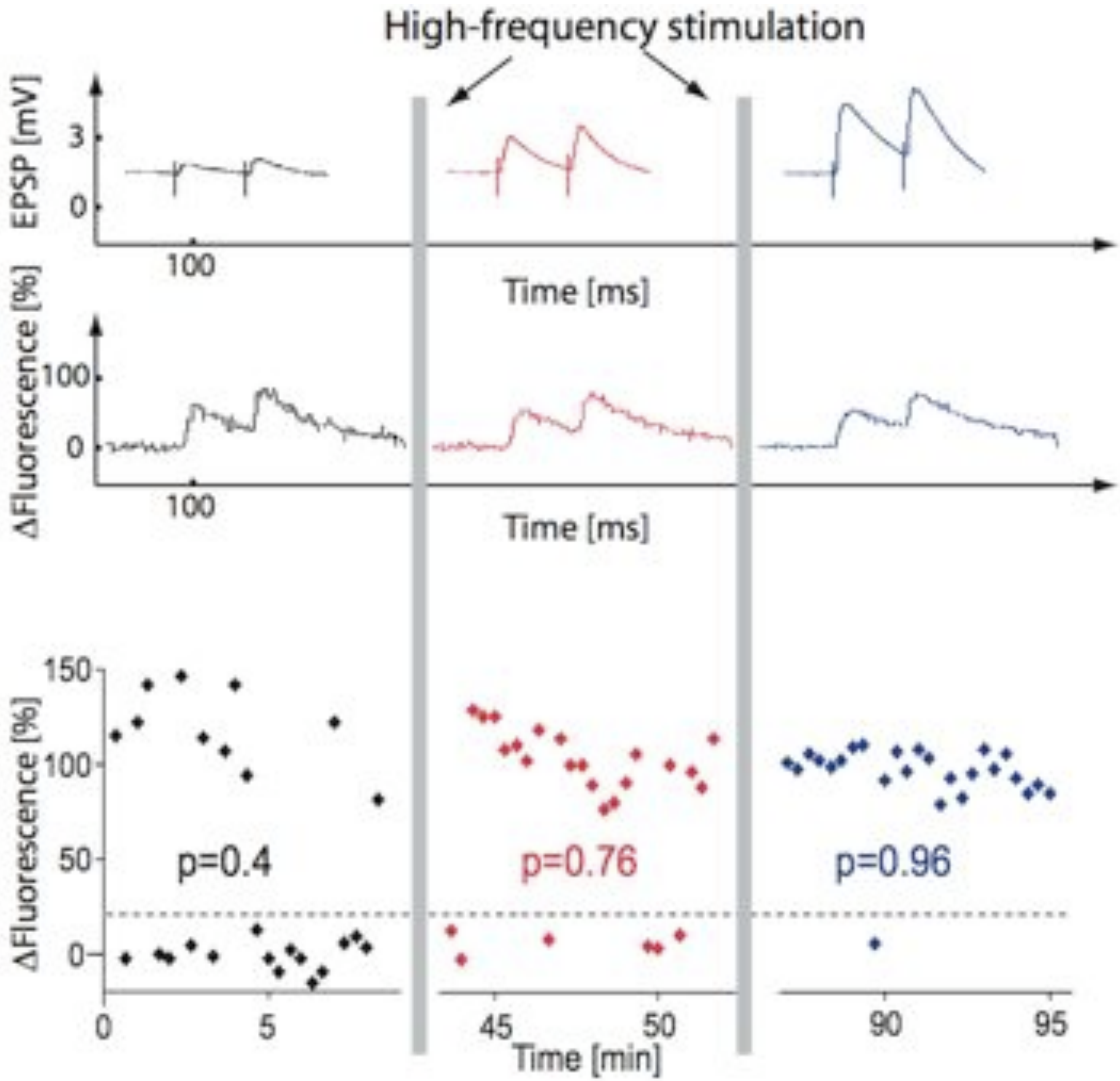


Mg2+
P
VGCC
Ca2+
NMDA
Ca2+
AMPA
Ca2+
Phosphatases
[Ca2+]
LTD
LTP
VGCC
Ca2+
Ca2+
stores
Protein
kinases
P
P

