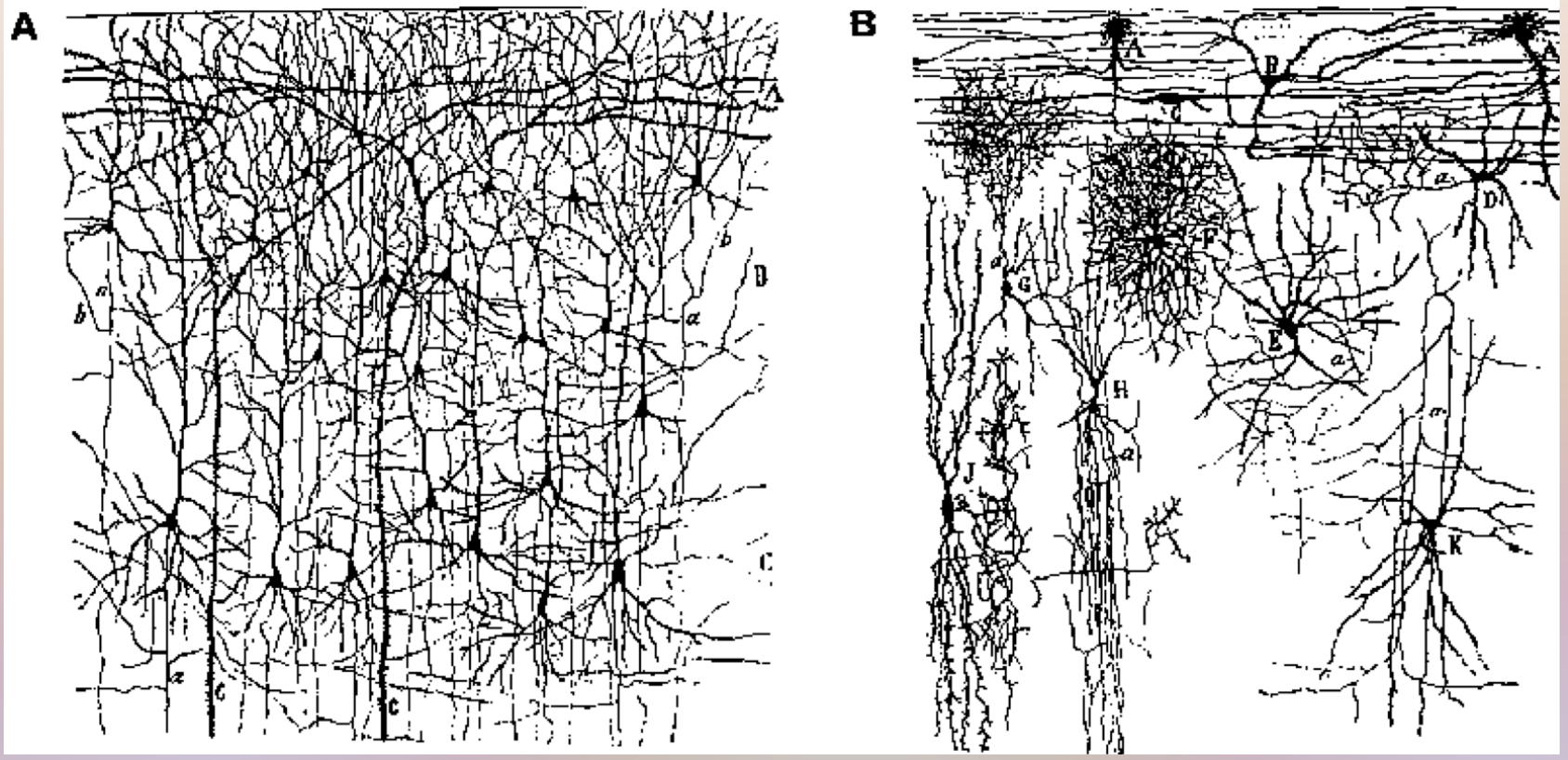
3. Networks

Networks

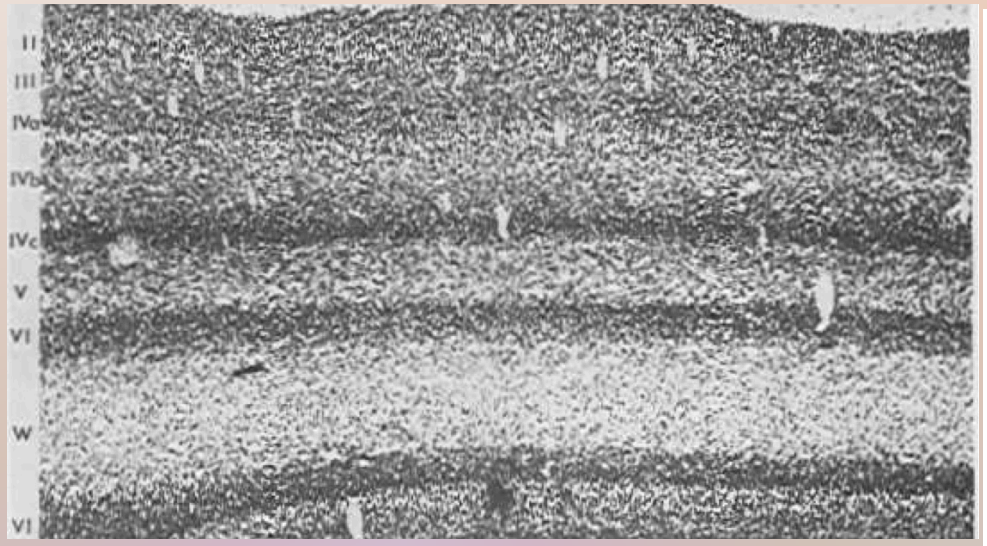
1. Biology of Neocortex (“cortex”)
2. Categorization and Distributed Reps
3. Bidirectional Excitation and Attractors
4. Inhibitory Competition and Activity Regulation

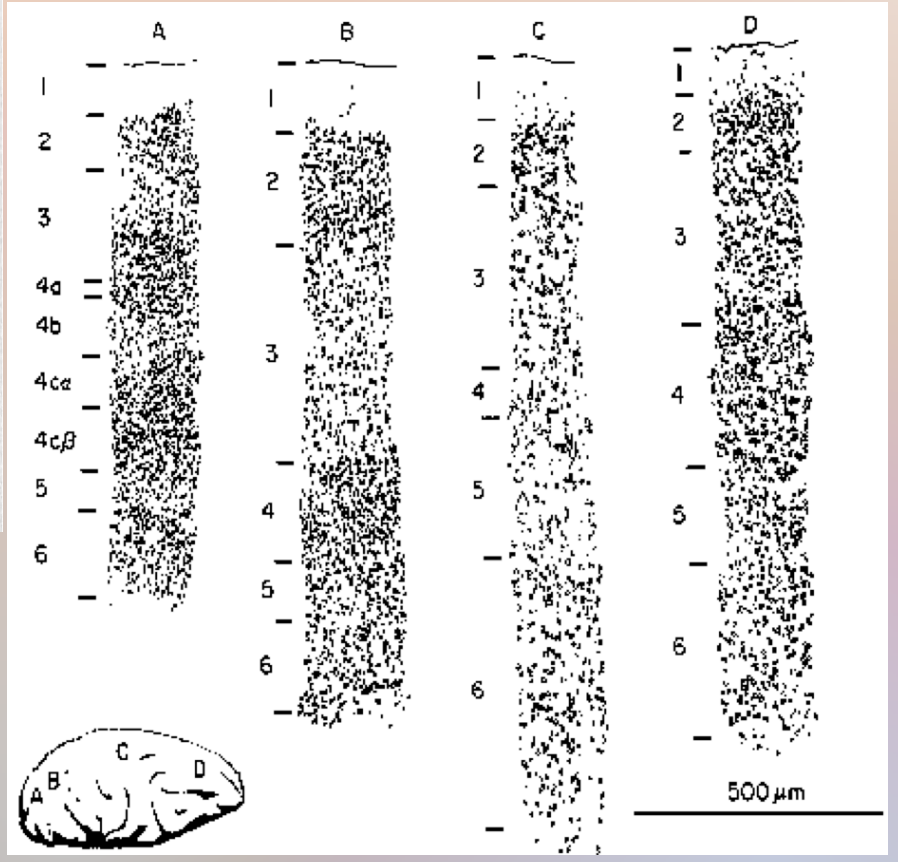
Neurons: Excitatory and Inhibitory



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

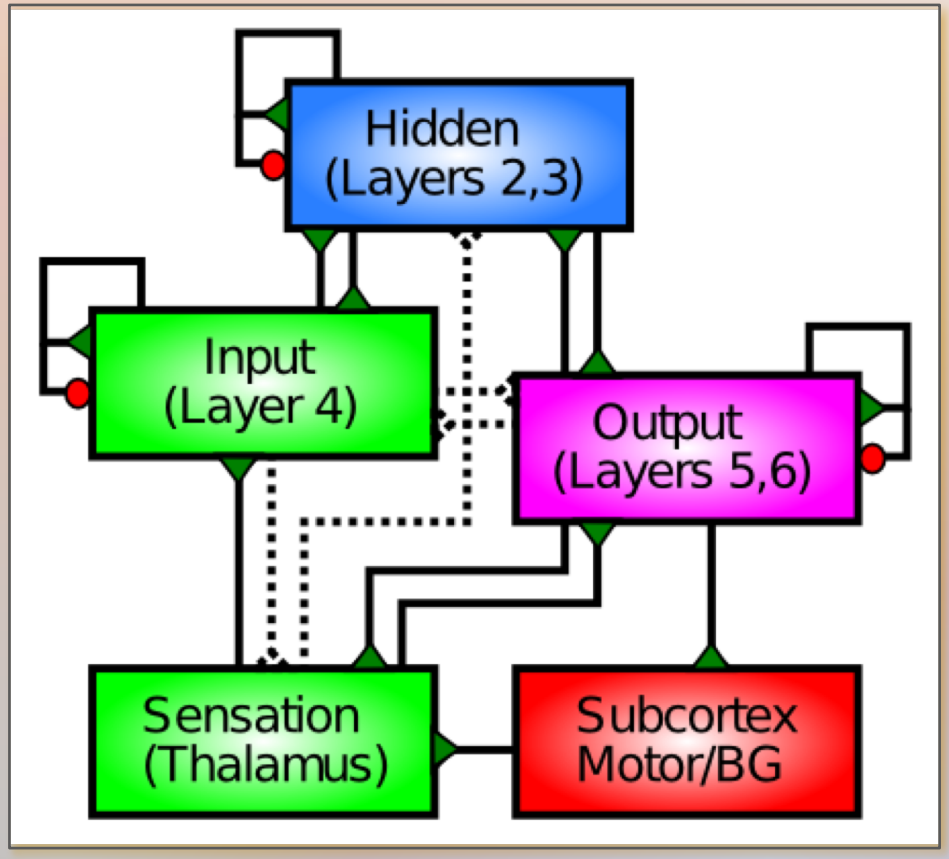
Hidden

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 area to Input in higher area

