

# Oscillations and Learning in Excitatory-Inhibitory Coupled Neurons

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# Oscillations

- are correlated with perception
- can be generated in recurrent networks
- functional role is largely unknown

# Borgers & Koppell (2003)

- Network of coupled Excitators and Inhibitors, inspired by OB
- The E-cells have a positive baseline ( $I > 0$ )
- The I-cells have  $I < 0$ , gate the E cells
- Strongly attracting trajectories in phase space

# The Theta Model:

- One variable

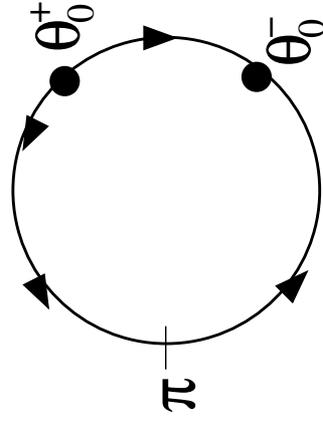
$$\frac{d\theta}{dt} = (1 - \cos\theta) + (1 + \cos\theta)I(t)$$

- Equivalent to the Quadratic IF model:

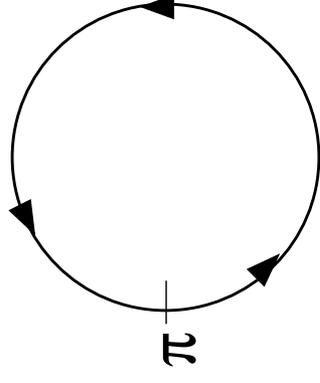
$$V = \tan(\theta/2)$$

- The neuron “spikes” whenever  $\theta$  crosses  $\pi$

# Phase Circle



$I < 0$

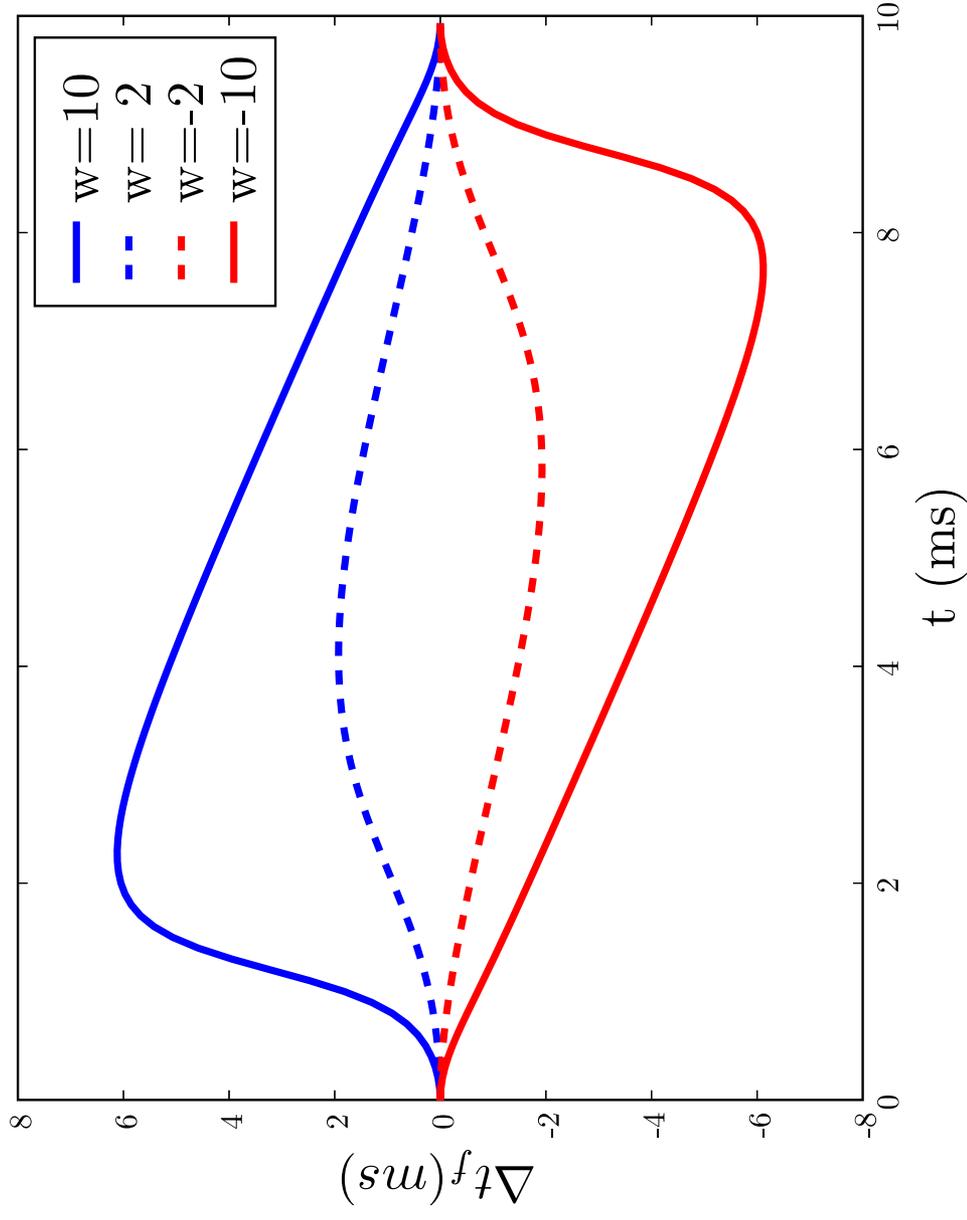


$I > 0$

$$d\theta/dt = (1 - \cos\theta) + (1 + \cos\theta)I$$

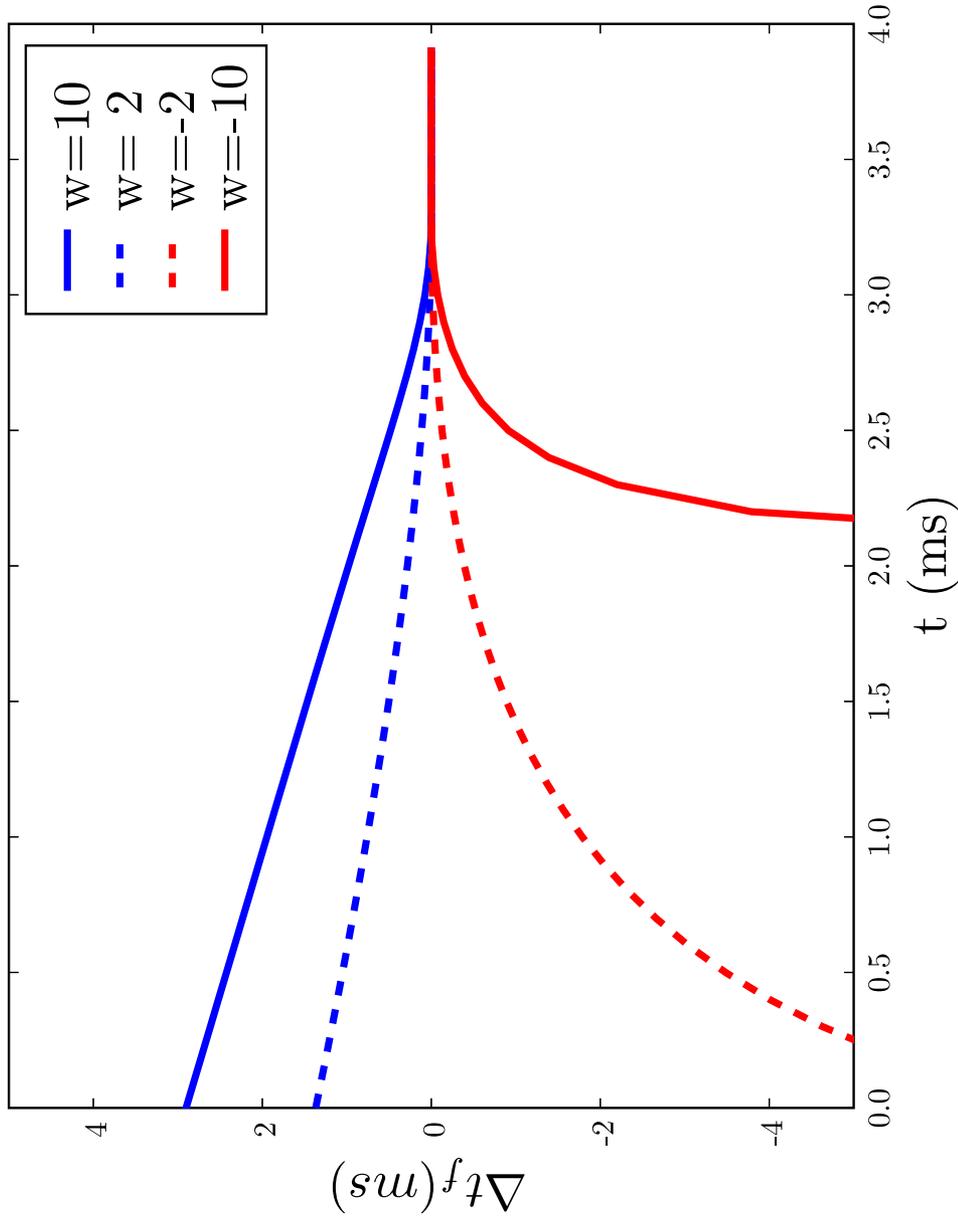
- $I > 0$  : fires regularly.
- $I < 0$  : two fixed points,  $\theta_0^-$  and  $\theta_0^+$

