Learning about vision:
things we now know,
things we still don't know,
and things we don't know we don't know.

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Helen Wills Neuroscience Institute, School of Optometry
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UC Berkeley

REDWOOD CENTER
for Theoretical Neuroscience

Learning about vision

It's a really hard problem.

We have made progress

...but we are still confronted with profound mysteries

and some of the most important questions have not yet been asked.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PROJECT MAC

Subgoal for July

Analysis of scenes consisting of non-overlapping objects from the following set:

balls

bricks with faces of the same or different colors or textures

cylinders.

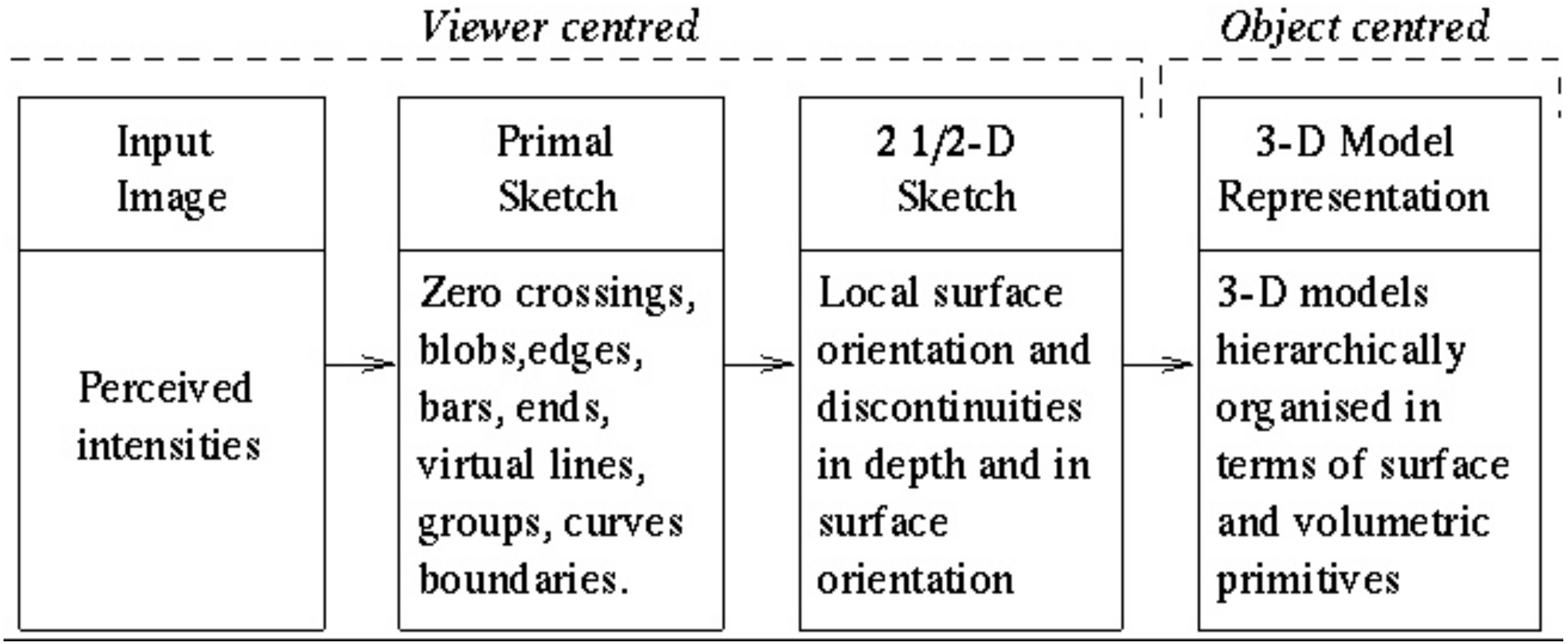
Each face will be of uniform and distinct color and/or texture. Background will be homogeneous.

Extensions for August

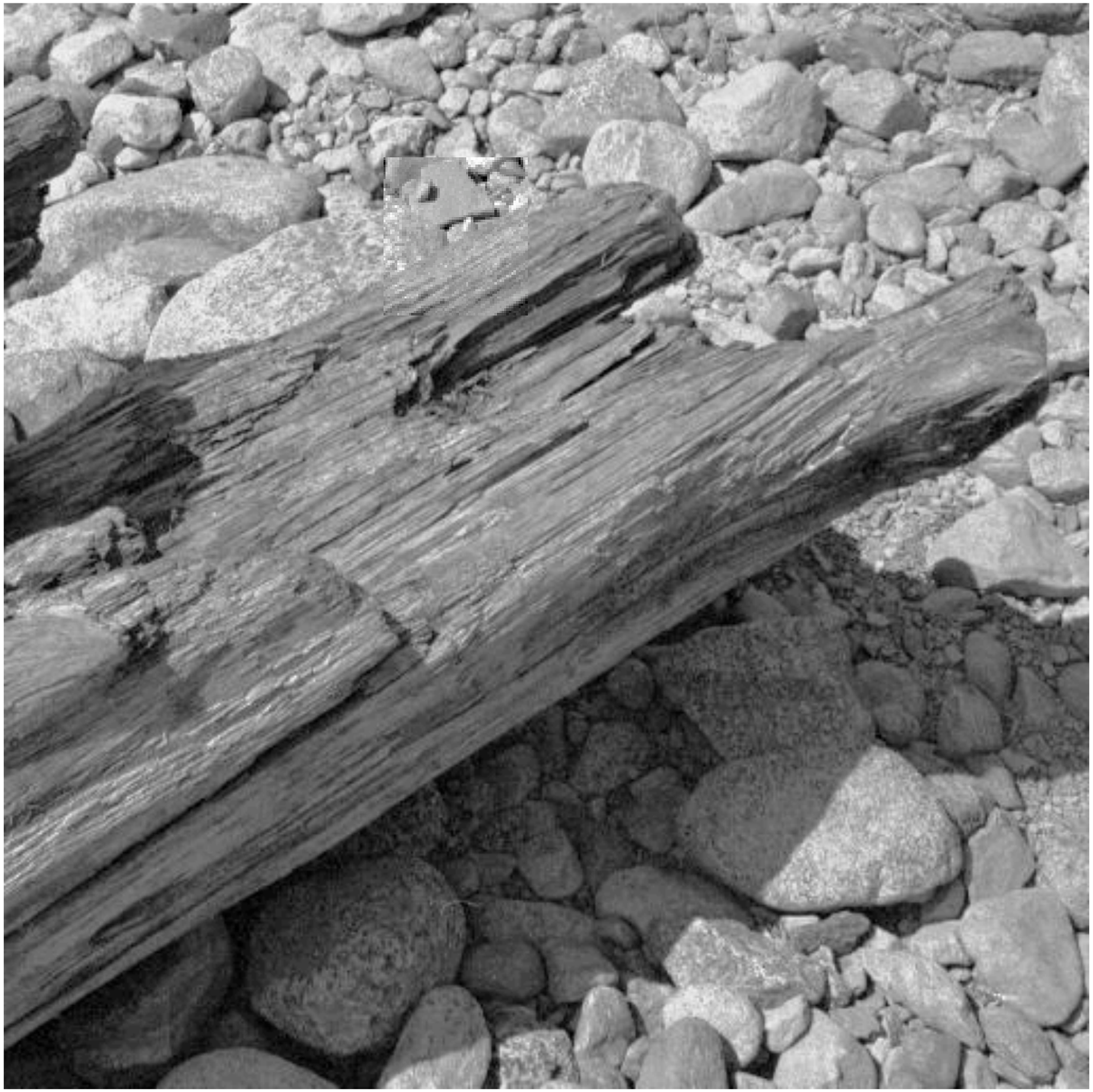
The first priority will be to handle objects of the same sort but with complex surfaces and backgrounds, e.g. cigarette pack with writing and bands of different color, or a cylindrical battery.

Then extend class of objects to objects like tools, cups, etc.

The approach of David Marr



Natural images are full of ambiguity



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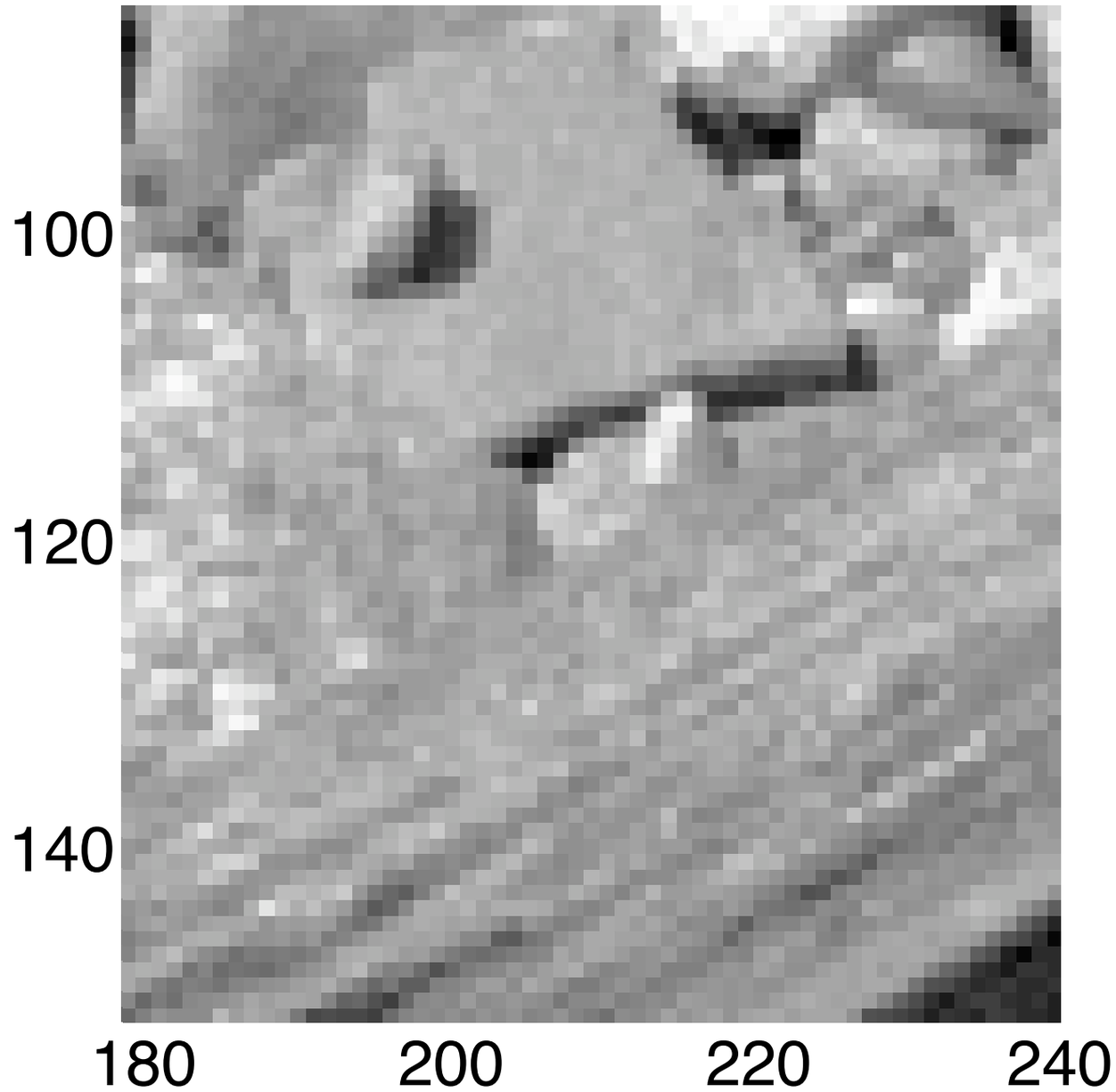
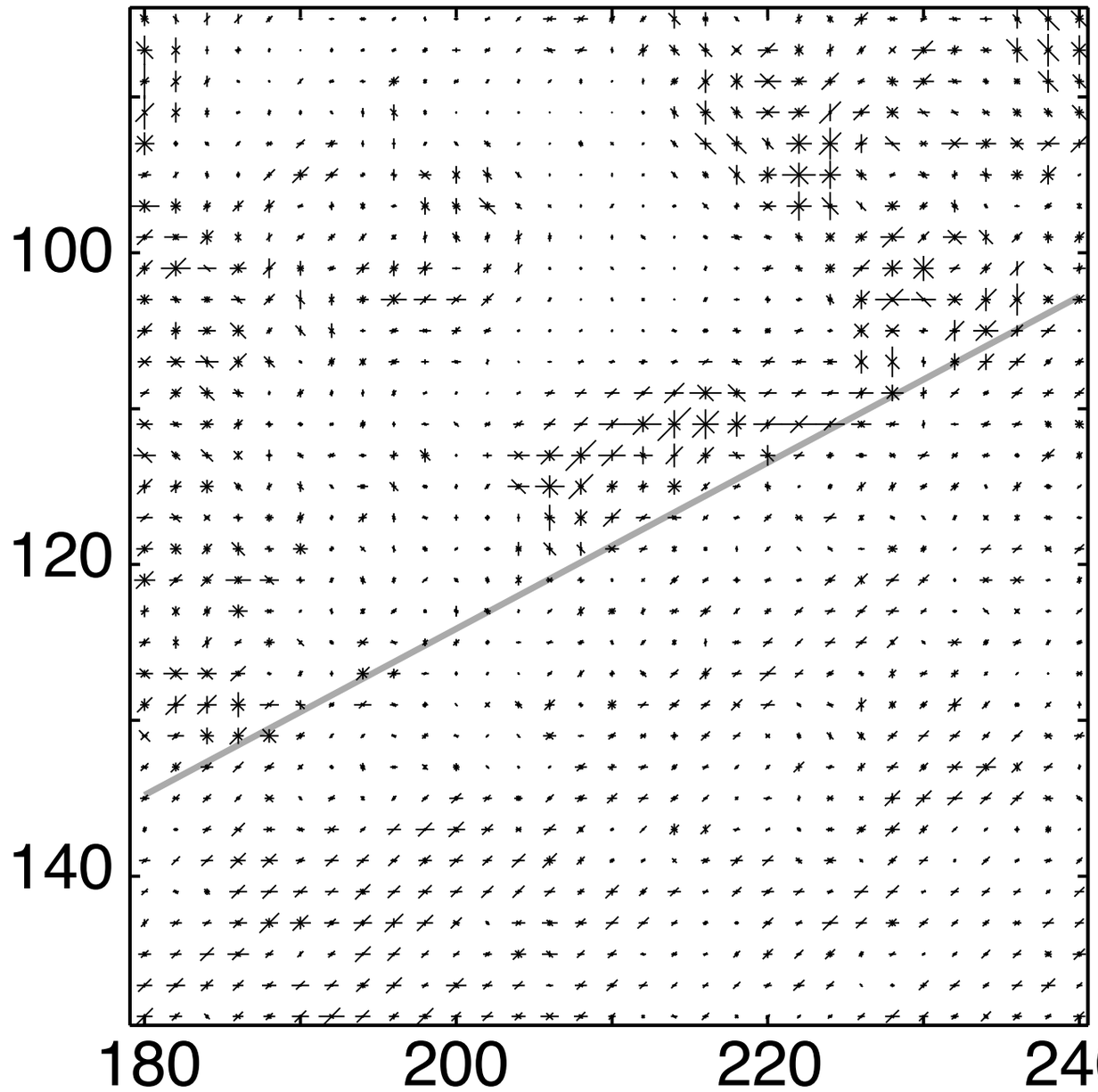
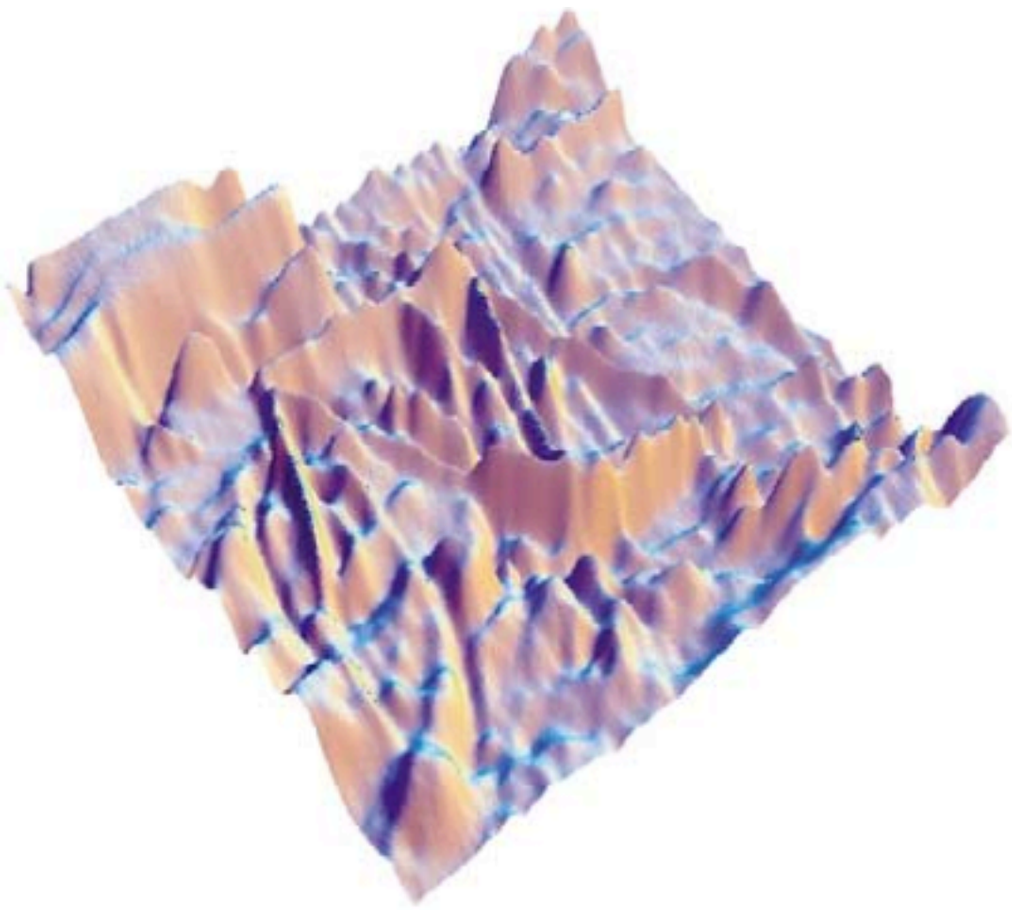
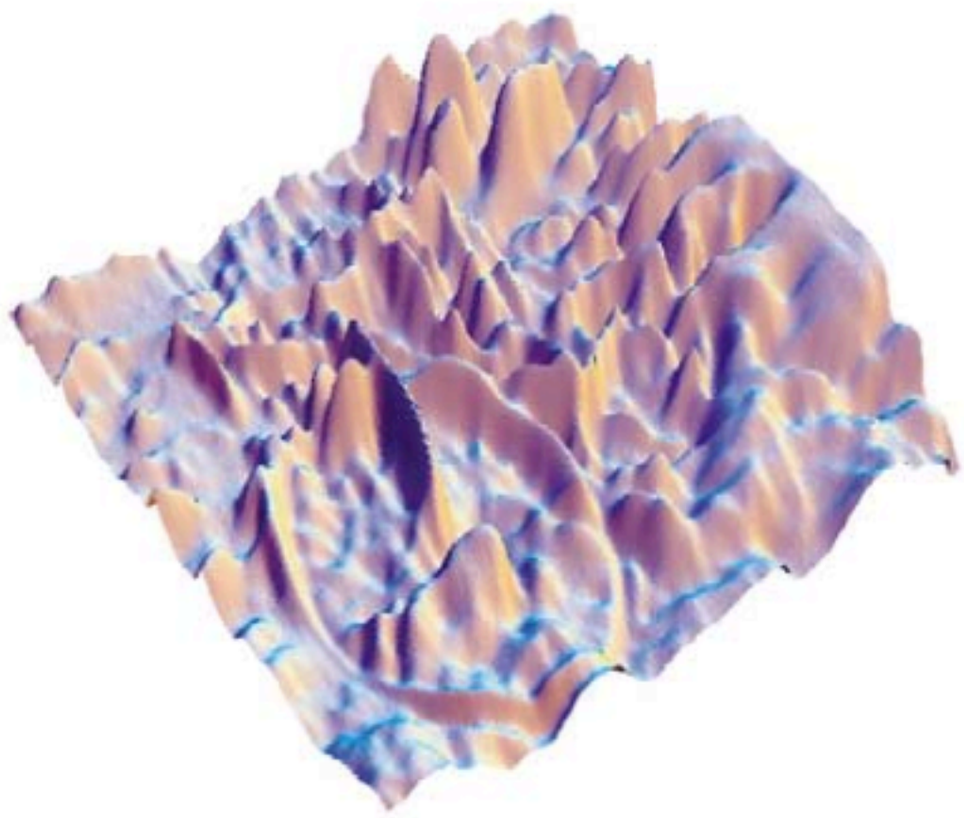