Feedback

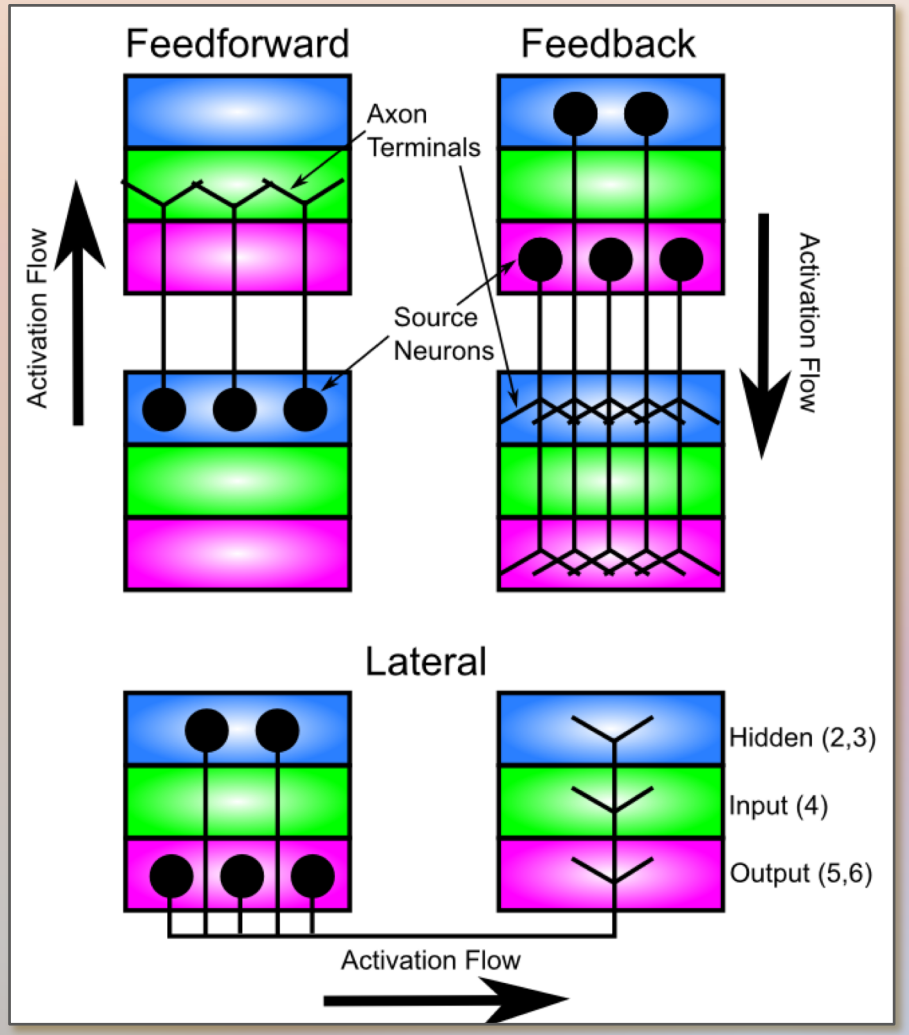
- from Hidden & Output in higher area to Hidden & Output in lower area

Lateral

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

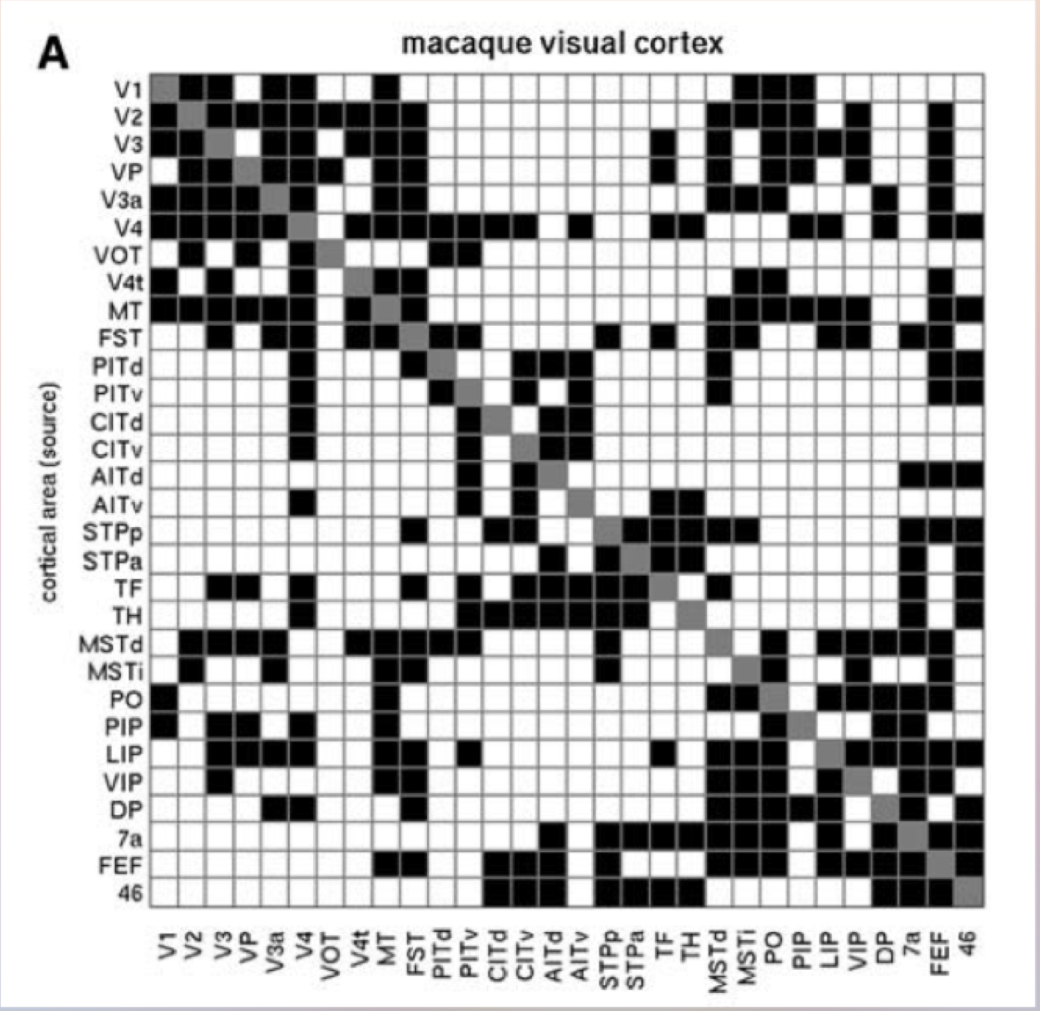
Bidirectionality

- pervasive



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

Bidirectional Symmetry



(slide < O'Reilly)

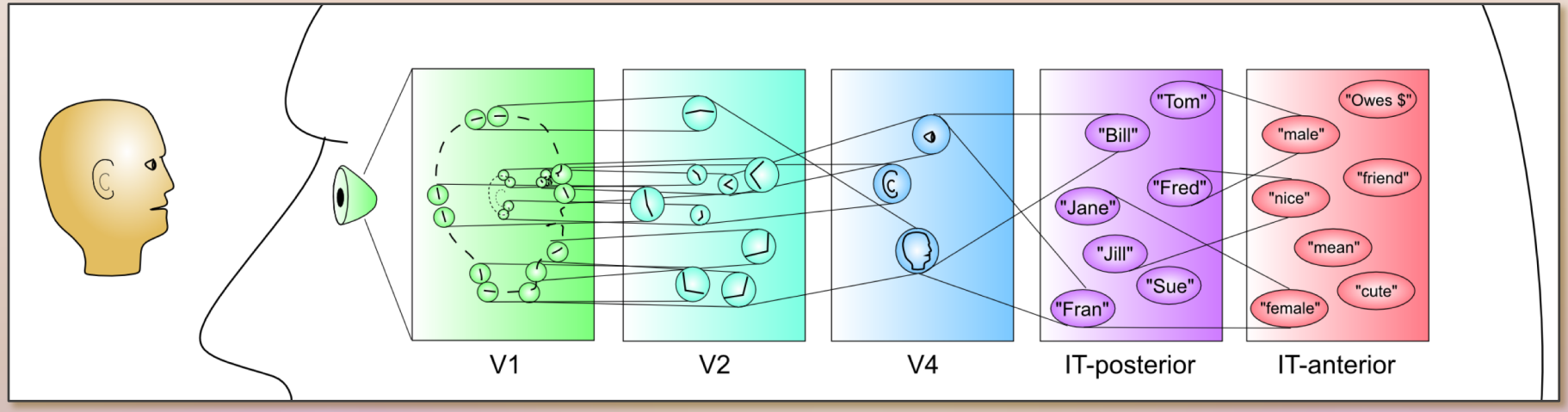
Biology ⇒ Function

- 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

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

Hierarchical Categorical Representations



- Successive layers of neural detectors
- Progressively more abstract

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

Getting the right representation 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?

The Chair Category

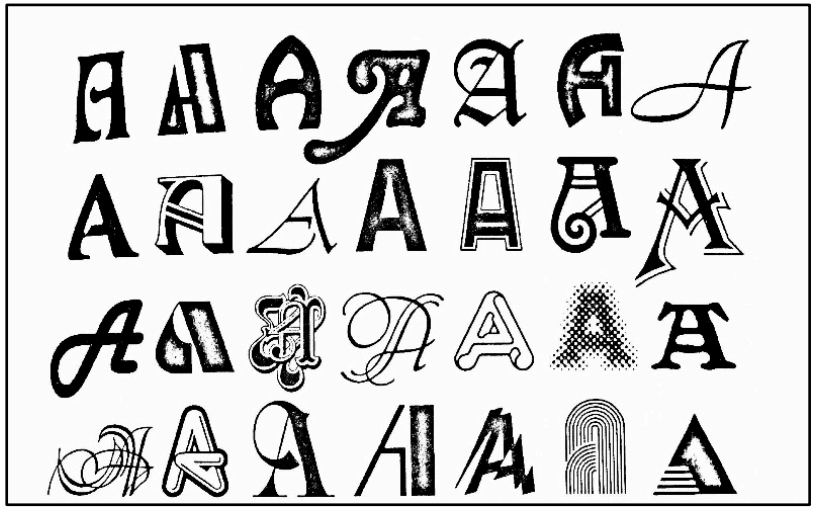
How would you define “chair”?