# Phase response curve



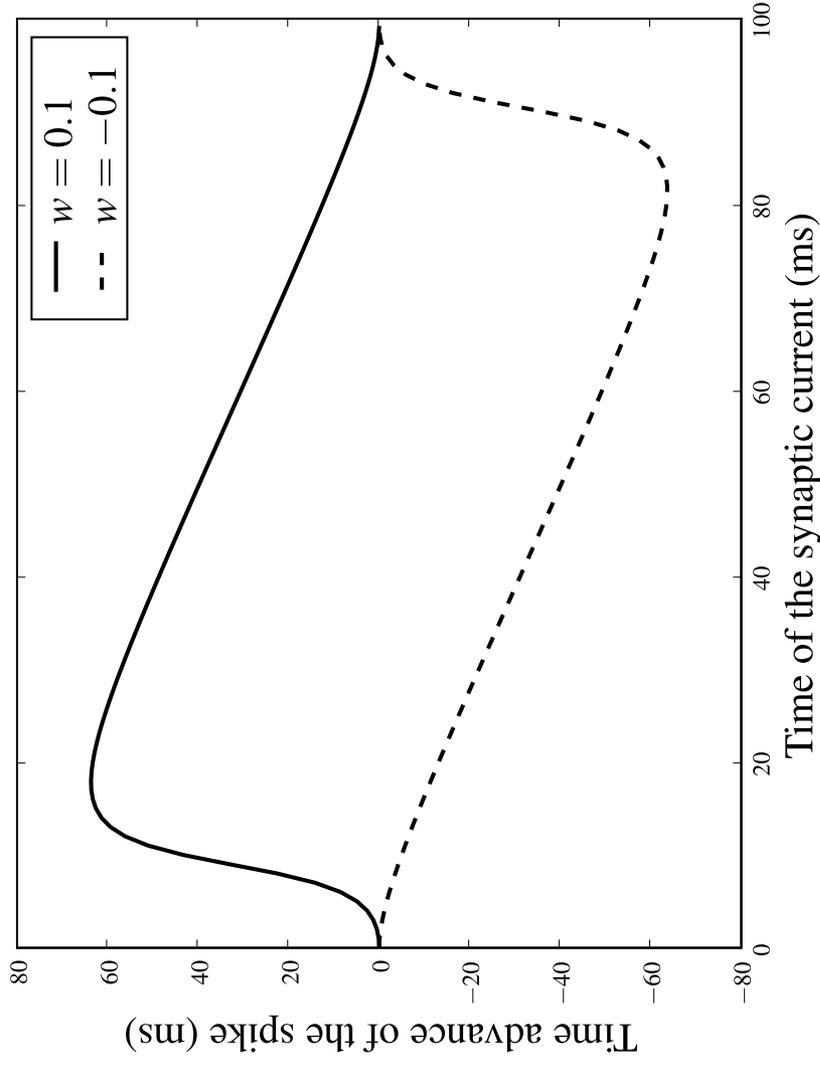
Type I neuron

# Response curve for $I < 0$



# Inhibition synchronizes the E-cells

Cells that are 'late' respond more



Synchronization induced by response properties

# Borgers & Koppell (2003)

- generation of oscillations
- synchronization induced by response properties
- simple
- no learning
- no answer about possible functional role

# Sensory learning

- Sensory systems do learn
- Unsupervised
- Learning modifies the response to known stimuli
- Olfaction : Synchronization increases with familiar stimuli (Stopfer & Laurent, 1999, Martin et al. 2004)

# Learning objectives

- Finding a suitable representation of the input
- Extracting correlations (1st order or higher)
- Set of relevant features
- Compressed information

