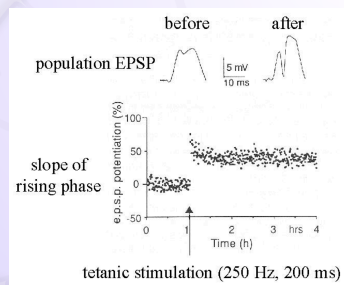# Learning

Computational Cognitive Neuroscience
Randall O'Reilly

Overview of Learning

- Biology: synaptic plasticity
- Computation:
  - Self organizing – soaking up statistics
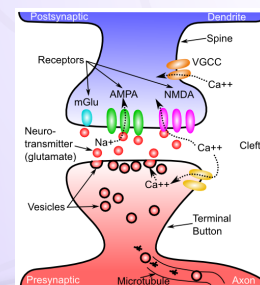 - Error-driven – getting the right answers

2

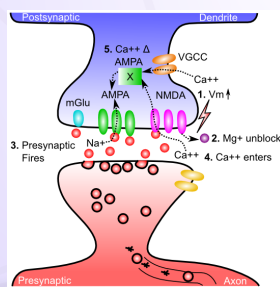## Synapses Change Strength
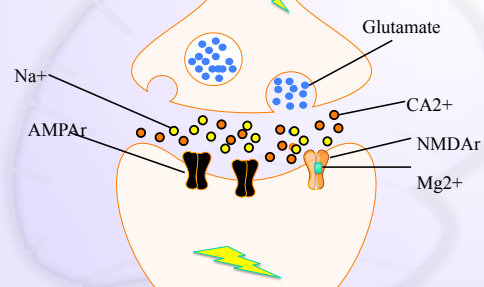### (in response to patterns of activity)

3

What Changes??

4

Gettin' AMPA'd

5

Opening the NMDA receptor calcium channel

Which Way?

Θ⁻ Θ⁺

LTP / LTD $[Ca^{2+}]_i$
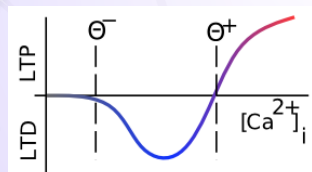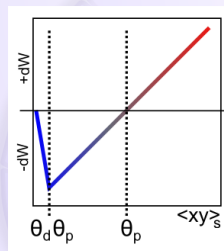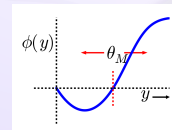
7

XCAL = Linearized BCM
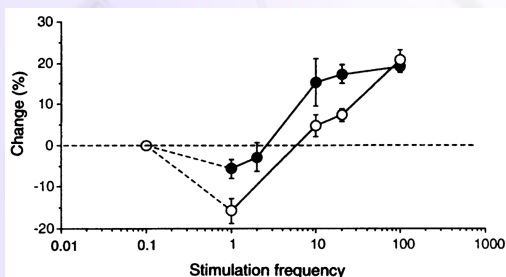
- Bienenstock, Cooper & Munro (1982) – BCM:
- **adaptive threshold** Θ
  - Lower when less active
  - Higher when more.. (homeostatic)

$\theta_d\theta_p$ θ_p $<xy>_s$

$\phi(y)$ θ_M $y \to$

8

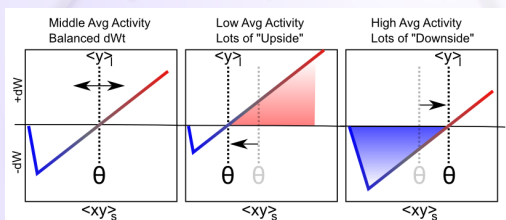## Threshold Does Adapt

Change (%)

Stimulation frequency

9

Computational: Self-Organizing and Error-Driven

- Self-organizing = learn general statistics of the world.
- Error-driven = learn from difference between expectation and outcome.
- Both can be achieved through XCAL.

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Floating Threshold = Long Term Average Activity (Self Org)

Middle Avg Activity
Balanced dWt

Low Avg Activity
Lots of "Upside"

High Avg Activity
Lots of "Downside"

$<y>$ $<y>$ $<y>$

θ θ θ θ θ

$<xy>_s$ $<xy>_s$ $<xy>_s$

11

Self Organizing Learning

- Inhibitory Competition: only some get to learn
- Rich get richer: winners detect even better
  - But also get more selective (hopefully)
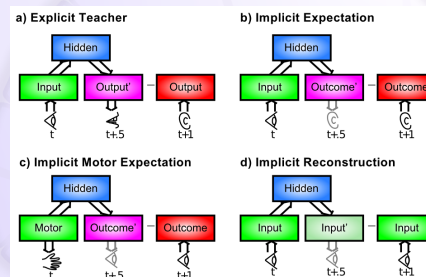- Homeostasis: keeping things more evenly distributed (higher taxes for the rich!)

