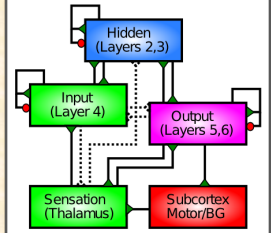


3. Neocortical Dynamics

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Functions of Layers

- **Input**
 - layer 4
 - from sensation or other areas
- **Hidden**
 - layers 2 & 3
- **Output**
 - layers 5 & 6
 - to motor systems or other areas

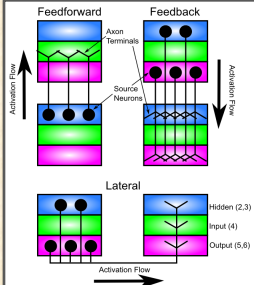


(fig. < O'Reilly, *Comp. Cog. Neurosci.*)

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Connection Directions

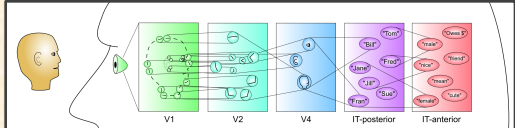
- **Feedforward**
 - from Hidden in lower to Input in higher
- **Feedback**
 - from Hidden & Output in higher to Hidden & Output in lower
- **Lateral**
 - from Hidden and Output to all three layers in same area
- **Bidirectionality**
 - pervasive



(fig. < O'Reilly, *Comp. Cog. Neurosci.*)

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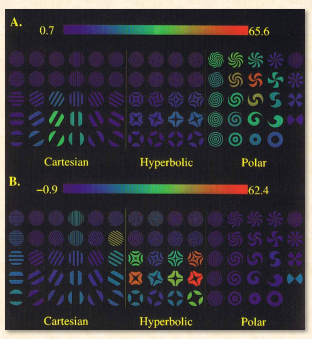
Hierarchical Categorical Representations



- Successive layers of neural detectors
- Progressively more abstract

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Cell Responses in V4



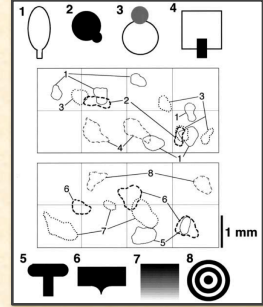
A. 0.7 to 65.6
 B. -0.9 to 62.4

Cartesian Hyperbolic Polar

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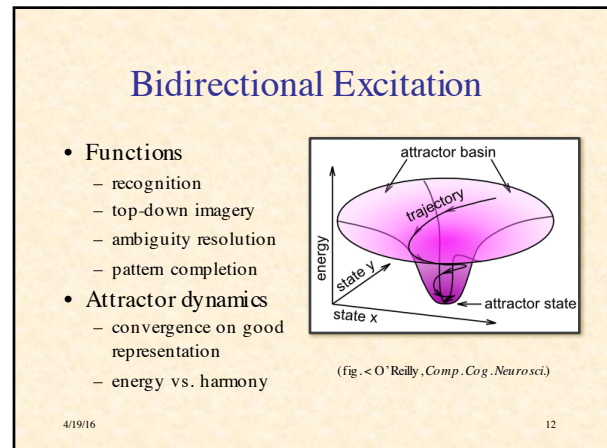
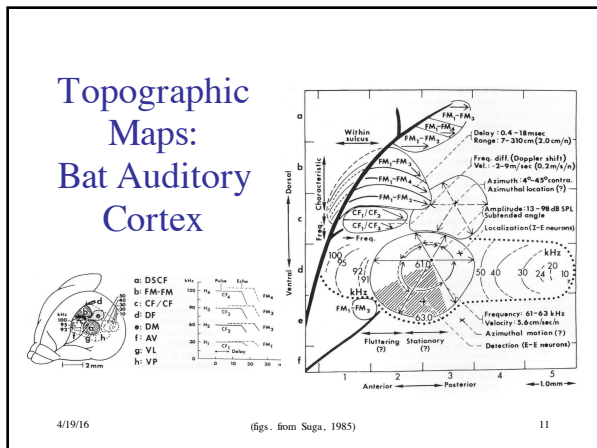
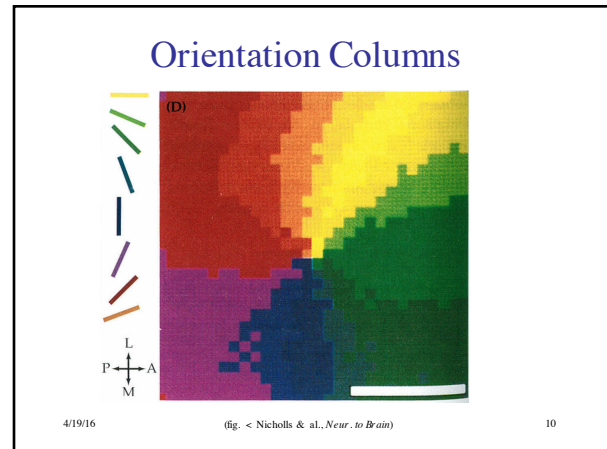
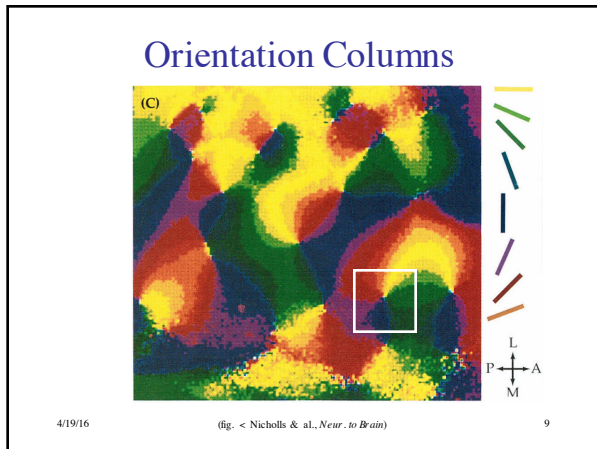
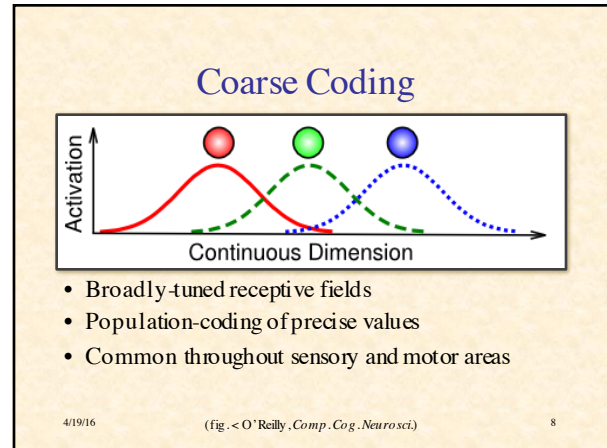
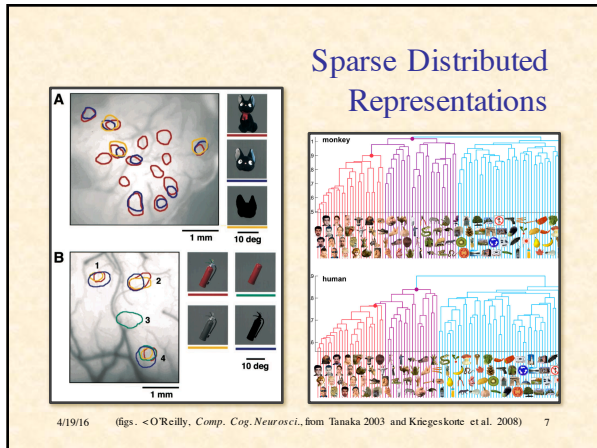
Sparse Distributed Representation