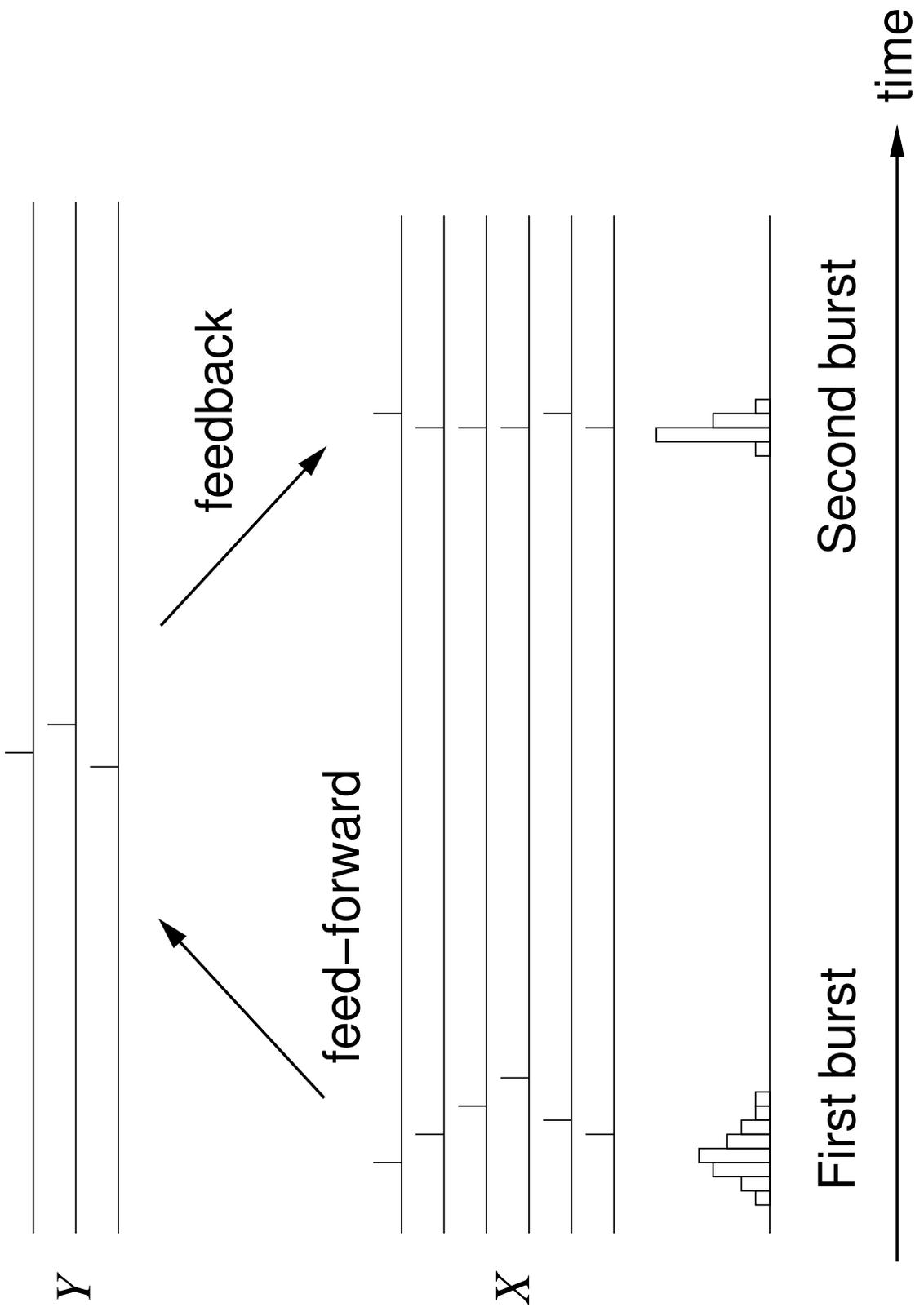
# Feature extraction (PCA, ICA...)

- 'Generative' models
- Input is compared to an expectation
- 'Predictive' learning rules
- Gradient descent:

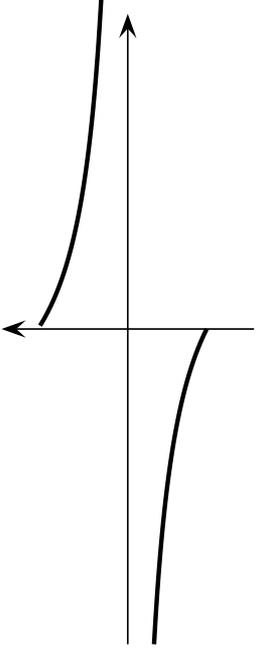
$$\frac{\partial E}{\partial w_{ij}} = \frac{\partial y_j}{\partial w_{ij}} (x_i - \bar{x}_i)$$

- Problem : there are 3 terms

# Synchronization as phase cancellation



# Spike Timing Dependent Plasticity



Hebbian interpretation:

- pre before post = 'causal order'
- unstable (positive feedback)
- bimodal distribution

