3. Networks
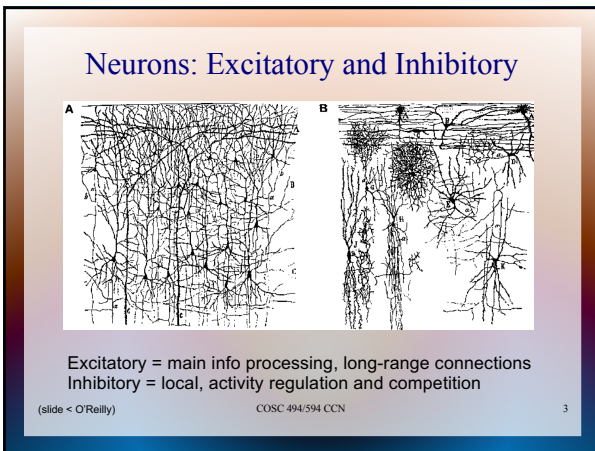
Networks

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

(slide < O'Reilly)   COSC 494/594 CCN   2

Neurons: Excitatory and Inhibitory

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

(slide < O'Reilly)   COSC 494/594 CCN   3

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.*)
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Connection Directions

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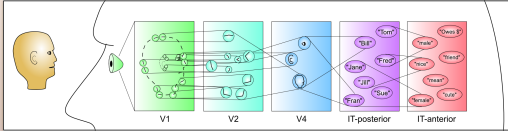 from Hidden in lower to Input in higher
Feedback
  from Hidden & Output in higher to Hidden & Output in lower
Lateral
  from Hidden and Output to all three layers in same area
Bidirectionality
  pervasive

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Bidirectional Symmetry

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

Ambiguity Resolution

Hierarchical Categorical Representations

- Successive layers of neural detectors
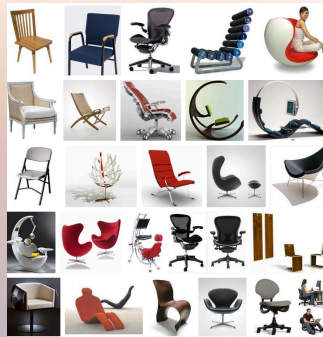- Progressively more abstract

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(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
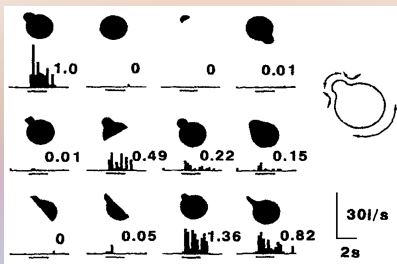
Distributed Representations

- 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?)