12

Limitations of Self-Organizing

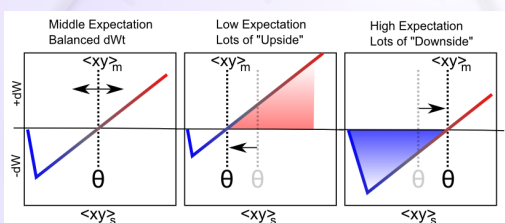- Can't learn to solve challenging problems – driven by statistics, not error..
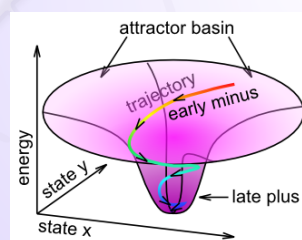
13

Where Does Error Come From?

14

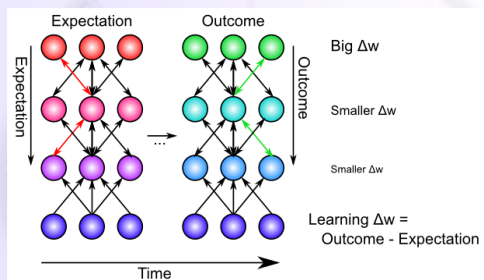## Floating Threshold = Medium Term Synaptic Activity (Error-Driven)

15

Fast Threshold Adaptation: Late Trains Early

Essence of Err-Driven: dW = outcome - expectation

16

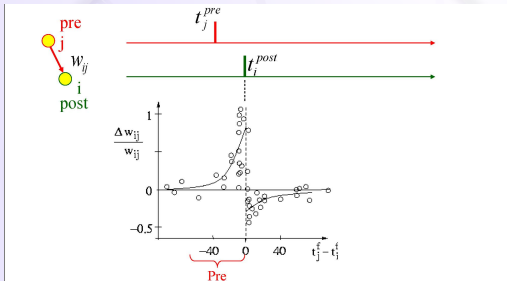## Backpropagation: Mathematics of Error-driven Learning

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Biological Derivation of XCAL Curve

- Can use a detailed model of Spike Timing Dependent Plasticity (STDP) to derive the XCAL learning curve
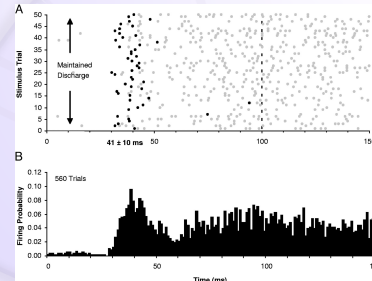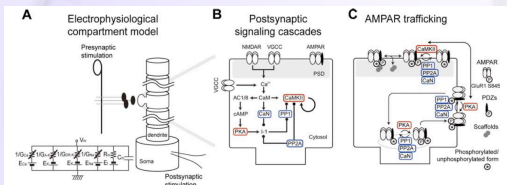- Provides a different perspective on STDP..
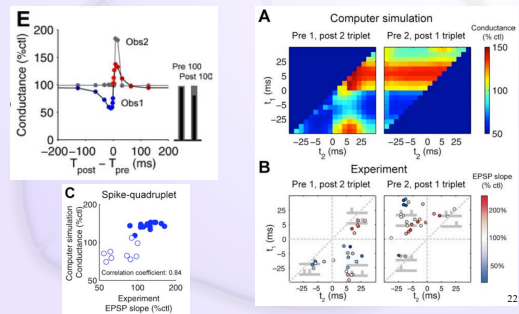
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Causal Learning?

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Let's Get Real..

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Urakubo et al, 2008 Model

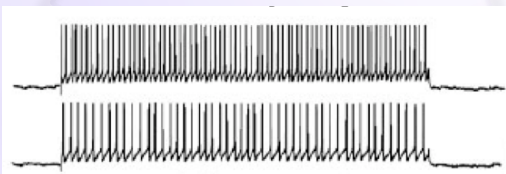- Highly detailed combination of 3 existing strongly-validated models:

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"Allosteric" NMDA Captures STDP
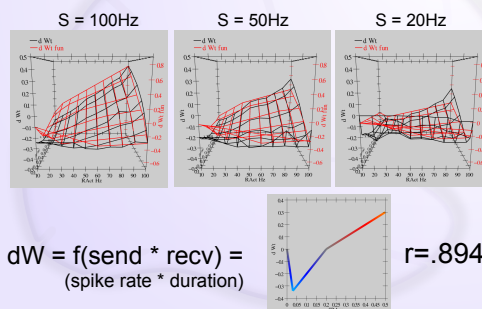### (including higher-order and time integration effects)
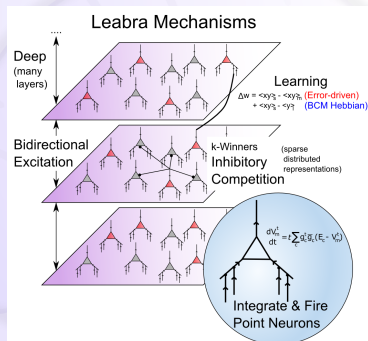

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What About Real Spike Trains?
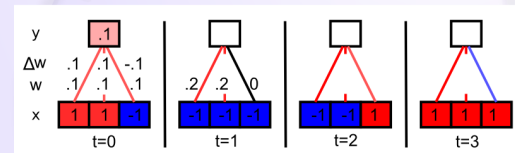

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Extended Spike Trains = Emergent Simplicity

dW = f(send * recv) =
(spike rate * duration)

r=.894

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Leabra

Hebbian Learns Correlations