# Are there conditions where STDP is stable

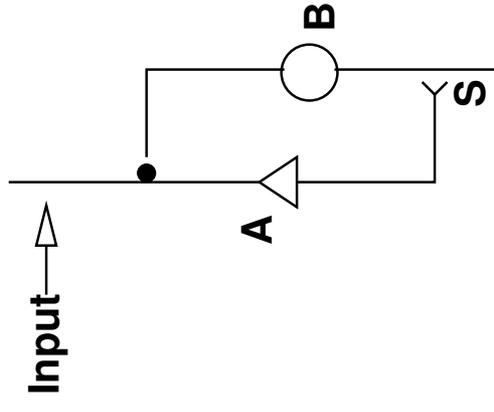
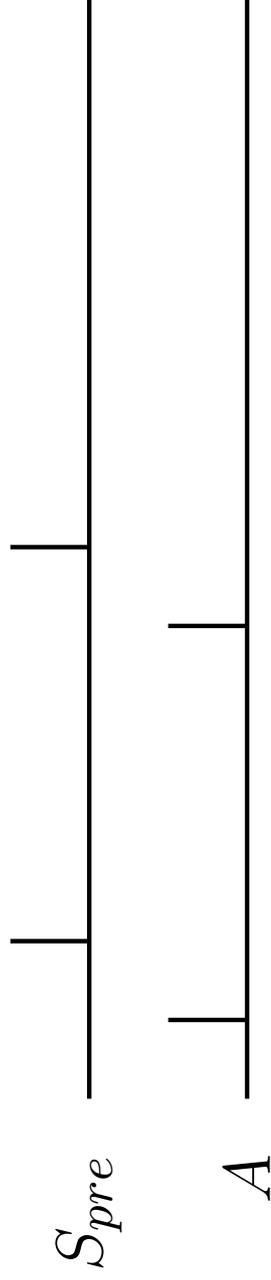
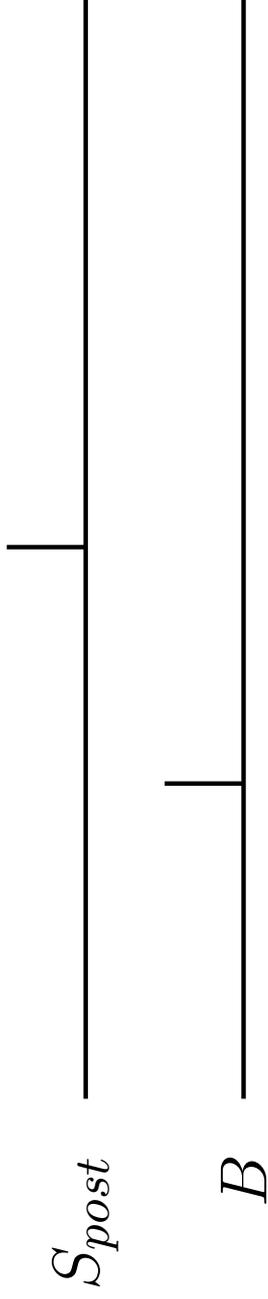
- STDP implements a negative feedback
- Predictive learning rule

$$\frac{\partial E}{\partial w_{ij}} = \frac{\partial y_j}{\partial w_{ij}} (x_i - \bar{x}_i)$$

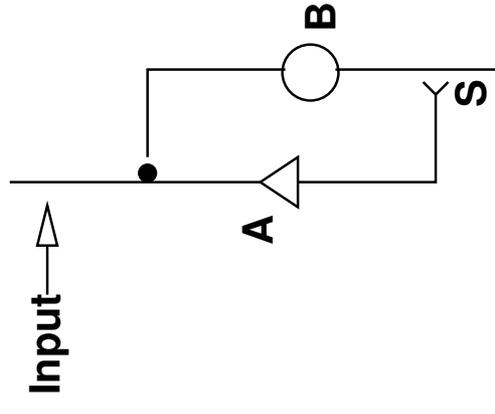
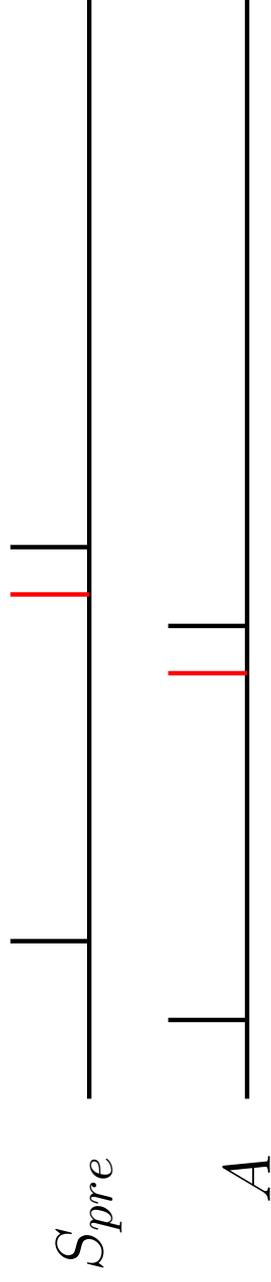
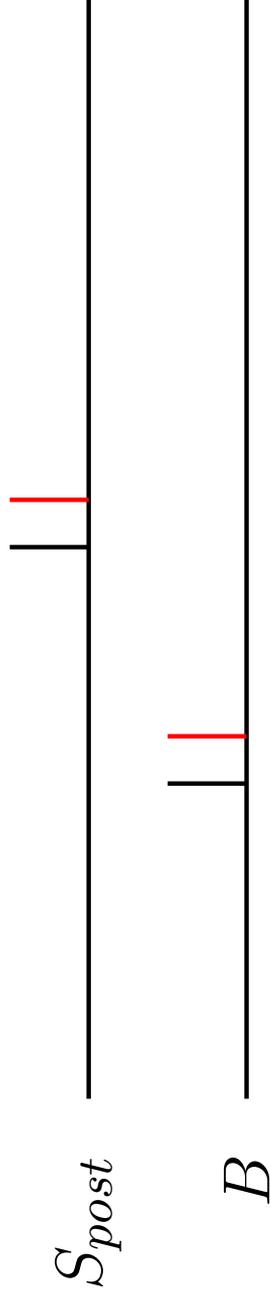
Sign change of STDP = comparison.

