Predictive Learning in Neurons and Robots

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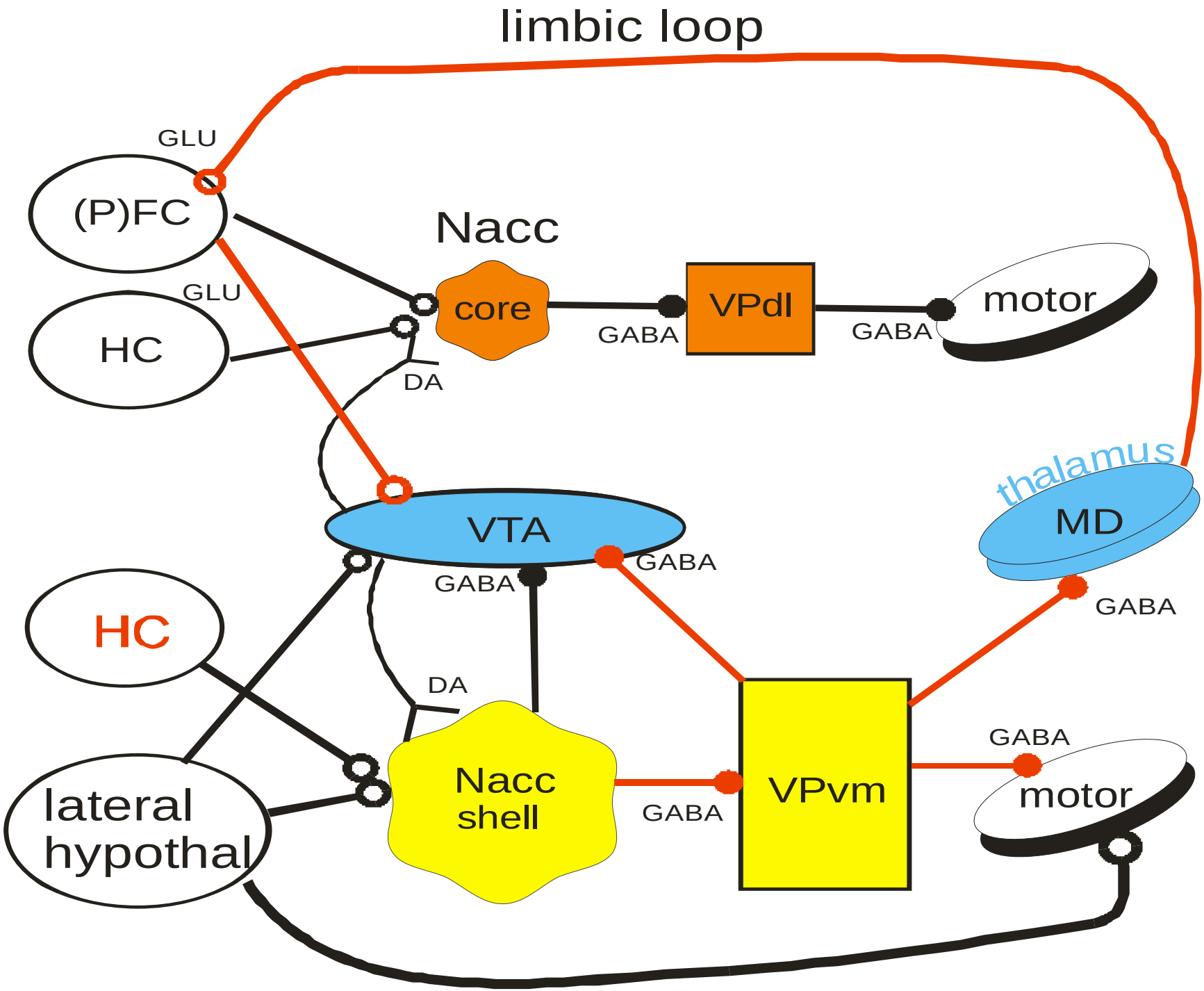
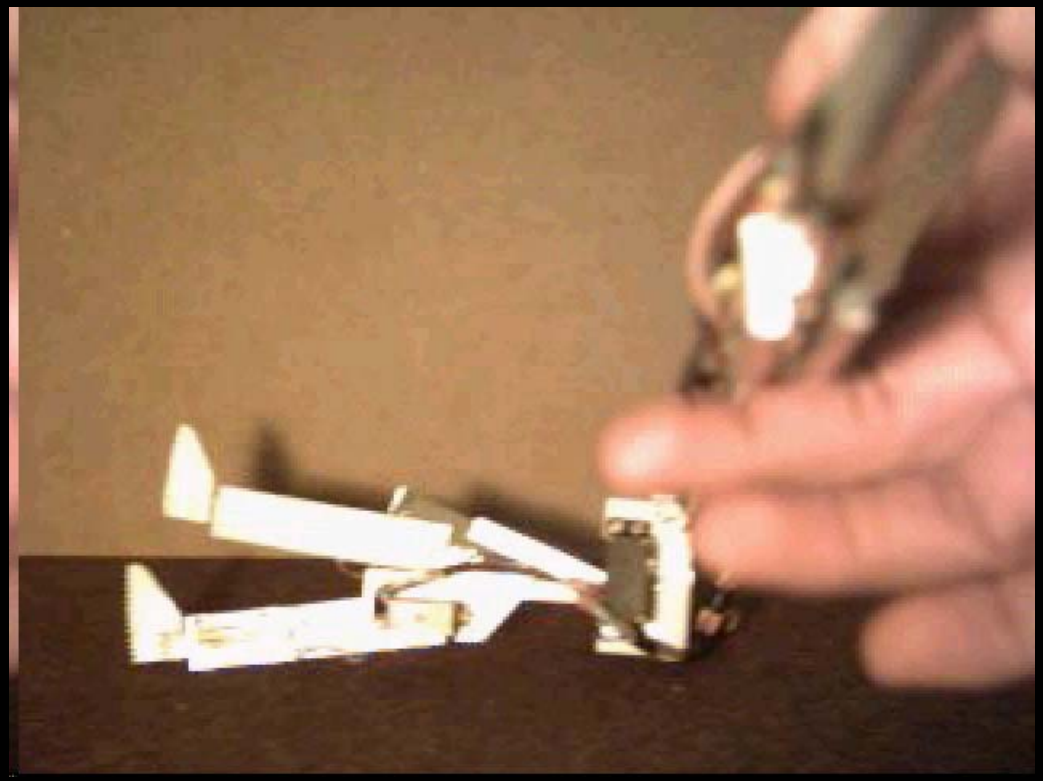
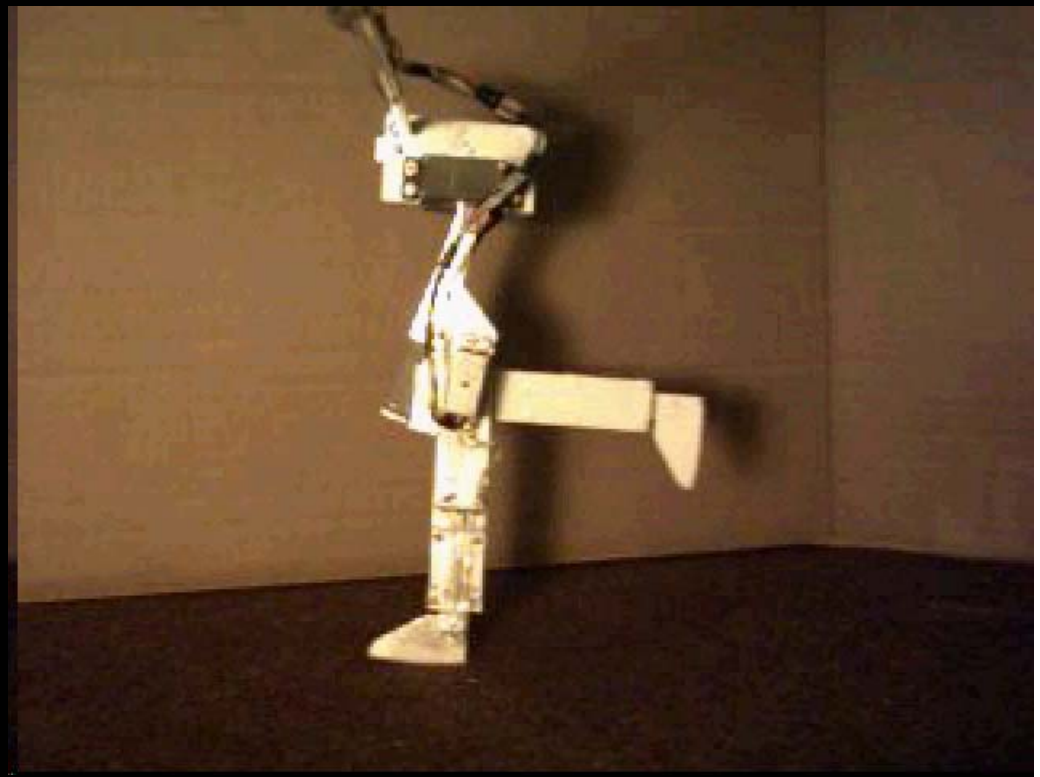
A cognitive (?) network



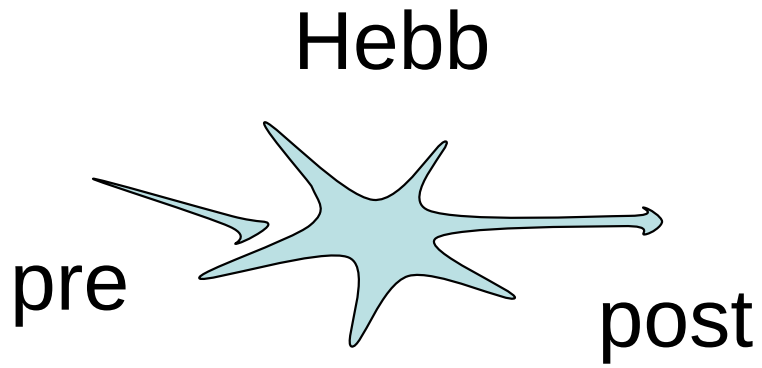
Our Goal: Network Control and Learning during Fast Walking



