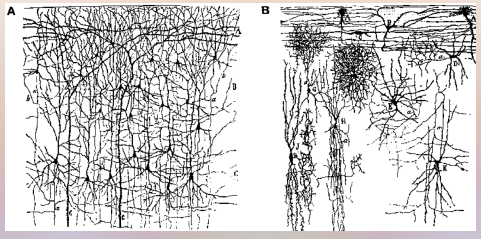
3. Networks

Networks

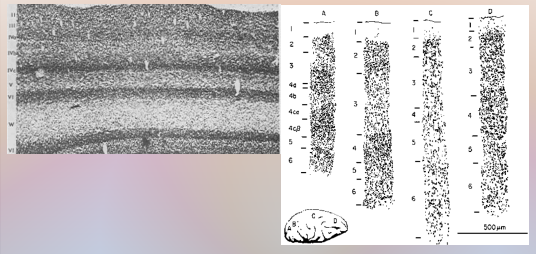
1. Biology of Neocortex ("cortex")
2. Categorization and Distributed Reps
3. Bidirectional Excitation and Attractors
4. Inhibitory Competition and Activity Regulation

Neurons: Excitatory and Inhibitory



Excitatory = main info processing, long-range connections
Inhibitory = local, activity regulation and competition

The 6 Cortical Layers

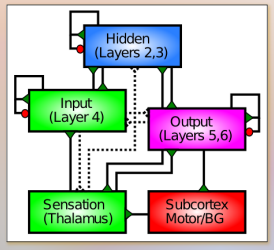


Functions of Layers

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.*)

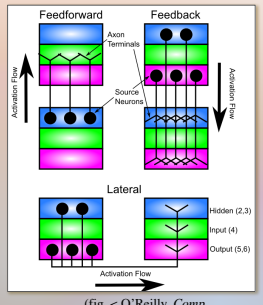
Connection Directions

Feedforward
- from Hidden in lower to Input in higher

Feedback
- from Hidden & Output in higher to Hidden & Output in lower

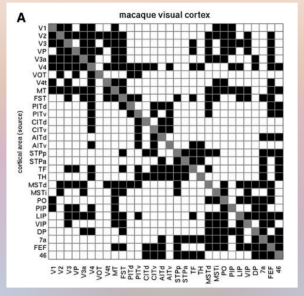
Lateral
- from Hidden and Output to all three layers in same area

Bidirectionality
- pervasive



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

Bidirectional Symmetry



(slide < O'Reilly) COSC 494/594 CCN 7

Biology ⇒ Function

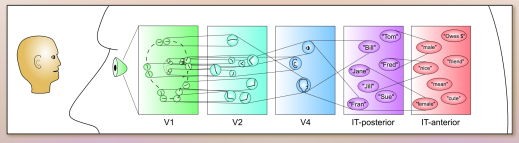
- Feedforward excitation = categorization of inputs
  — larger patterns, more invariant w.r.t instances & space
- Feedback excitation = attractor dynamics
  — ambiguity resolution & constraint satisfaction
- Lateral inhibition = competition, activity regulation
  — sharpens response

(slide based on O'Reilly) COSC 494/594 CCN 8

Ambiguity Resolution

(fig. < O'Reilly, *Comp. Cog. Neurosci.*) COSC 494/594 CCN 9

Hierarchical Categorical Representations



- Successive layers of neural detectors
- Progressively more abstract

COSC 494/594 CCN 10
(fig. < O'Reilly, *Comp. Cog. Neurosci.*)

The Chair Category

How would you define "chair"?

Socrates asks, "what is that common quality, which is the same in all these cases, and which is called courage?" (*Laches* 191e)

(slide based on O'Reilly) COSC 494/594 CCN 11

Getting the right ones is key

- Two men are dead in a cabin in the woods.
- The cabin itself is not burned, but the forest all around is burned to cinders.
- How did the men die?

(slide based on O'Reilly) COSC 494/594 CCN 12

Categories: A Philosophical Problem

- A long-standing problem:
  - — Socrates (d. 399 BCE) says, "that which we know we must surely be able to tell." (*Laches* 190c)
  - — Must knowledge be encoded in language-like structures?
- What makes a mental categorization accurate? Is there something "real" about a "chair?"
- Stereotypes are mental categories…
- Can you encode multiple categories at the same time?