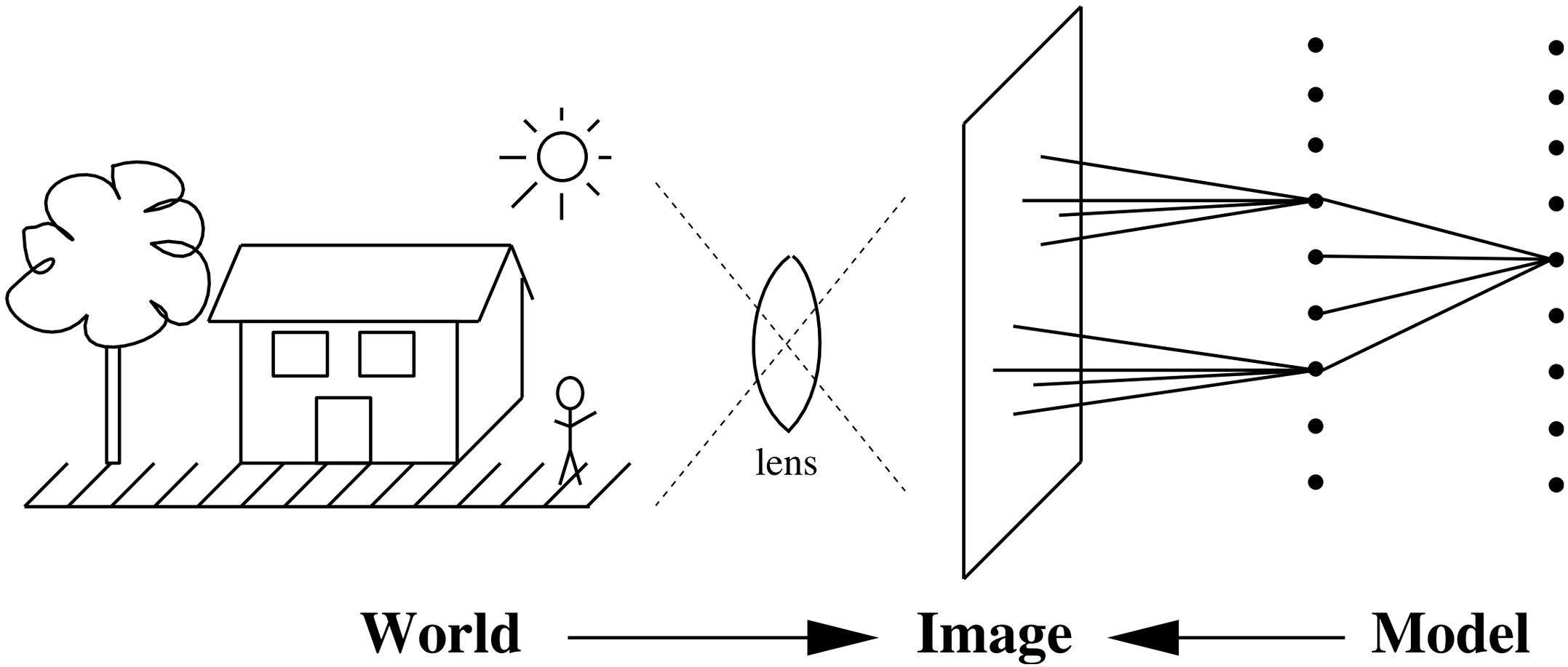
What do these patterns depict?



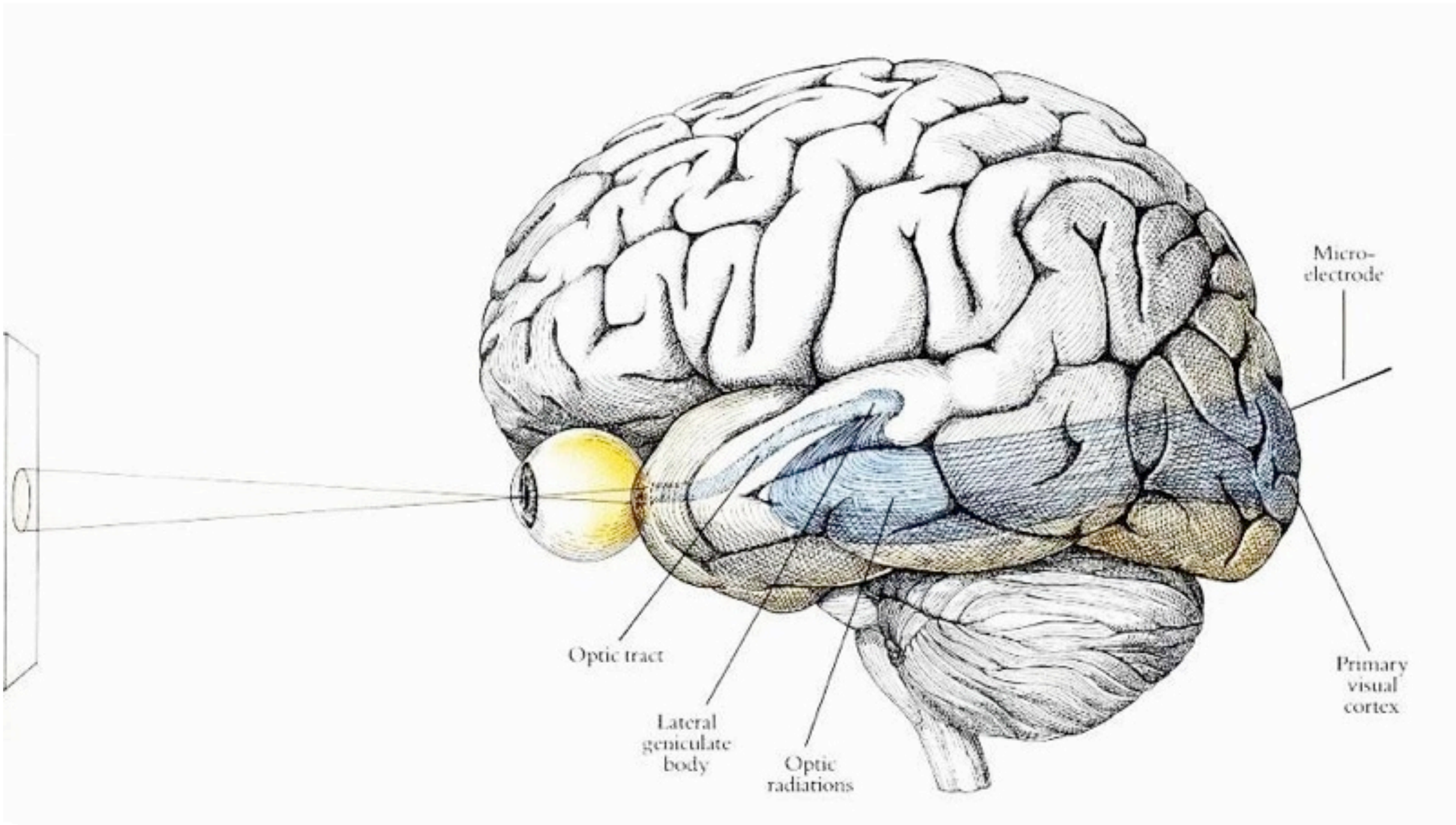


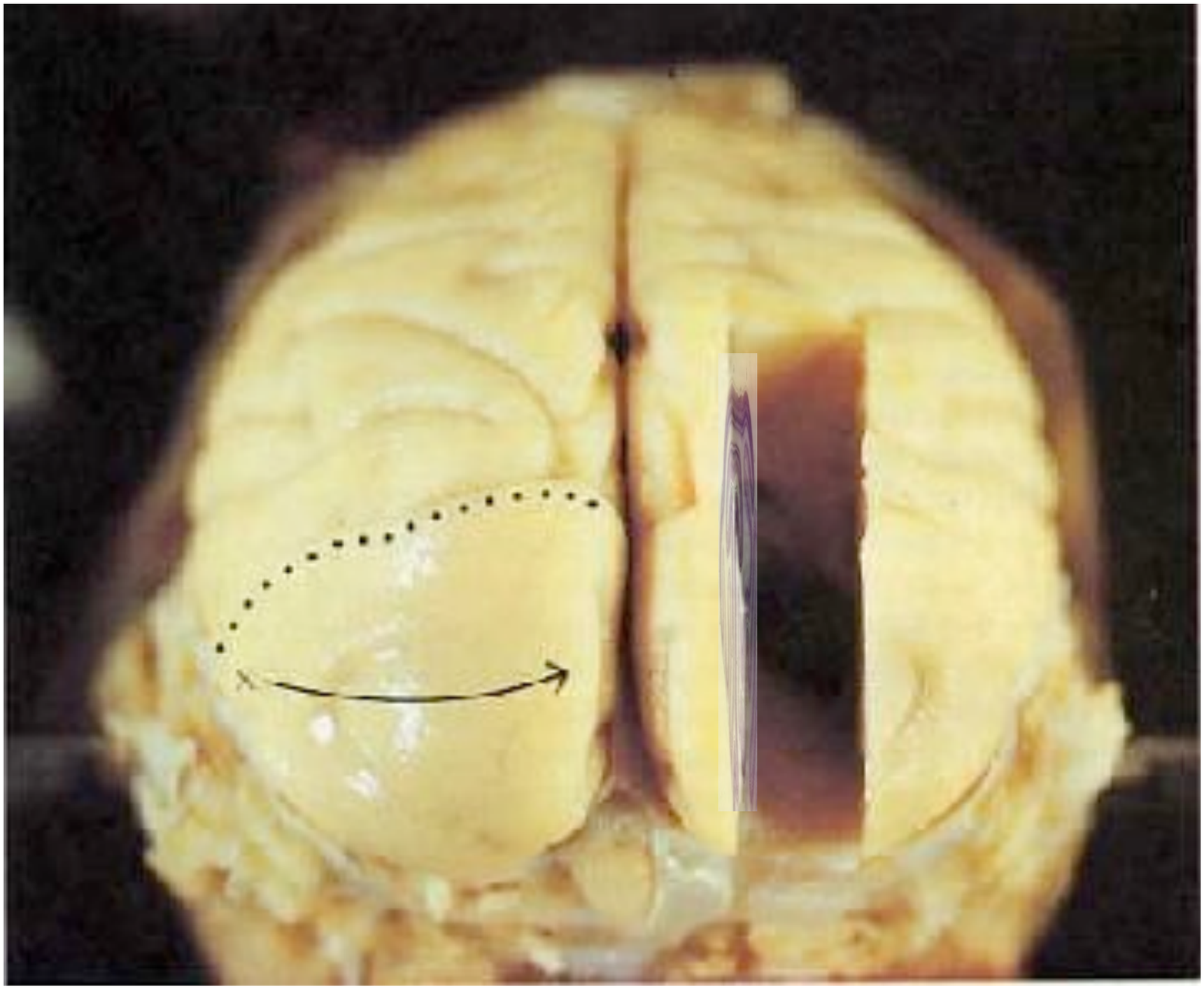
(from Kersten & Yuille, 2003)