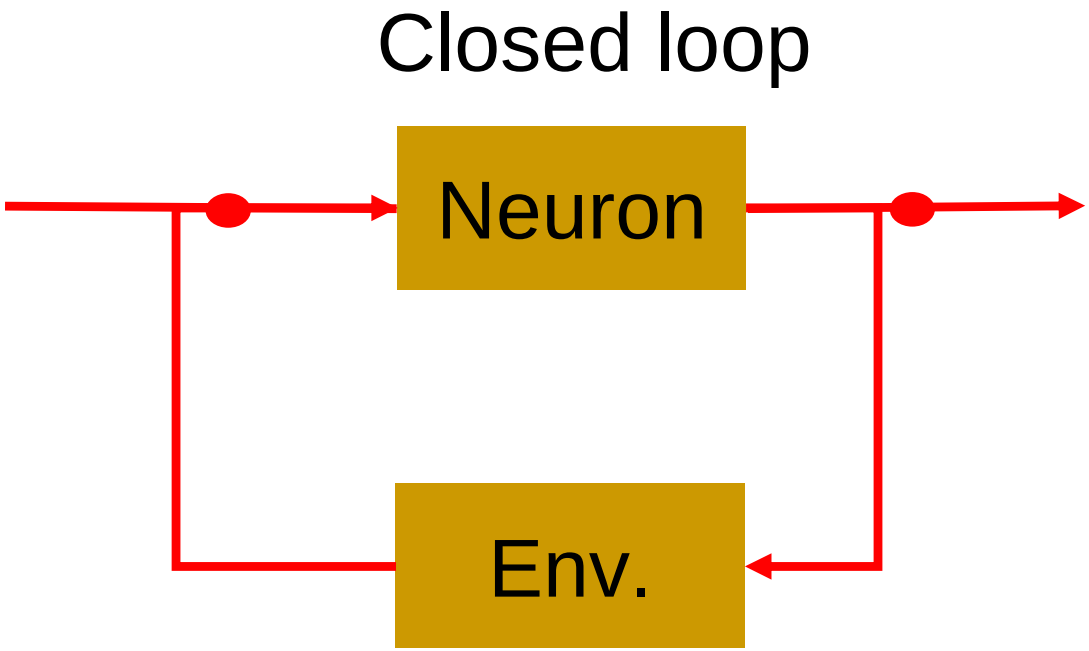


Three Steps

Neuronal Plasticity (single neuron):

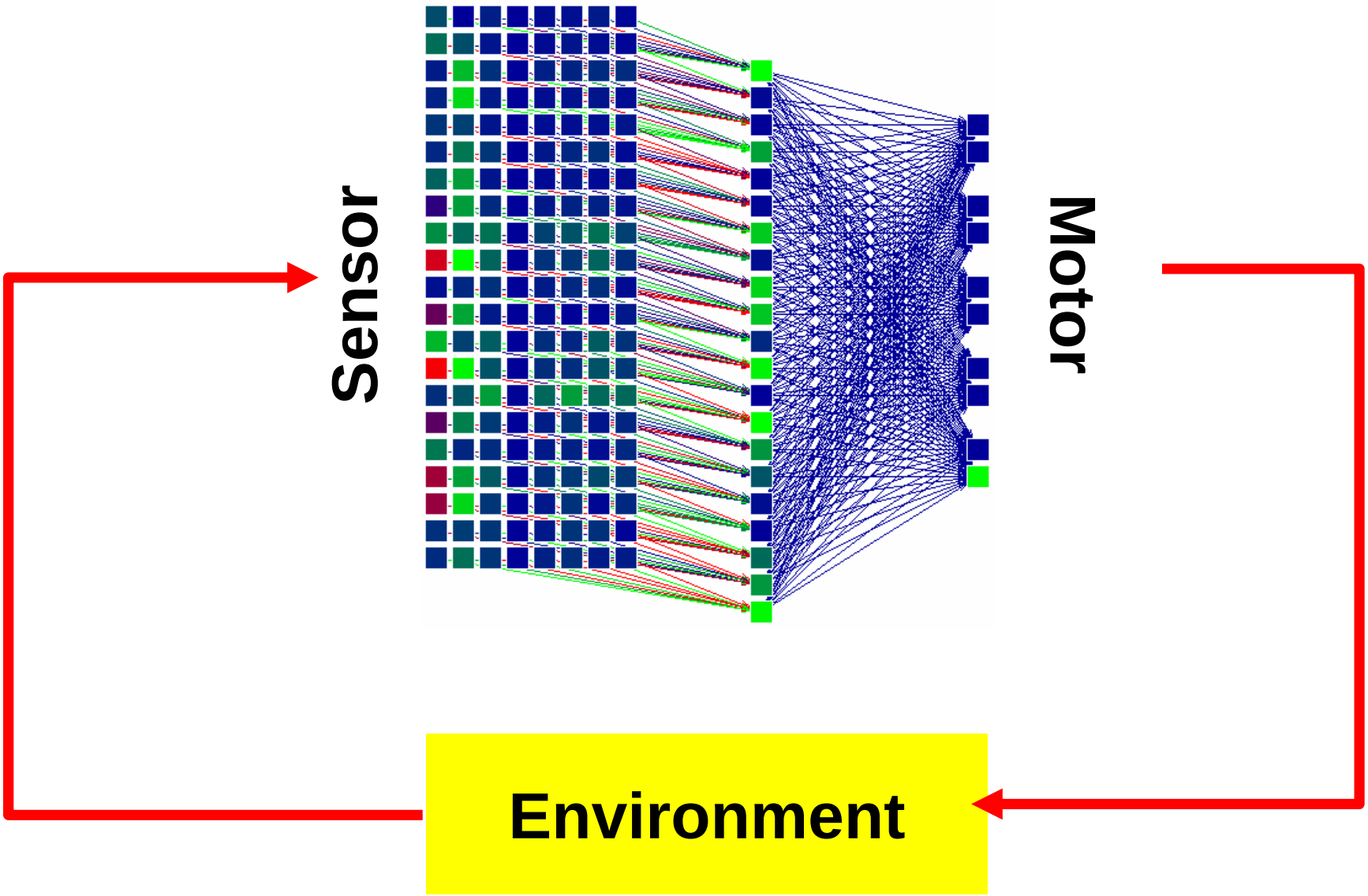


Reflex based Control Networks (single neuron + “world”)

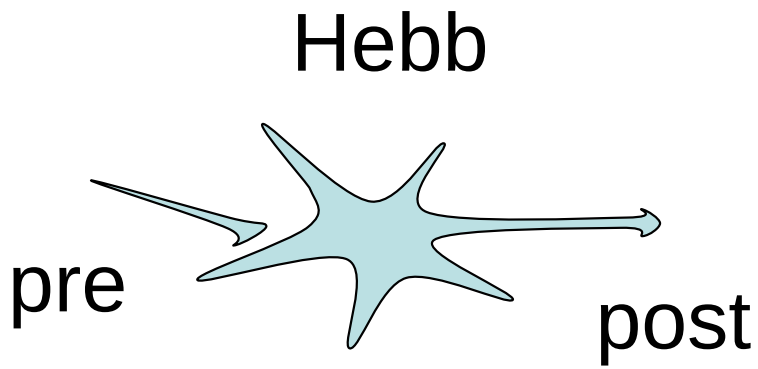


A simple ☺ adaptive anticipatory Network

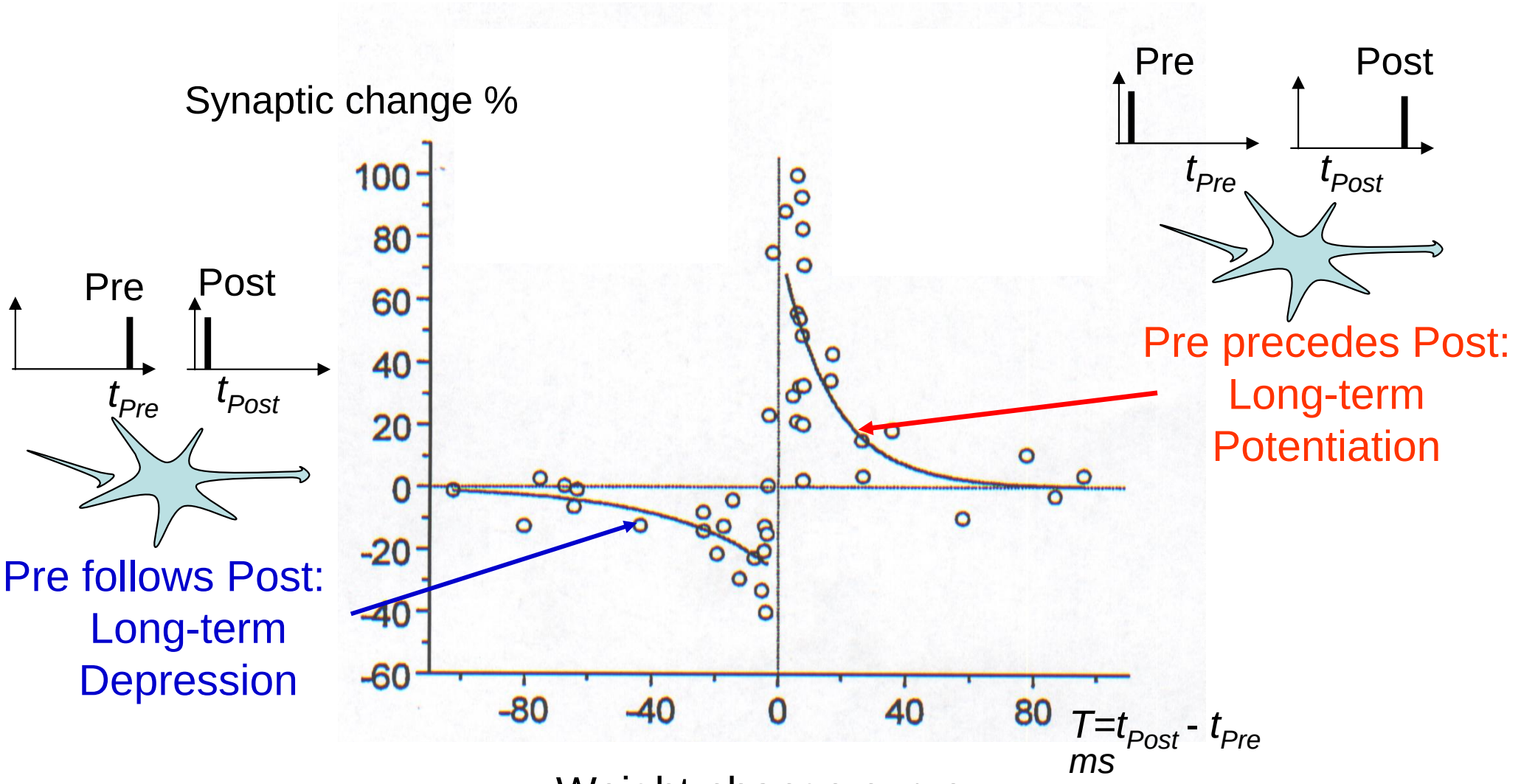
(+ ”world”)



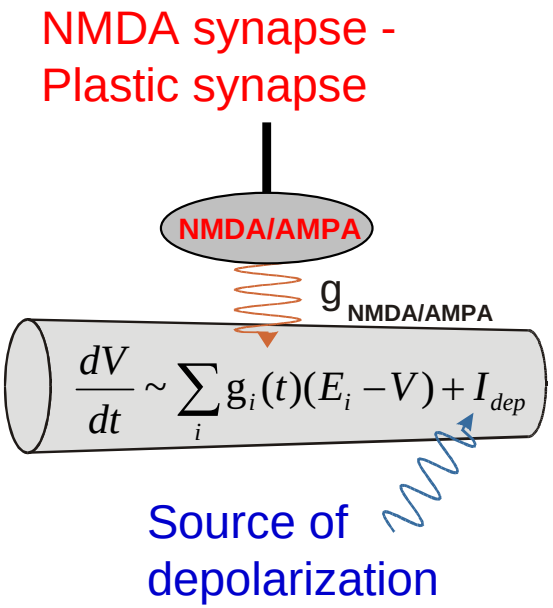
The first component: An adaptable neuron