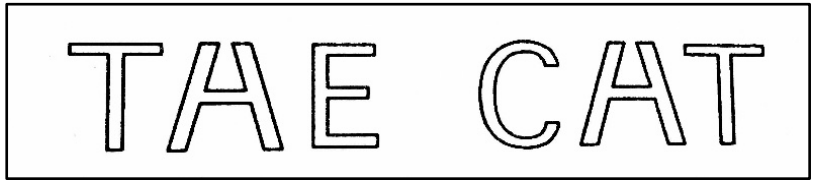
Socrates asks, “what is that common quality, which is the same in all these cases, and which is called courage?” (*Laches* 191e)

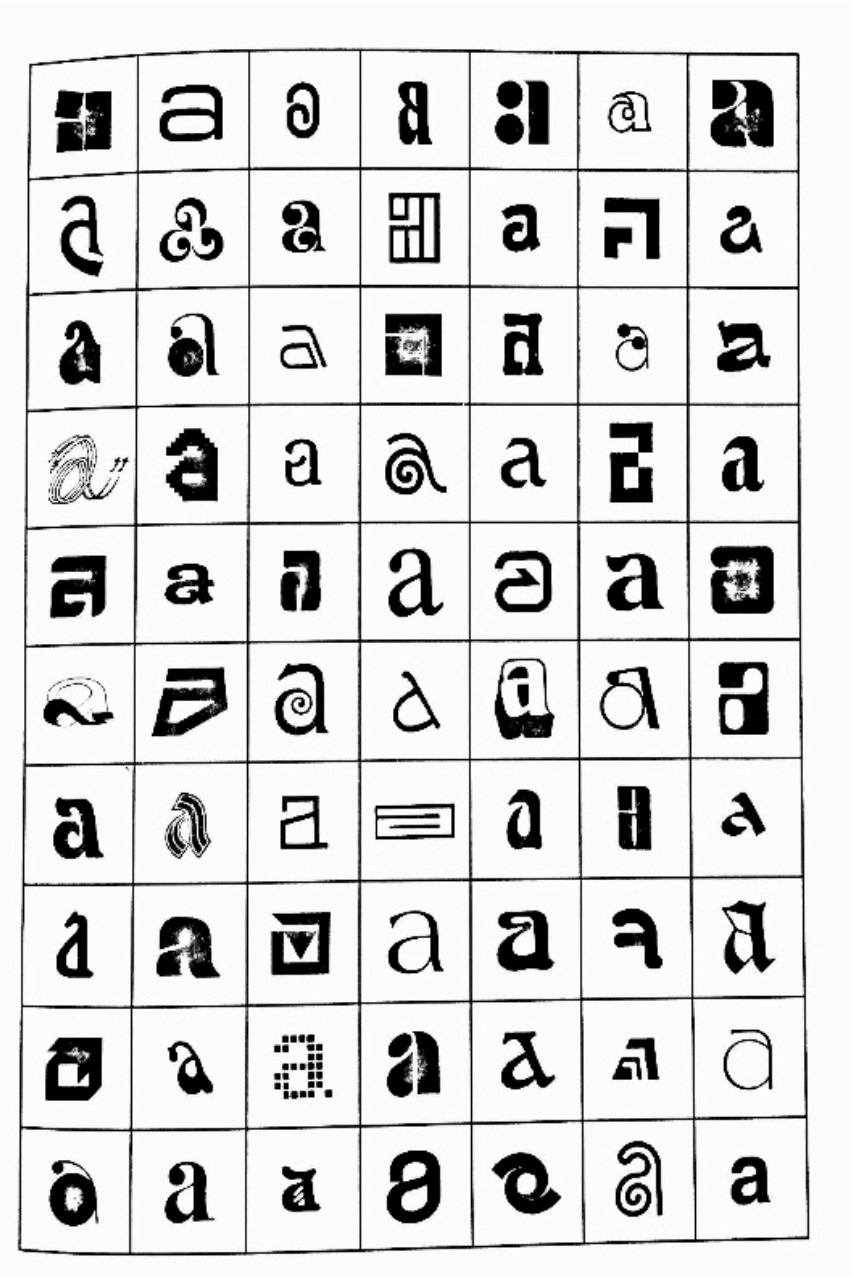
(slide based on O’Reilly)

The central problem of AI is: What are *a* and *i*?

— Douglas Hofstadter







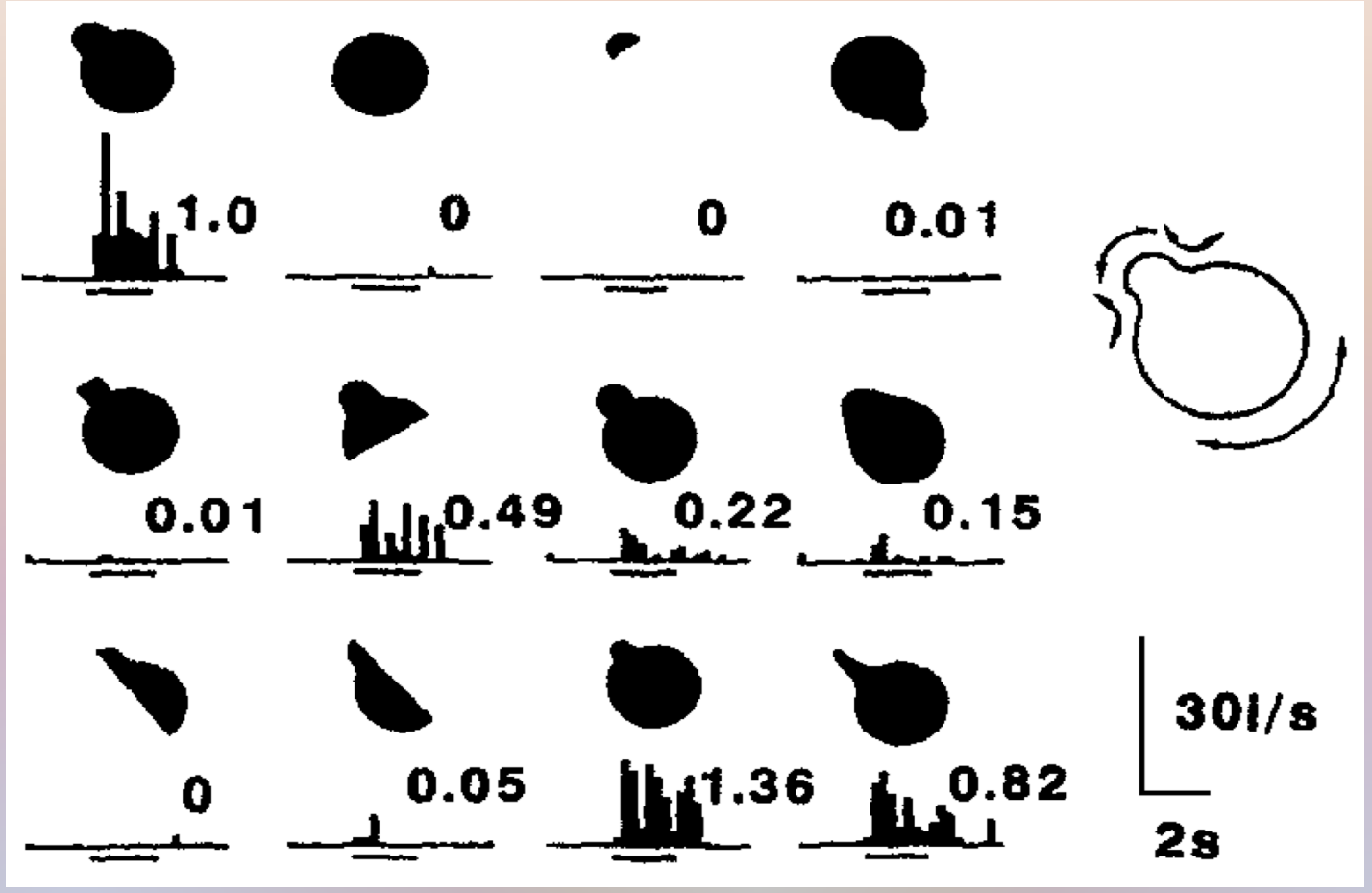
Categories: A Philosophical Problem

- 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?

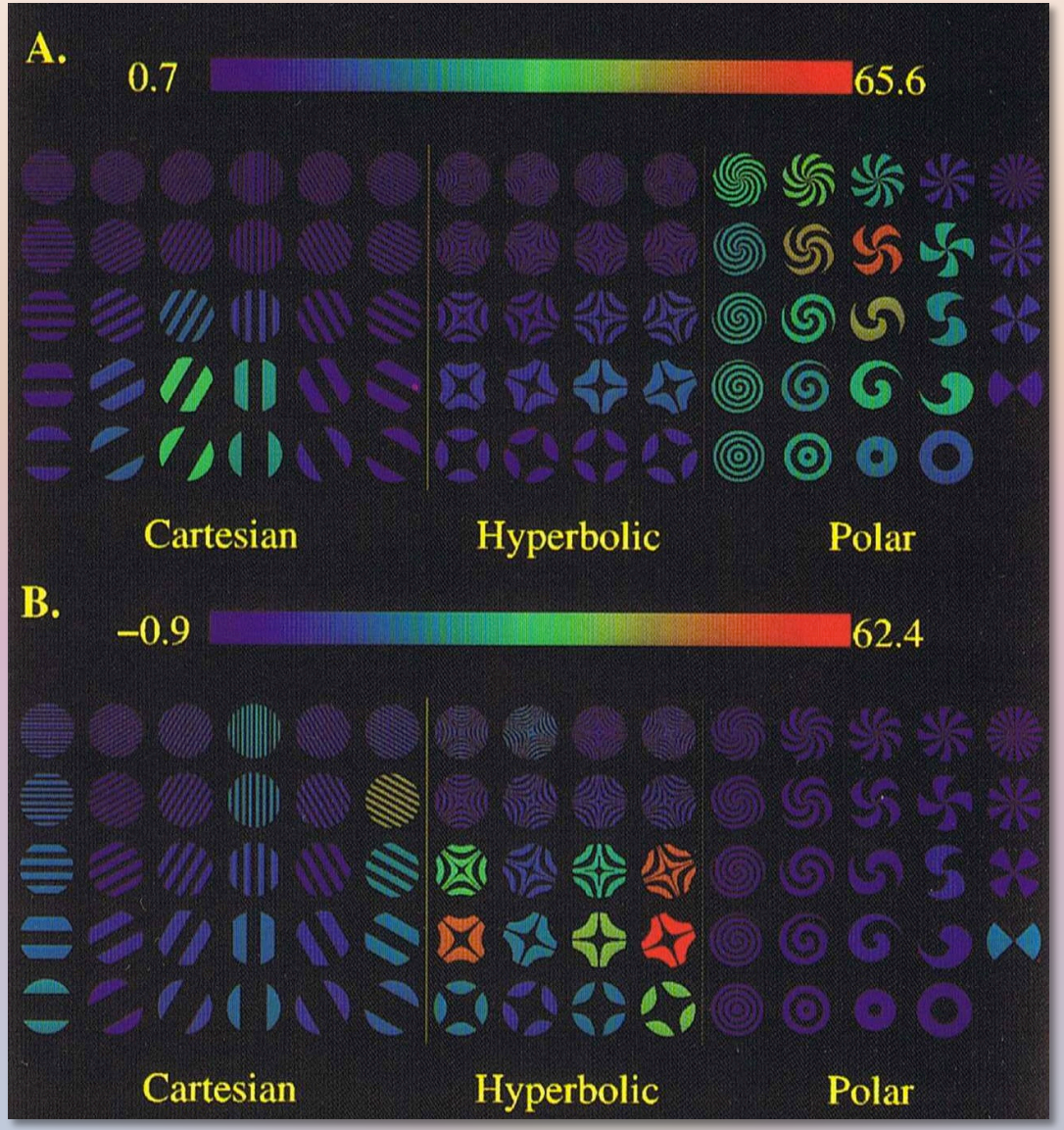
Distributed Representations

- 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?)