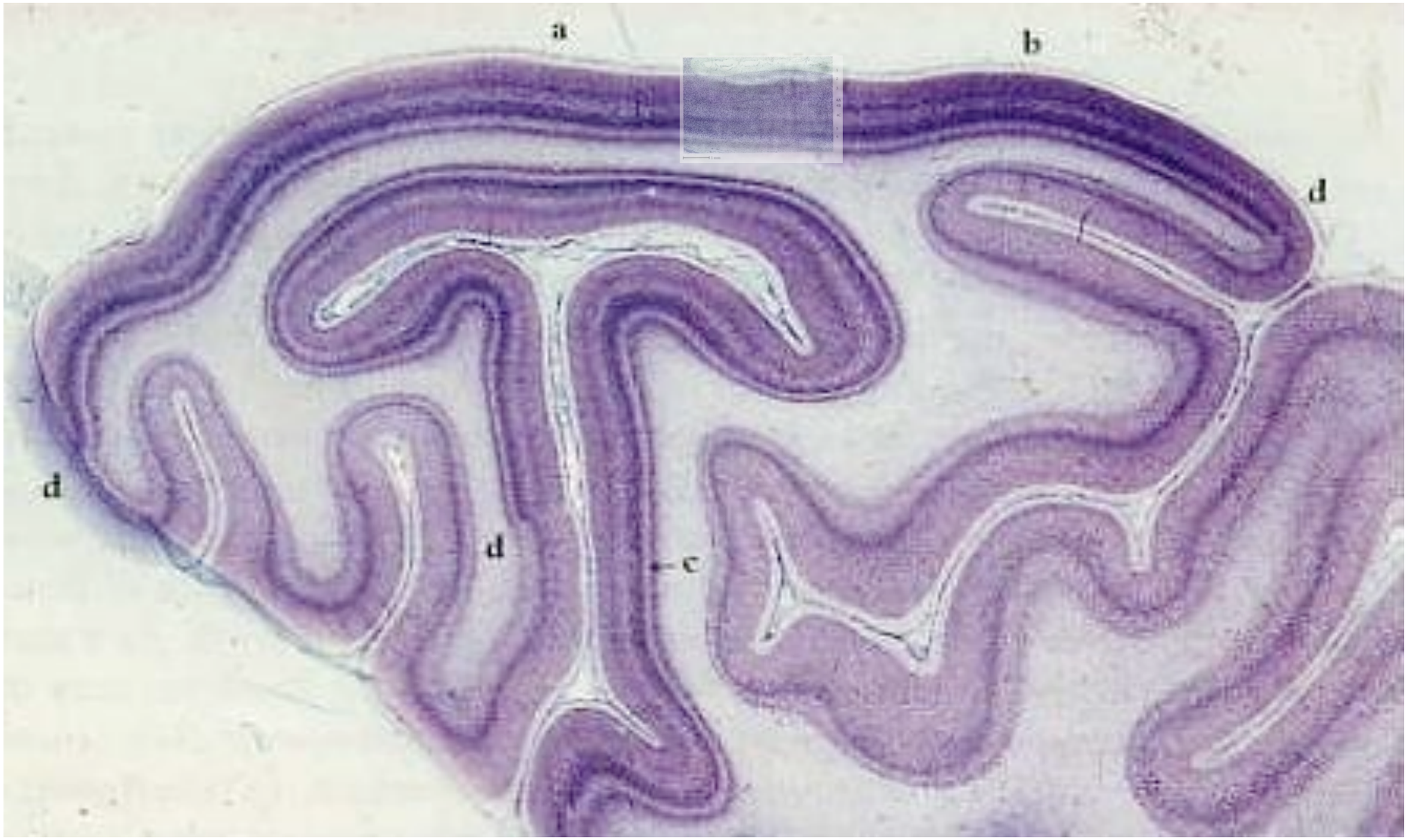
Vision as inference

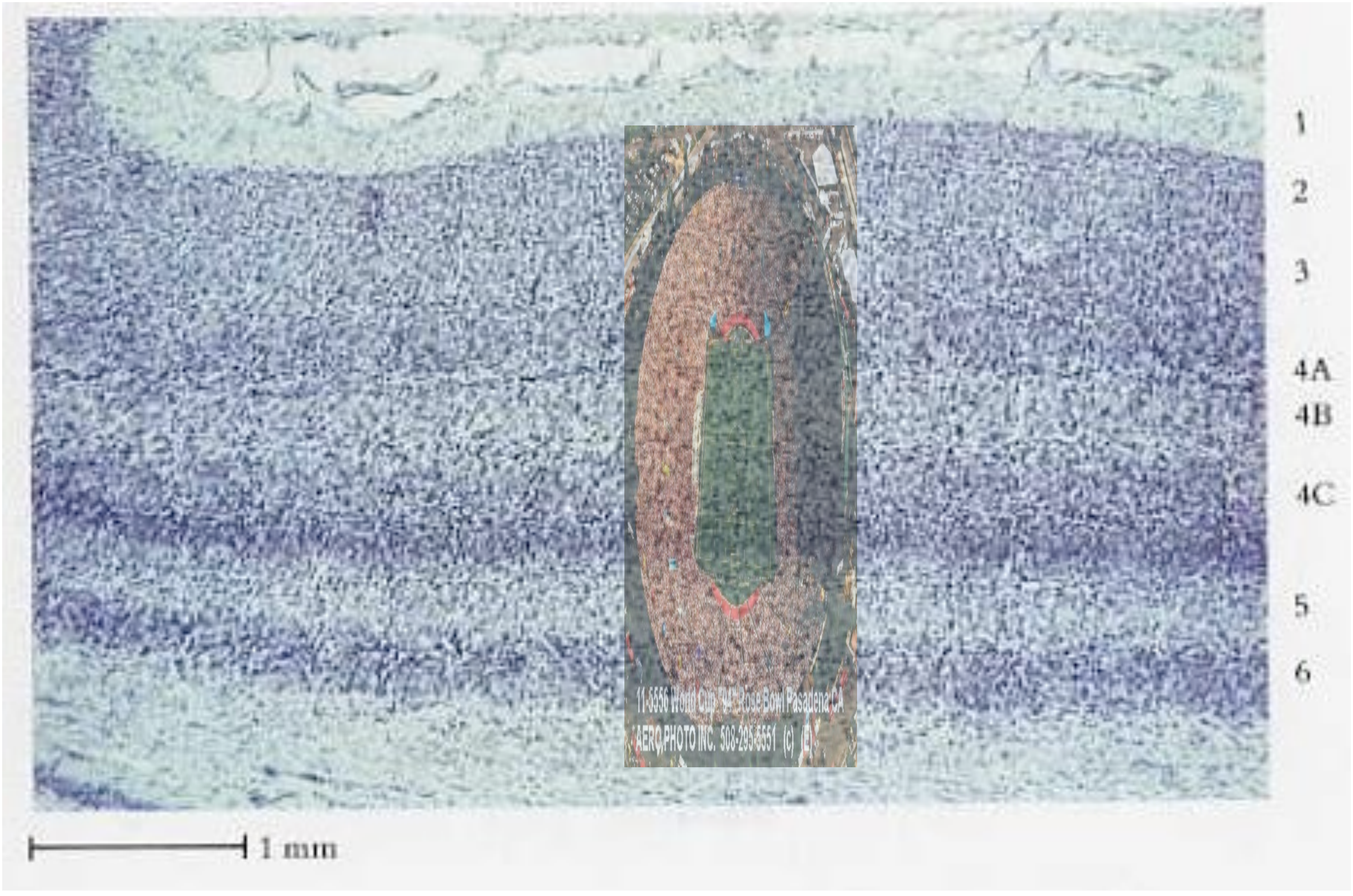


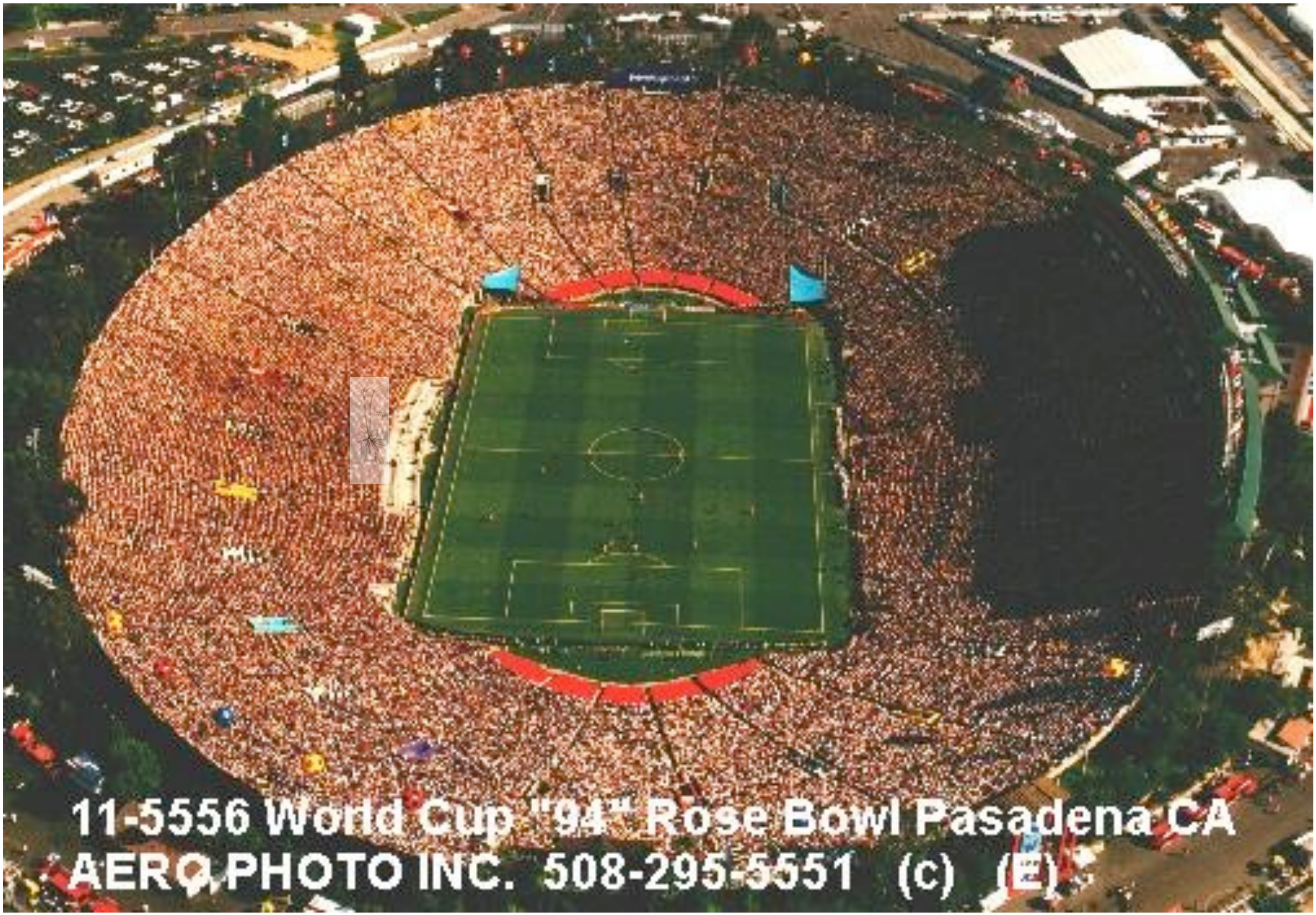
Nervous systems are difficult to penetrate

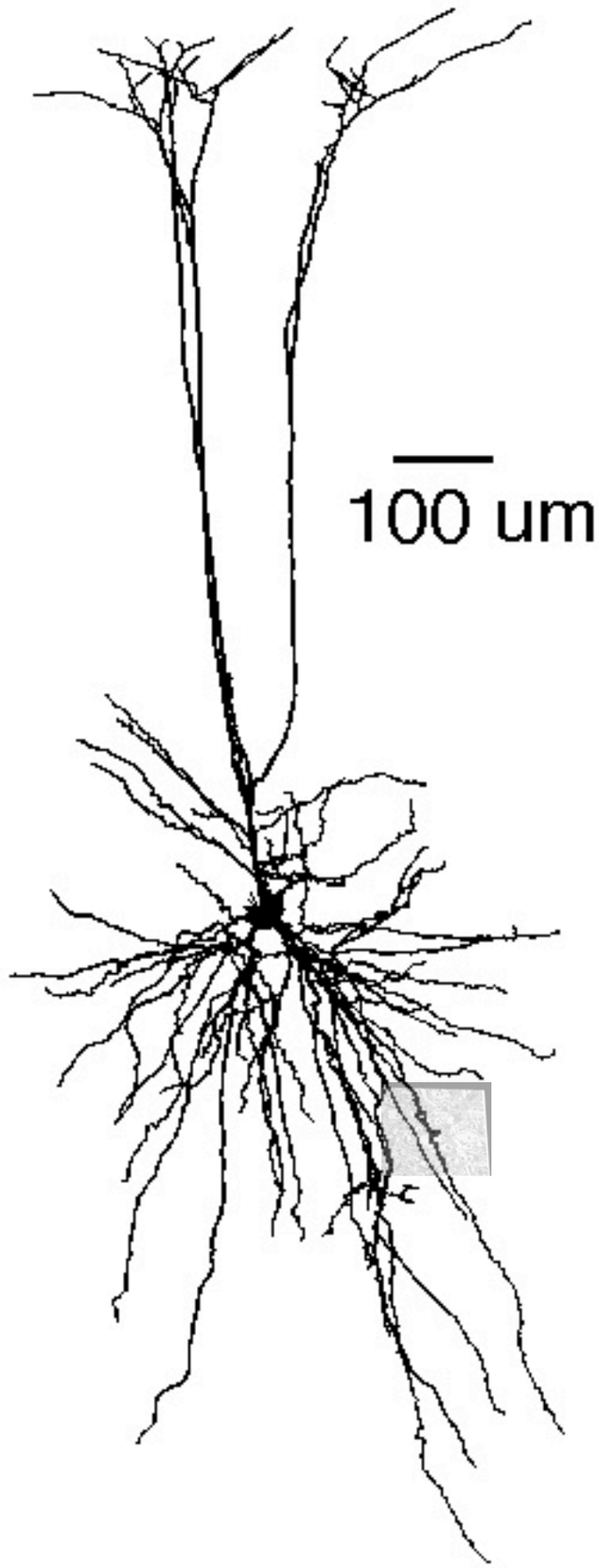


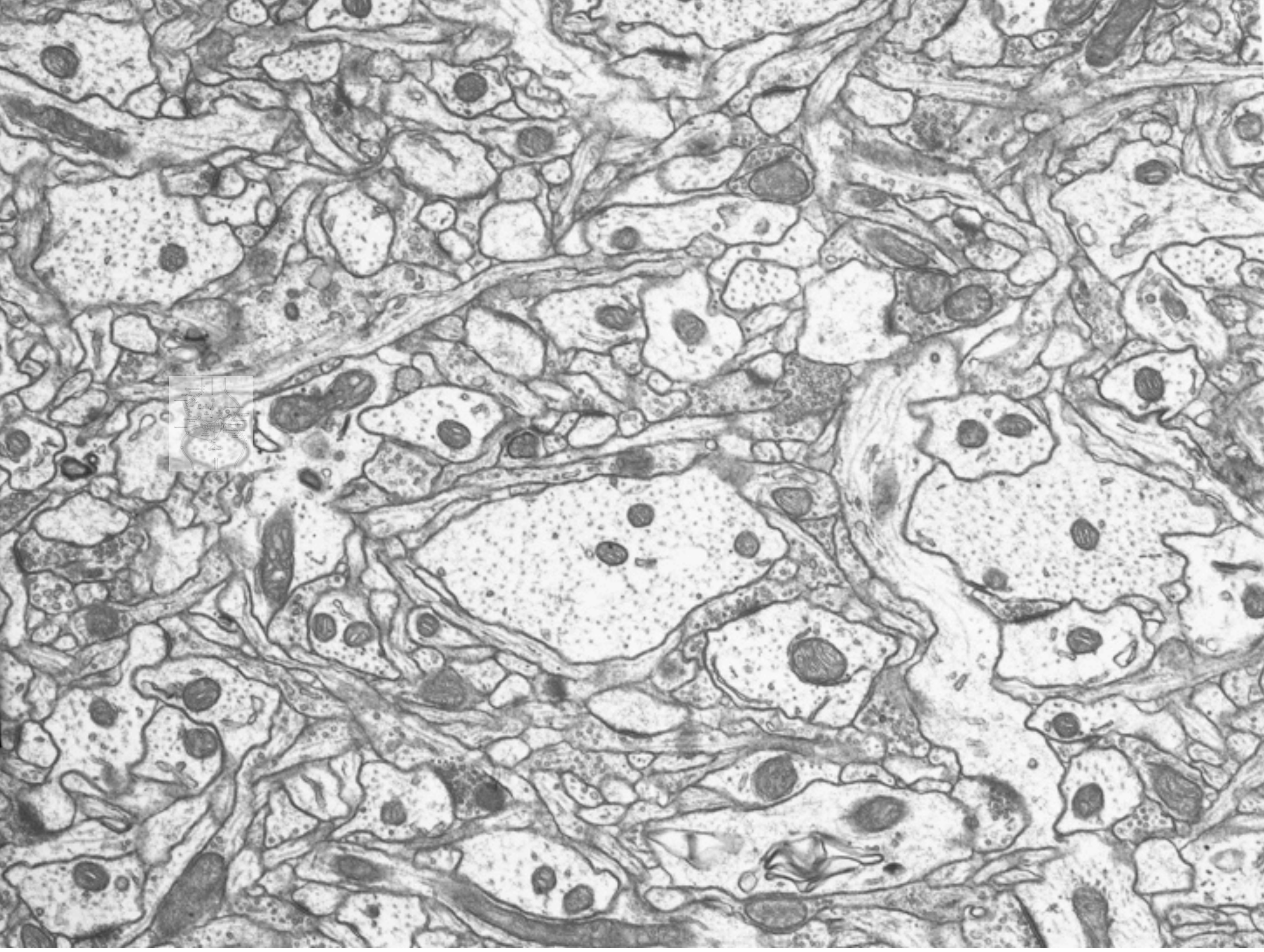



a
b
d
d
d
c


1
2
3
4A
4B
4C
5
6
11-5556 World Cup '94 Rose Bowl Pasadena CA
AERO PHOTO INC. 508-295-5551 (c)
1 mm

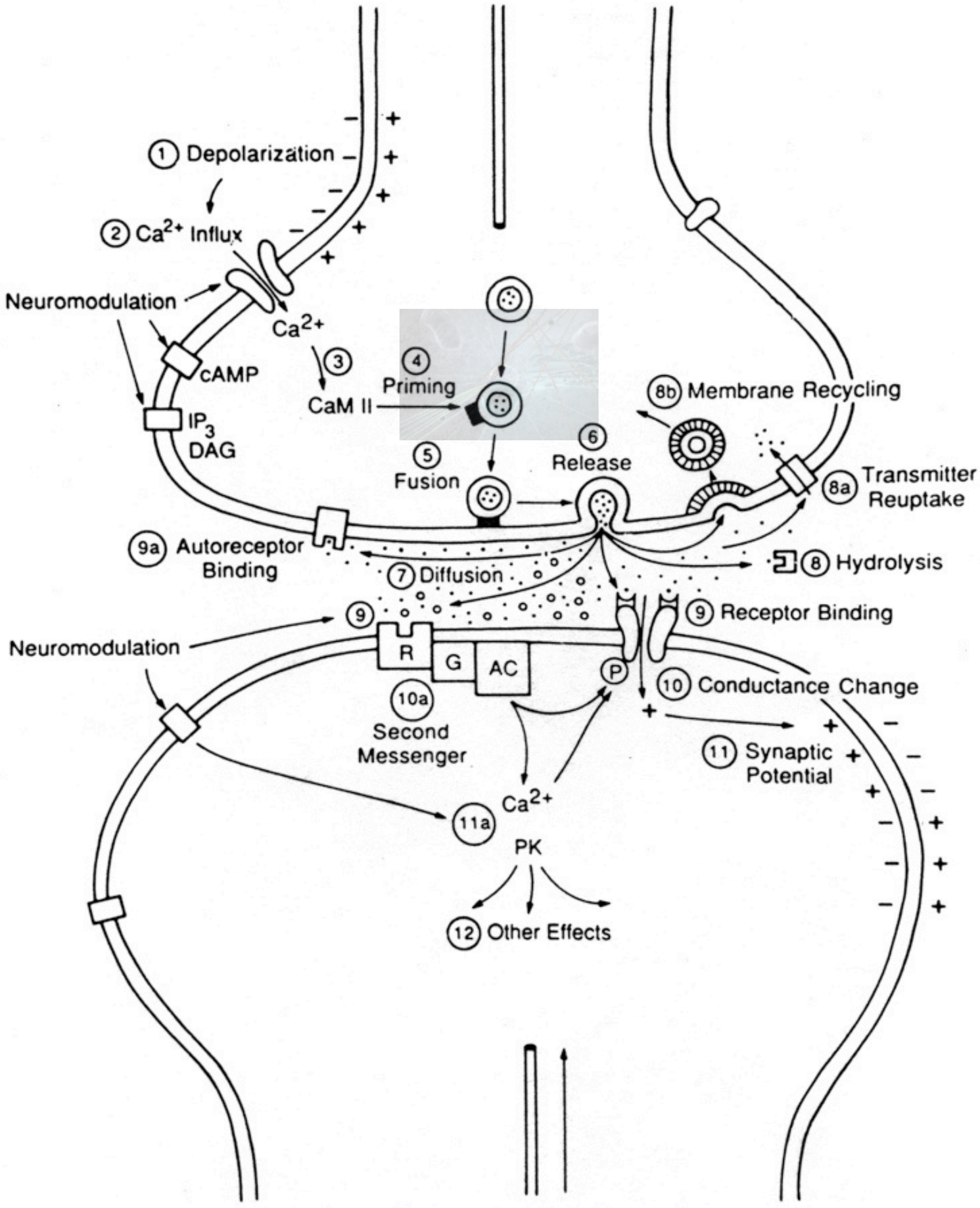

11-5556 World Cup '94" Rose Bowl Pasadena CA
AERO PHOTO INC. 508-295-5551 (c) (E)