The finding: Spike-timing-dependent plasticity (STDP) can be used for Sequence Learning



Weight-change curve
(Bi&Poo, 2001)



Model structure

Plasticity Rule
(Differential Hebb)

Instantaneous weight change:

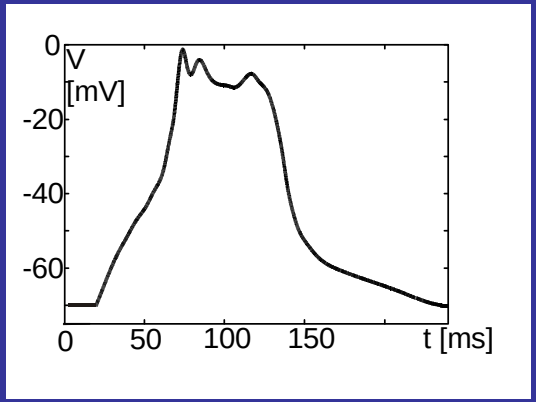
$$\frac{d}{dt}\omega(t) = \mu\, c_N(t)\, F'(t)$$

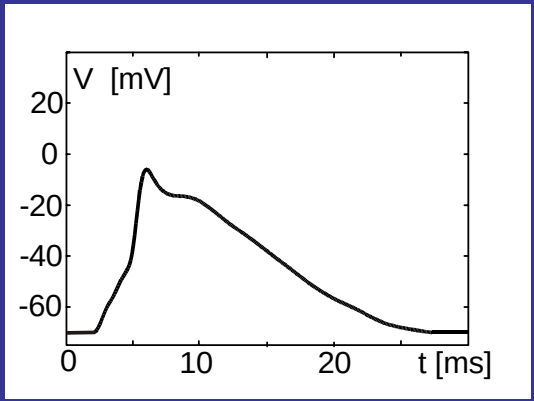
Presynaptic influence
Glutamate effect on
NMDA channels