- Non Hebbian interpretation

# Stable STDP



# Stable STDP

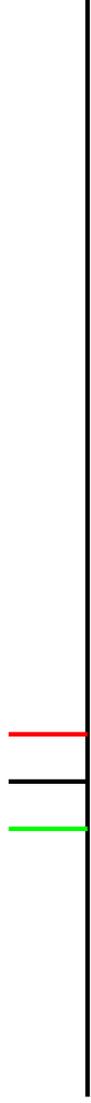


# Stable STDP

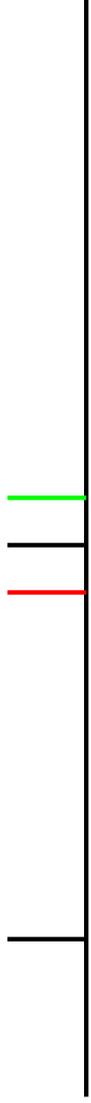
$S_{post}$



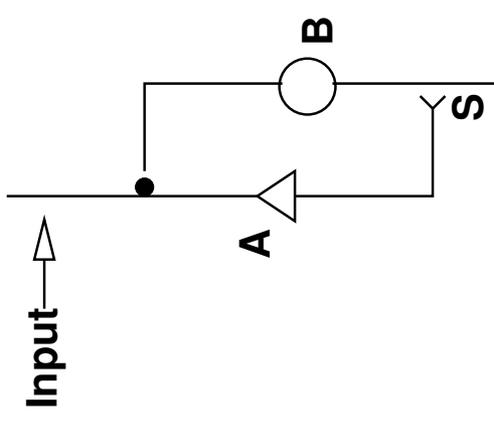
$B$



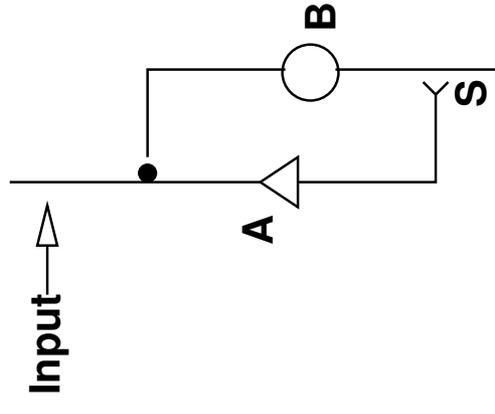
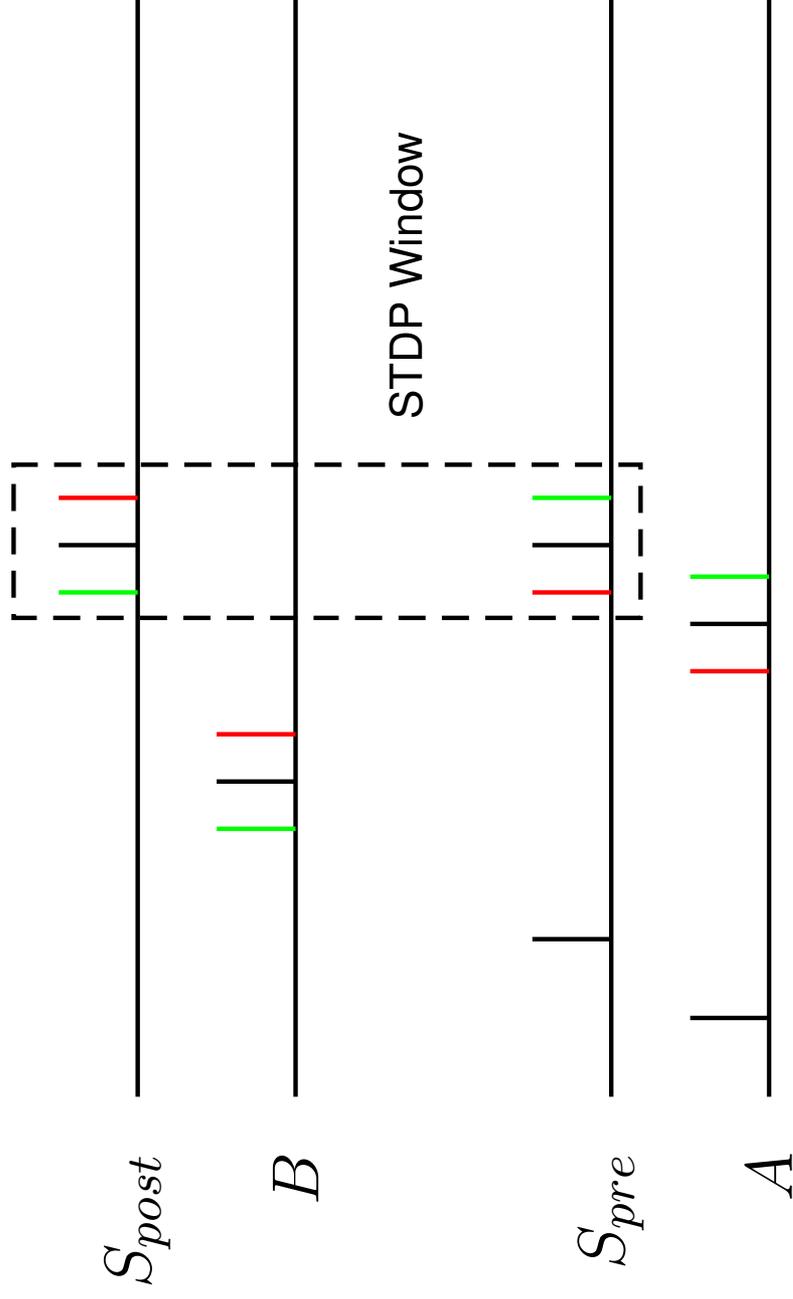
$S_{pre}$