100 um



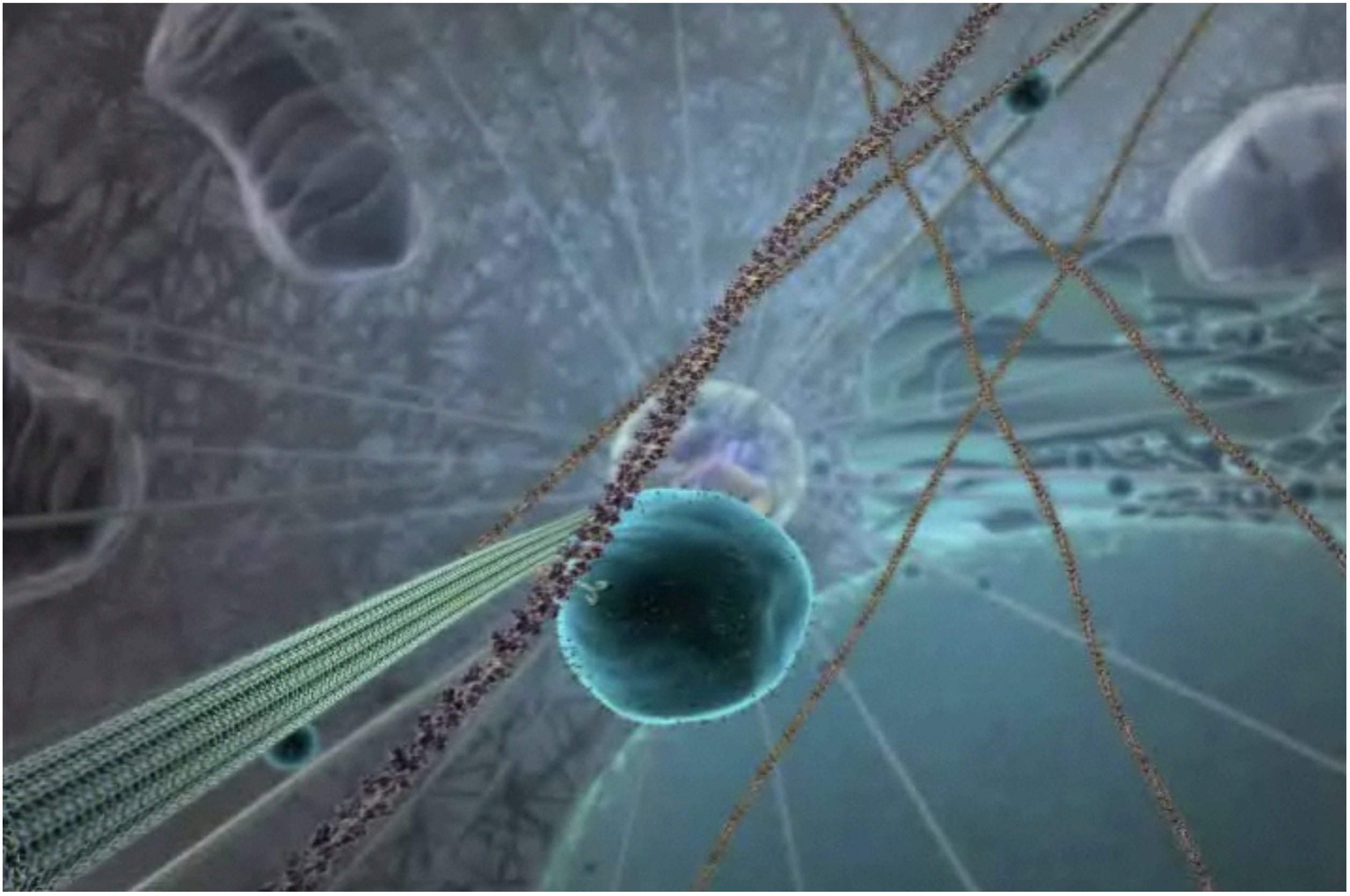
Thursday, August 12, 2010

Anatomy of a synapse



Inner life of the cell

http://multimedia.mcb.harvard.edu/



Progress

Adaptive optics retinal circuitry

Functional imaging and multiple unit recording

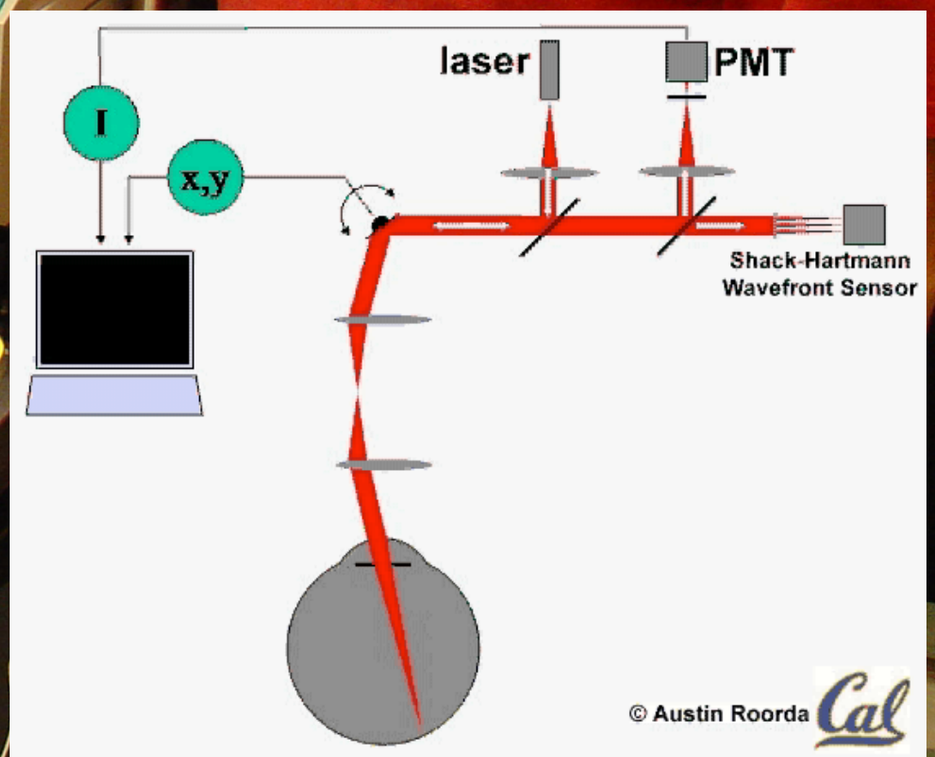
Natural scene statistics and visual coding

Computer vision: multiple-view geometry

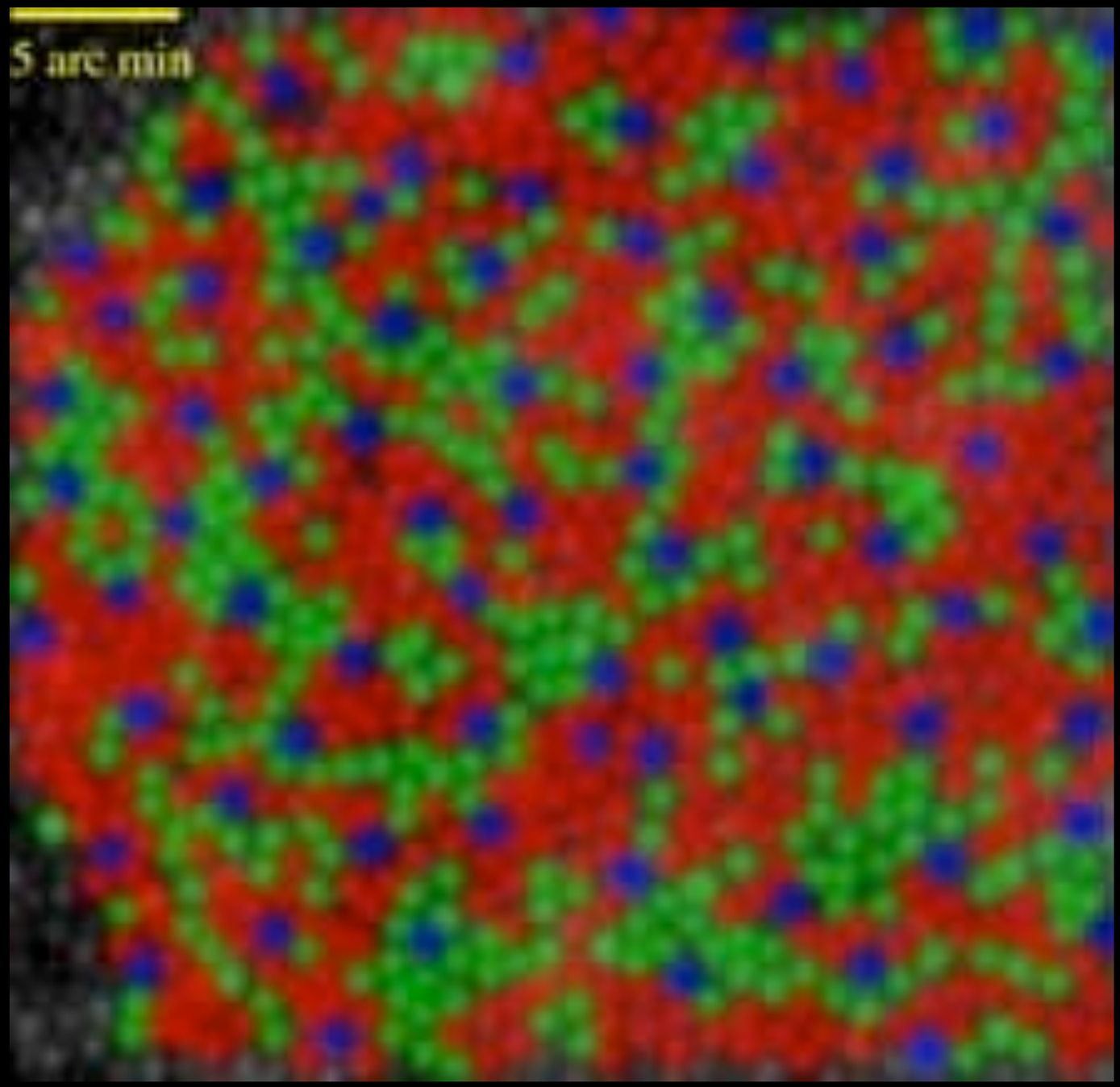
Adaptive Optics Scanning Laser Ophthalmoscope