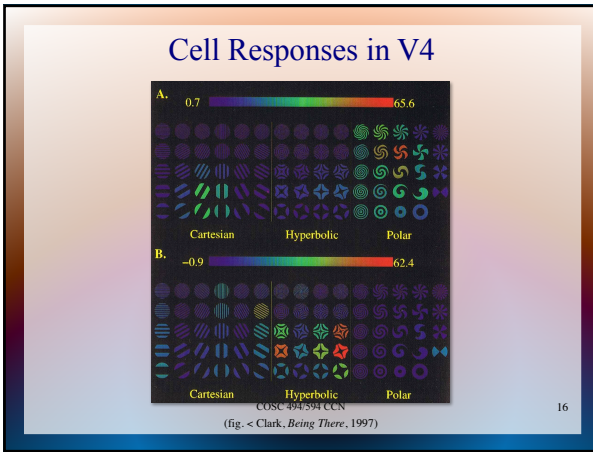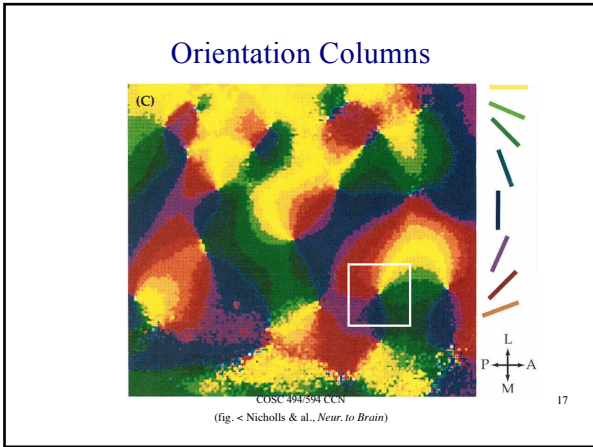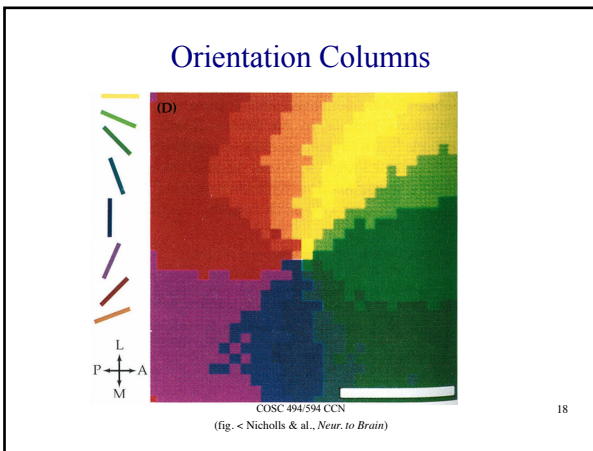(slide < O'Reilly)   COSC 494/594 CCN   14

Graded Responses

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

Cell Responses in V4

Cartesian   Hyperbolic   Polar

Cartesian   Hyperbolic   Polar

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

Orientation Columns

(C)

L
P — A
M

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

Orientation Columns

(D)

L
P — A
M
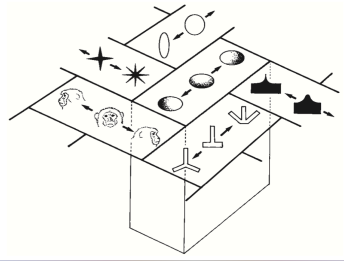
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(fig. < Nicholls & al., *Neur. to Brain*)
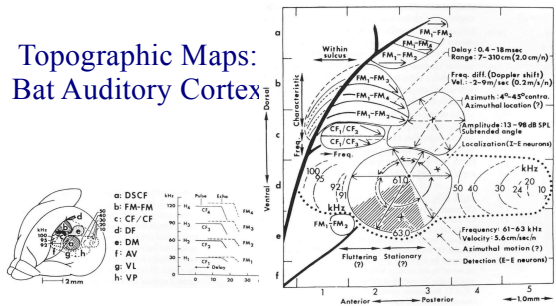
Topographic Organization
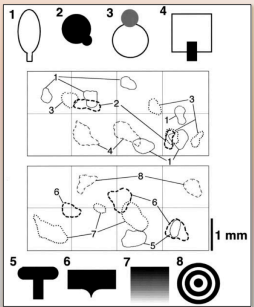
Topographic Maps:
Bat Auditory Cortex

a: DSCF
b: FM-FM
c: CF/CF
d: DF
e: DM
f: AV
g: VL
h: VP

Within sulcus

FM$_1$-FM$_2$
FM$_1$-FM$_3$
FM$_1$-FM$_4$
FM$_1$-FM$_4$
FM$_1$-FM$_3$
CF$_1$/CF$_2$
CF$_1$/CF$_3$
Freq.

FM$_1$-FM$_2$

Delay : 0.4 – 18msec
Range : 7 – 310 cm (2.0 cm/n)

Freq. diff. (Doppler shift)
Vel. : 2 – 9m/sec (0.2m/s/n)

Azimuth : 4° – 45° contra.
Azimuthal location (?)