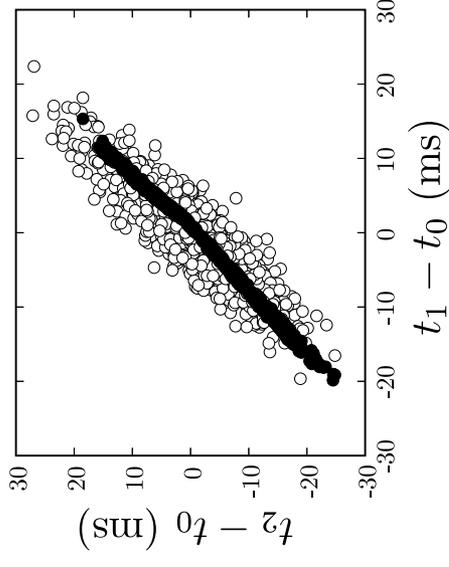
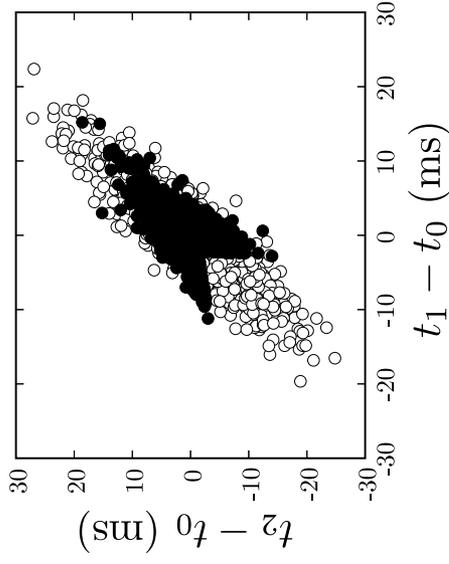
$A$