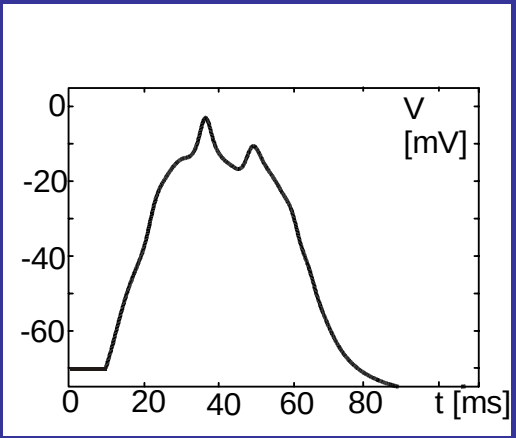
Postsynaptic
influence

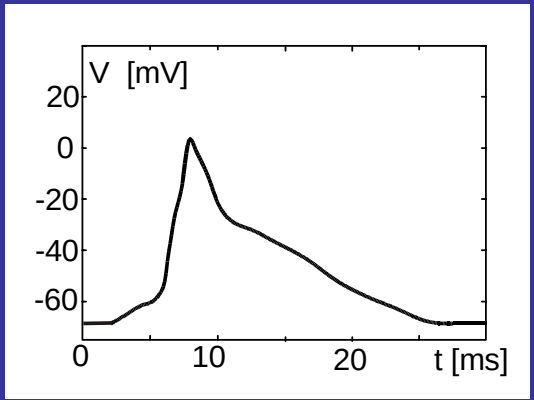
=Depolarization
Source

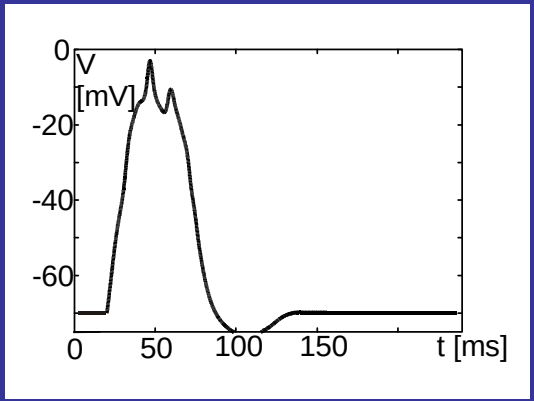
Some Signals F

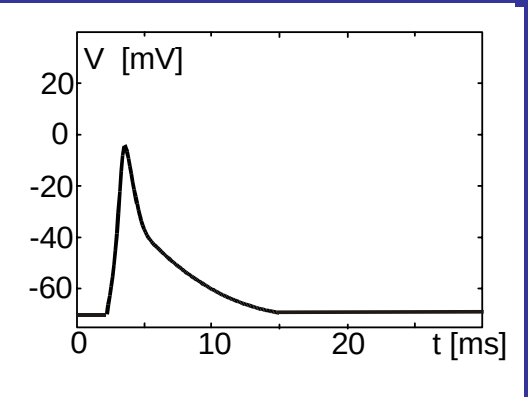


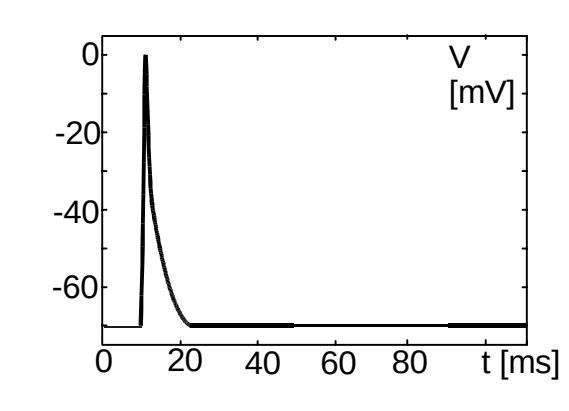


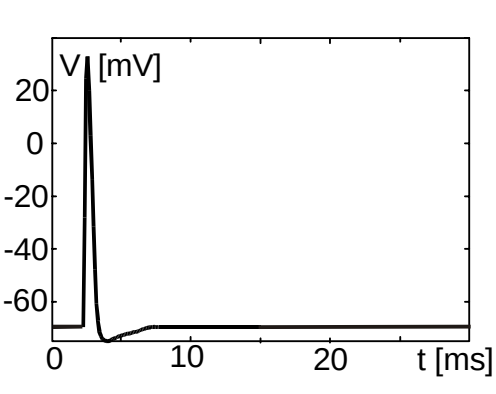








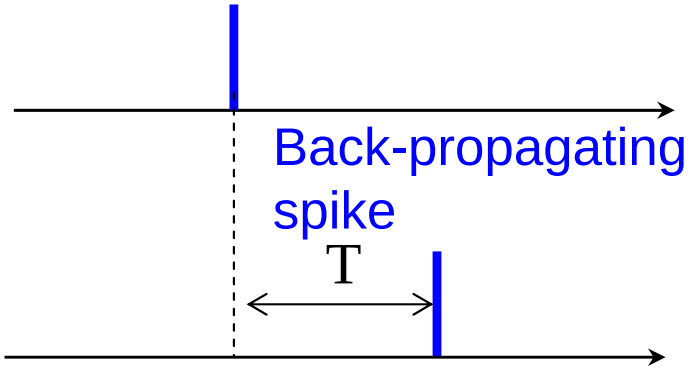




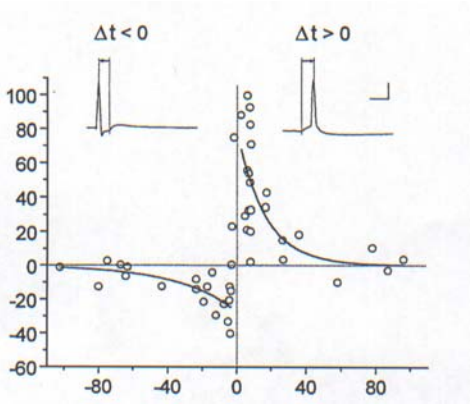
Weight Change Curves

Source of Depolarization: Back-Propagating Spikes

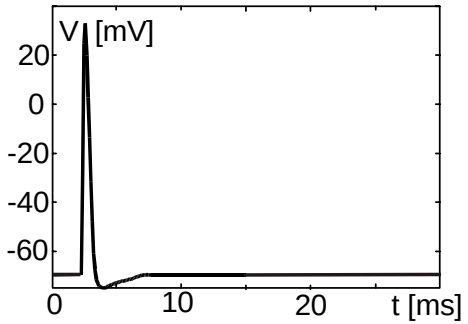
NMDAr activation

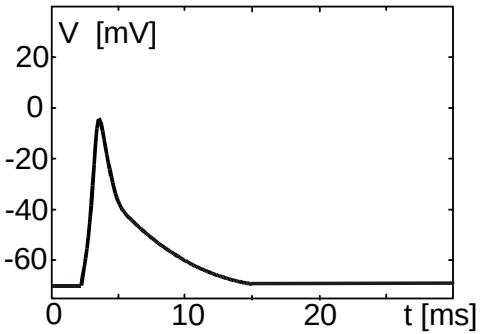


$T = t_{Post} - t_{Pre}$

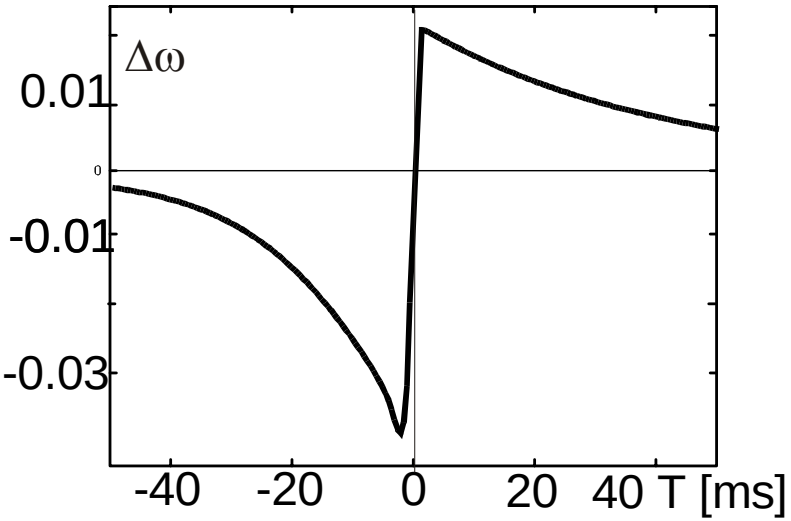


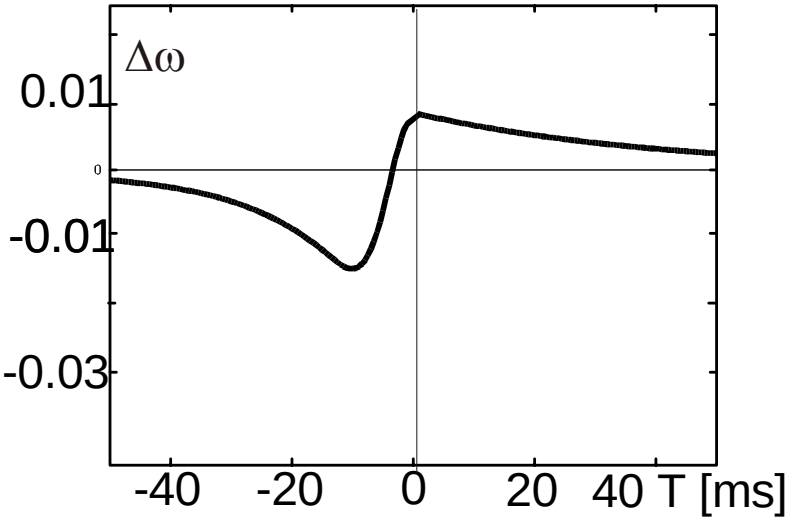
Back-propagating spike





Weight change curve



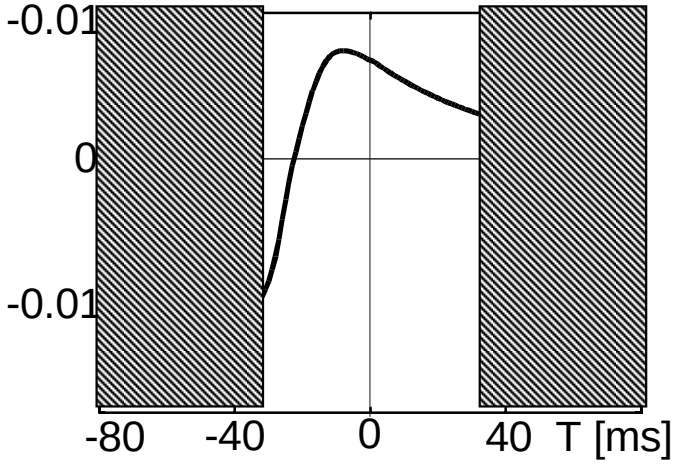


Local Learning Rules

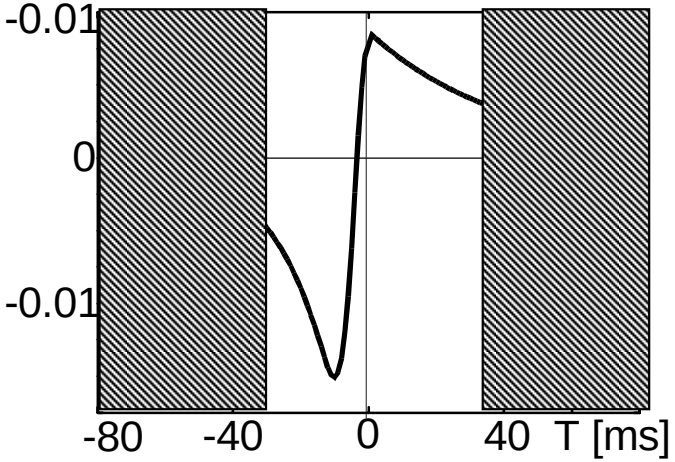
The same learning rule:

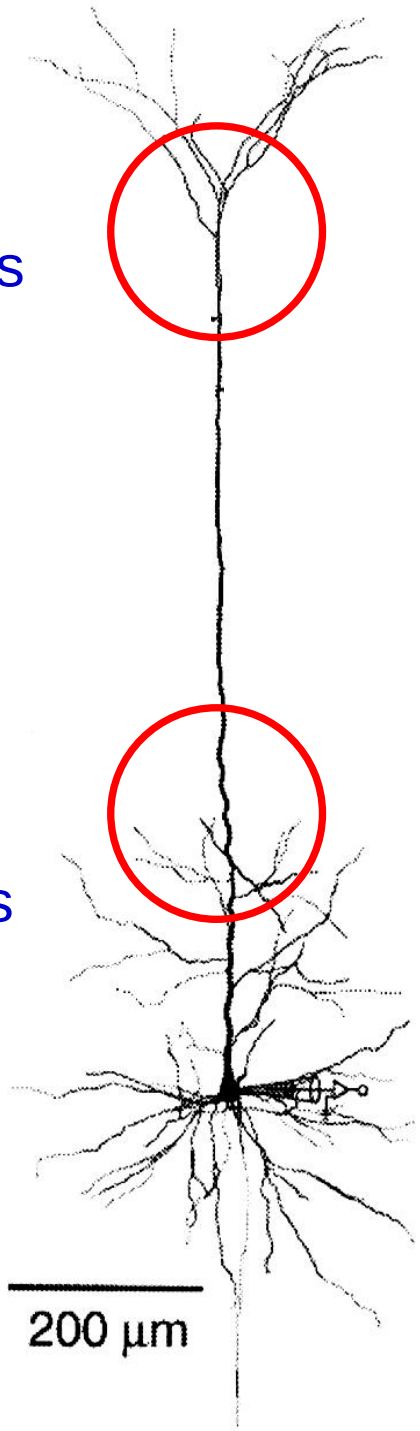
Hebbian learning for distal synapses

Correlations beyond +-30 ms are mostly random



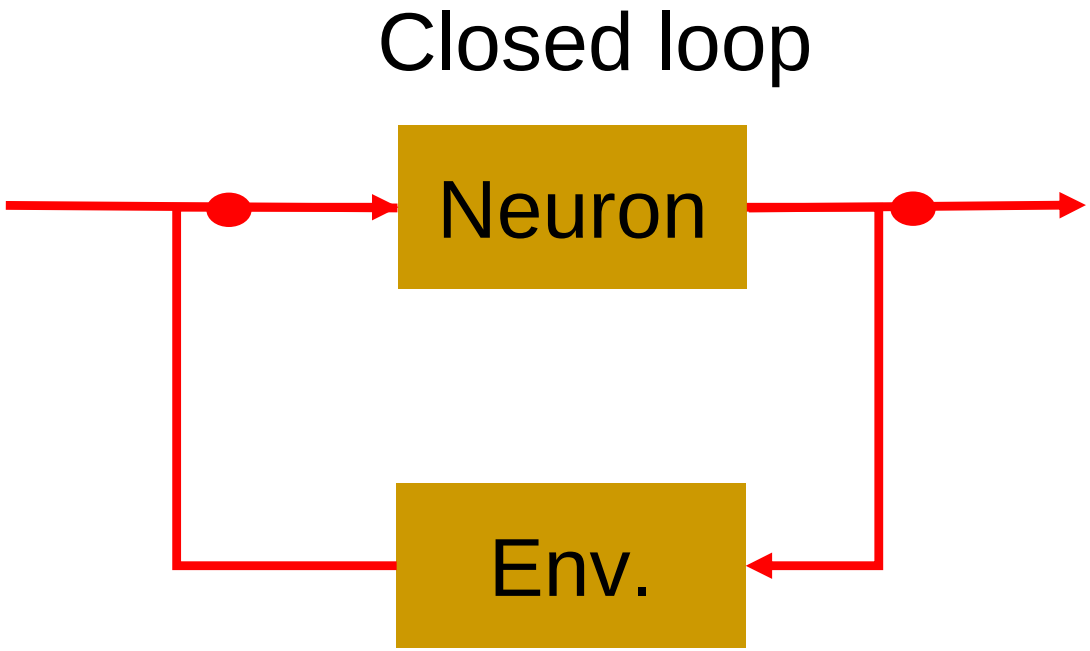
Differential Hebbian learning for proximal synapses





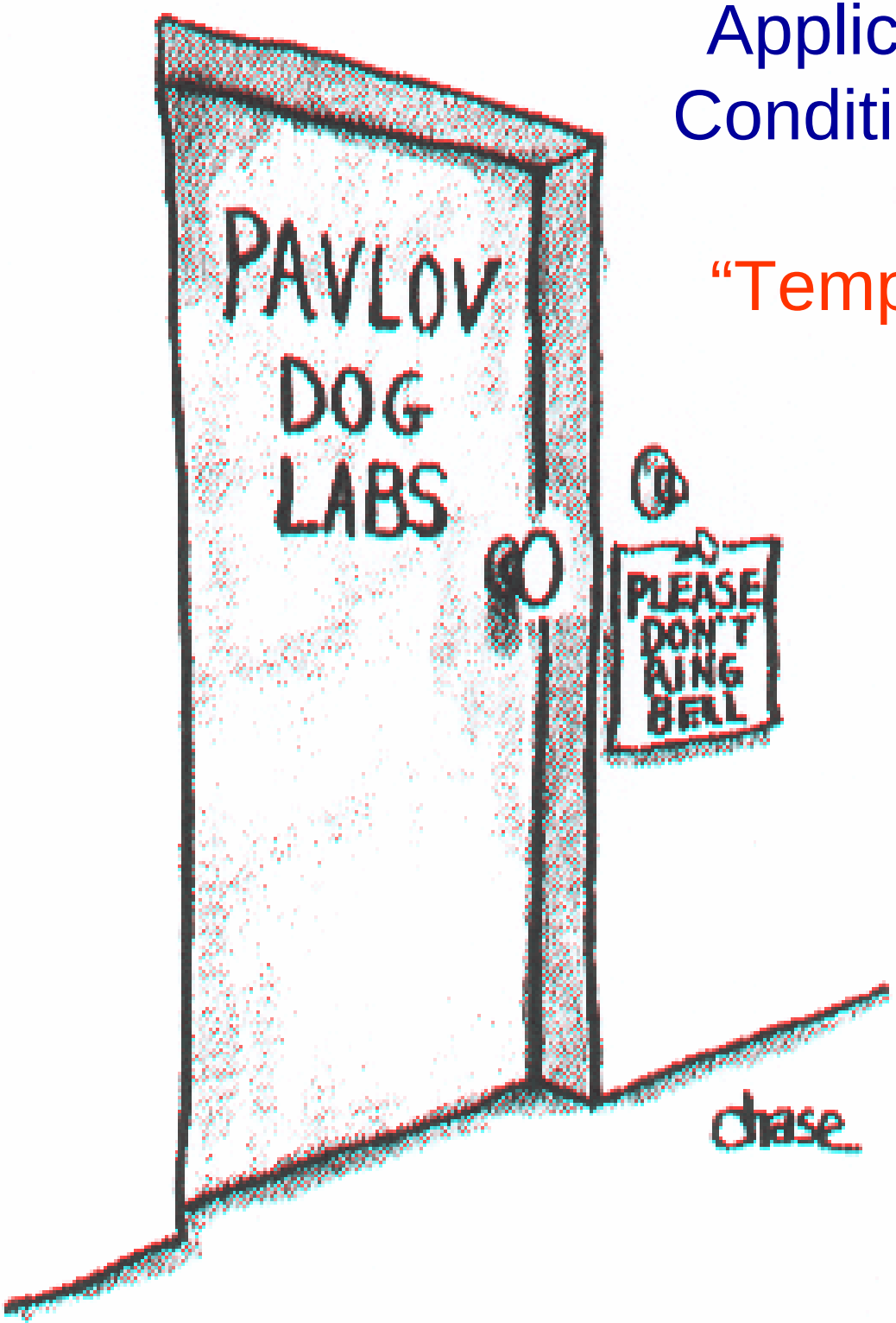
Saudargiene et al Neural Comp. 2004

The second component: A reflex as the *basic* control structure.