Graded Responses

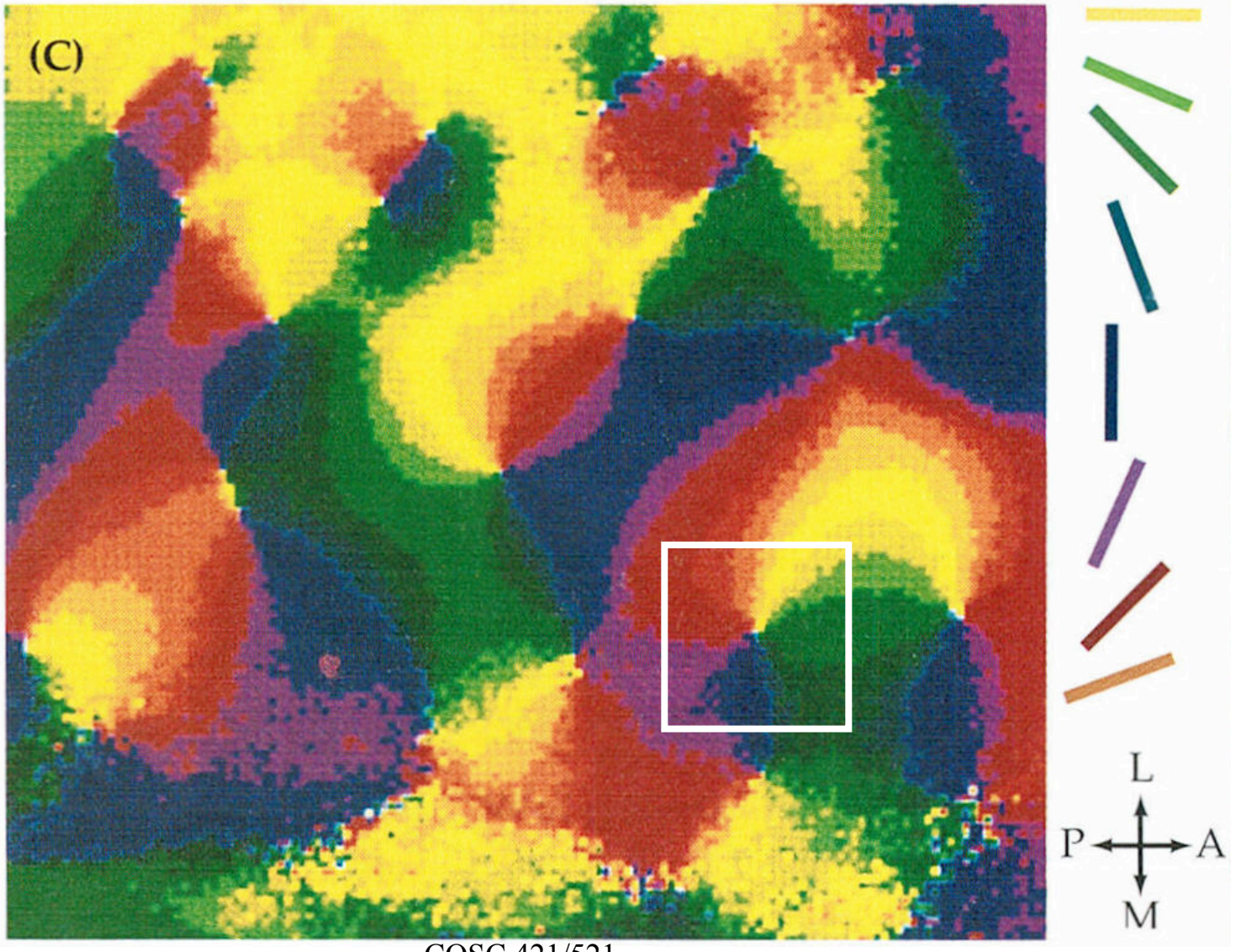


Cell Responses in V4



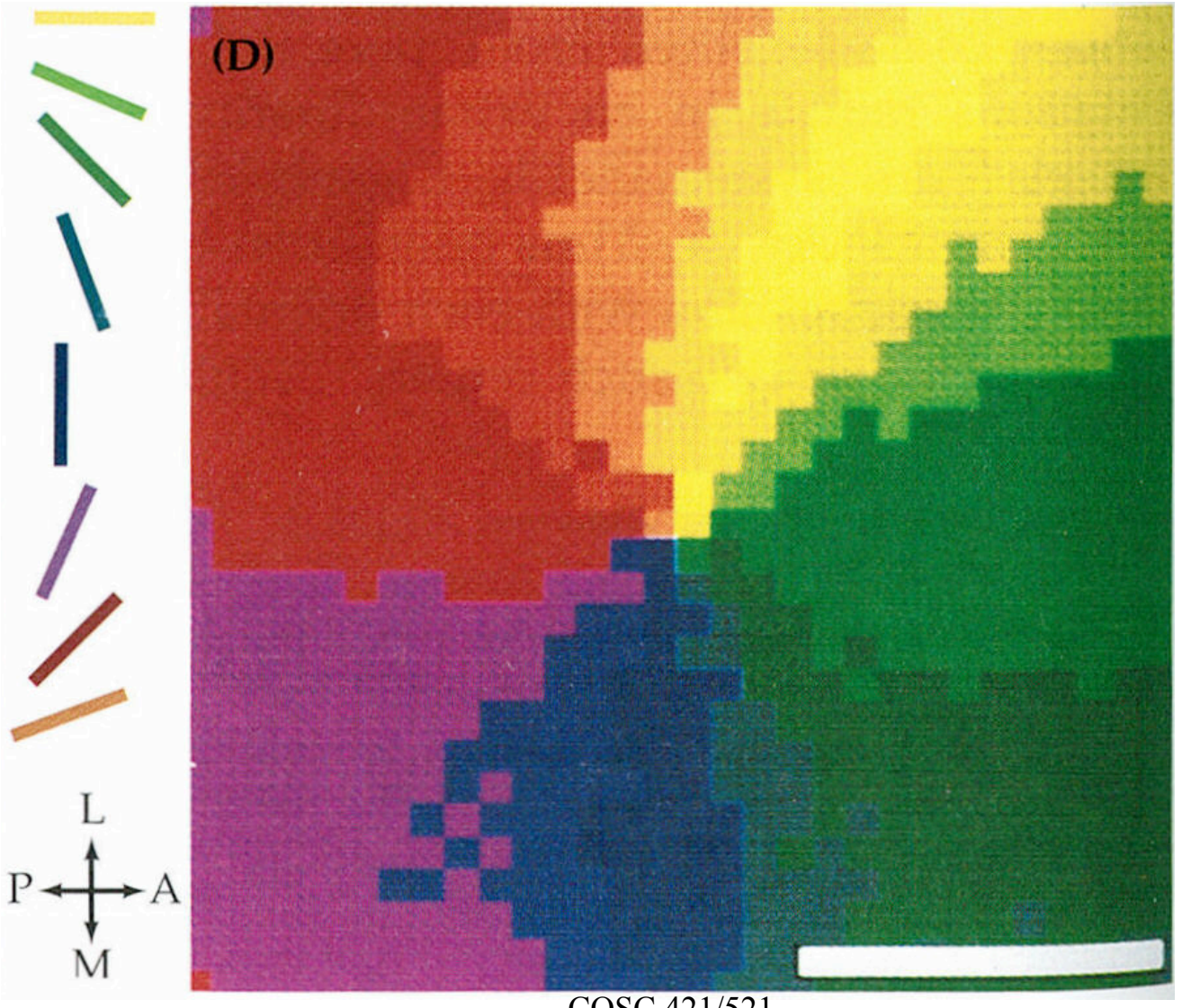
(fig. < Clark, *Being There*, 1997)

Orientation Columns



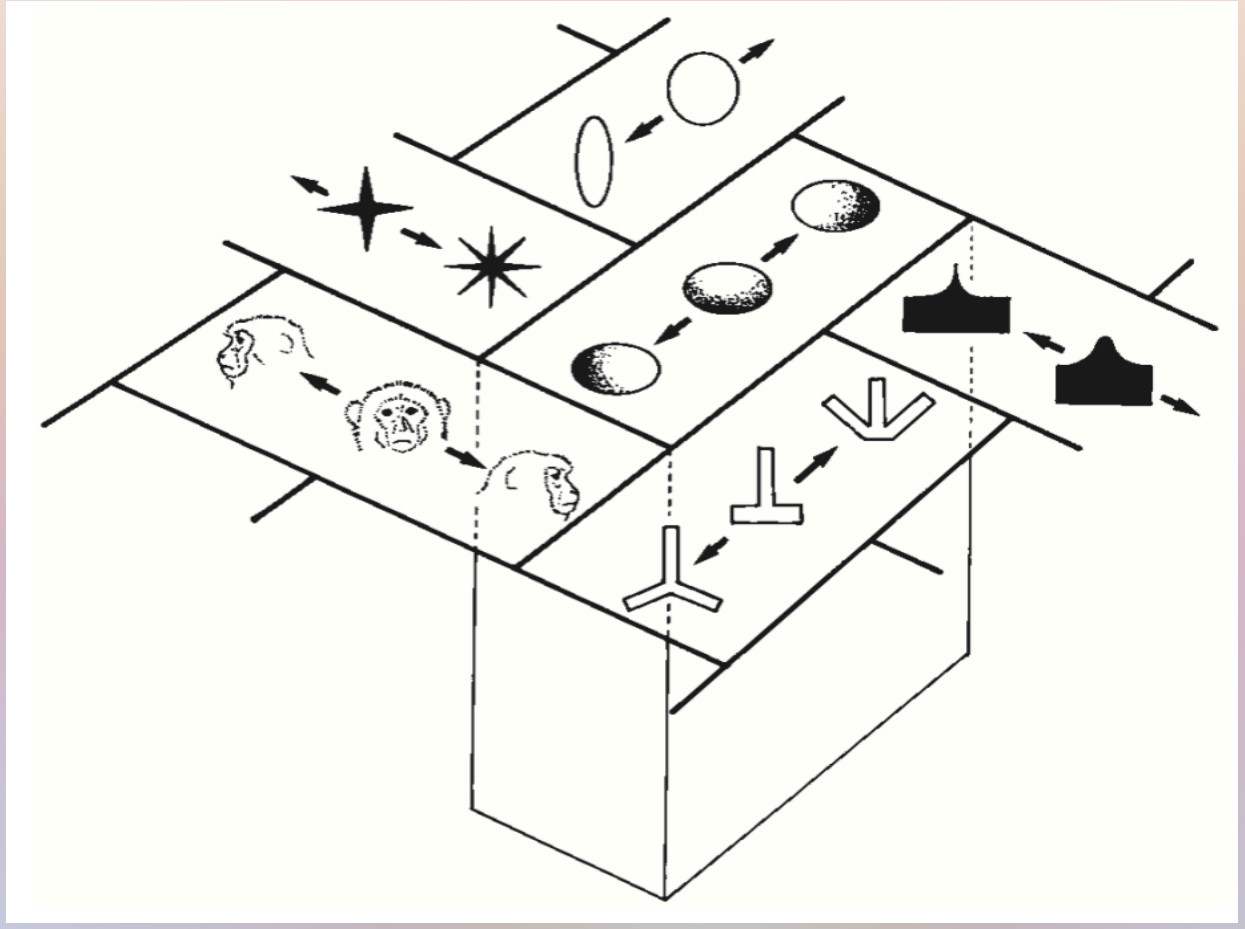
(fig. < Nicholls & al., *Neur. to Brain*)