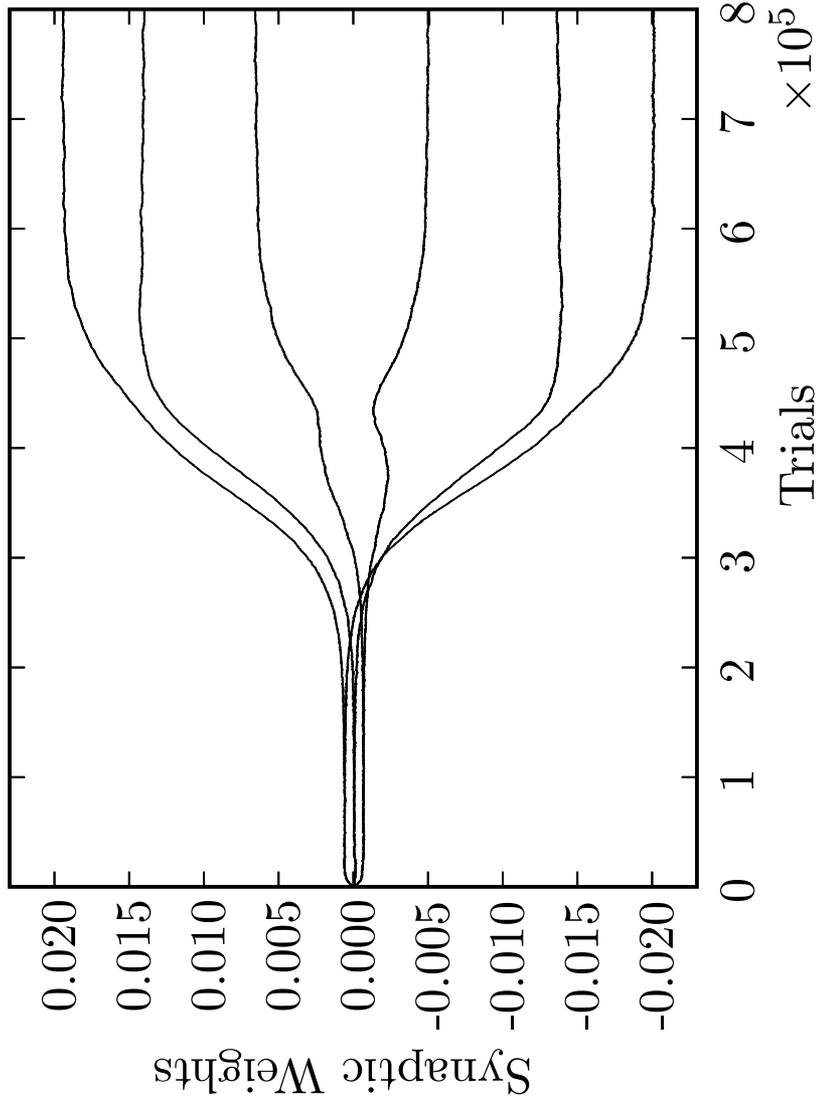
# Stable STDP



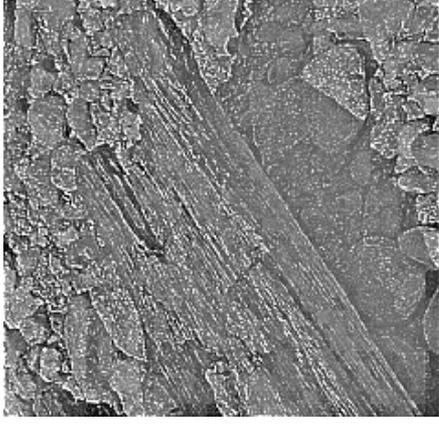
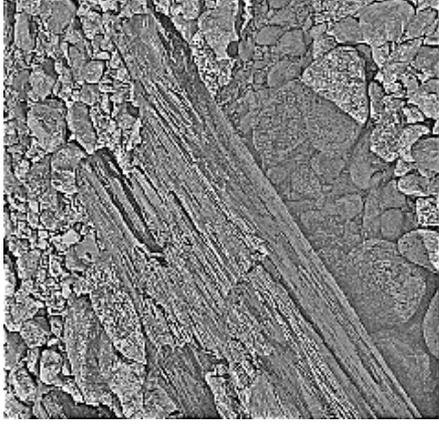
# Example : PCA of a Gaussian distribution



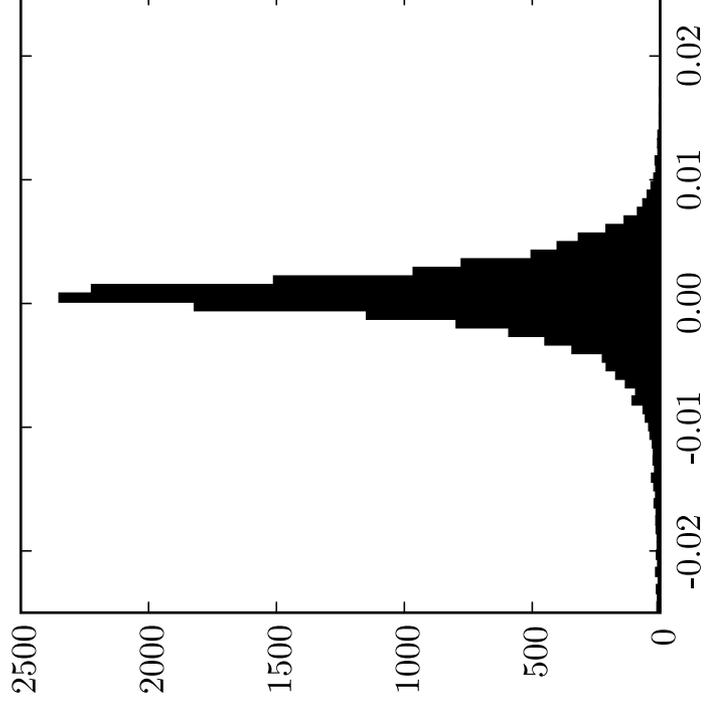
# Stability



# Example 2 : Natural images



# Unimodal distribution



# Conclusion

- Learning in a coupled E-I network
- Possible functional role for oscillations
- Predictive learning rule (3 terms)