Application: Classical Conditioning in a Robot

"Temporal Sequence Learning"



Natural Temporal Sequences in life and in “control” situations

Real Life

- Heat radiation predicts pain when touching a hot surface.
- Sound of a prey may precede its smell will precede its taste.

Control

- Force precedes position change.
- Electrical (disturbance) pulse may precede change in a controlled plant.

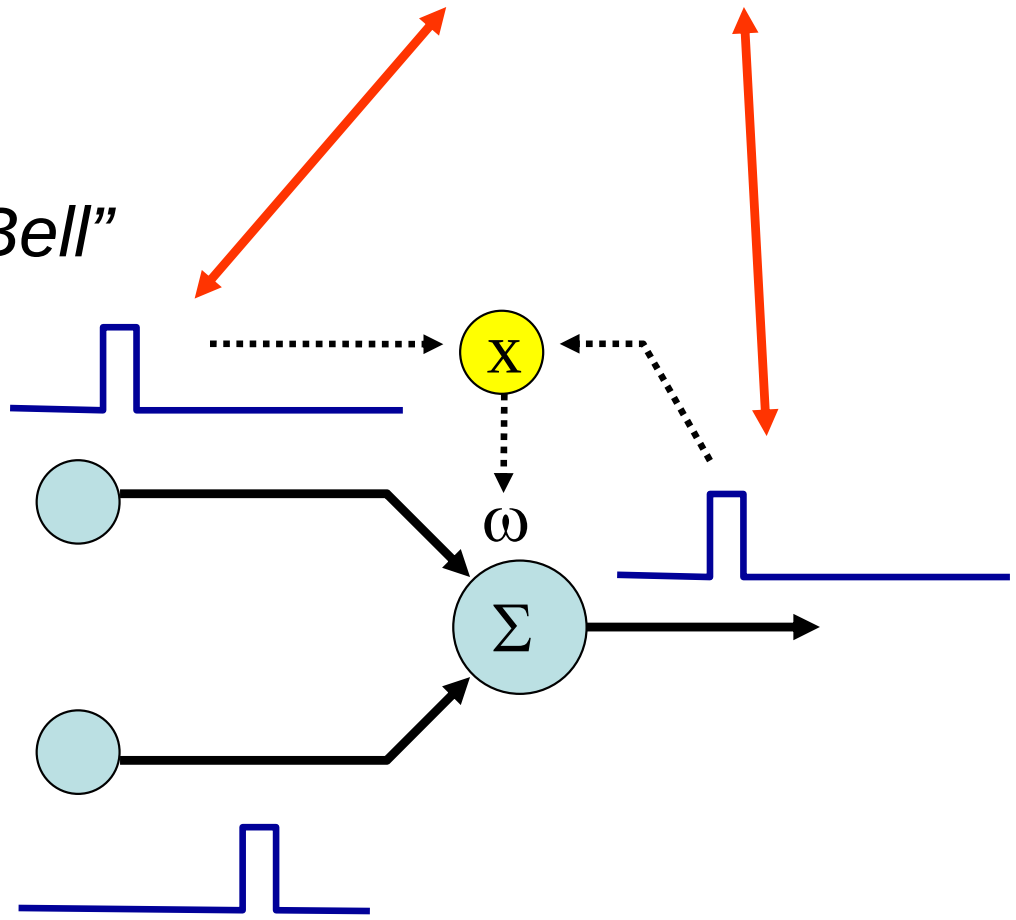
Psychological Experiment

- Pavlovian and/or Operant Conditioning: Bell precedes Food.

Same STDP as before only now with two inputs

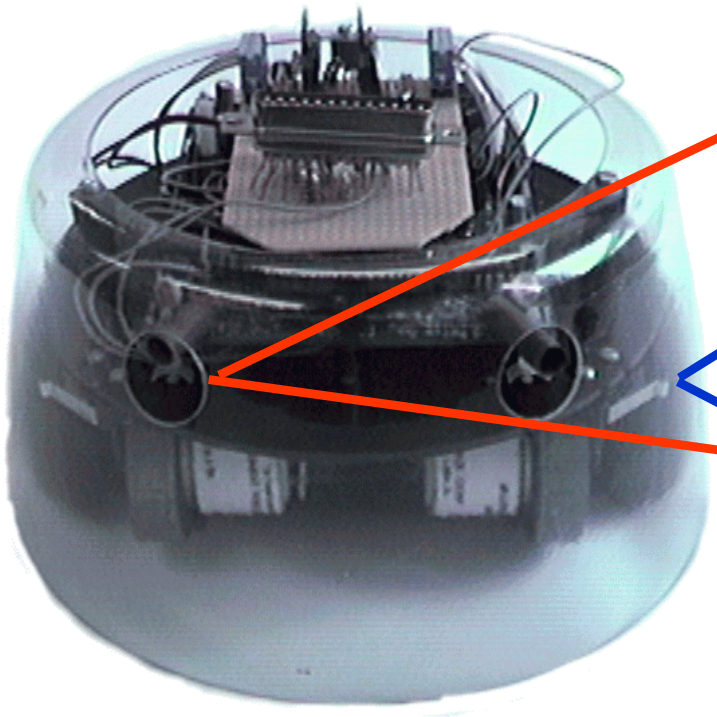
$$\frac{d}{dt}\omega_i(t) = \mu\, u_i(t)\, y'(t)$$