Orientation Columns

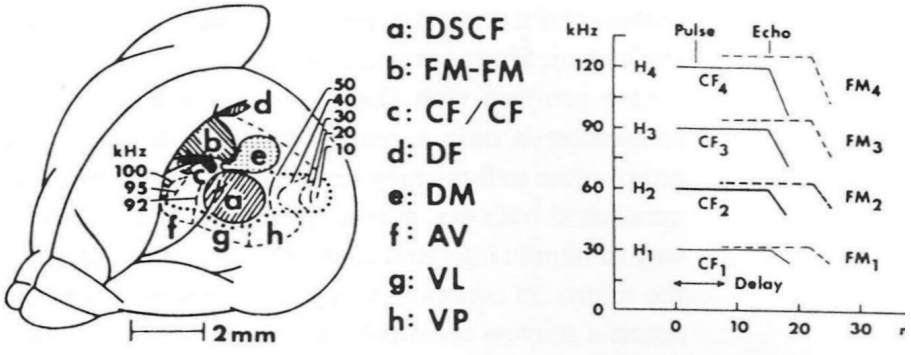


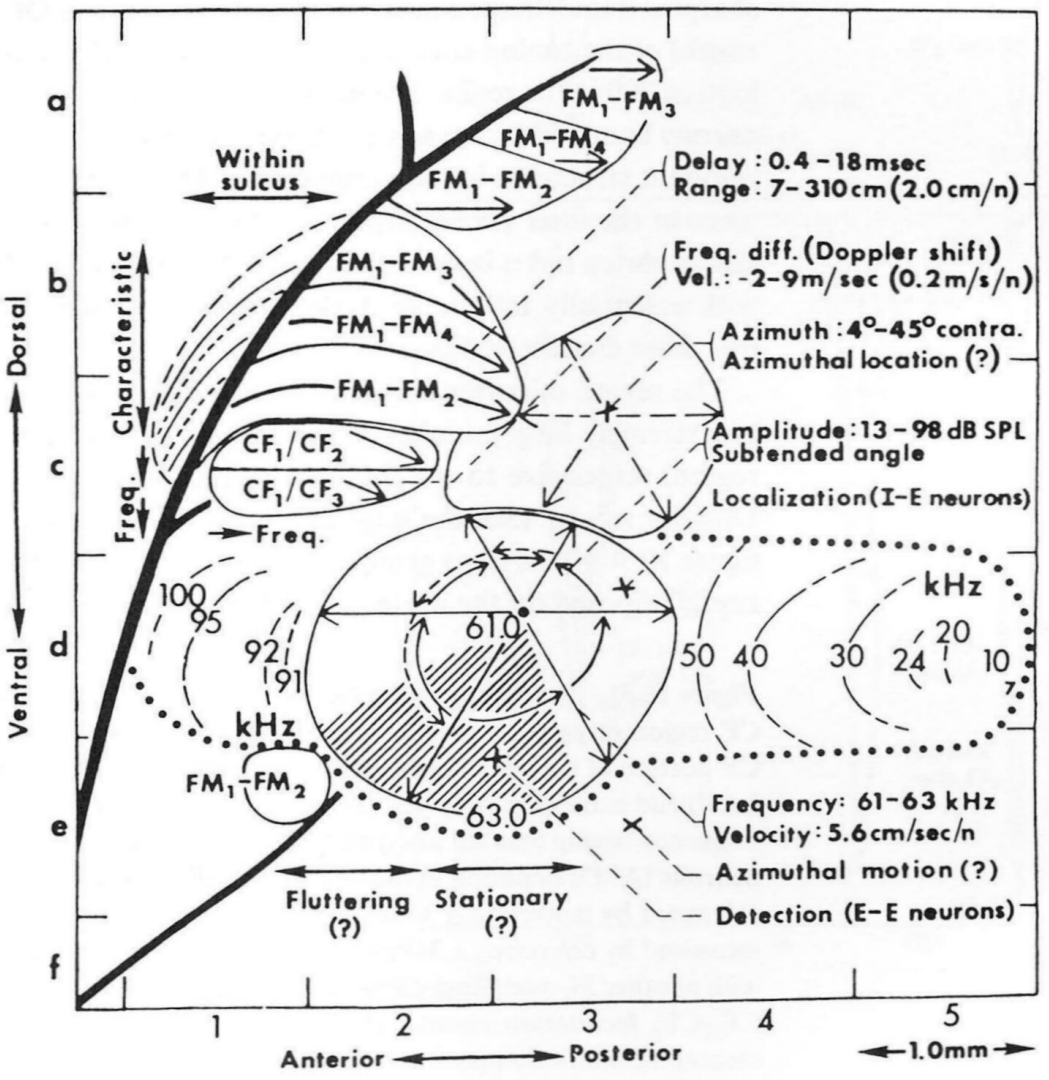
(fig. < Nicholls & al., *Neur. to Brain*)

Topographic Organization



Topographic Maps: Bat Auditory Cortex



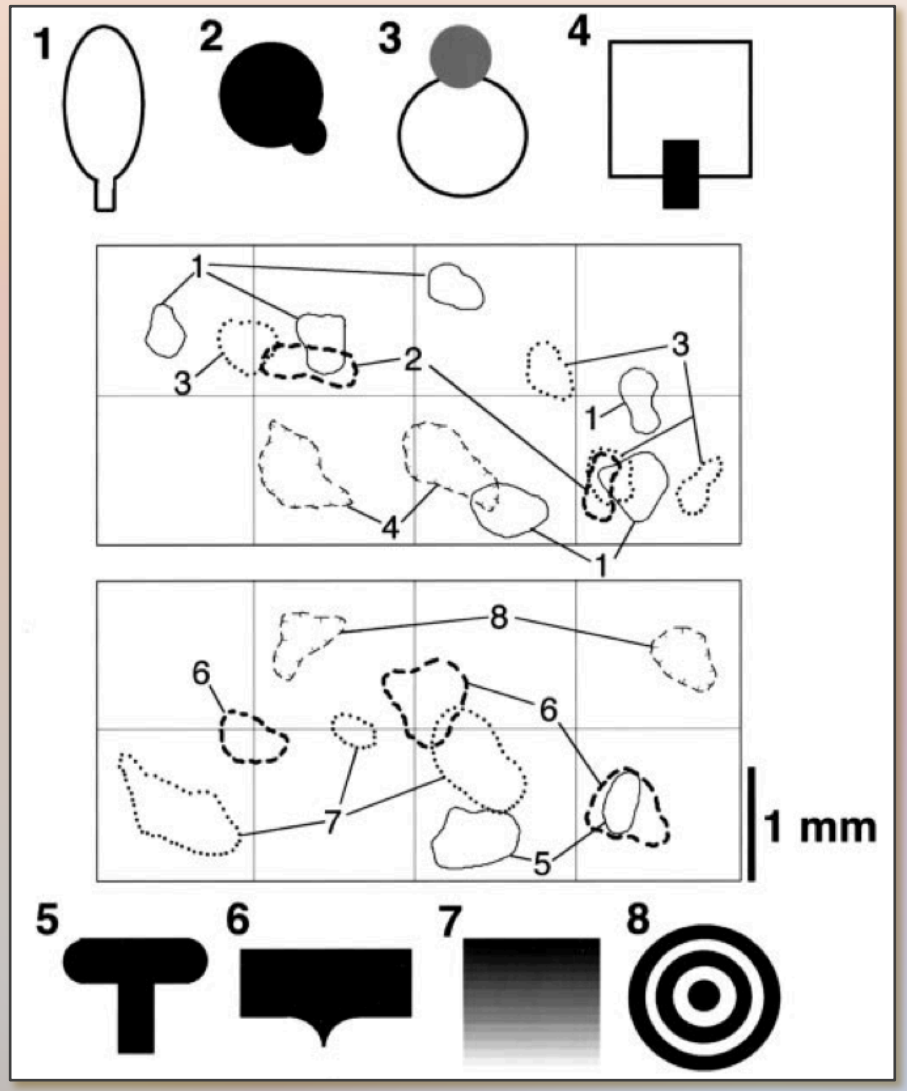


(figs. from Suga, 1985)