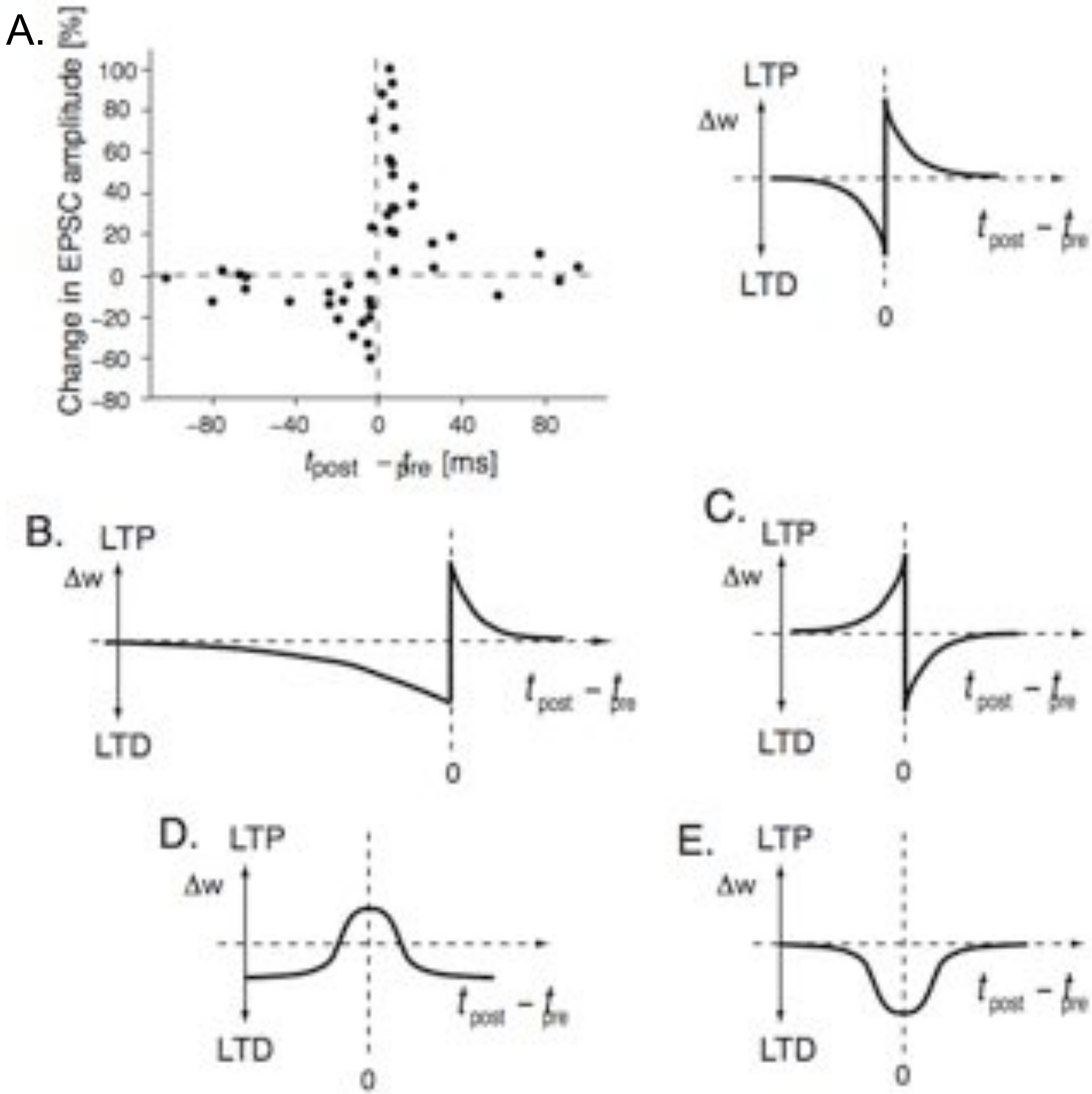


Presynaptic changes
① ↑ release probability
② ↑ # of release sites
③ ↑ # of vesicles
normal synapse
①
②
③
④
⑤
⑥
Key
Hyper-sensitive receptor
Active receptor
Silent receptor
Synaptic vesicle
Released synaptic vesicle
Release site
Postsynaptic changes
④ ↑ receptor sensitivity
⑤ ↑ # of functional receptors