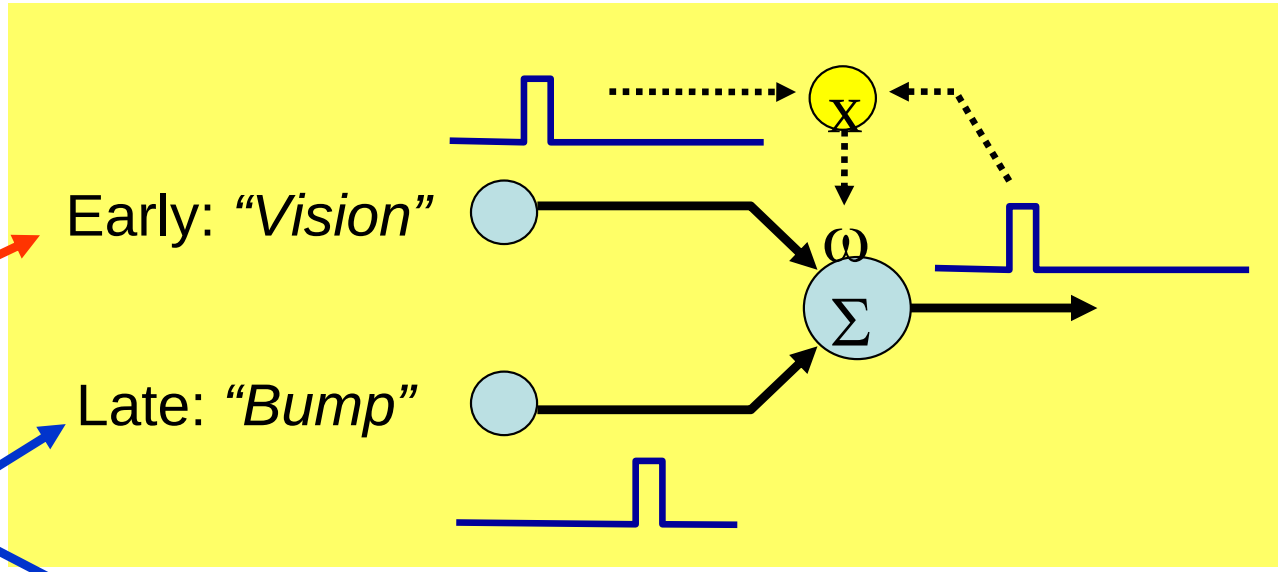
Early: *"Bell"*

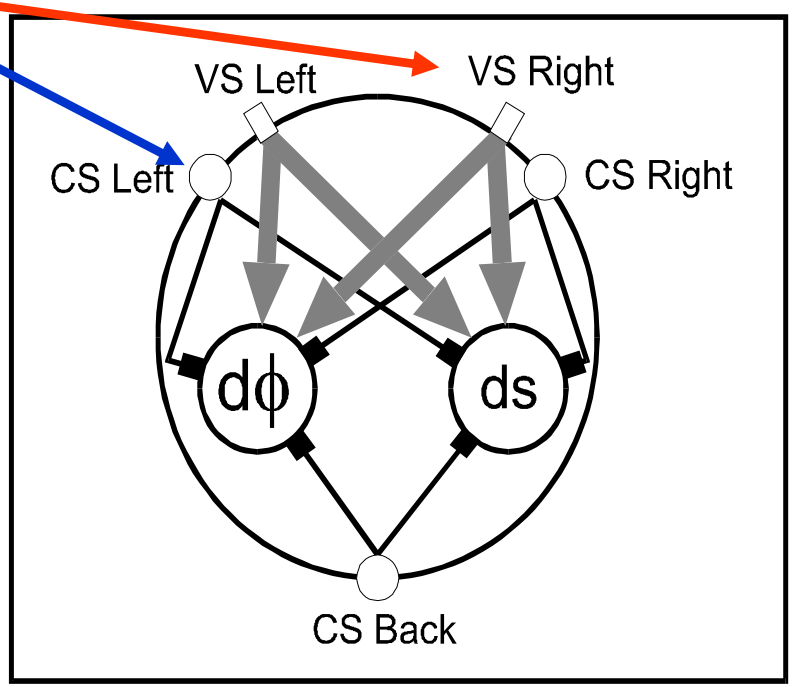


Late: *"Food"*

Robot Application

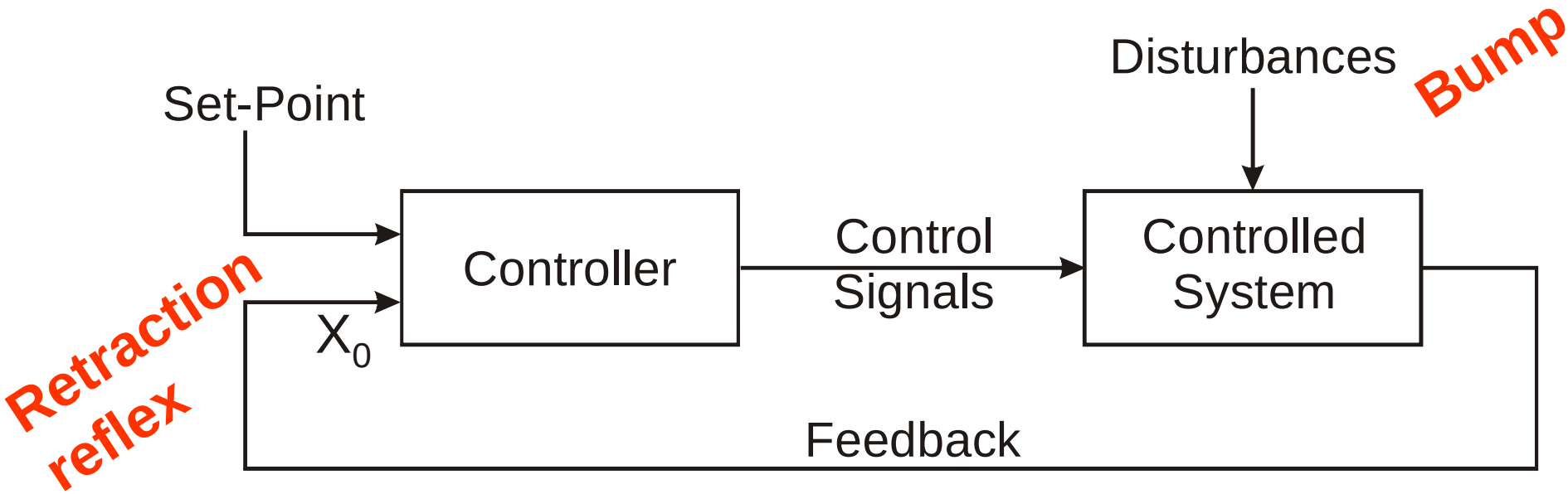






How to assure behavioral stability ?
(Avoiding the “tabula rasa” problem)

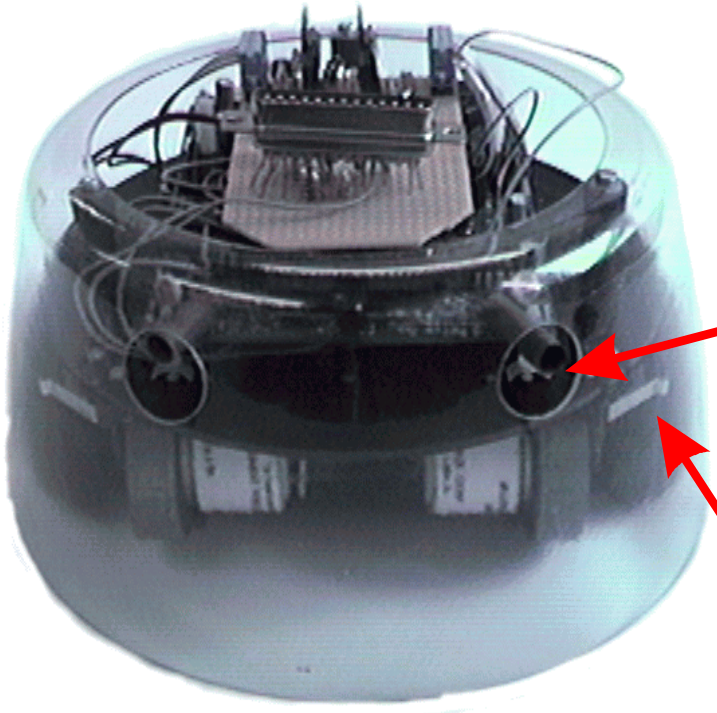
A very basic animal (Reflexes only)



This structure assures initial behavioral stability (“homeostasis”) as well as stability during the learning (“fall-back behavior”).

Porr & Woergoetter, Neural Comp. 2003, 2006 (in press)

Robot Application

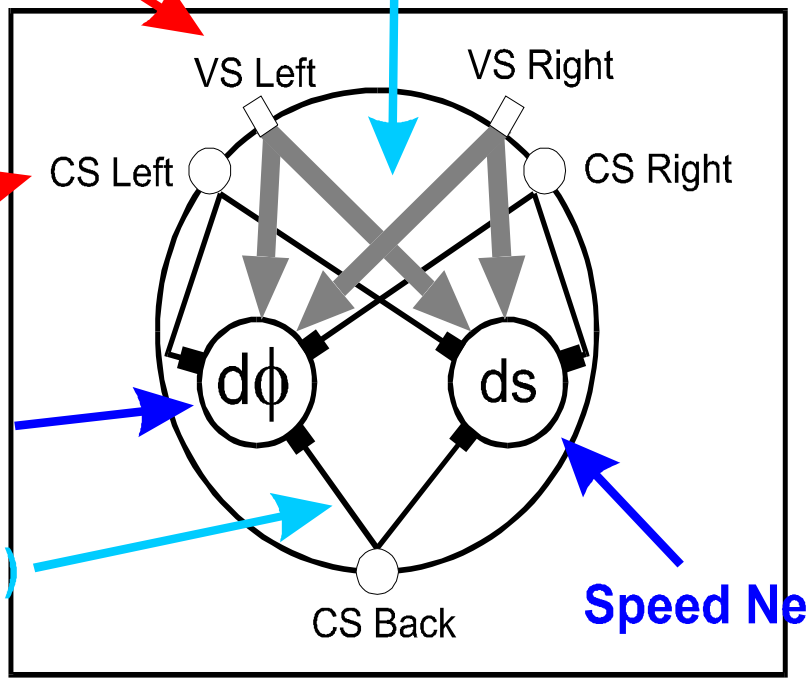


Learning Goal:
Correlate the vision signals with the touch signals and navigate without collisions.

Vision Sensors (VS)

Learned (plastic) Connections

Collision Sensors (CS)



Steering Neuron

Speed Neuron

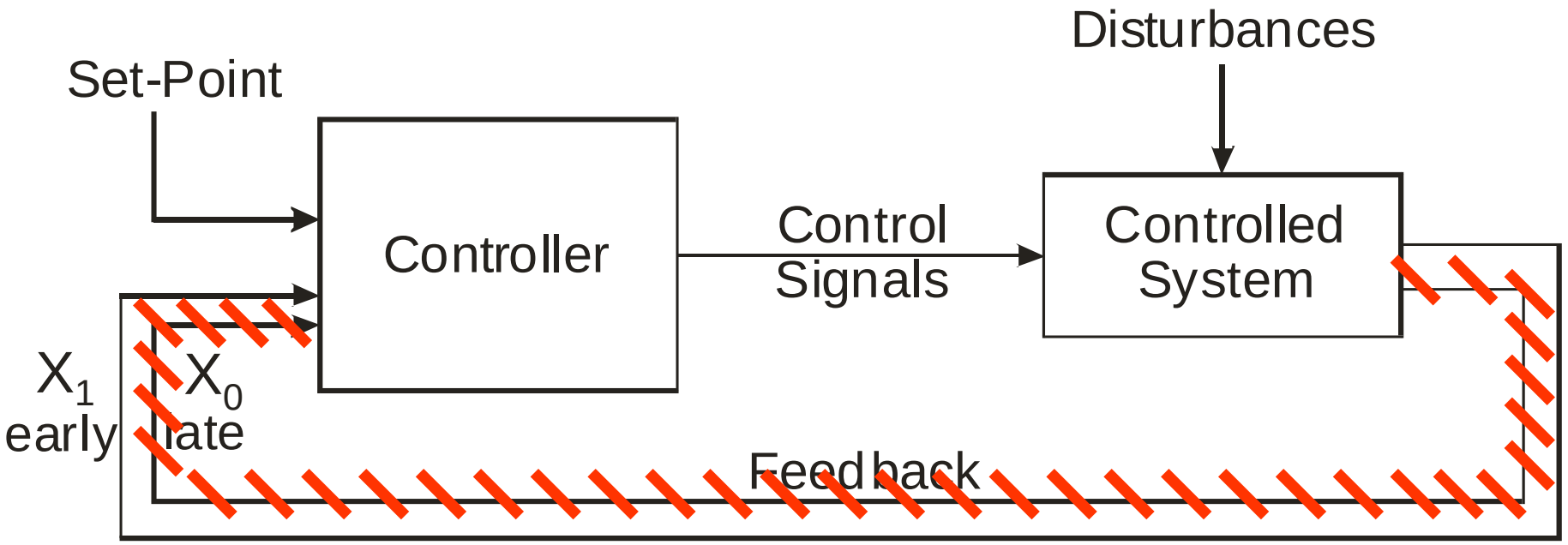
Initially built-in behavior:
Retraction reaction whenever an obstacle is touched.

fixed (unconditioned) Connections

Learning to Retract:
A Vision Signal Predicts a Bump

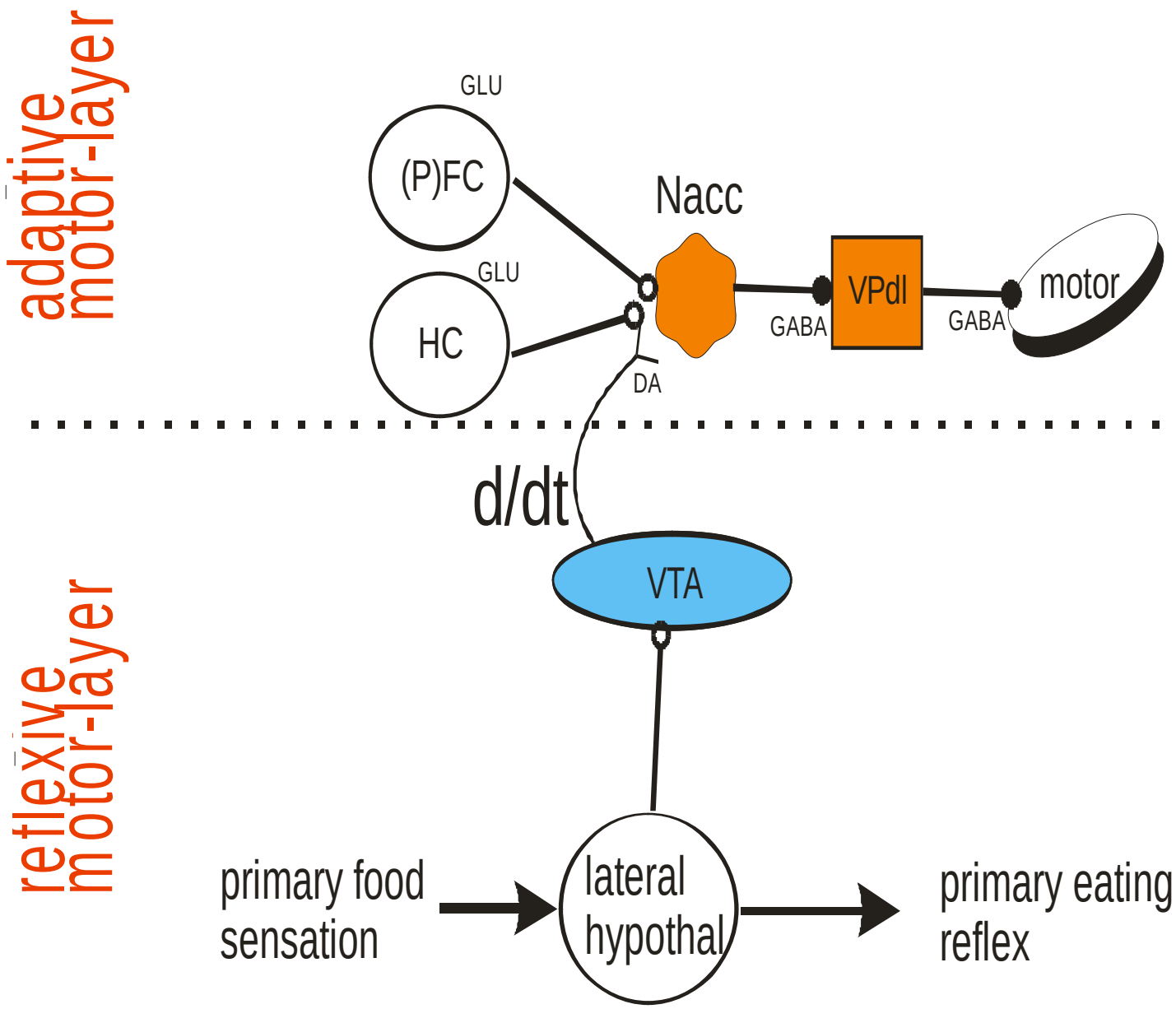
What has happened during learning to the system ?