Amplitude :13 – 98 dB SPL
Subtended angle
Localization (I–E neurons)

Frequency : 61 – 63 kHz
Velocity : 5.6cm/sec/n
Azimuthal motion (?)
Detection (E–E neurons)

Fluttering (?)   Stationary (?)
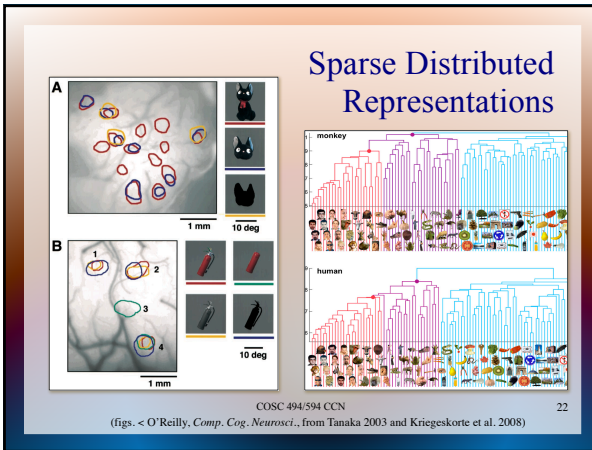
COSC 494/594 CCN   20
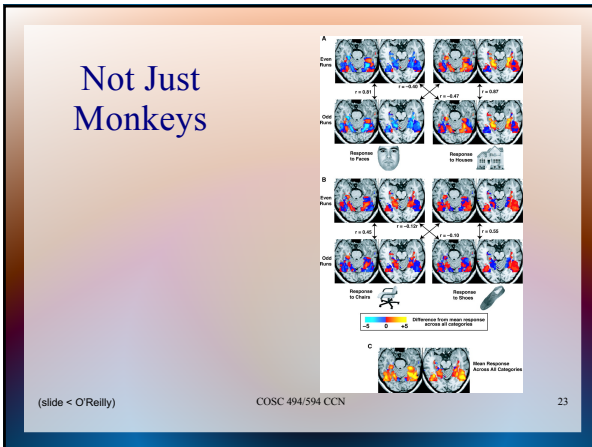(figs. from Suga, 1985)

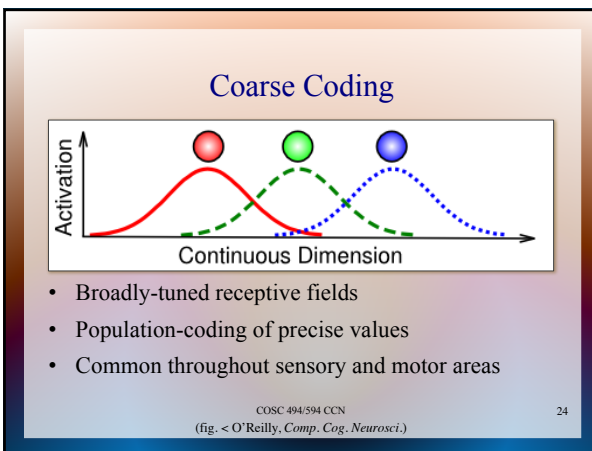## Sparse Distributed Representation

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

(monkey IT cortex)

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

Sparse Distributed Representations

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

Not Just Monkeys

(slide < O'Reilly) COSC 494/594 CCN 23

Coarse Coding

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

COSC 494/594 CCN 24
(fig. < O'Reilly, *Comp. Cog. Neurosci.*)

Localist Representations?

(slide < O'Reilly)   COSC 494/594 CCN   25

emergent demonstration:
Face Categorization I

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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.*)

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What Are These?

A Big Network Model…

Naming output "fish" Semantic properties
IT
V2/V4
V1
Retina/LGN filtered input

Bidirectional Dynamics

Occlusion = 50%

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

emergent demonstration:
Face Categorization II

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emergent demonstration:
Cats and Dogs

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emergent demonstration:
Necker Cube

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Inhibitory Competition and Activity Regulation

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

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Activity Regulation

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

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

Competitive Network

W

1/27/17   36

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

1/27/17   37

FFFB Inhibition Approximation

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

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emergent demonstration: Inhibition

COSC 494/594 CCN   39