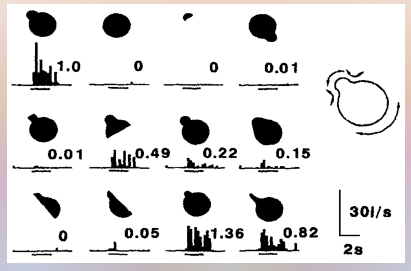
(slide based on O'Reilly) COSC 494/594 CCN 13

Distributed Representations

- Let a 1,000 categories bloom… You've got the room in your head (billions of neurons)
- Each neuron can respond to multiple things (graded similarity)
- And each thing activates many neurons (who knows what is going to be relevant this time?)

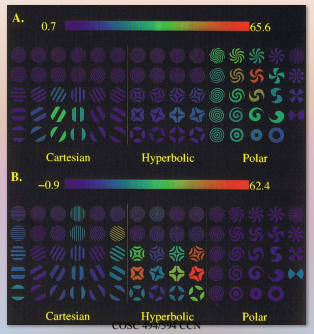
(slide < O'Reilly) COSC 494/594 CCN 14

Graded Responses



(slide < O'Reilly) COSC 494/594 CCN 15

Cell Responses in V4



(fig. < Clark, *Being There*, 1997)

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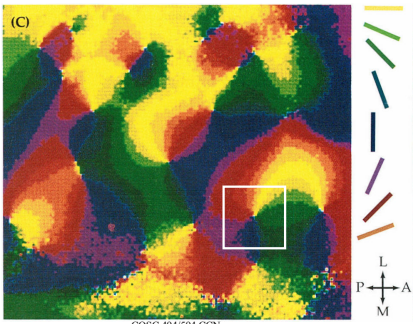
Orientation Columns



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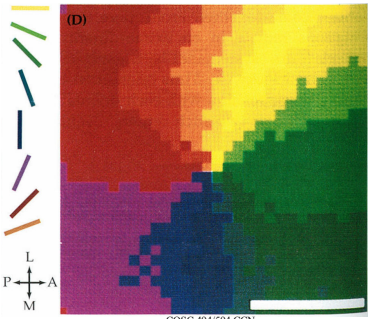
(fig. < Nicholls & al., *Neur. to Brain*)

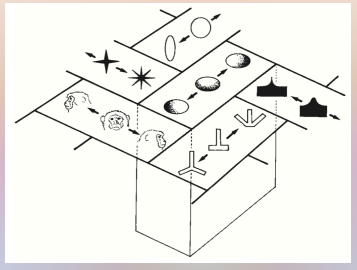
Orientation Columns



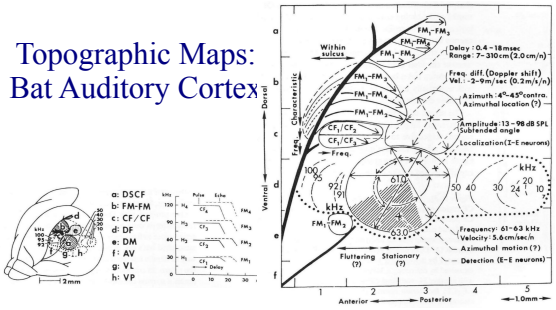
COSC 494/594 CCN 18

(fig. < Nicholls & al., *Neur. to Brain*)

Topographic Organization



Topographic Maps: Bat Auditory Cortex

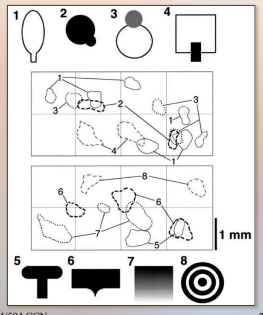


(figs. from Suga, 1985)

Sparse Distributed Representation

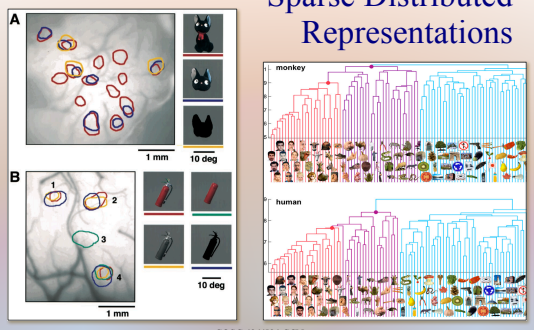
- Localist representation
  - — "grandmother cells"
  - — unlikely in brain
- K-out-of-N detectors
  - — typically 15–25% of neurons active
- Approximate orthogonality

(monkey IT cortex)



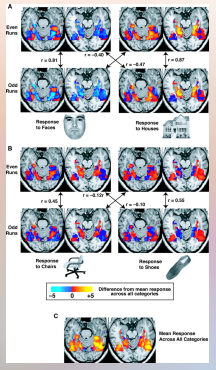
(fig. < O'Reilly, *Comp. Cog. Neurosci.*, from Tanaka, 2003)