The primary reflex re-action has effectively been eliminated and replaced by an anticipatory action

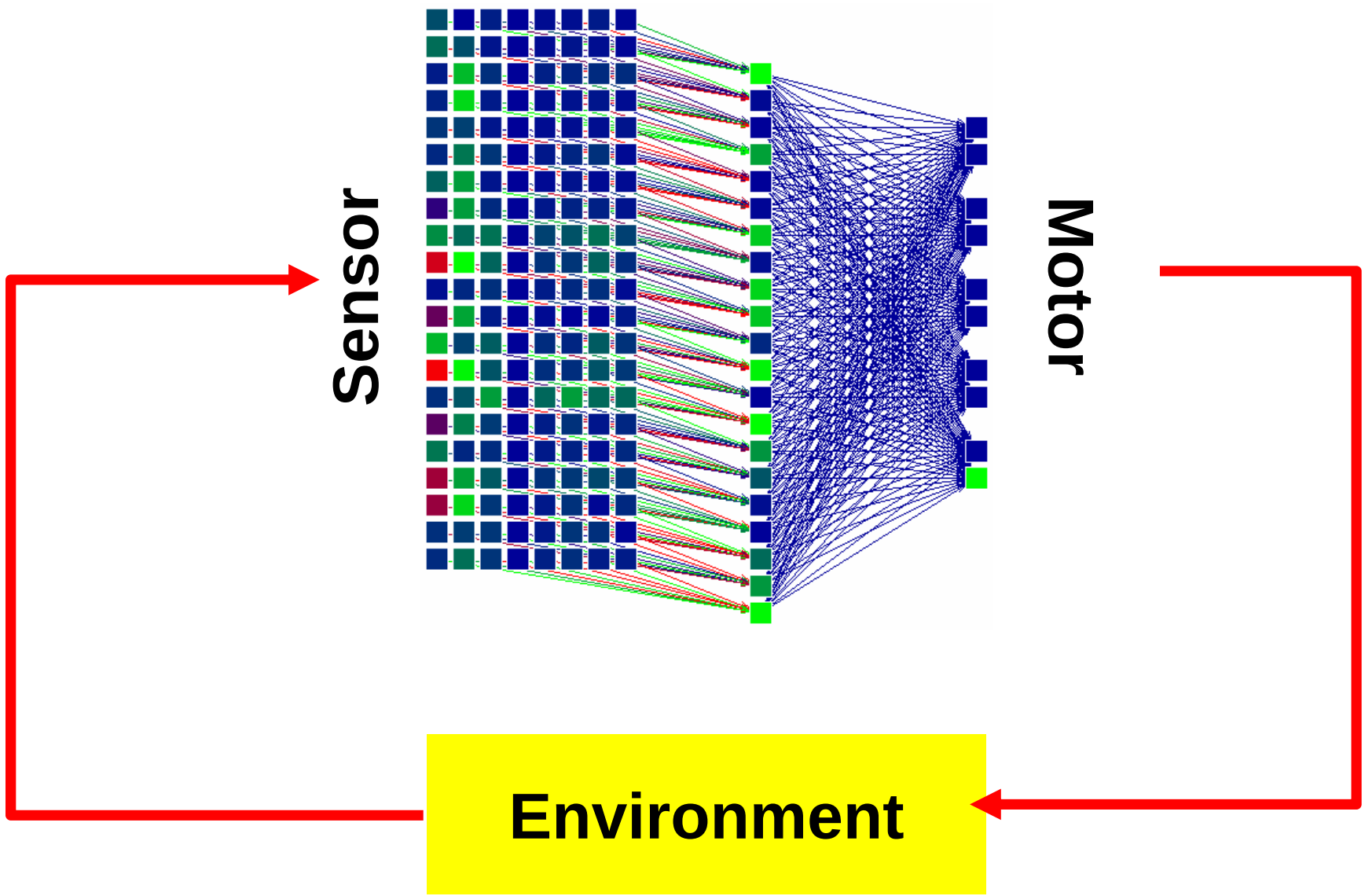


Mapping Theory to the Limbic System

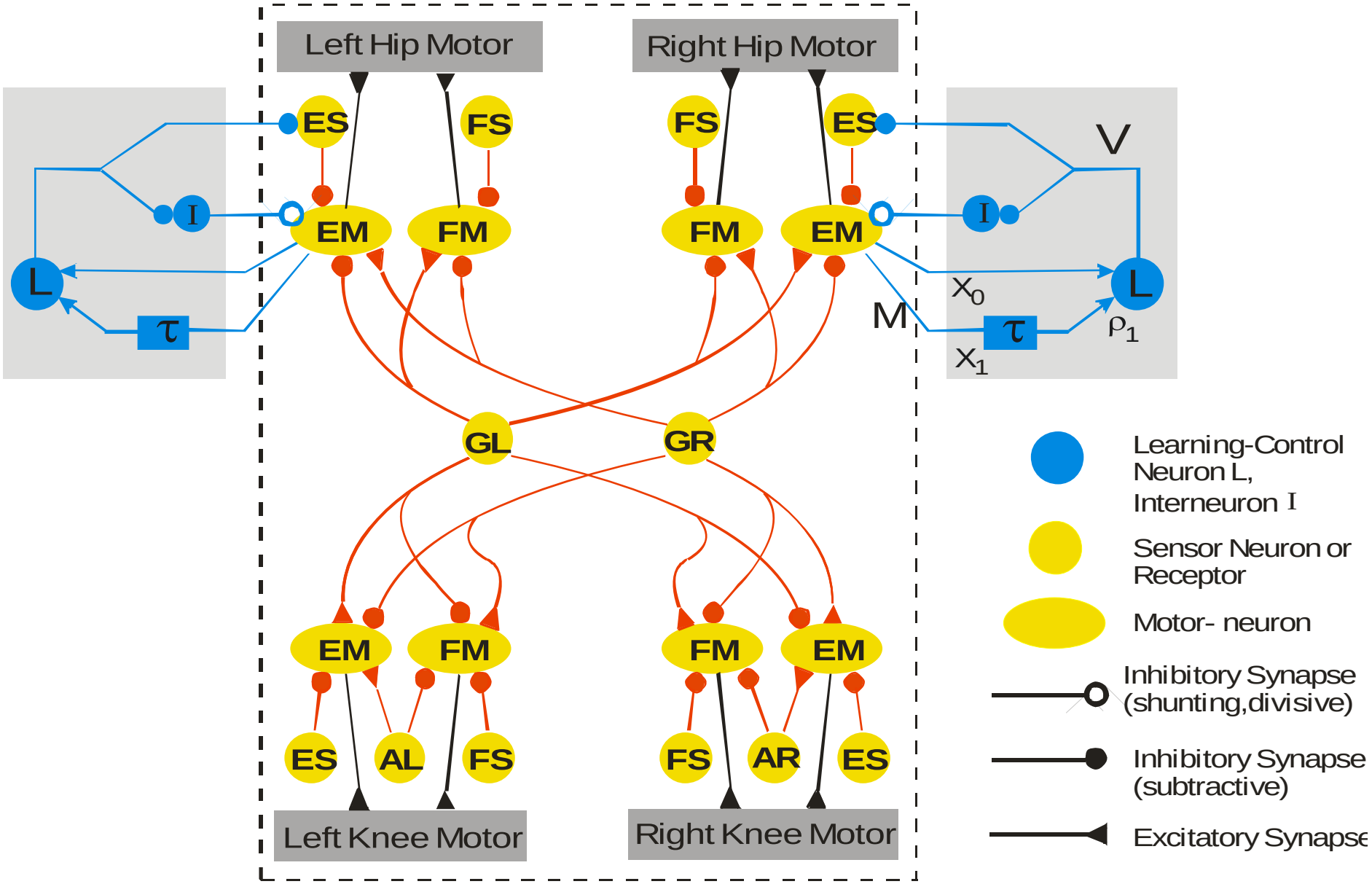
An early cognitive (?), anticipatory (!) pathway



The third component: A simple layered control structure for temporal network learning