Synaptic neurotransmitter release probability



Spike timing dependent plasticity (STDP)



Hebbian learning in population and rate models

General: $\Delta w_{ij} = \epsilon(t, w)[f_{\text{post}}(r_i) f_{\text{pre}}(r_j) - f(r_i, r_j, w)]$

Mnemonic equation (Caianiello): $\Delta w_{ij} = \epsilon(w)[r_i r_j - f(w)]$

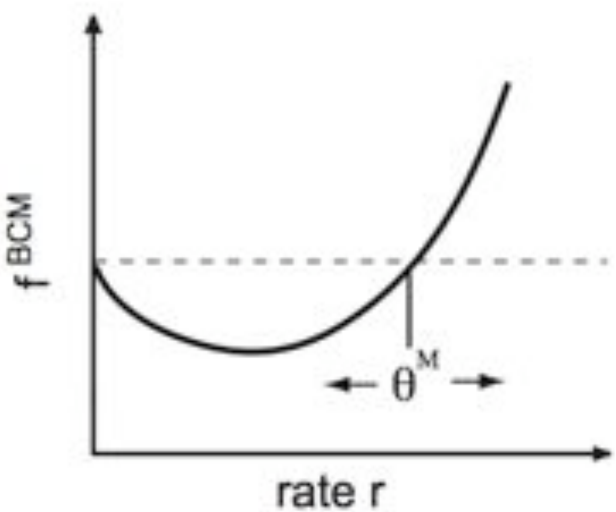
Basic Hebb: $\Delta w_{ij} = \epsilon r_i r_j$

Covariance rule: $\Delta w_{ij} = \epsilon(r_i - \langle r_i \rangle)(r_j - \langle r_j \rangle)$

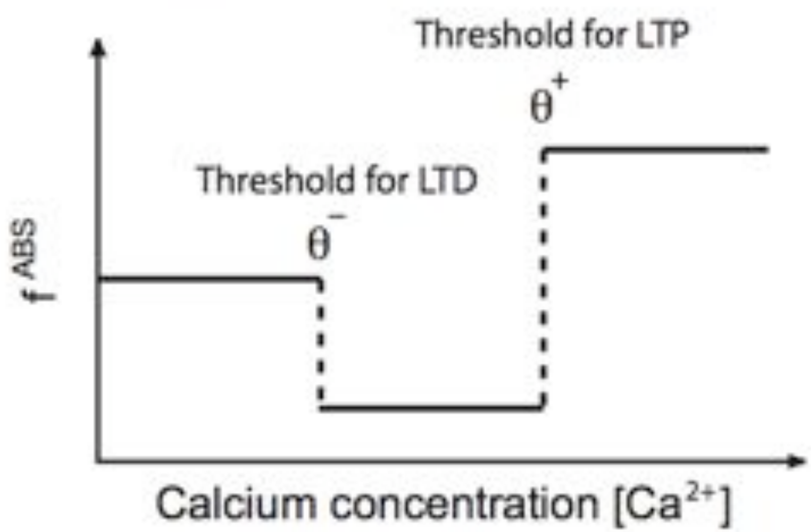
BCM theory: $\Delta w_{ij} = \epsilon(f^{\text{BCM}}(r_i; \theta^M)(r_j) - f(w))$

ABS rule: $\Delta w_{ij} = \epsilon(f_{\text{ABS}}(r_i; \theta\ \ , \theta^{+}) \text{sign}(r_j - \theta^{\text{pre}}))$