Sparse Distributed Representations

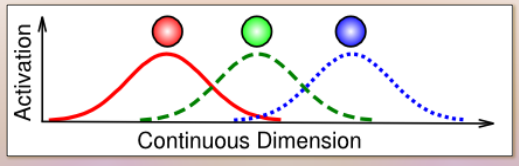


(figs. < O'Reilly, *Comp. Cog. Neurosci.*, from Tanaka 2003 and Kriegeskorte et al. 2008)

Not Just Monkeys



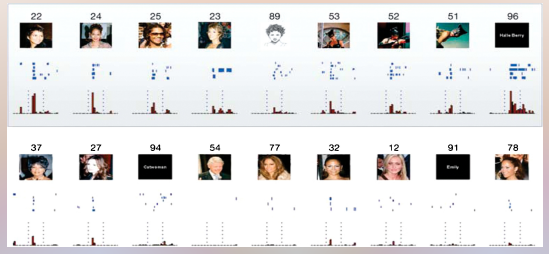
Coarse Coding



- Broadly-tuned receptive fields
- Population-coding of precise values
- Common throughout sensory and motor areas

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

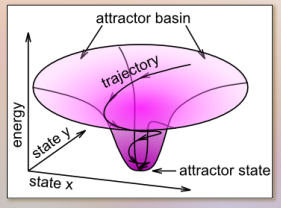
Localist Representations?



emergent demonstration: Face Categorization I

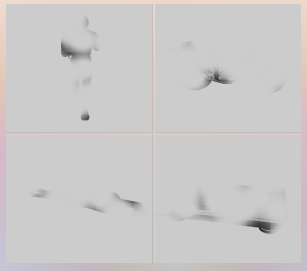
Bidirectional Excitation

- Functions
  - recognition
  - top-down imagery
  - ambiguity resolution
  - pattern completion
- Attractor dynamics
  - convergence on good representation
  - energy vs. harmony

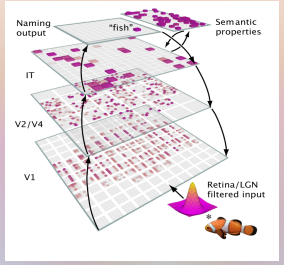


(fig. < O'Reilly, *Comp. Cog. Neurosci.*)

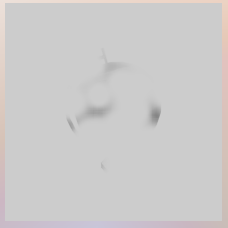
What Are These?

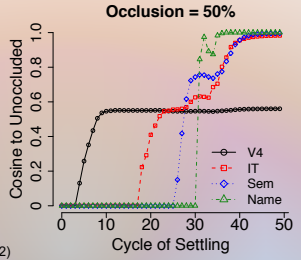


A Big Network Model…



Bidirectional Dynamics





Wyatte, Herd, Mingus, O'Reilly (2012)

emergent demonstration: Face Categorization II

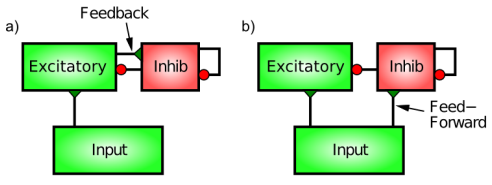
emergent demonstration: Cats and Dogs

emergent demonstration: Necker Cube

Inhibitory Competition and Activity Regulation

- Activity regulation
- Selective attention
- Competition
- Sparse distributed representation

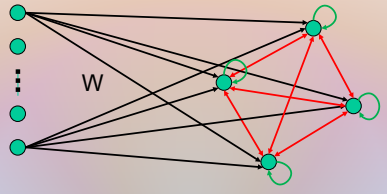
Activity Regulation



- 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.*)

Competitive Network



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

FFFB Inhibition Approximation

- Approximates total effect of all inhibition in a layer
- Inhibition determined by feedforward and feedback terms:
  $$g_i(t) = \text{gi}[\text{FF}(t) + \text{FB}(t)]$$
- FF term is excess average input over set point:
  $$\text{FF}(t) = \text{ff}[\langle \eta \rangle - \text{ff0}]^+$$
  where $\langle \eta \rangle = n^{-1} \sum_{i=1}^{n} \eta_i$ is average input
- FB term varies with average activity:
  $$\dot{\text{FB}}(t) = \text{dt}[\text{fb}\langle y \rangle - \text{FB}(t)]$$
  where $\langle y \rangle = n^{-1} \sum_{i=1}^{n} y_i$ is average activity
- Will stabilize with $\text{FB}(t) = \text{fb}\langle y \rangle$

emergent demonstration: Inhibition