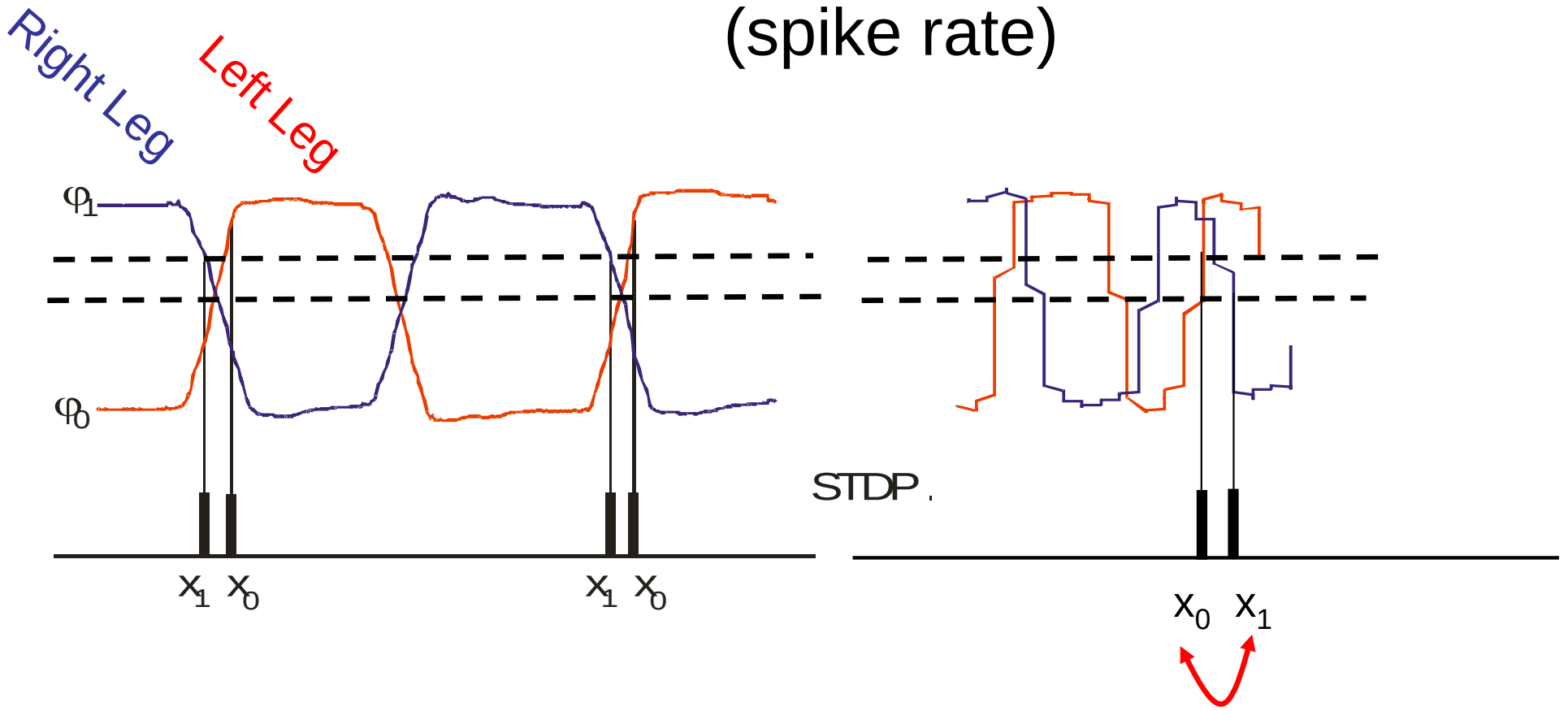


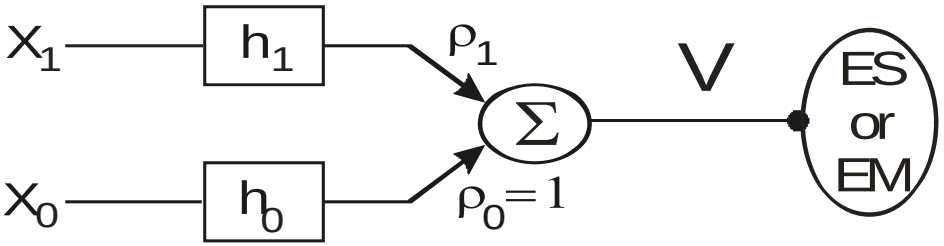
Applying this in a walking robot: The Neuronal Circuitry



AL, (AR) Stretch receptor for anterior angle of left (right) hip; GL, (GR) Sensor neuron for ground contact of left (right) foot; EI (FI) Extensor (Flexor) reflex inter-neuron, EM (FM) Extensor (Flexor) reflex motor-neuron; ES (FS) Extensor (Flexor) reflex sensor neuron

Motor Neuron Signal Structure
(spike rate)





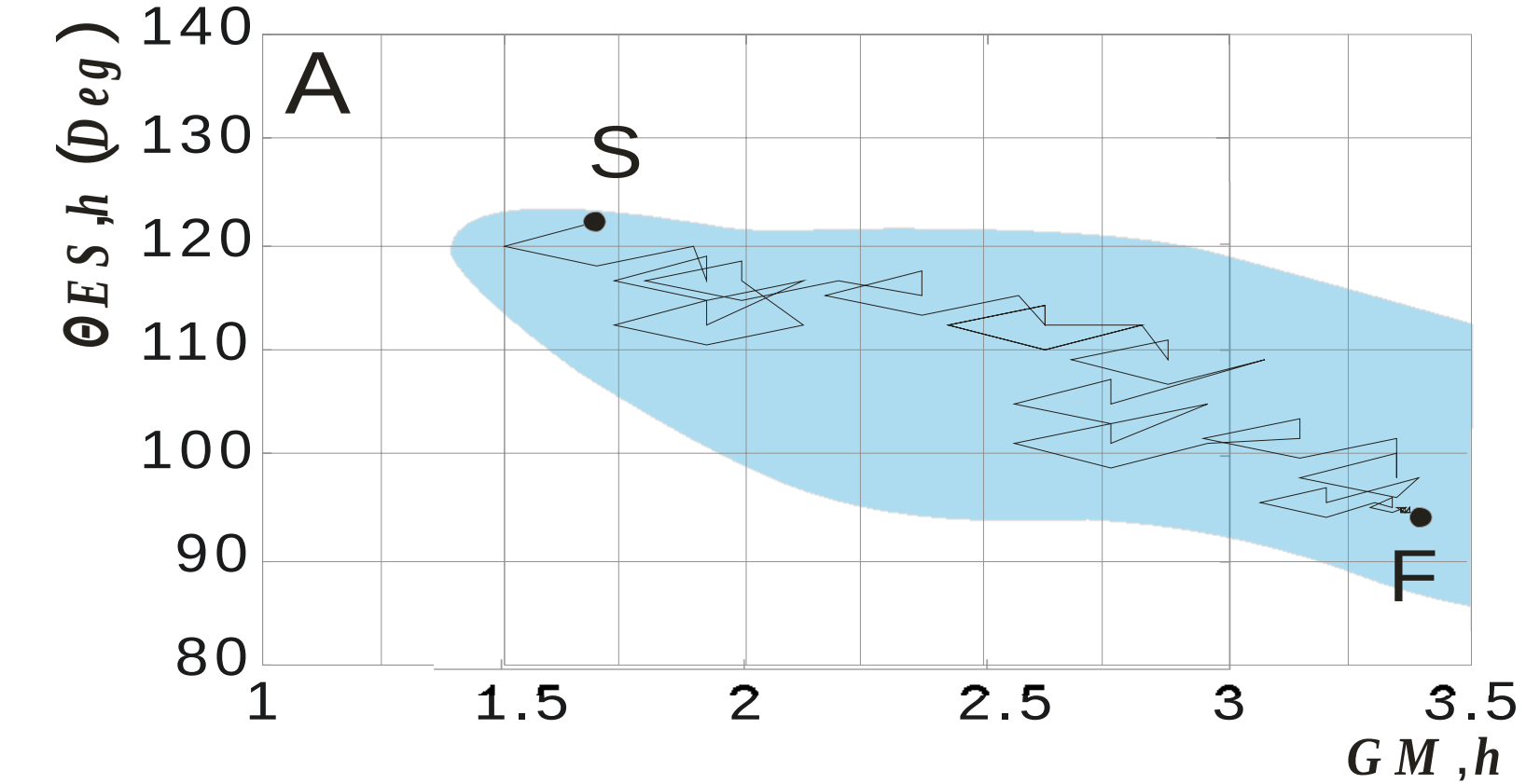
Learning reverses pulse sequence

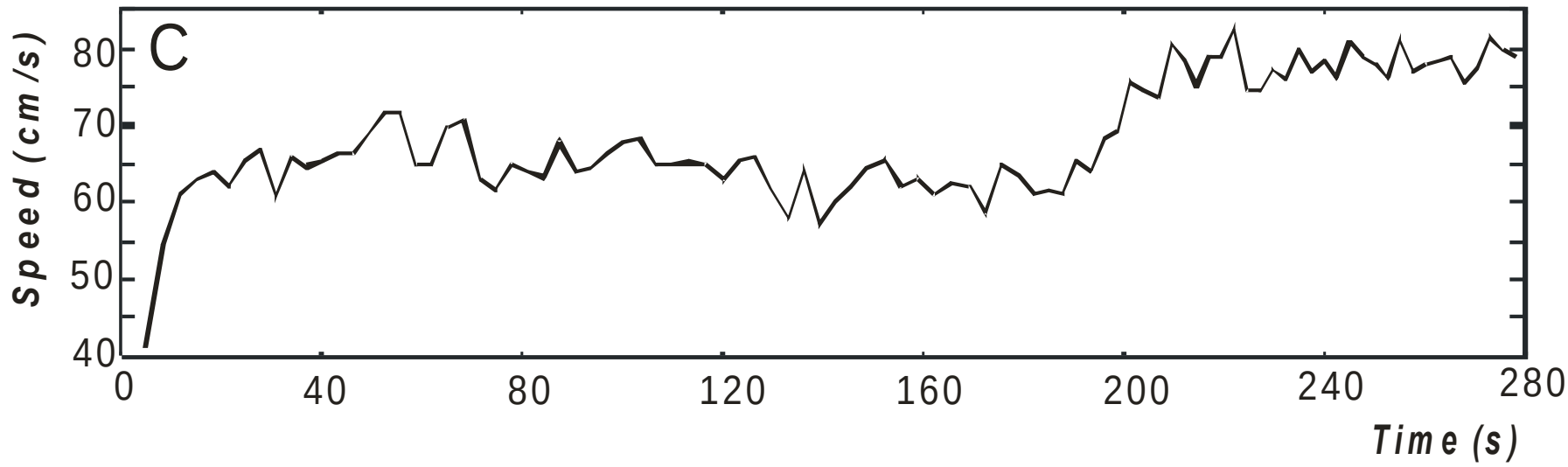
➔

Stability of STDP

The actual Experiment

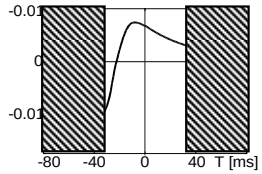
Walking Robot Movie here

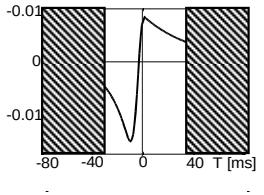




Geng et al. Neural Comp. 2006 (in press) and Geng et al. Int. J. Rob. Res. 2006 (in press)

The Approach:





Parameterization of STPD to make it usable in ANN architectures

Closed loop reflex based single neuron learners

Adaptive networks for anticipatory control.

Anticipation as an early cognitive feature !

Acknowledgements

T. Geng (Walking Robot)
B. Porr (Theory of Learning)
A. Saudargiene (Local STDP)

ADVERT

Job offer for Postdocs and Phd students at the:

Bernstein Center for Computational Neuroscience (BCCN)
University of Göttingen, Germany

In the fields of
Learning, Robotics and Computer Vision,
funded through two European Projects.

by Feb 2006.

See http://www.cn.stir.ac.uk for our work and/or contact me at worgott@chaos.gwdg.de