Yuhua Zhang

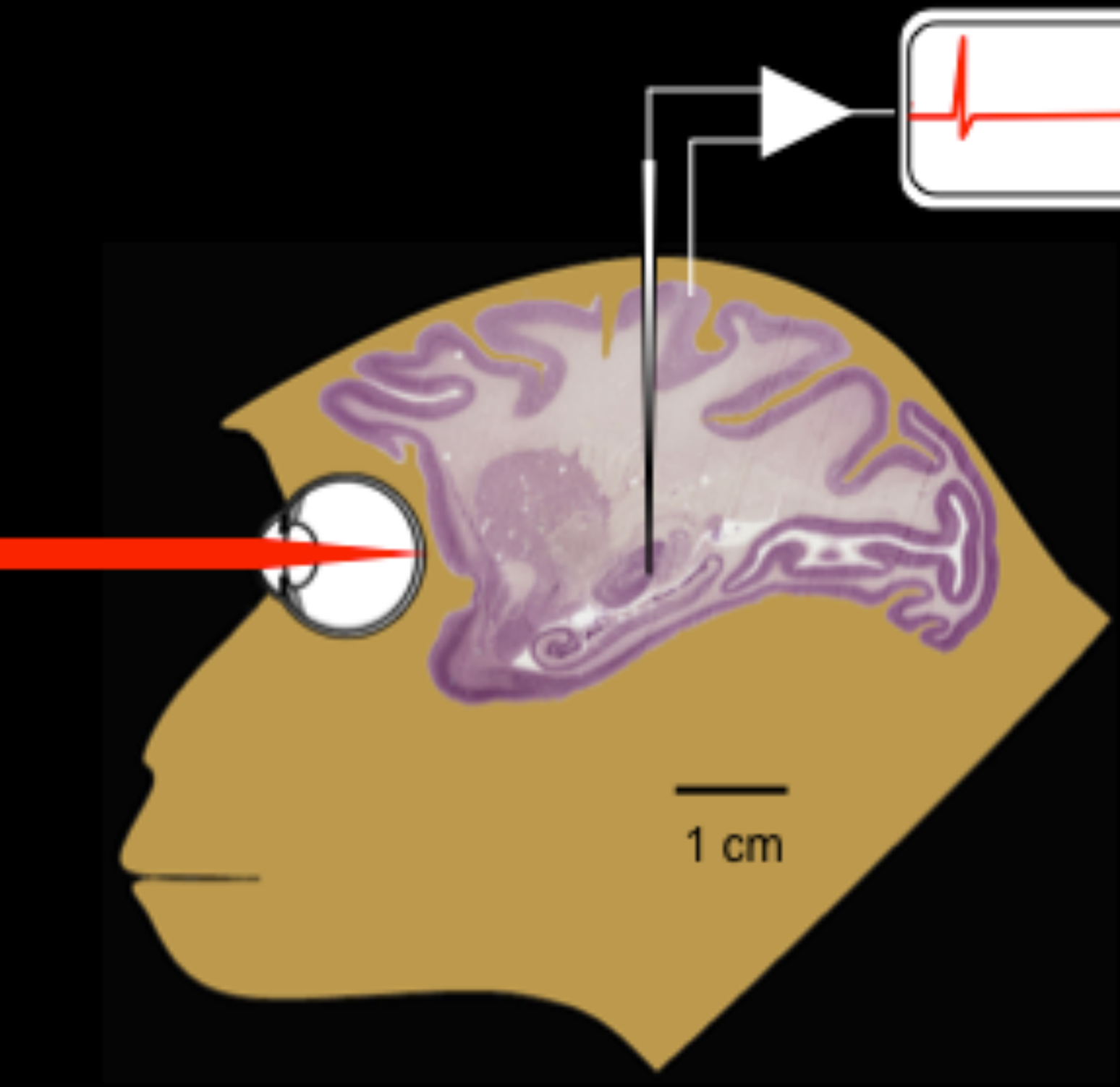
Austin Roorda



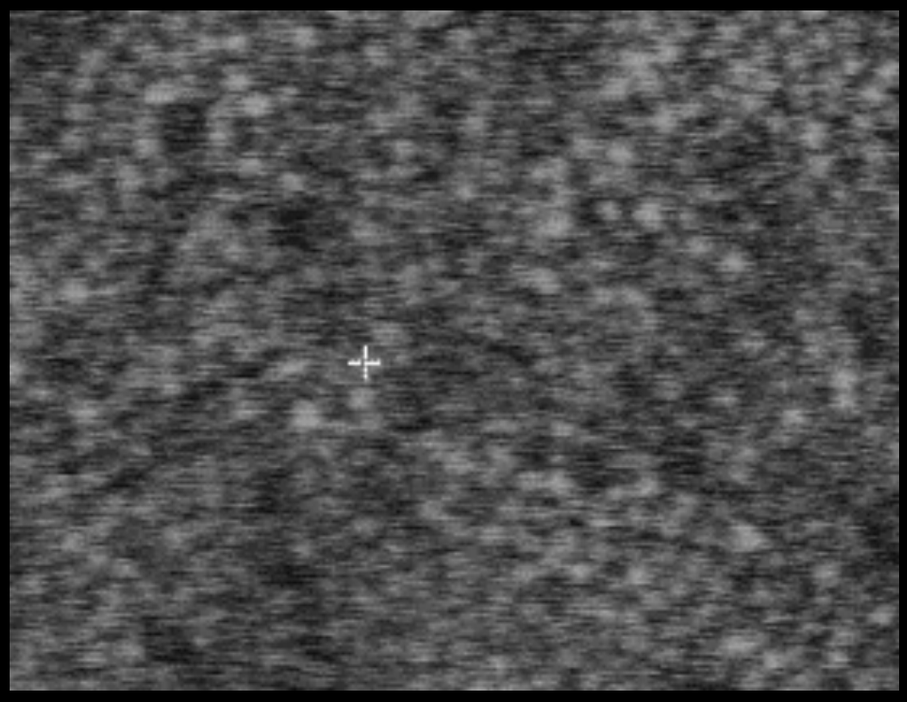
Human retina - cone mosaic



Combined Stimulus Delivery and Electrophysiology

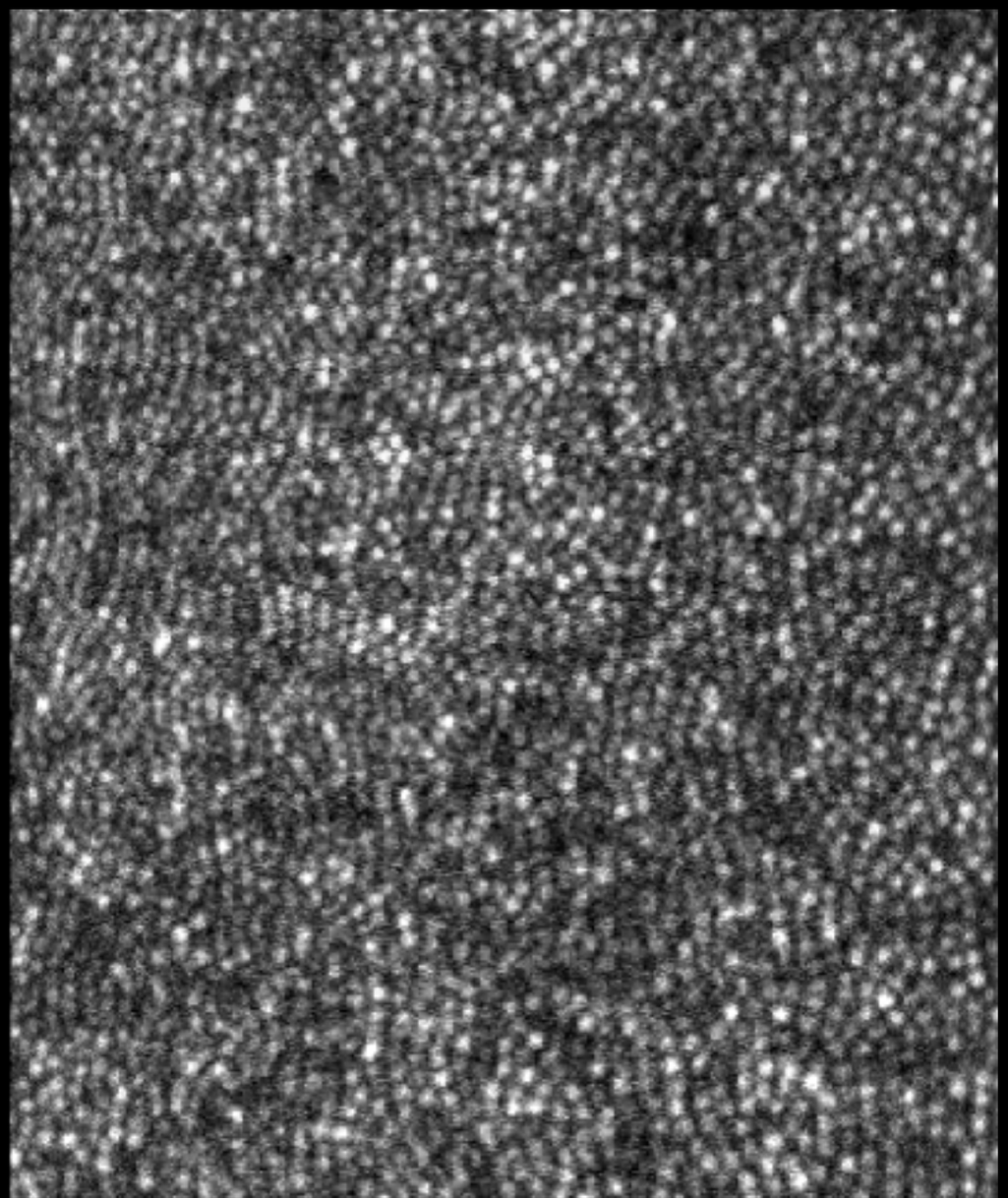


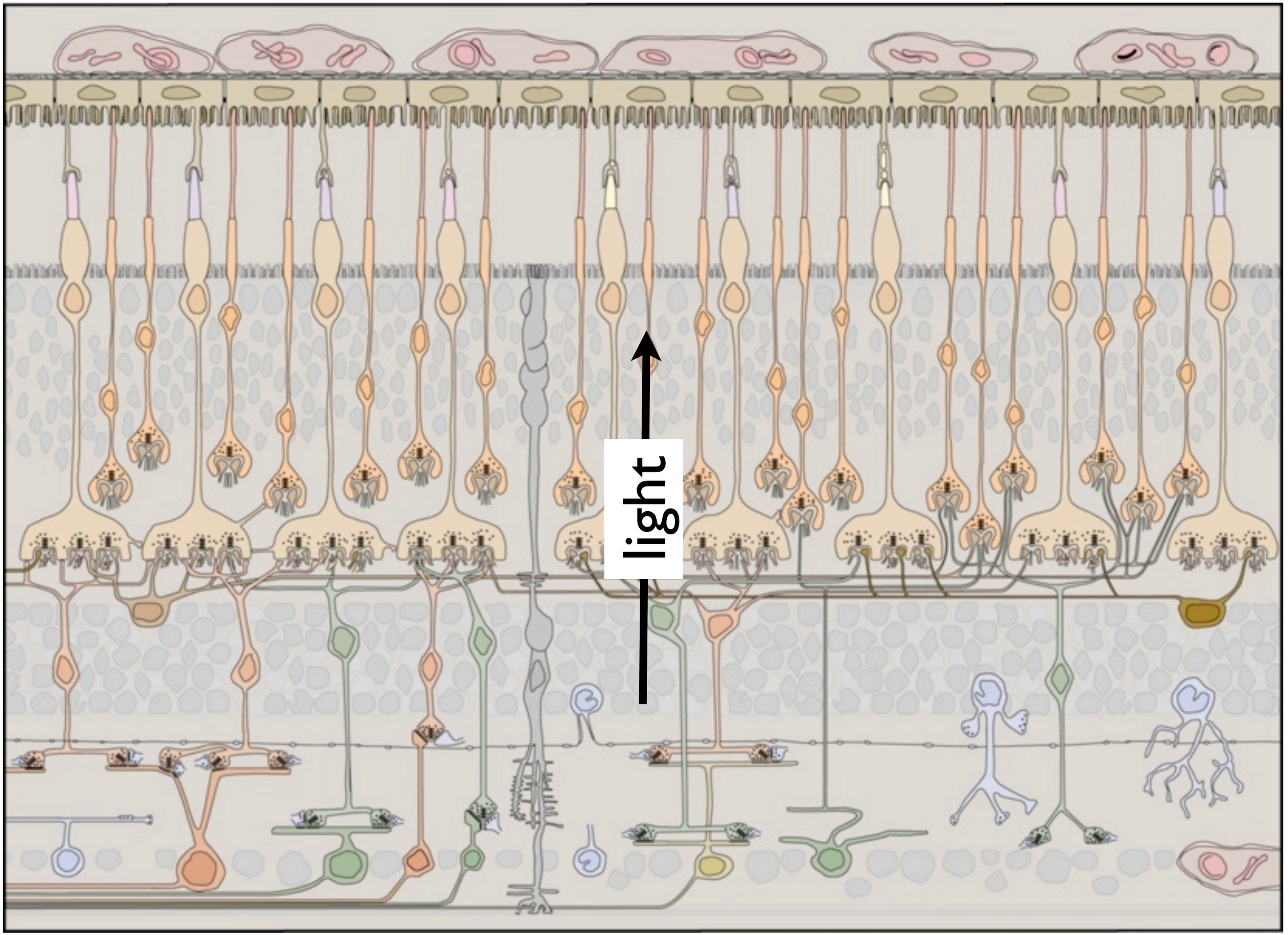
imaging: 840 nm
stimulus: 680 nm



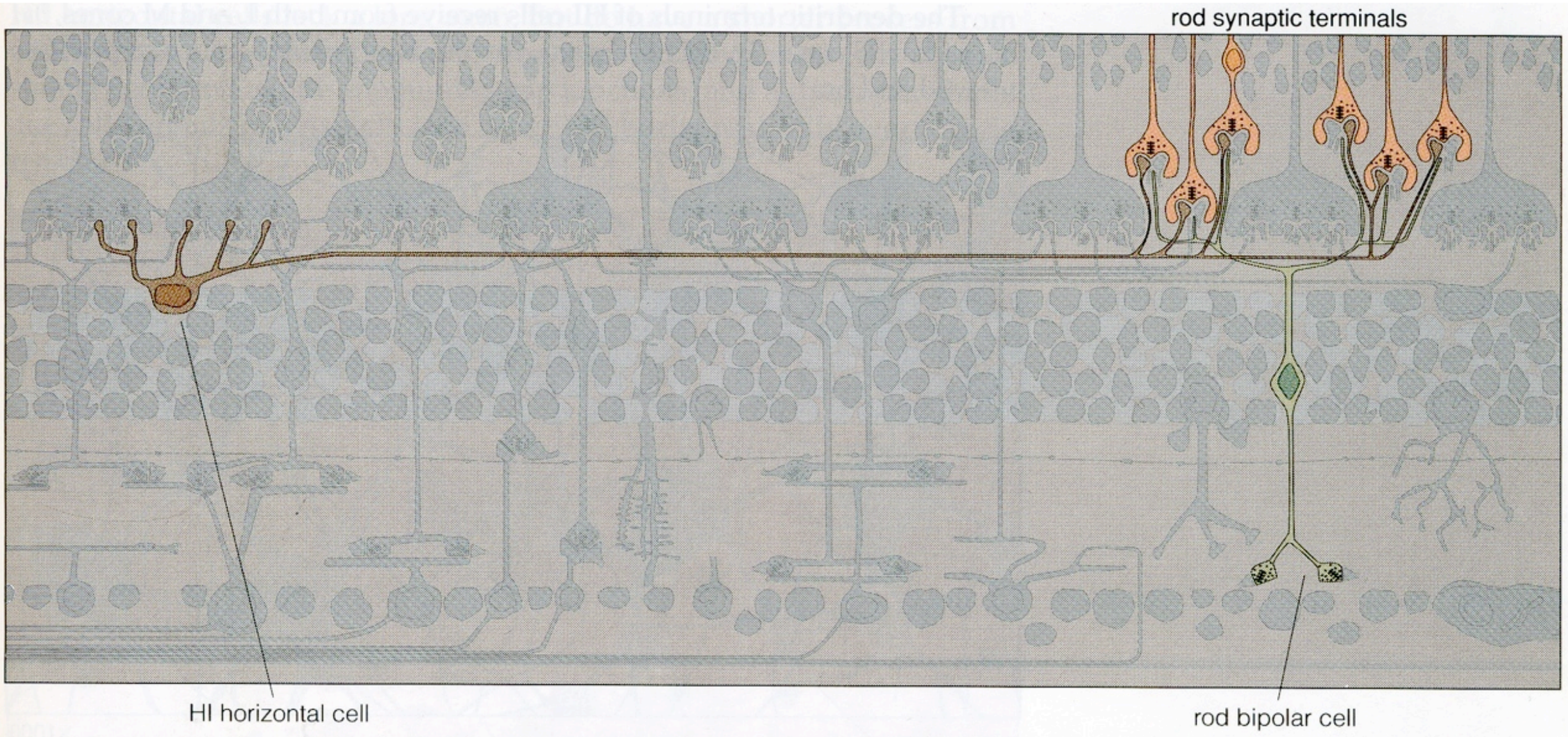
Saggital section from brainmaps.org

Human fixational eye movements
(Austin Roorda, UCB)

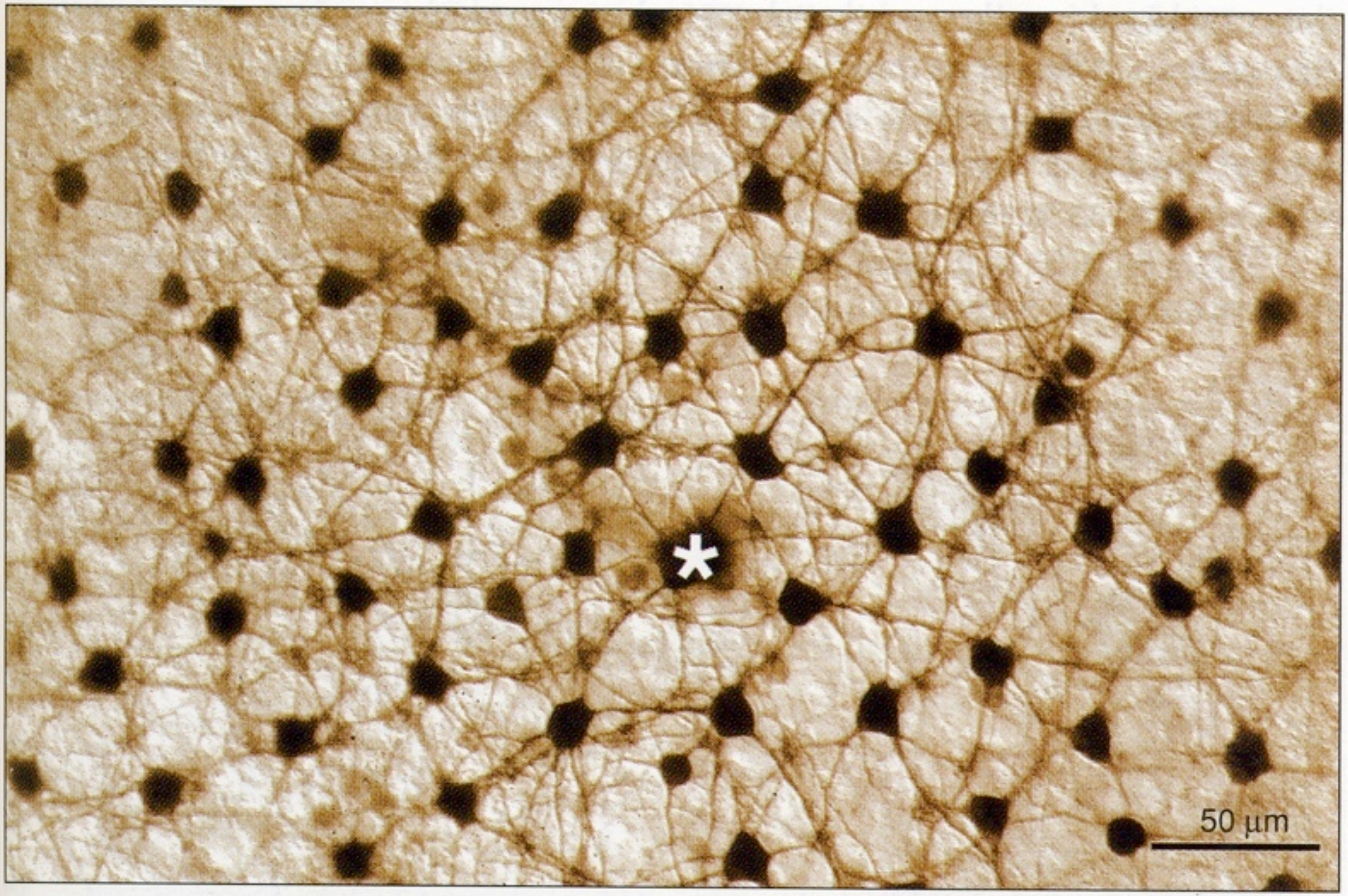



light

HI horizontal cell



HI horizontal cells connected via gap junctions

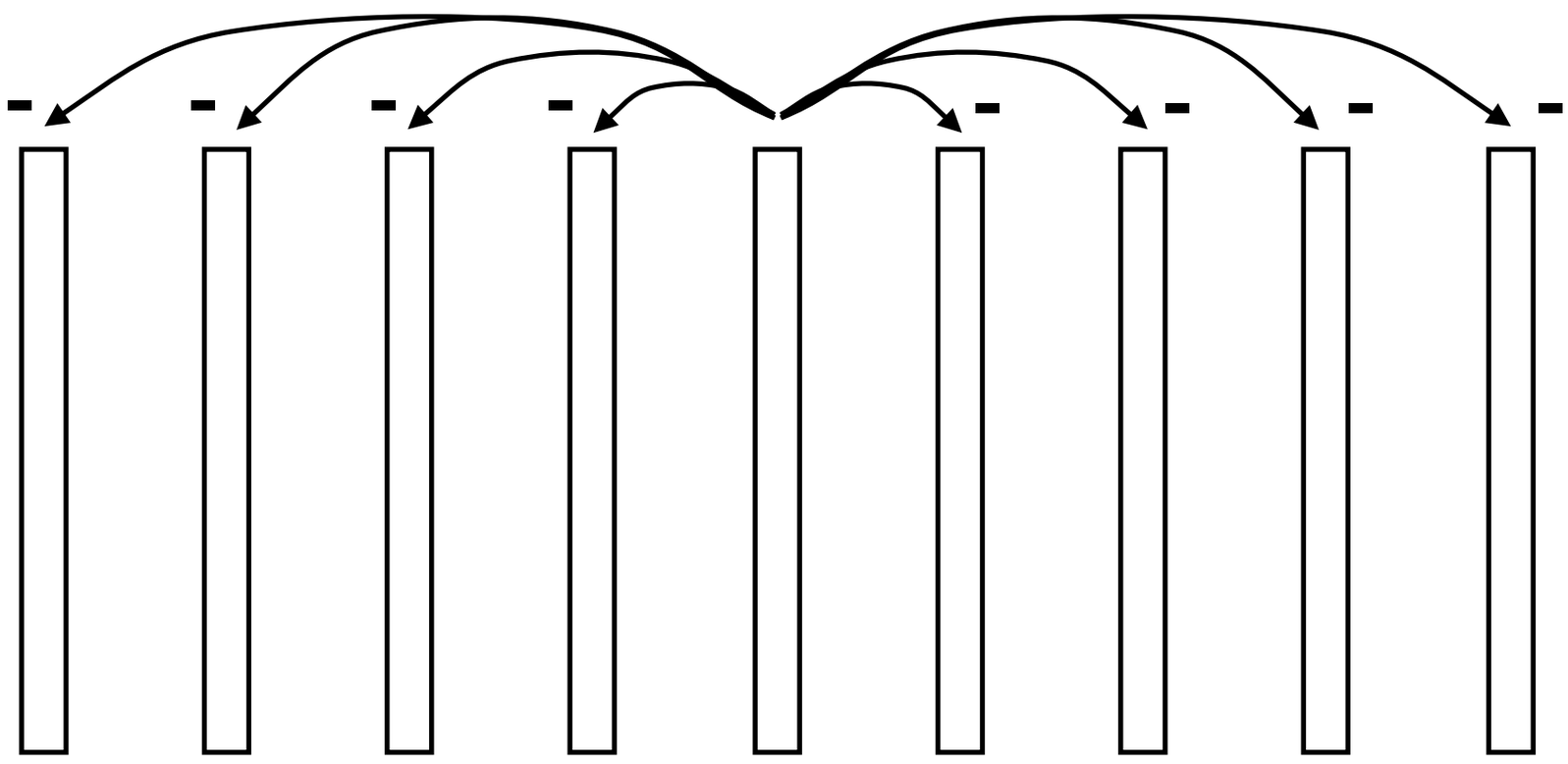


HI horizontal cells labeled following injection of one HI cell (*) ×300

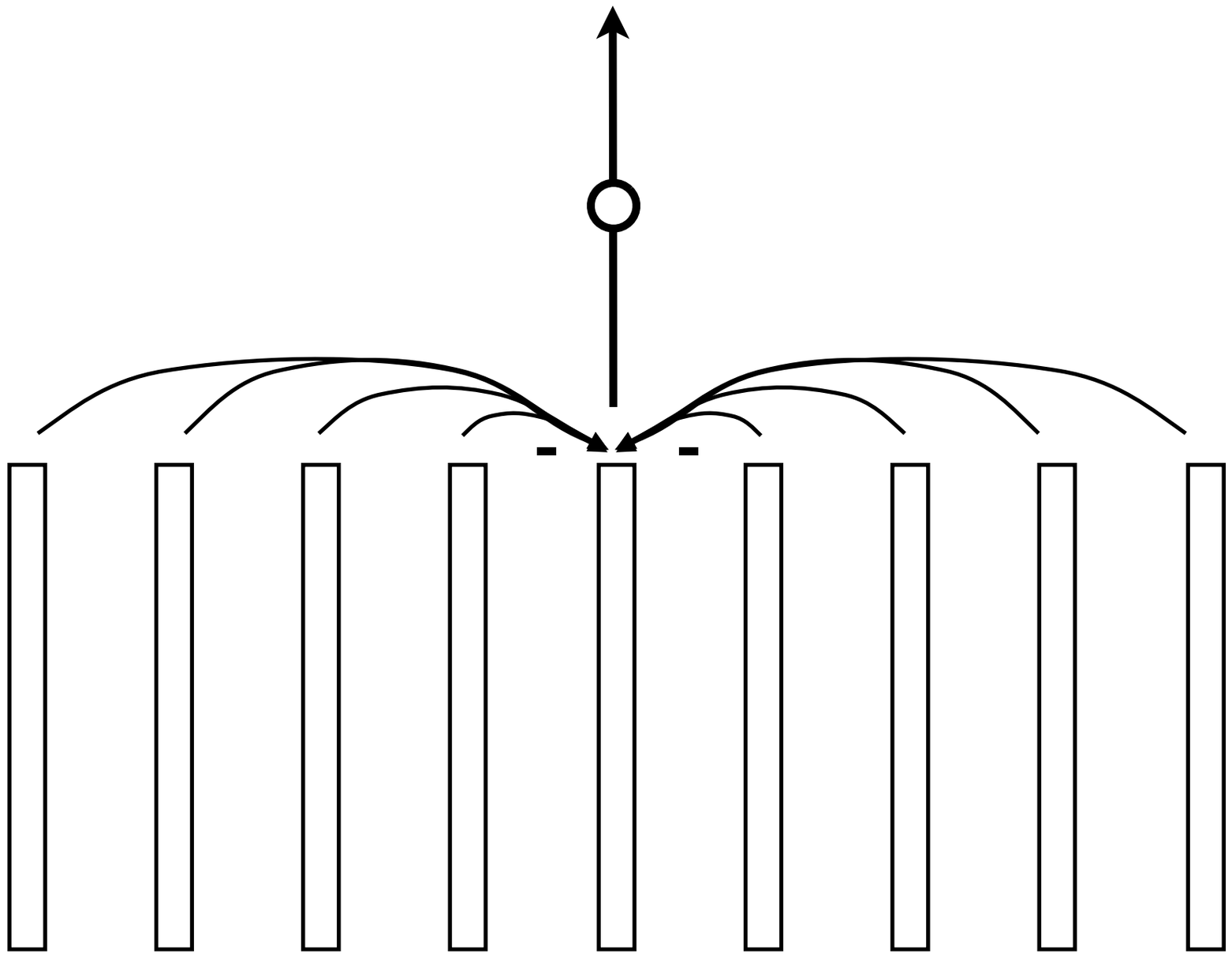
after Dacey, Lee, and Stafford, 1996

Lateral inhibition:

activation of one photoreceptor inhibits neighboring photoreceptors

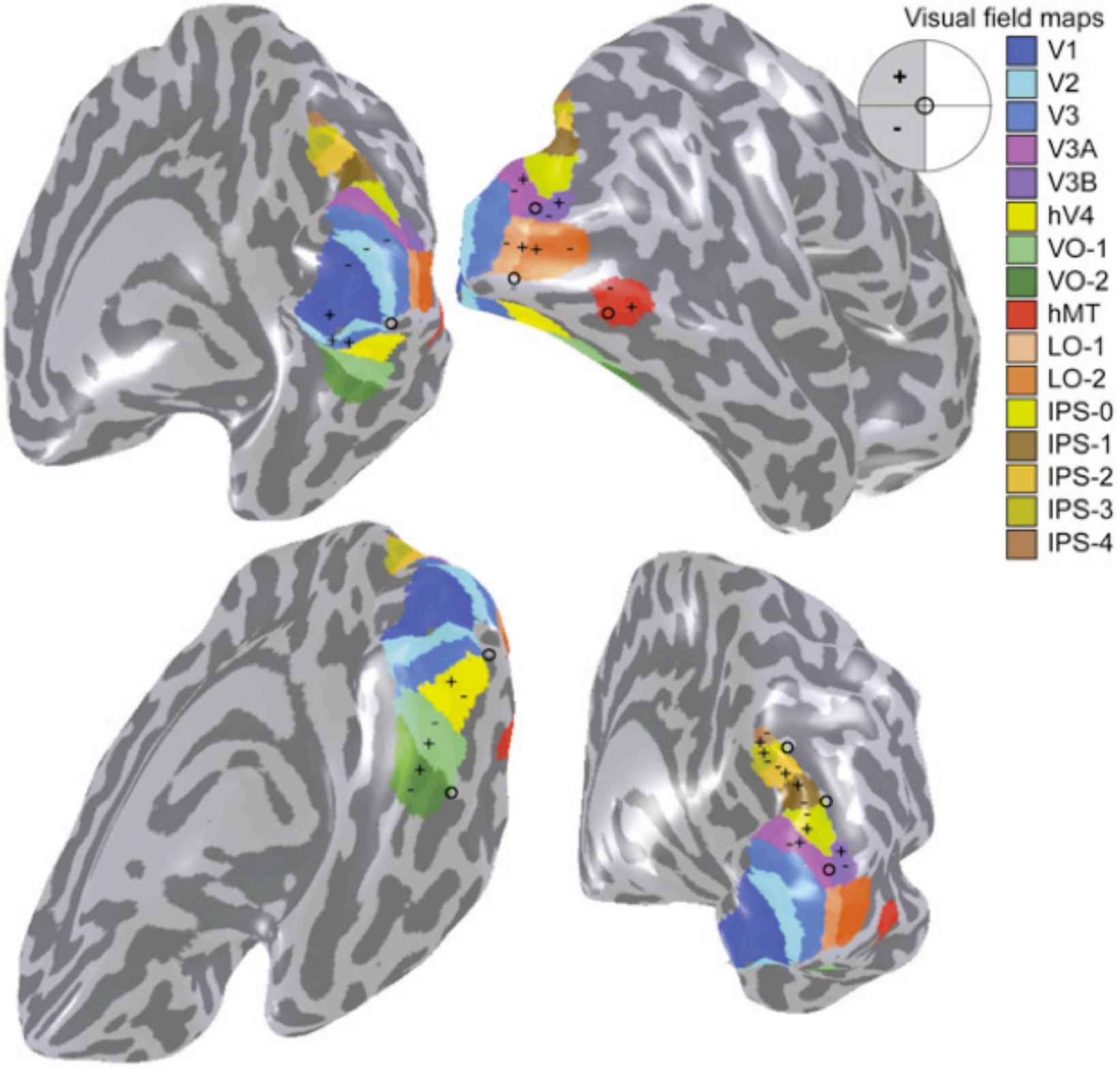


Bipolar cells read out differences between one photoreceptor's activity and its neighbors as computed by horizontal cell network



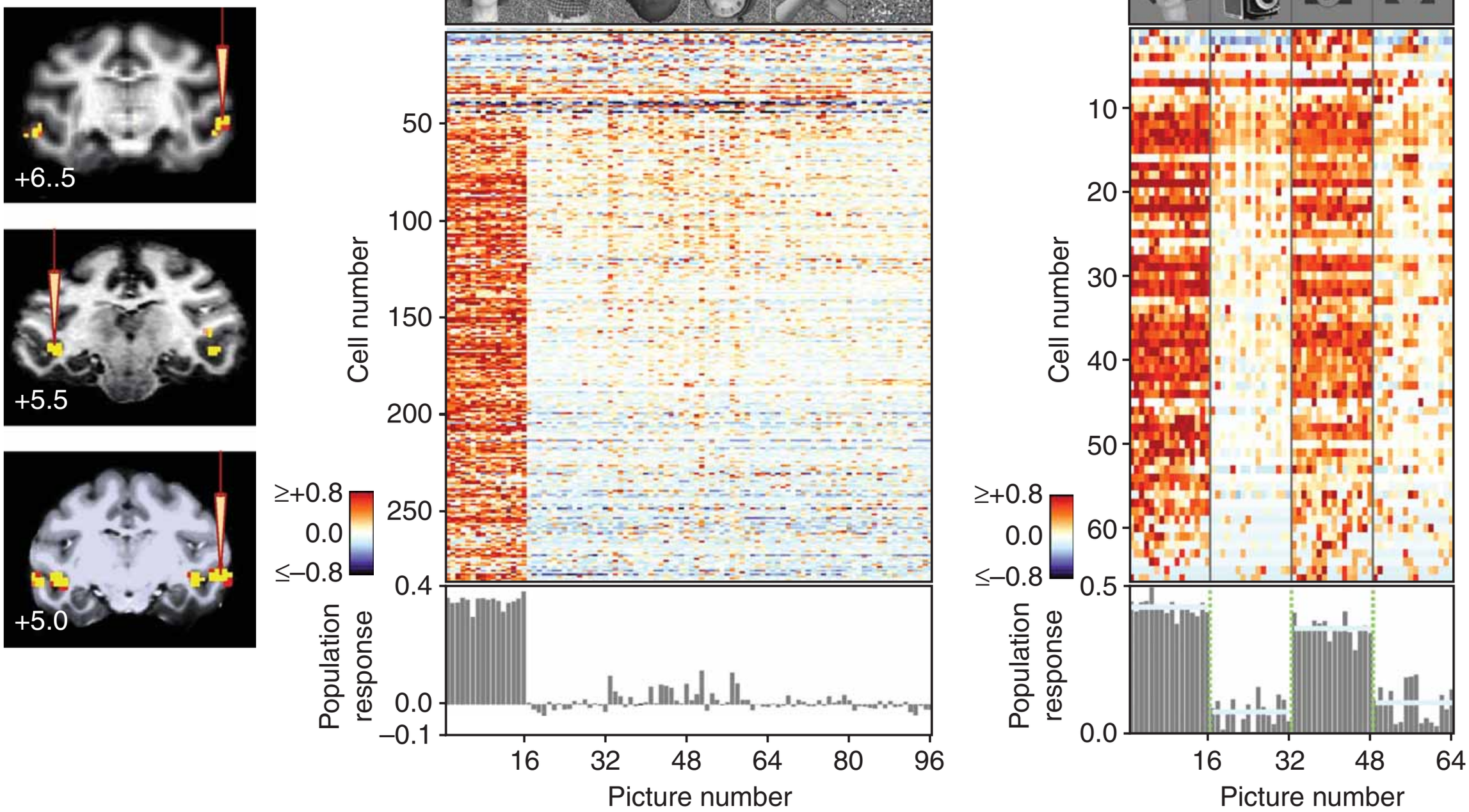
Human visual cortex

(Wandell, Dumoulin, & Brewer, 2007)

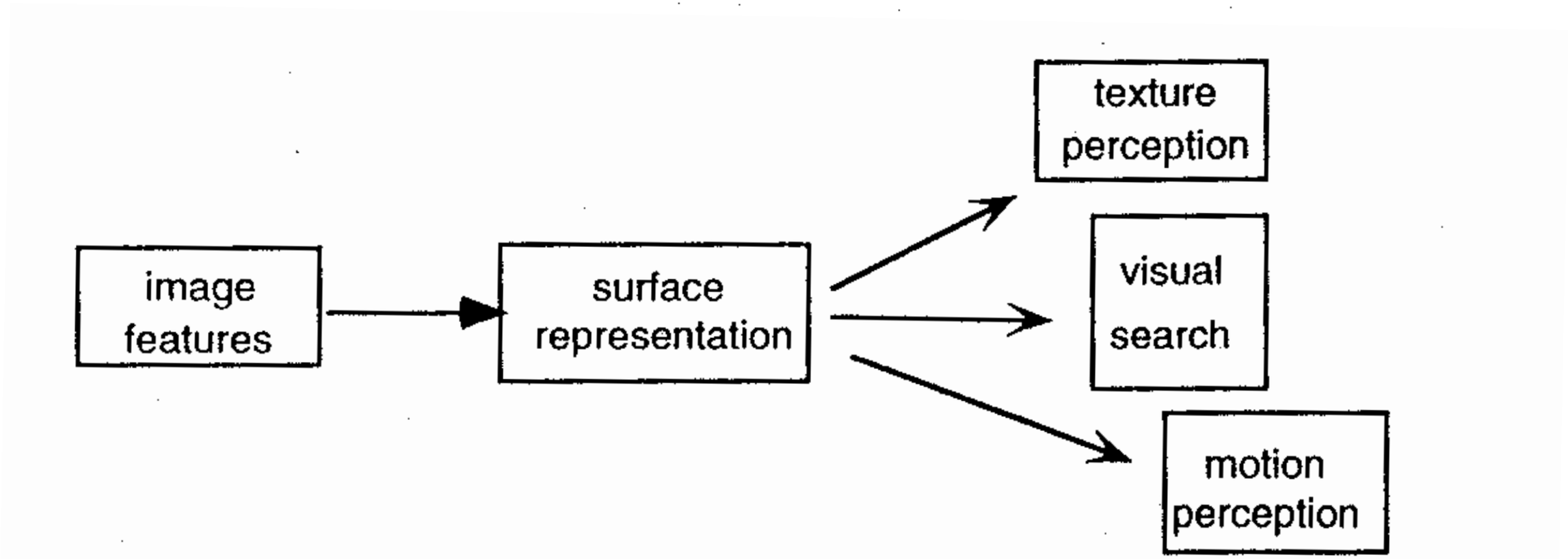


Face feature spaces

(Freiwald, Tsao & Livingstone 2009)

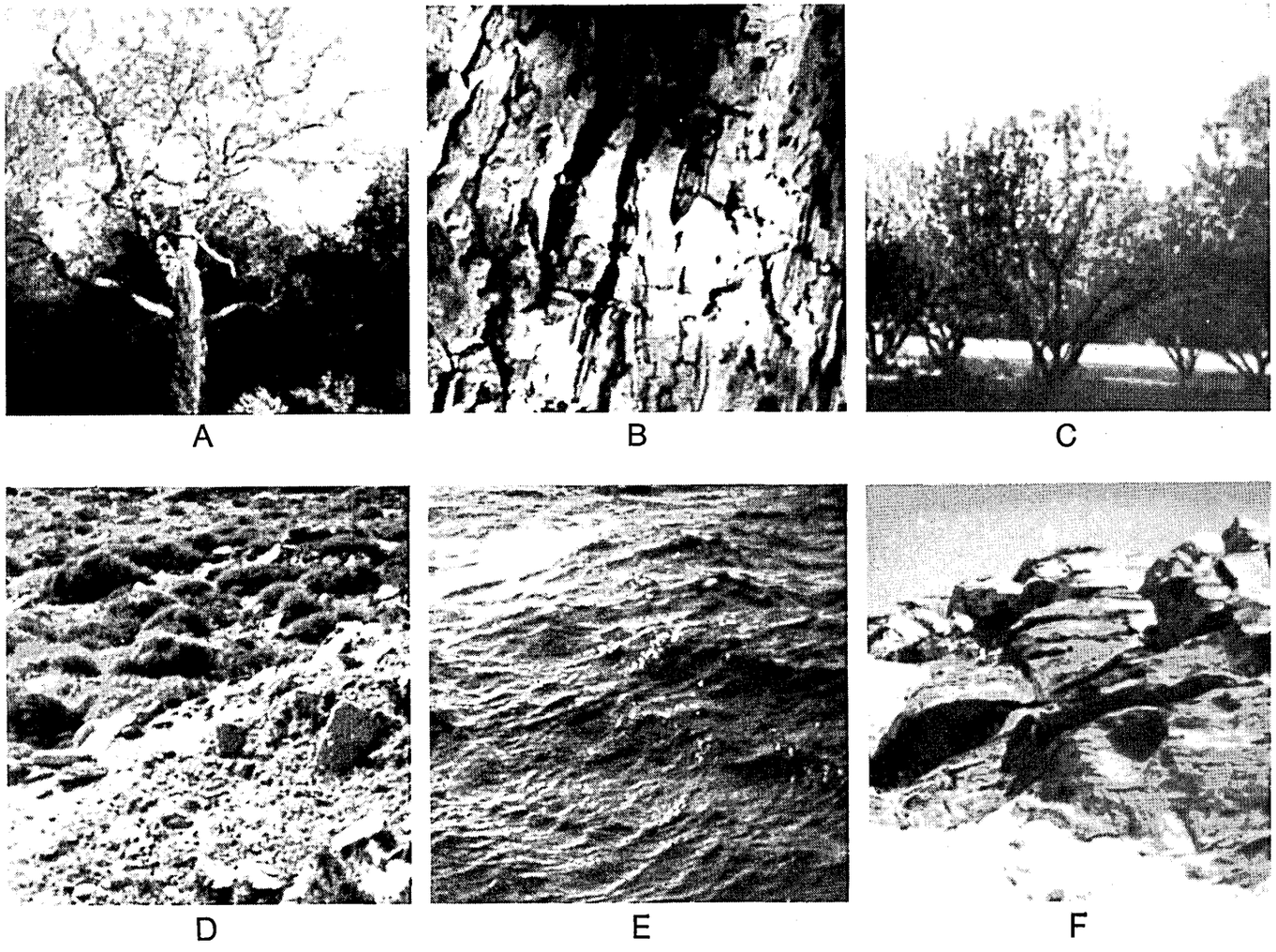


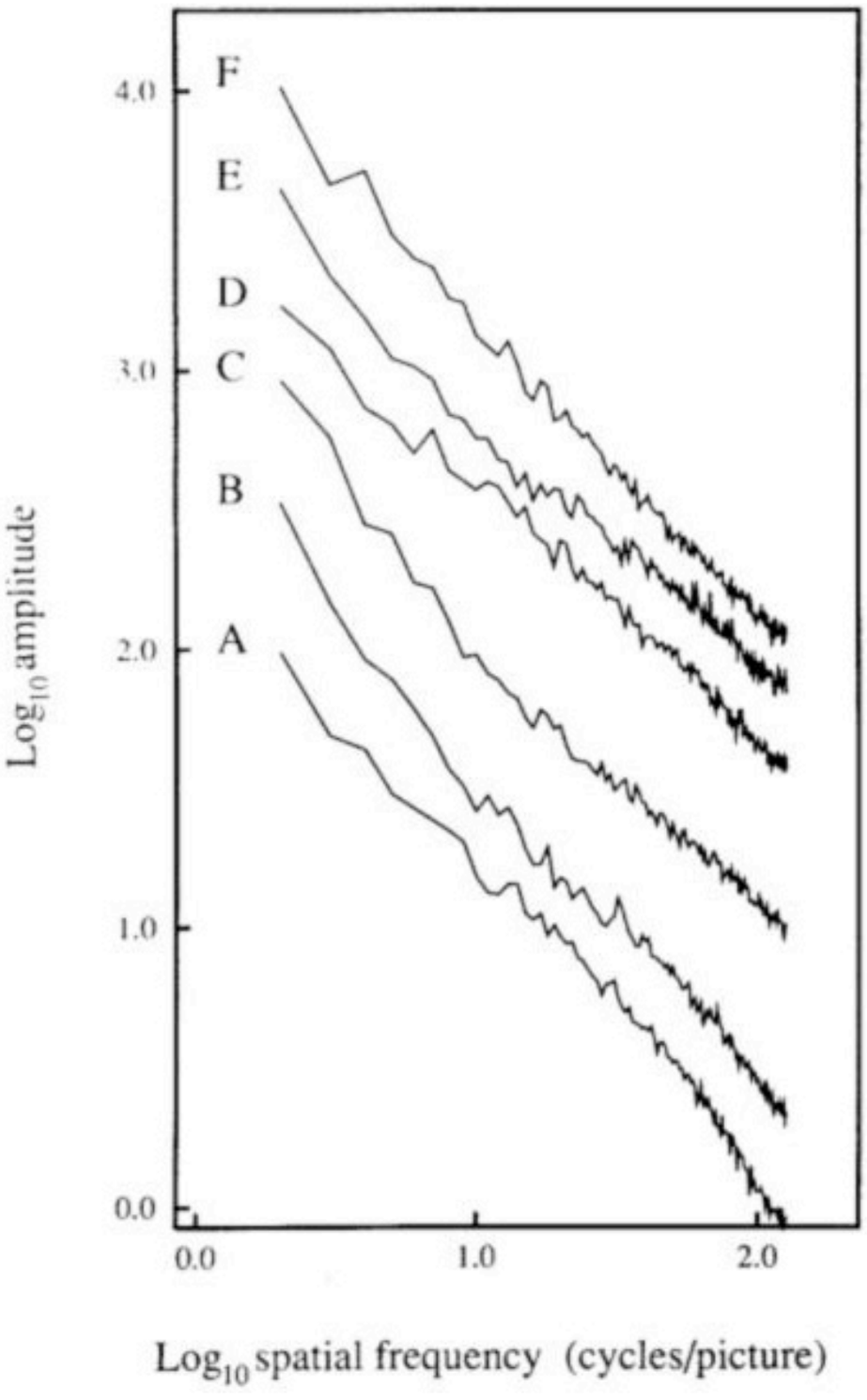
Intermediate-level vision



(Nakayama, He & Shimojo 1995)