- **Localist representation**
 - "grandmother cells"
 - unlikely in brain
- **K-out-of-N detectors**
 - typically 15-25% of neurons active
- **Approximate orthogonality**




(monkey IT cortex)

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Ambiguity Resolution



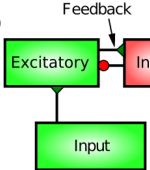
(fig. < O'Reilly, Comp. Cog. Neurosci.)

Inhibitory Competition and Activity Regulation

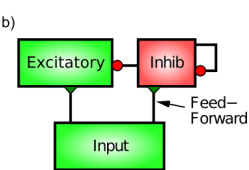
- Activity regulation
- Selective attention
- Competition
 - K winners take all
 - can be implemented algorithmically
- Sparse distributed representation

Activity Regulation

a)



b)



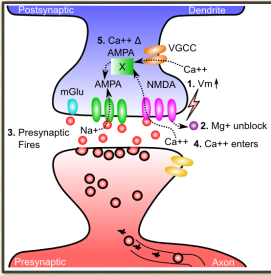
- Feedback: reactive, reflects actual level of activity, robust, responsive, may be unstable
- Feedforward: anticipatory, limits feedback oscillation, slow, brittle
- Work well together

(fig. < O'Reilly, Comp. Cog. Neurosci.)

4. Learning Mechanisms

Spike Timing Dependent Plasticity (STDP)

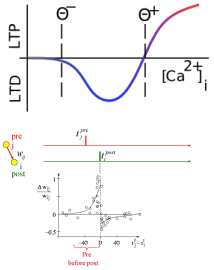
1. V_m elevated by backpropagating action potential
2. Repels Mg^{+} opening NMDA channels
3. Presynaptic neuron fires, releasing glutamate
4. Glutamate binds unblocked NMDA channels, allowing Ca^{++} influx
5. Ca^{++} increases number & efficacy of AMPA receptors



(fig. < O'Reilly, Comp. Cog. Neurosci.)

Long-term Potentiation (LTP) vs. Long-term Depression (LTD)

- LTP vs. LTD depends on Ca^{++} concentration over several 100 msec
- Records possible causal connection
- Actual situation is more complicated with multiple APs



(figs. < O'Reilly, Comp. Cog. Neurosci.)