Sparse Distributed Representation

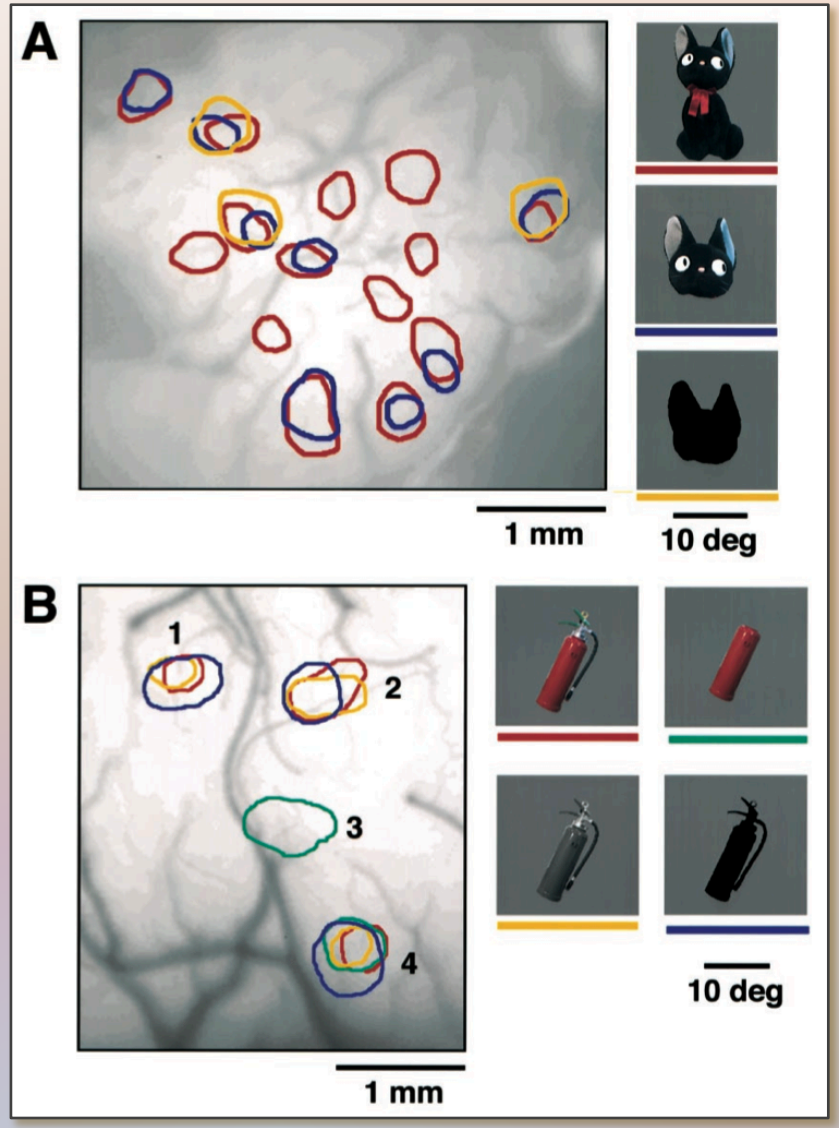
- Localist representation
  - — "grandmother cells"
  - — unlikely in brain
- K-out-of-N detectors
  - — typically 15–25% of neurons active
- Approximate orthogonality

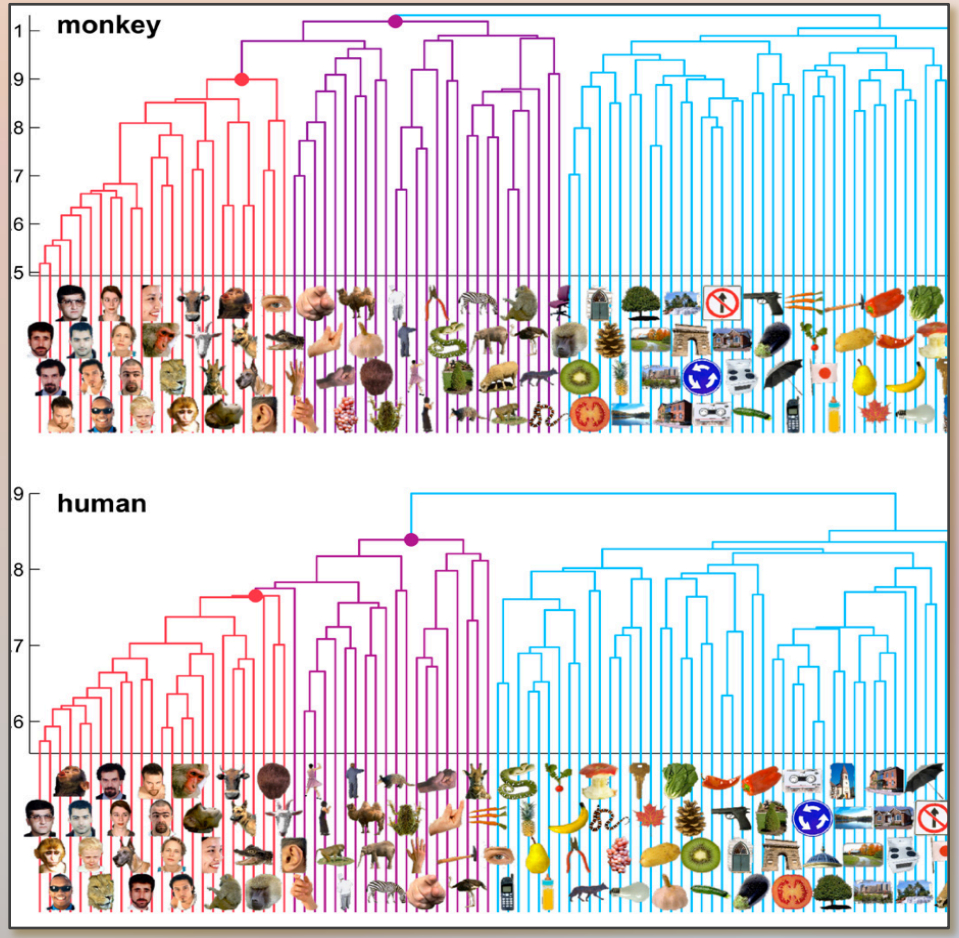
(monkey IT cortex)



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

Sparse Distributed Representations

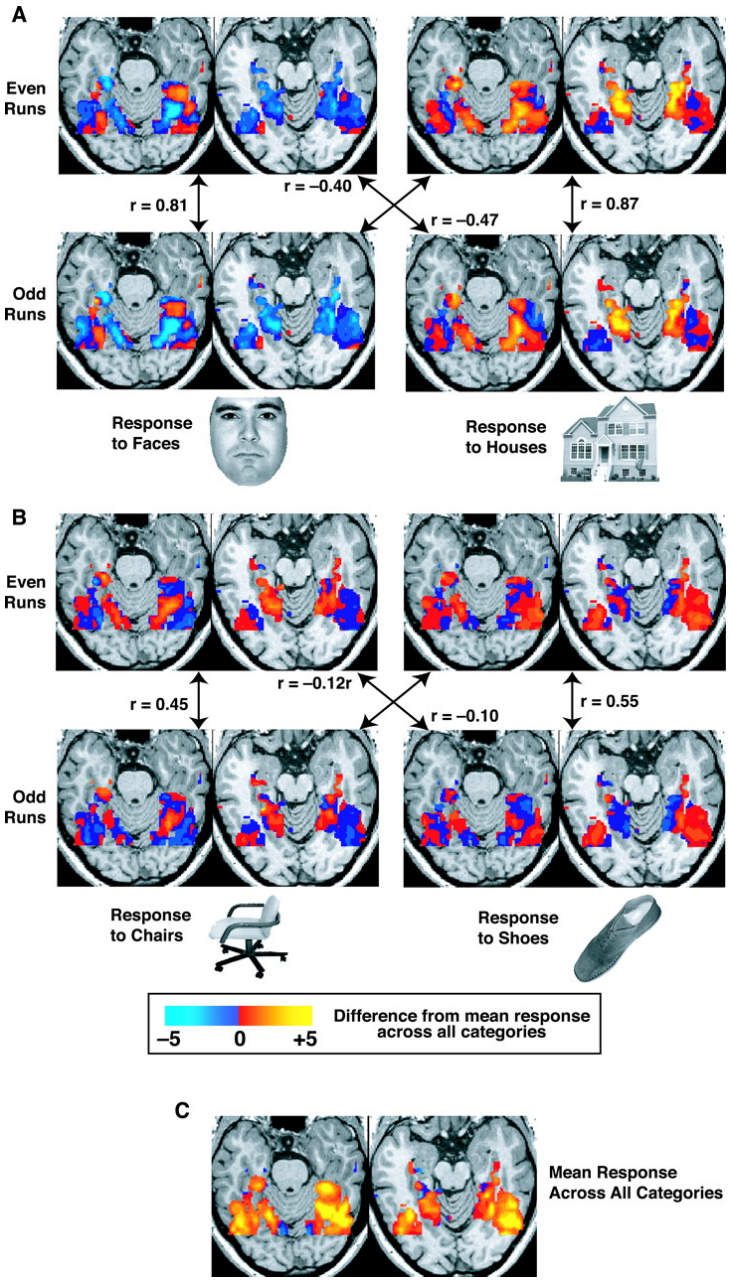




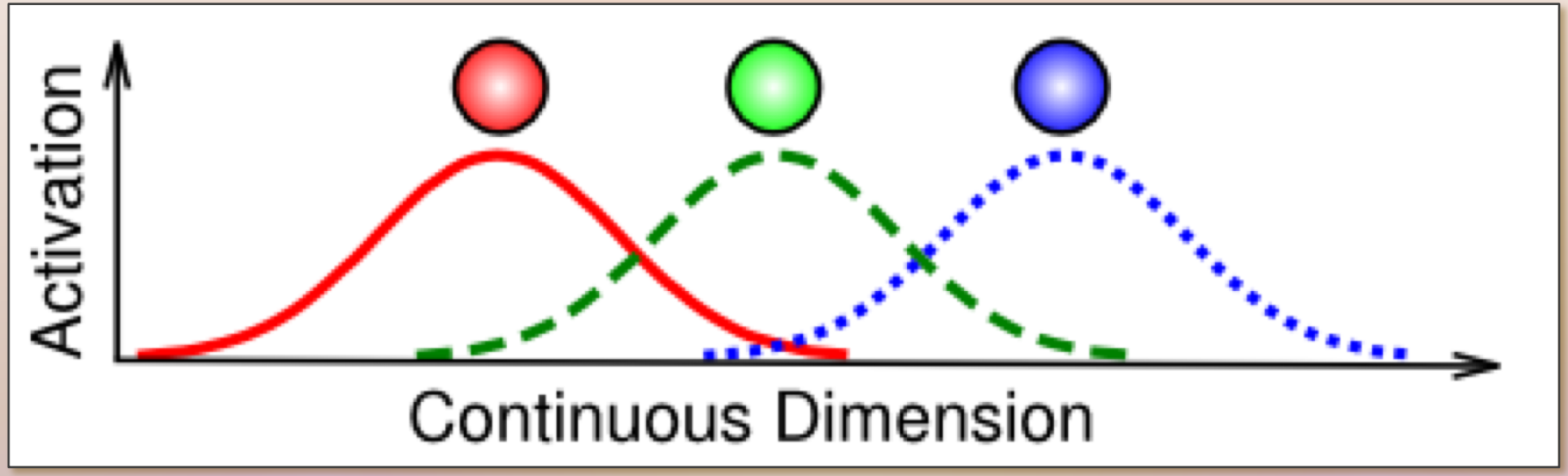
(figs. < O'Reilly, *Comp. Cog. Neurosci.*, from Tanaka 2003 and Kriegeskorte et al. 2008)