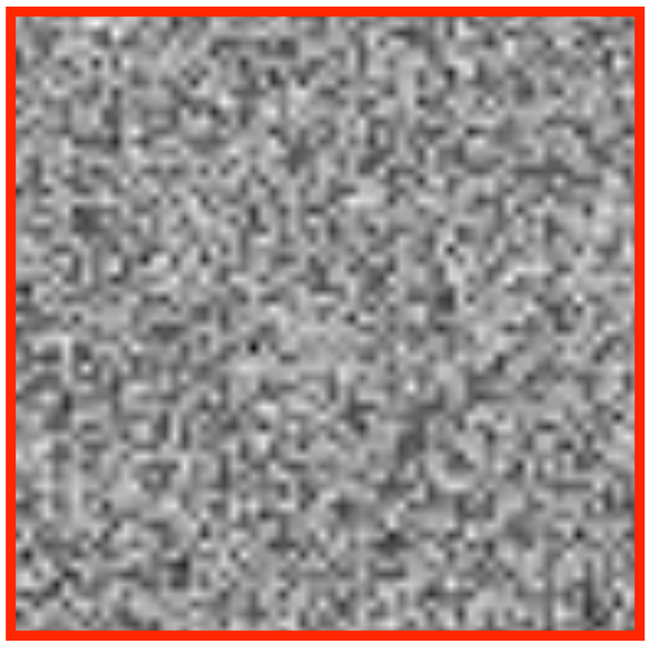
Natural scene statistics and visual coding

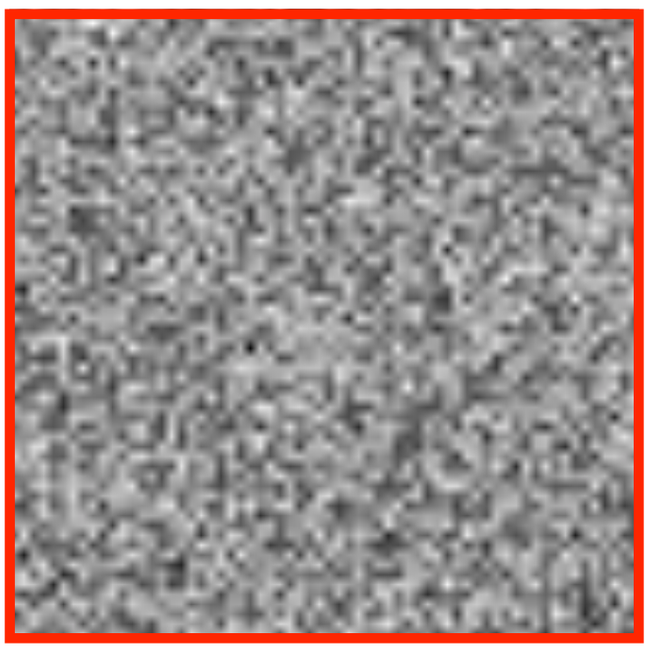


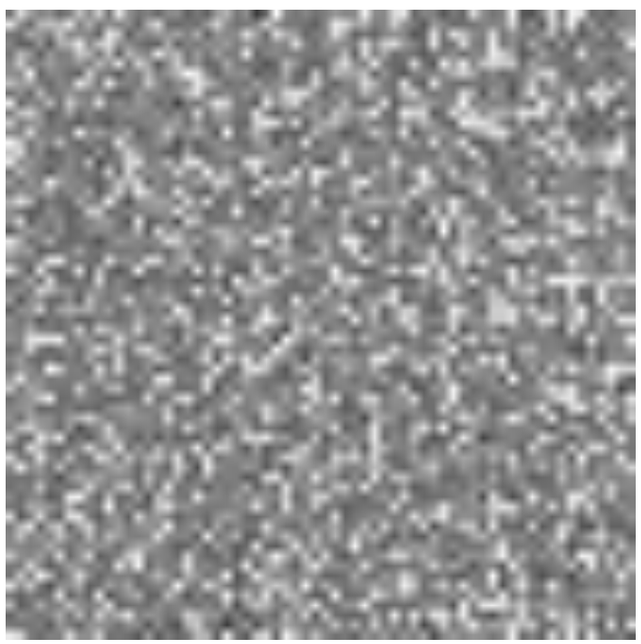


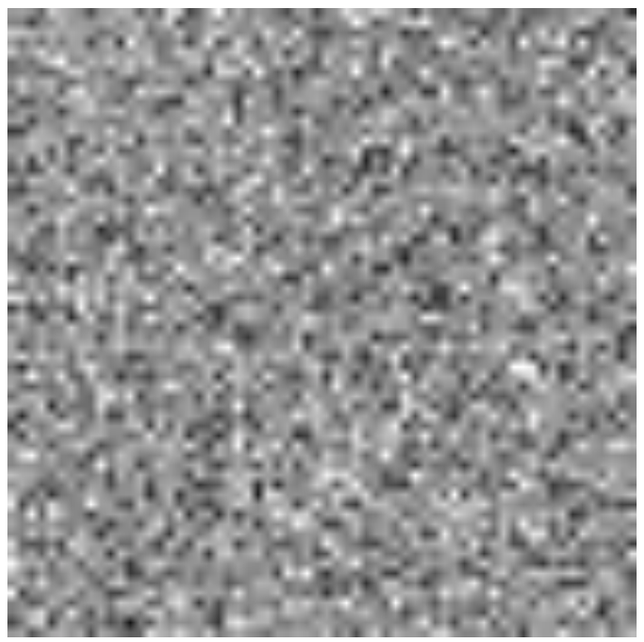
(Field 1987)

Which two images are the same?









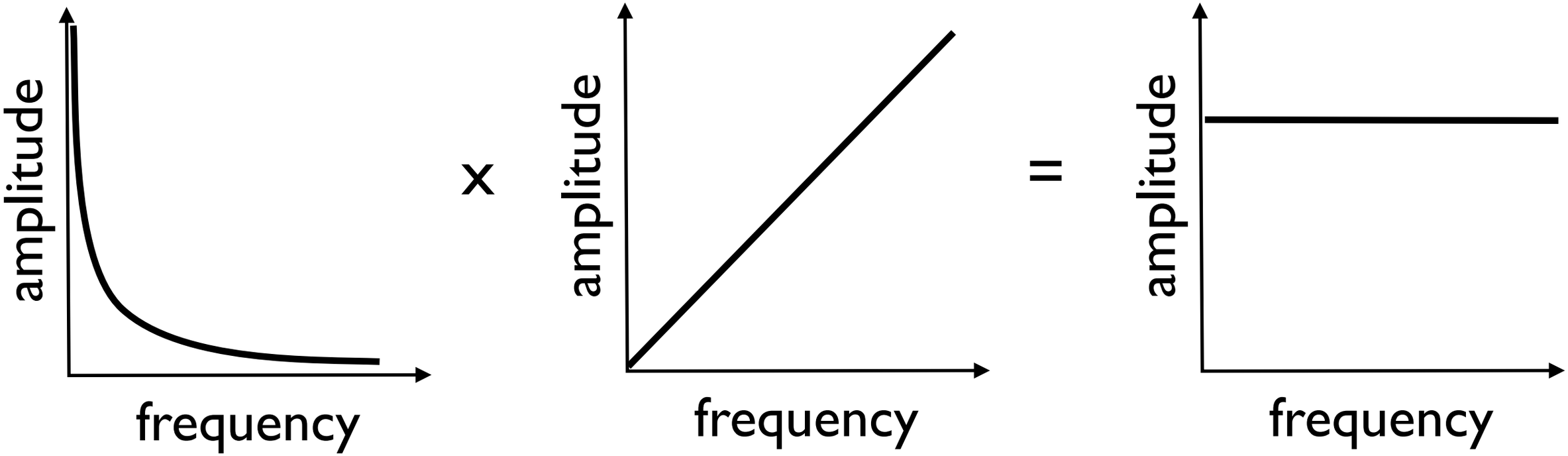
Which two images are the same?

Whitening (or decorrelation) theory
(Atick & Redlich, 1992)

1/f image

whitening filter

decorrelated image



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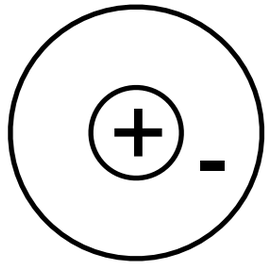

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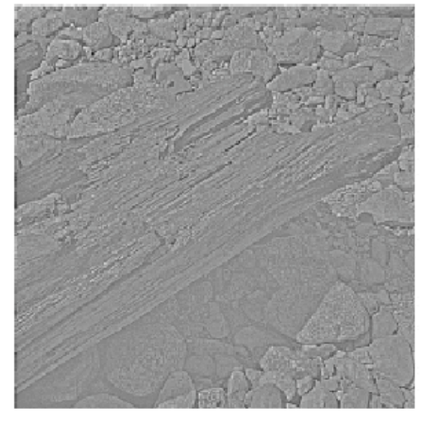
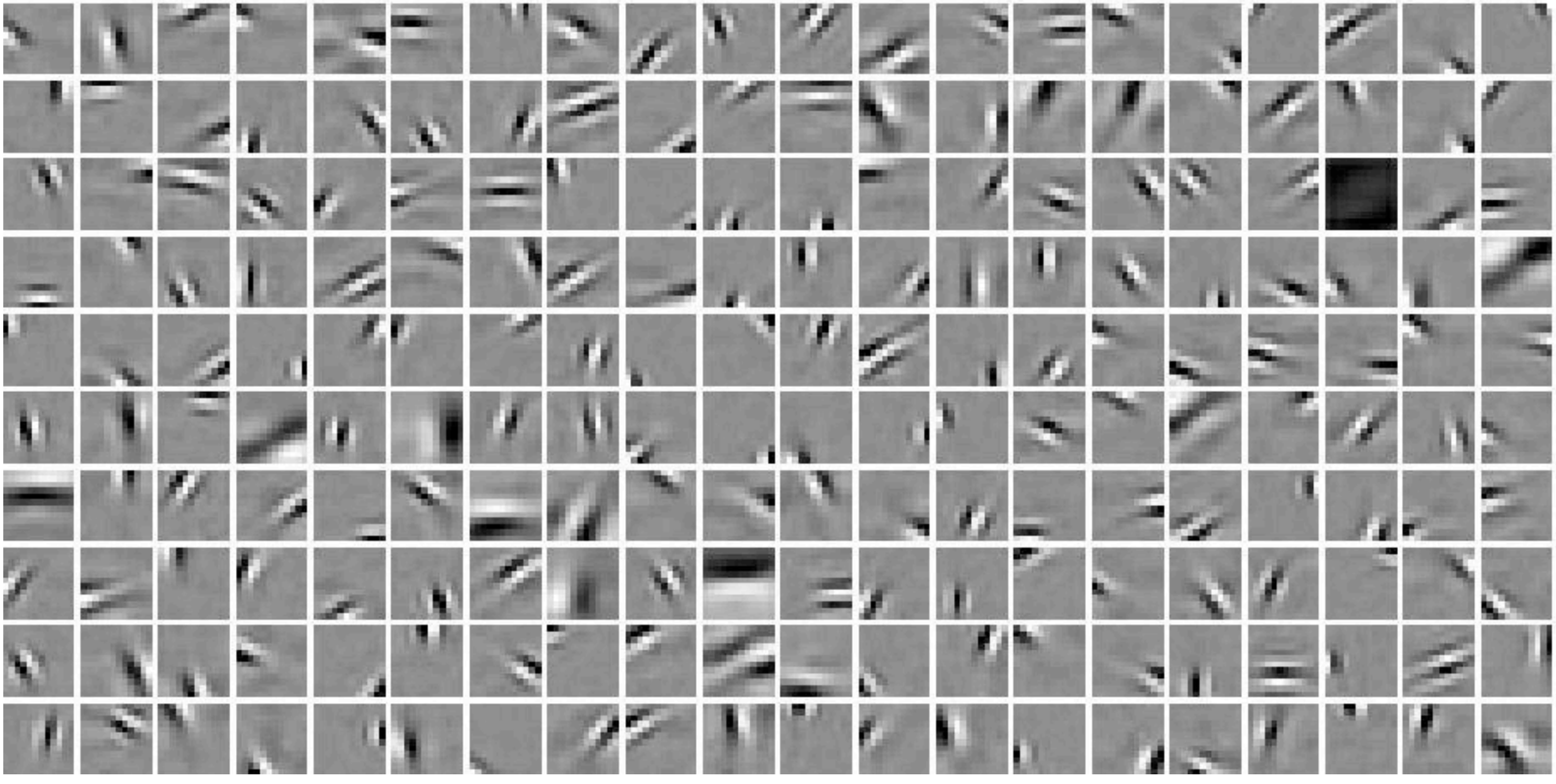


Features learned from sparse coding of natural images resemble V1 simple cell receptive fields (Olshausen & Field 1996)



statistics	**coding strategy**	**neurobiological substrate**
contrast histogram	histogram equalization	photoreceptors/ bipolar cells
autocorrelation function	whitening	retina/LGN
sparse components	localized, oriented, bandpass feature decomposition	V1 ‘simple cells’
amplitude components	texture coding	V1/V2 ‘complex cells’
phase components	motion coding	MT