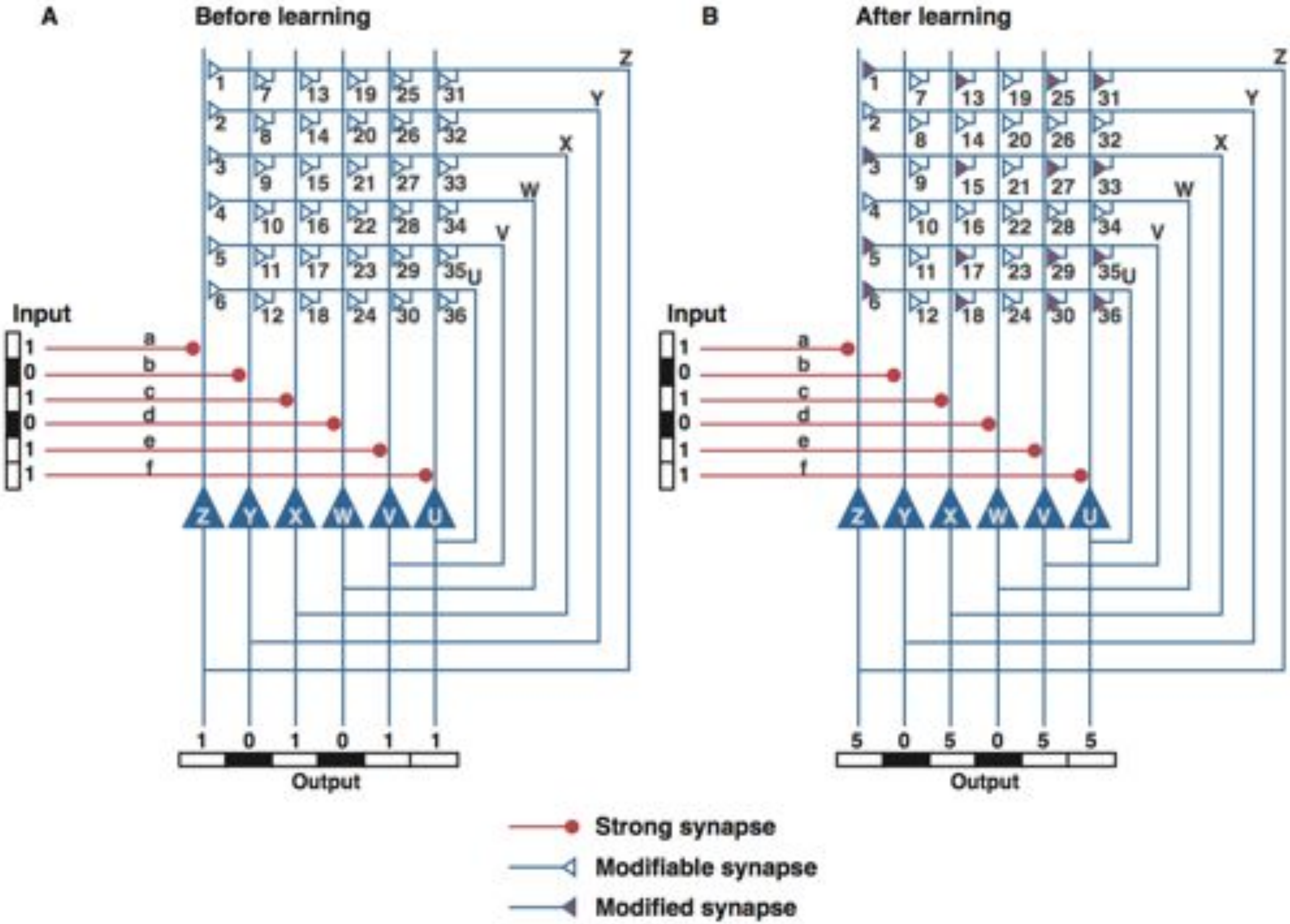
Function used in BCM rule



Function used in basic ABS rule



Eduardo Caianiello


A
Before learning
B
After learning
Input
Output
1 0 1 0 1 1
5 0 5 0 5 5
Strong synapse
Modifiable synapse
Modified synapse