Not Just Monkeys

- Maps of neural activity in the human brain in response to different visual input stimuli
- (as shown — faces, houses, chairs, shoes)
- Recorded using functional magnetic resonance imaging (fMRI)
- There is a high level of overlap in neural activity across these different stimuli, in addition to some level of specialization
- This is the hallmark of a distributed representation



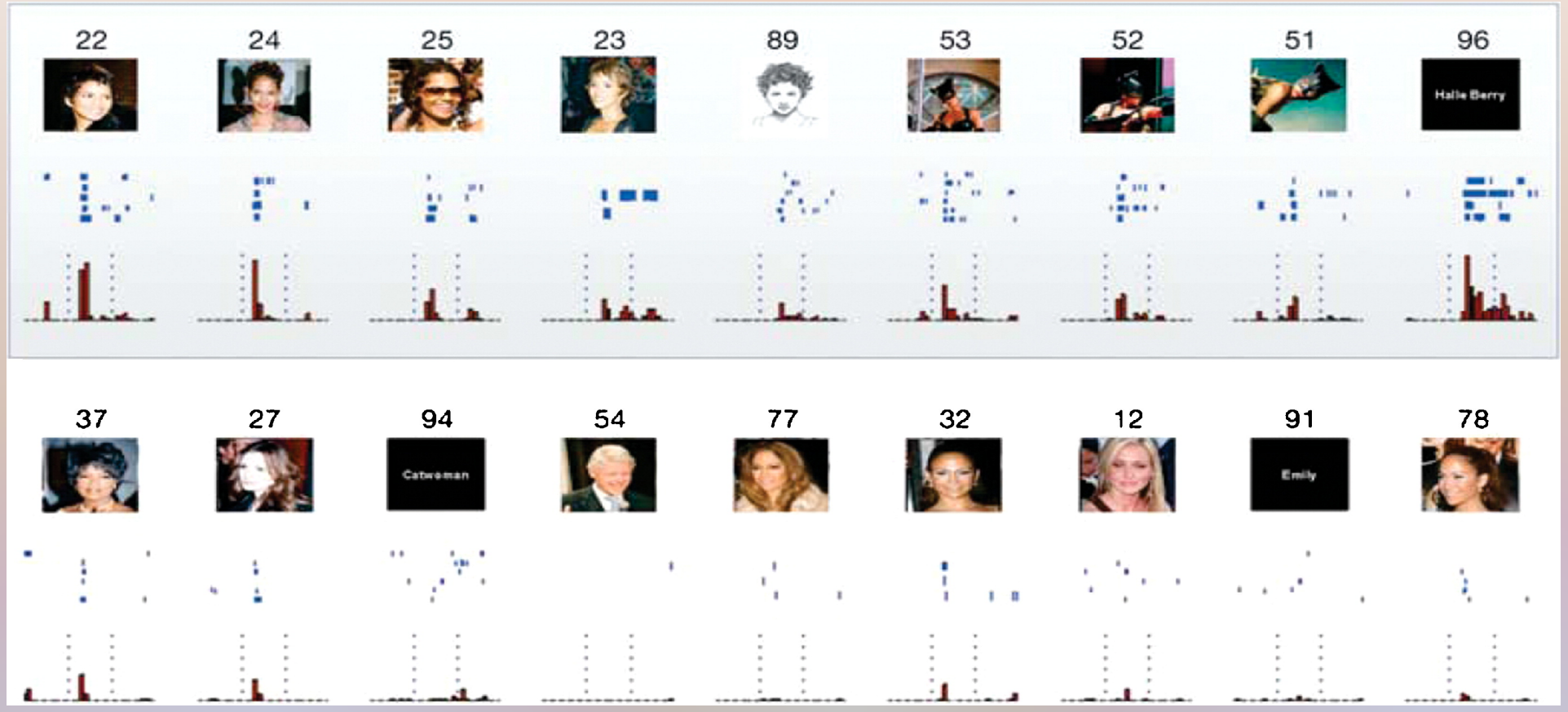
Coarse Coding



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

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

Localist Representations?

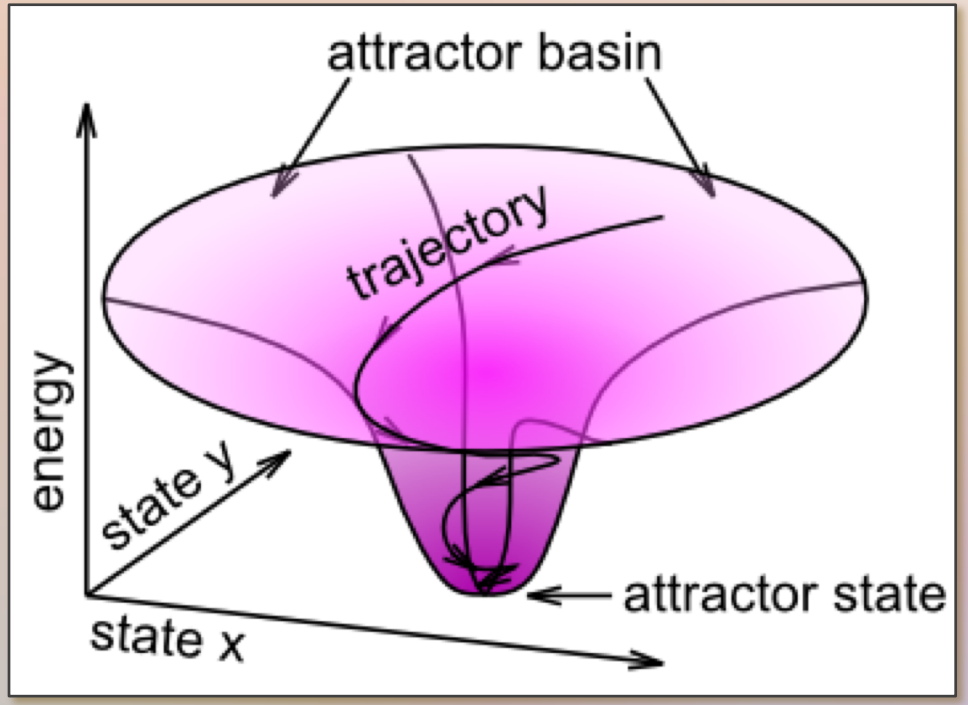


(slide < O'Reilly)