LTP/LTD Approximation

- Piecewise linear approximation to LTP/LTD
- Typical $\theta_d = 0.1$
- Floating threshold
- $\Delta W = \eta f_{XCAL}(\langle xy \rangle_s, x \langle y \rangle_1)$

$$f_{XCAL}(c, \theta_p) = \begin{cases} c - \theta_p & \text{if } c > \theta_p \\ -c(1 - \theta_p) / \theta_d & \text{otherwise} \end{cases}$$

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Homeostatic Behavior

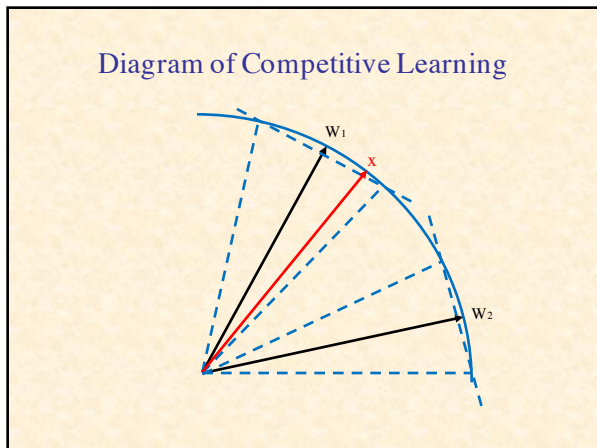
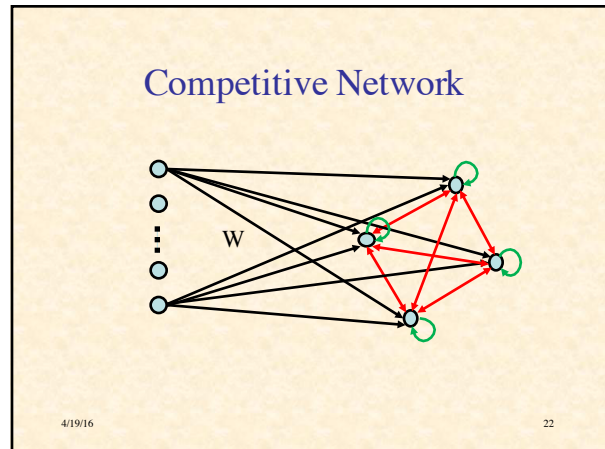
- Floating threshold adapts to long-term postsynaptic activity
- Tends to equalize activity among neurons

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Competitive Learning

- Competitive learning network
 - two layers, randomly initialized weights
 - second is self-reinforcing, mutually inhibitory
 - “winner takes all” dynamics
- Learning
 - winner moves toward last
 - weight vectors move to centers of clusters

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Self-Organizing Learning

- Inhibitory competition
 - ensures sparse representation
- Hebbian “rich get richer”
 - adjustment toward last pattern matched
- Slow threshold adaptation
 - adjusts receptive fields
 - equalizes cluster probabilities
- Homeostasis
 - distributes activity among neurons
 - more common patterns are more precisely represented
- Gradually develops statistical model of environment

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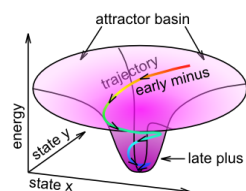
Error-Driven Learning

- For achieving intended outcomes
- Fast threshold adaptation
- Short-term outcome – medium-term expectation
 - ✓ “plus phase” – “minus phase”
- Depends on bidirectional connections
 - ✓ communicates error signals back to earlier layers
- Contrastive Attractor Learning (CAL)
 - ✓ approximately equivalent to BP when combined with bidirectional connections

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Contrastive Attractor Learning

- Network learns contrast between:
 - early phase/expectation (minus)
 - late phase/outcome (plus)
- Gets more quickly to late phase, which has integrated more constraints



$$f_{XCAL}(c, \theta_p) = \begin{cases} c - \theta_p & \text{if } c > \theta_p \theta_d \\ -c(1 - \theta_p) / \theta_d & \text{otherwise} \end{cases}$$

$$\Delta W = \eta f_{XCAL}(\langle x_s y_s \rangle, \langle x_m y_m \rangle) \approx \eta(x_s y_s - x_m y_m)$$

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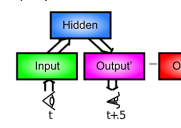
Learning Signals?

- What constitutes an “outcome”?
- Dopamine bursts arise from unexpected rewards or punishments (reinforcers)
 - violation of expectation
 - needs correction
- Dopamine modulates synaptic plasticity
 - controls λ : $\Delta W = \eta f_{XCAL}(x_s y_s, x_m (\lambda y_l + (1 - \lambda) y_m))$
- Probably not the whole story

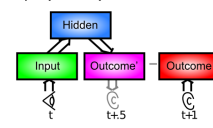
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Learning Situations

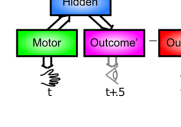
a) Explicit Teacher



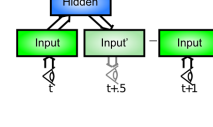
b) Implicit Expectation



c) Implicit Motor Expectation



d) Implicit Reconstruction



(fig. < O' Reilly, Comp. Cog. Neurosci.) 28