emergent demonstration: Face Categorization I

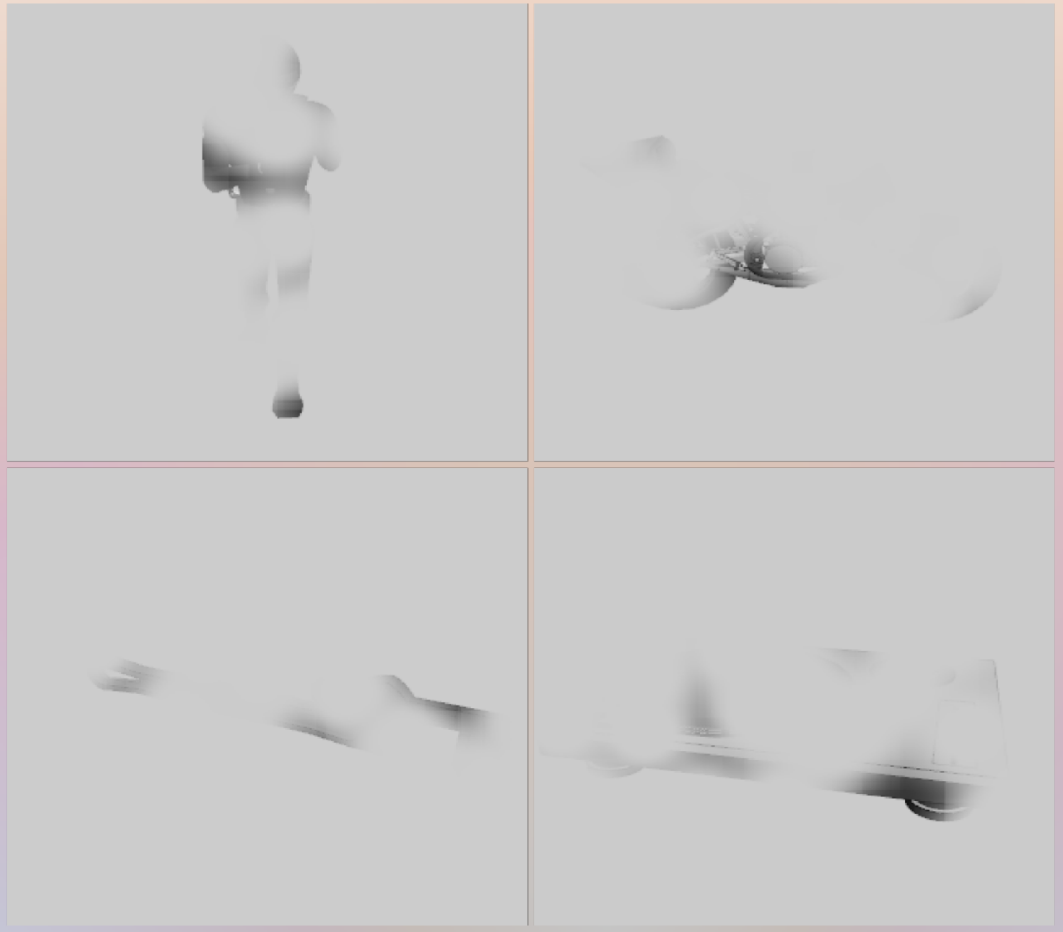
Bidirectional Excitation

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

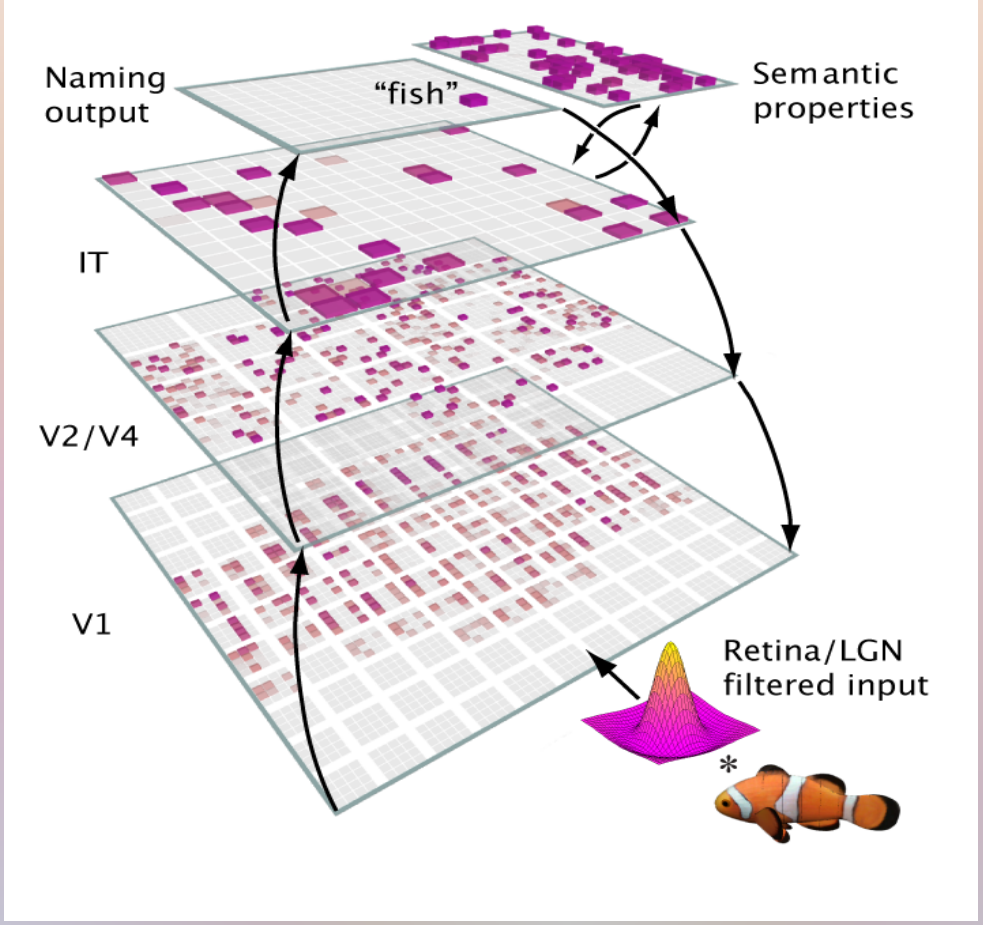


(fig. < O'Reilly, *Comp. Cog. Neurosci.*)

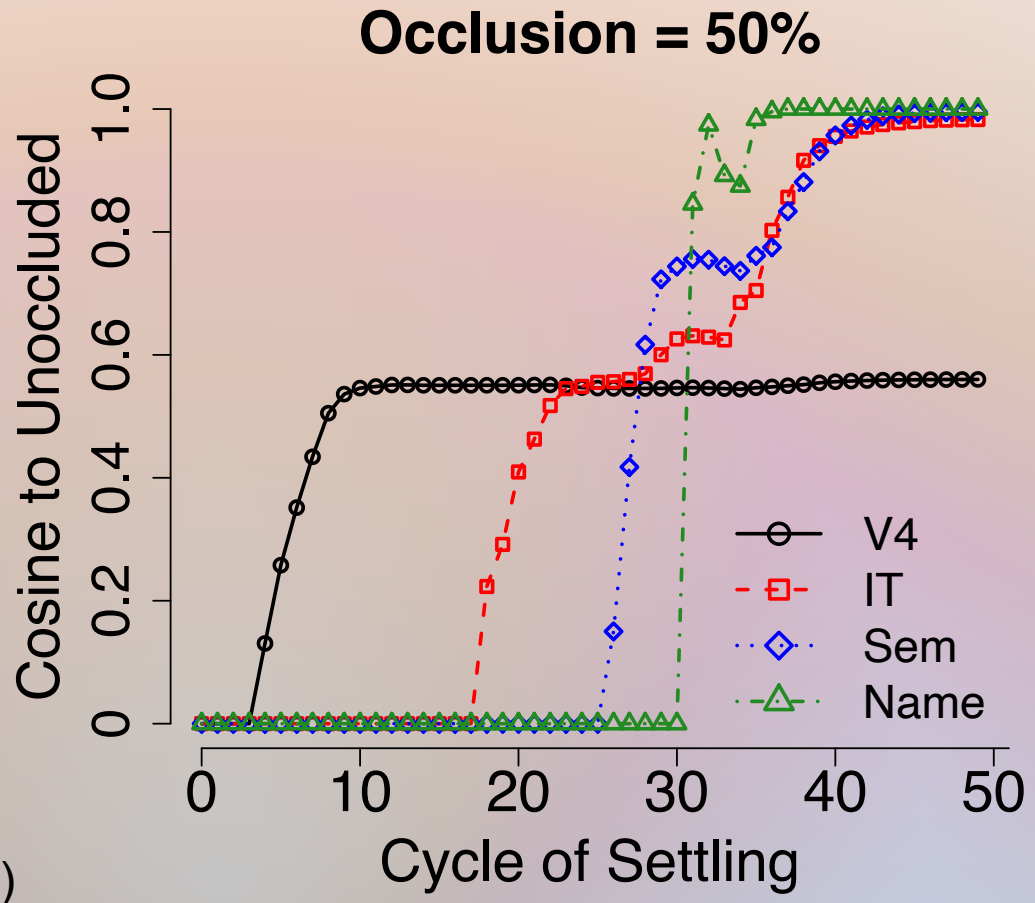
What Are These?



A Big Network Model…



Bidirectional Dynamics



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

(slide < O'Reilly)

emergent demonstration: Face Categorization II

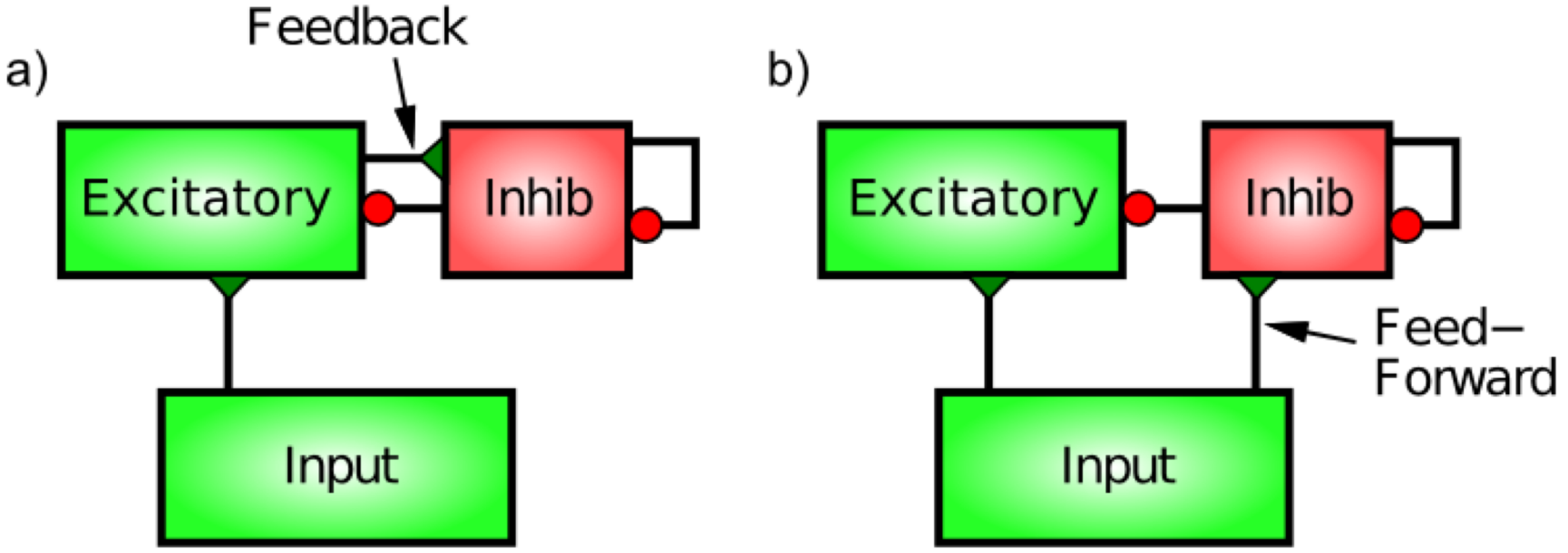
emergent demonstration: Cats and Dogs

emergent demonstration: Necker Cube

Inhibitory Competition and Activity Regulation

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

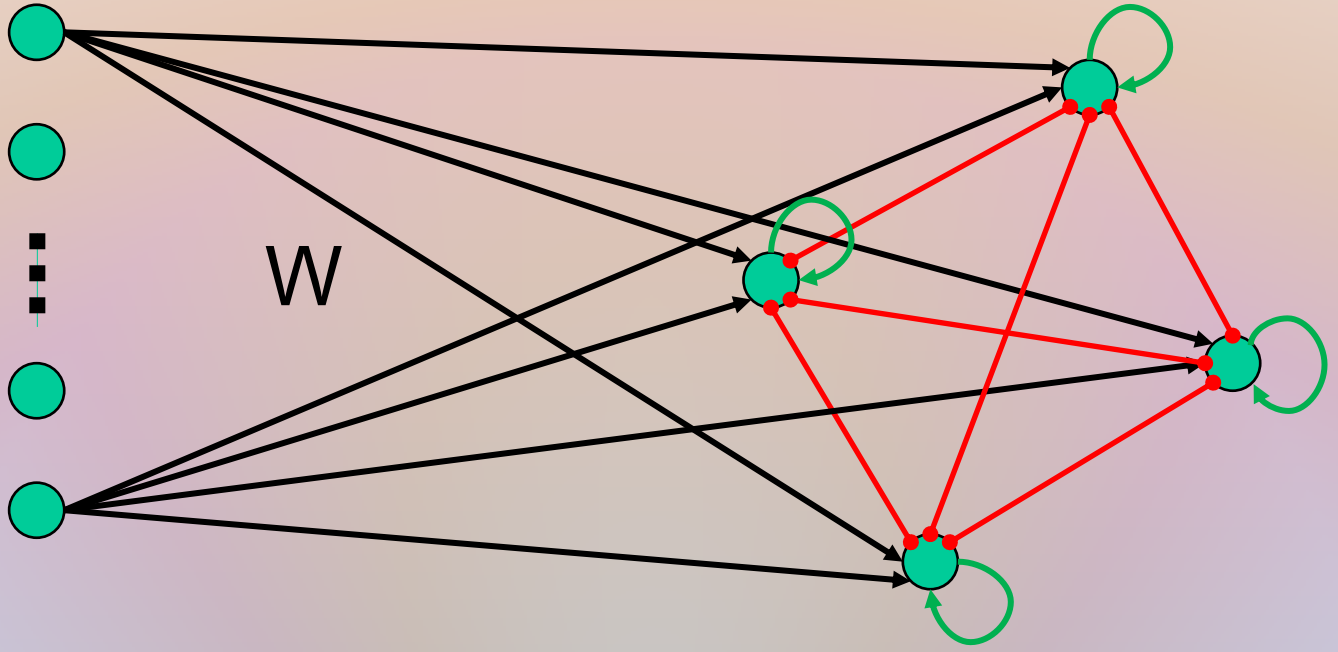
Activity Regulation



- 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 Classification

- two layers
- first layer of detectors
- second is self-reinforcing, mutually inhibitory
- “winner takes all” dynamics
- implements nearest neighbor classification

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