Computer vision - multiple view geometry

Mysteries

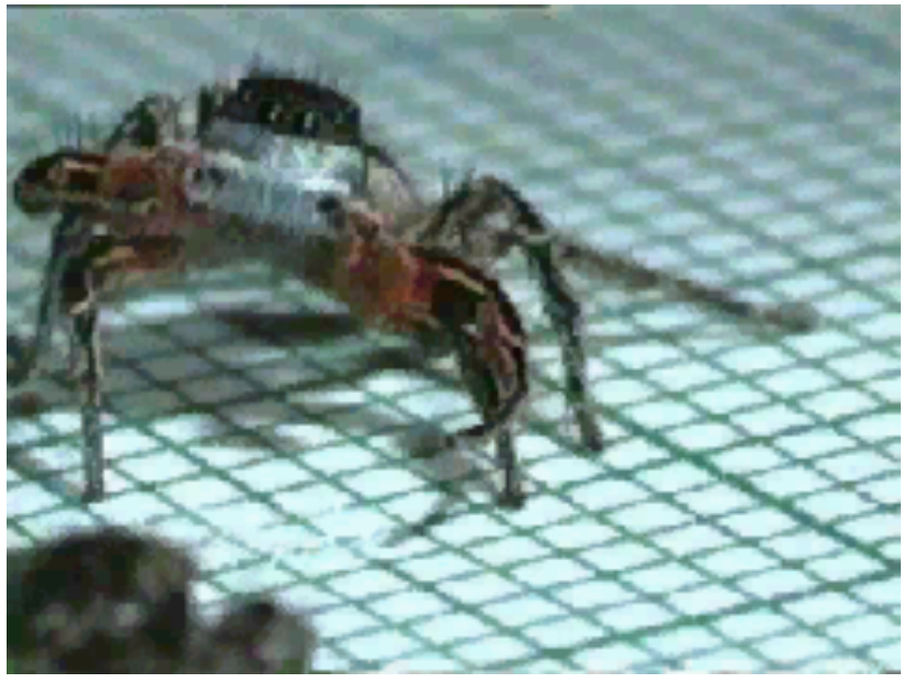
Tiny nervous systems

Neocortical microcircuit

Neuronal oscillations

Computer vision: action-perception loops

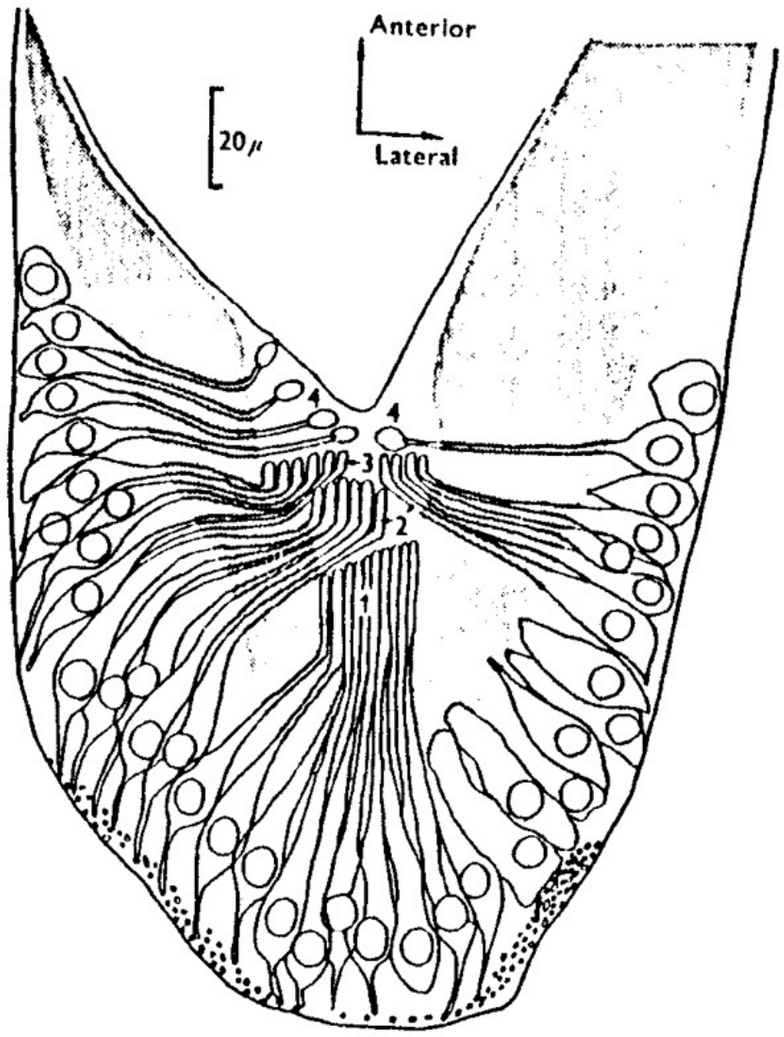
Jumping spiders



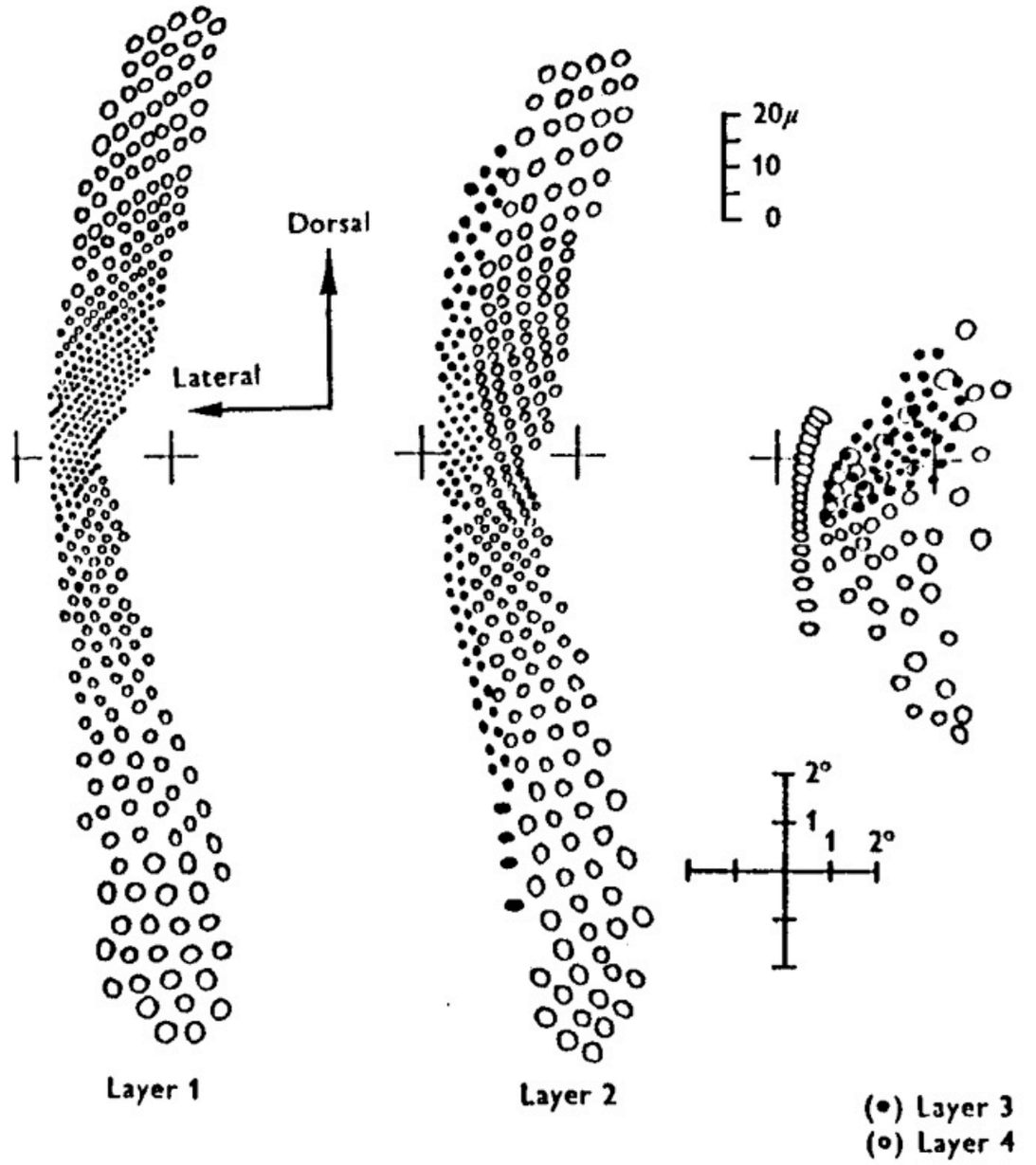
Jumping spider visual system

Jumping spider retina

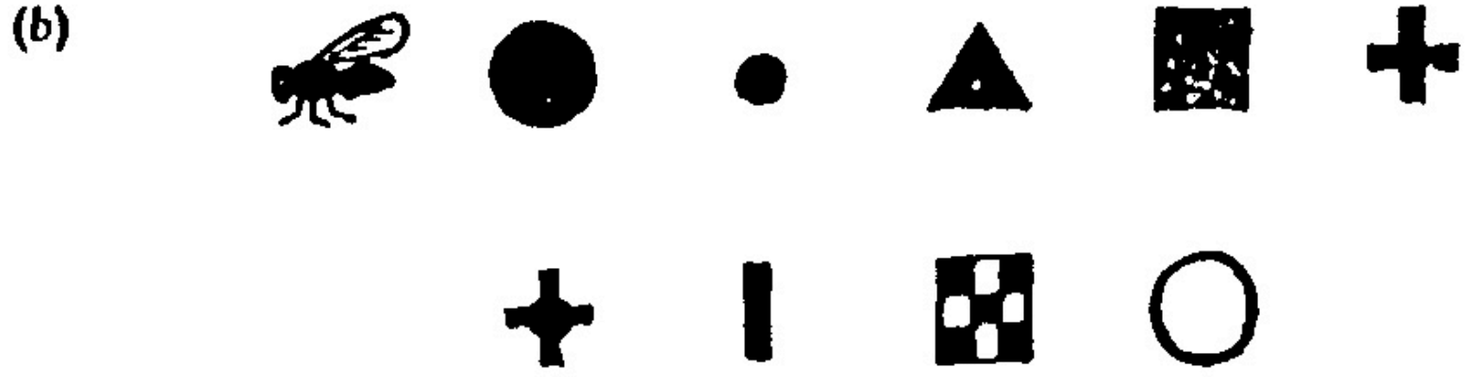
horizontal section



photoreceptor array

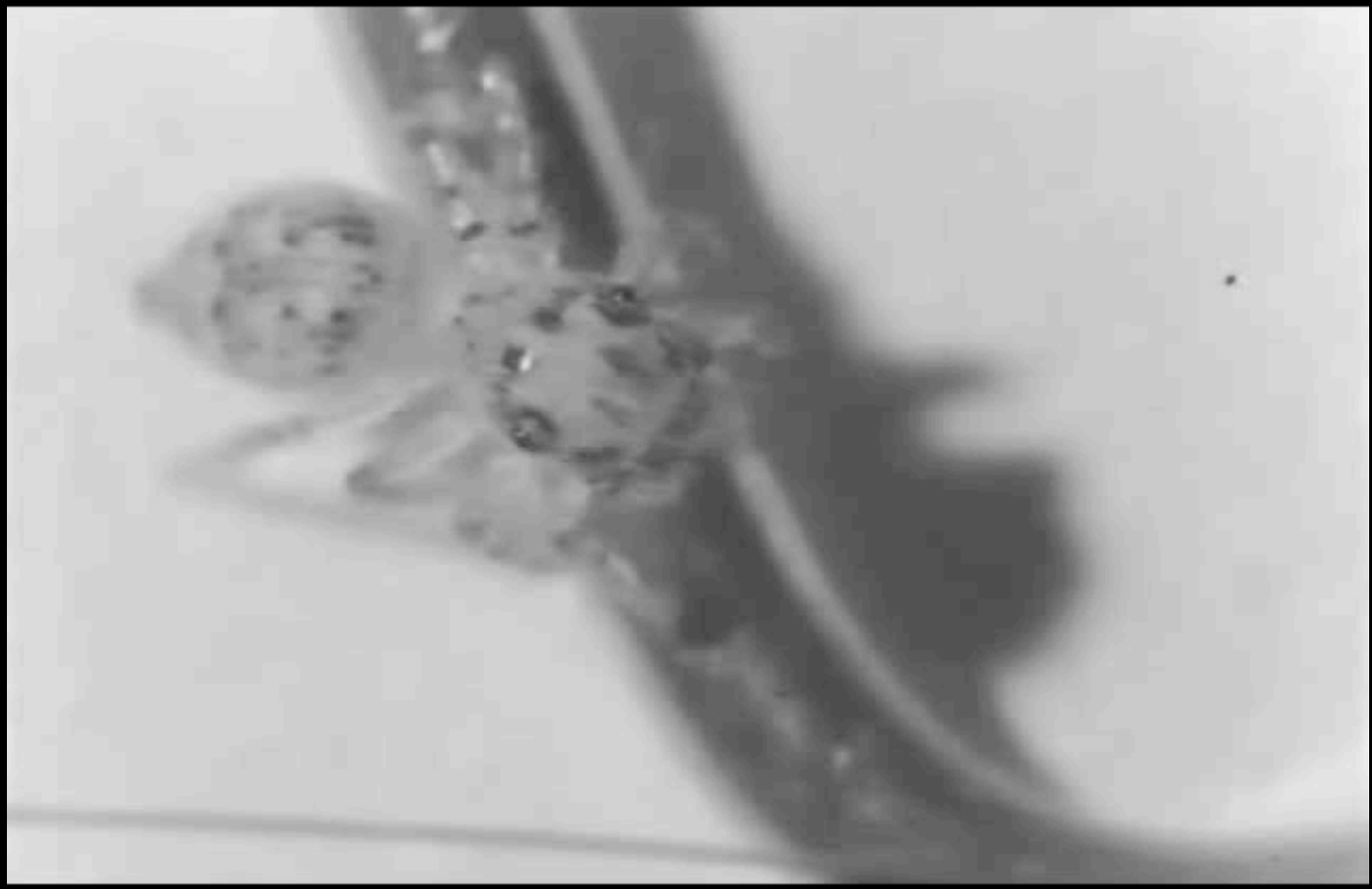


Jumping spiders do object recognition



Text-fig. 12. Stimuli found by Drees to evoke courtship (*a*) and prey capture (*b*) in male jumping spiders (*Epiblemum scenicum*). The numbers beneath each figure in (*a*) are the percentage of trials on which courtship was evoked. After Drees (1952).

One-day old jumping spider
(filmed in the Bower lab, Caltech 1991)

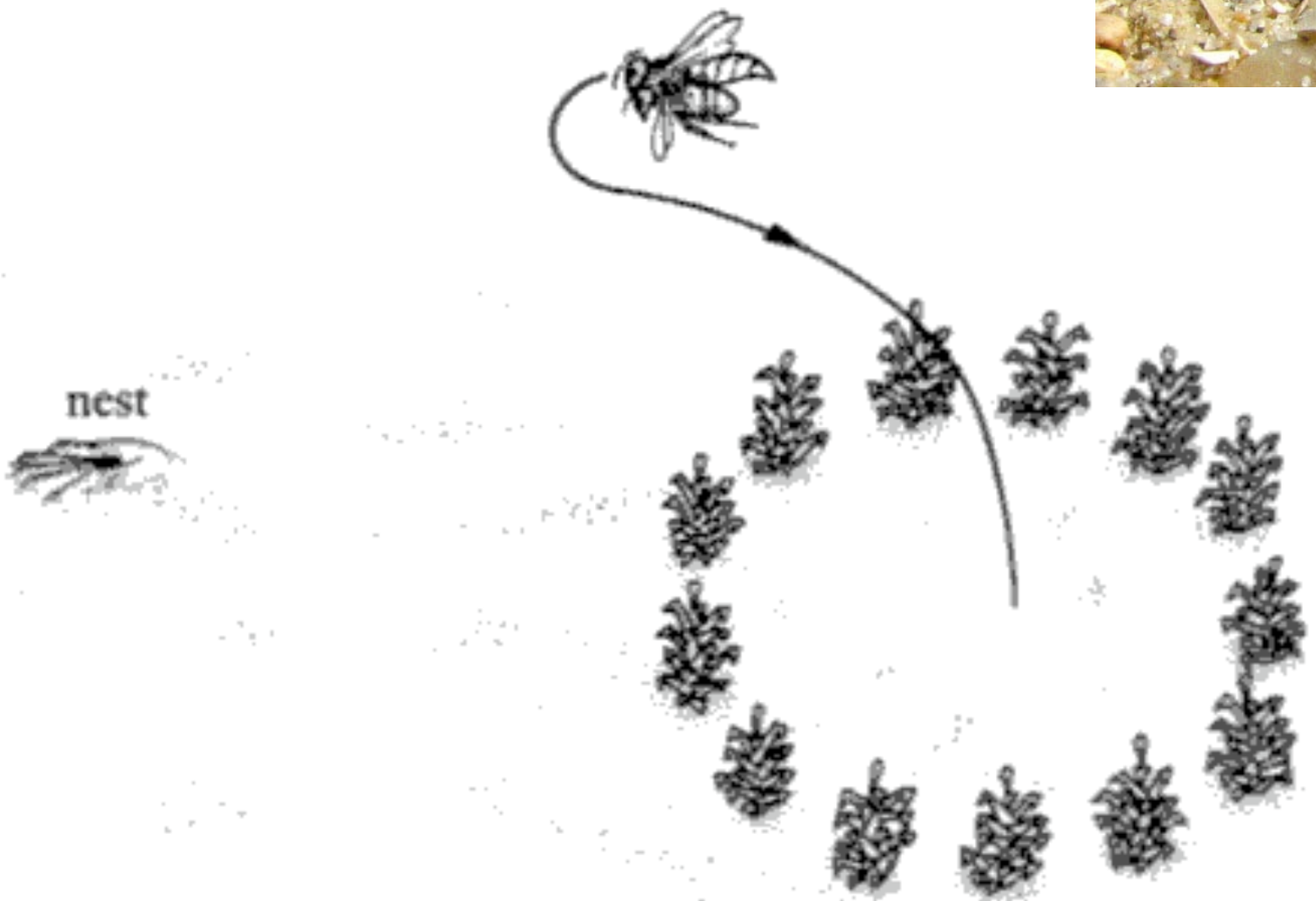


One-day old jumping spider
(filmed in the Bower lab, Caltech 1991)

One-day old jumping spider
(filmed in the Bower lab, Caltech 1991)

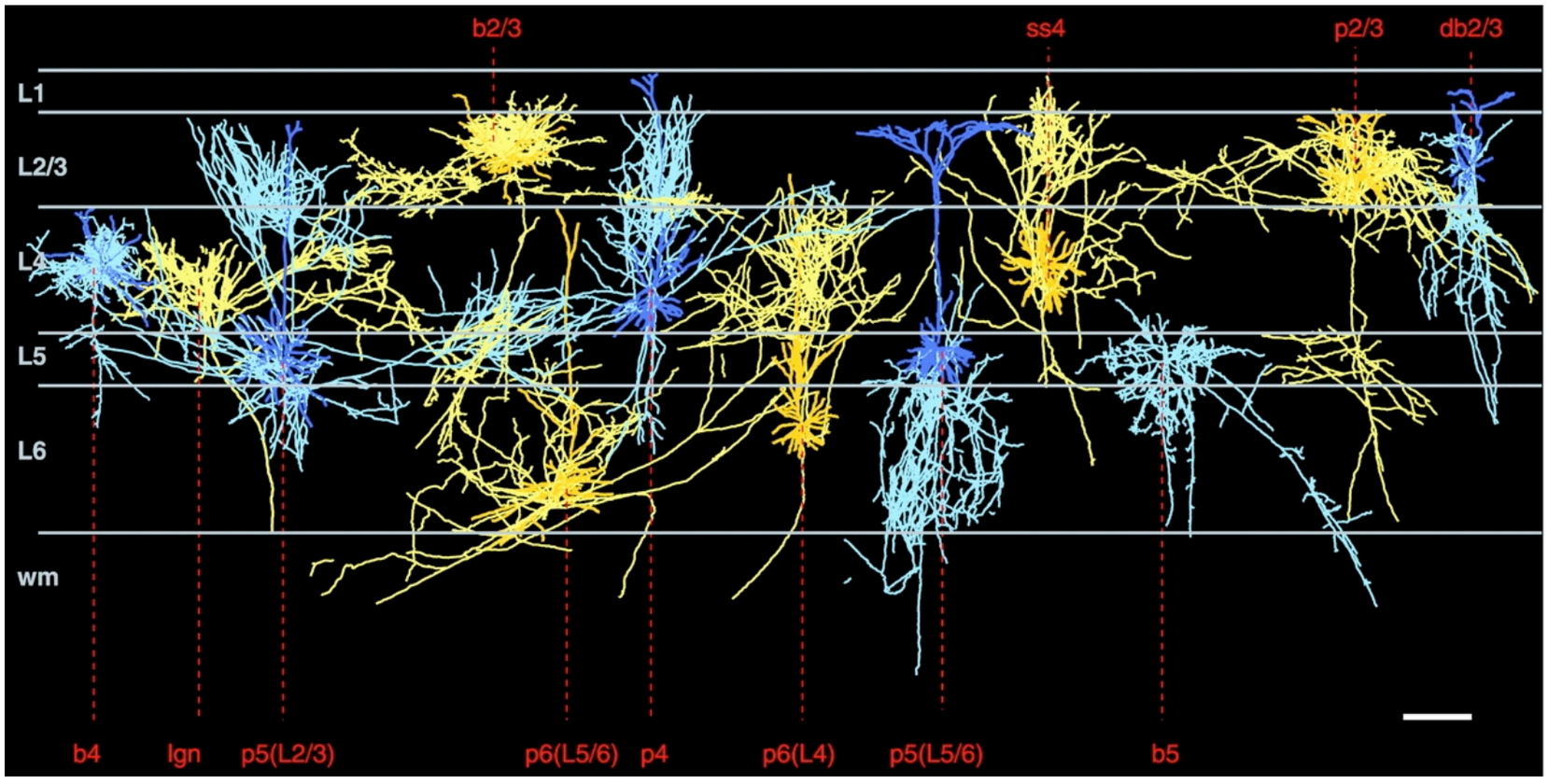
One-day old jumping spider
(filmed in the Bower lab, Caltech 1991)

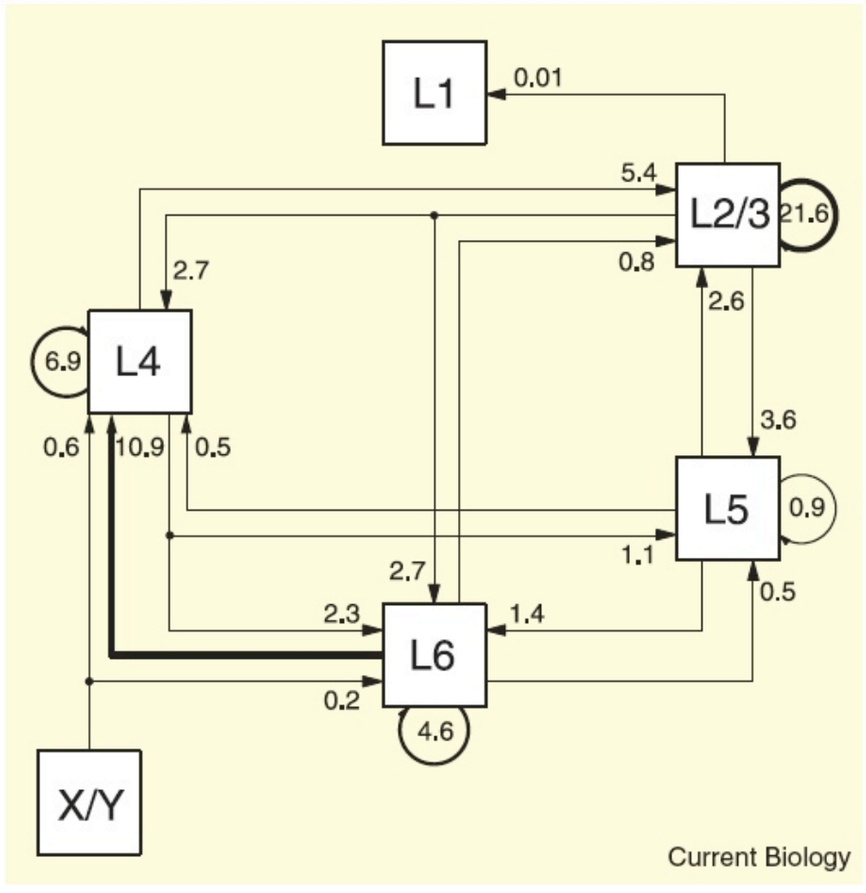
Philanthus triangulum (sand wasp)



(See *Curious Naturalists*, by Niko Tinbergen)

What is the function of the cortical microcircuit?

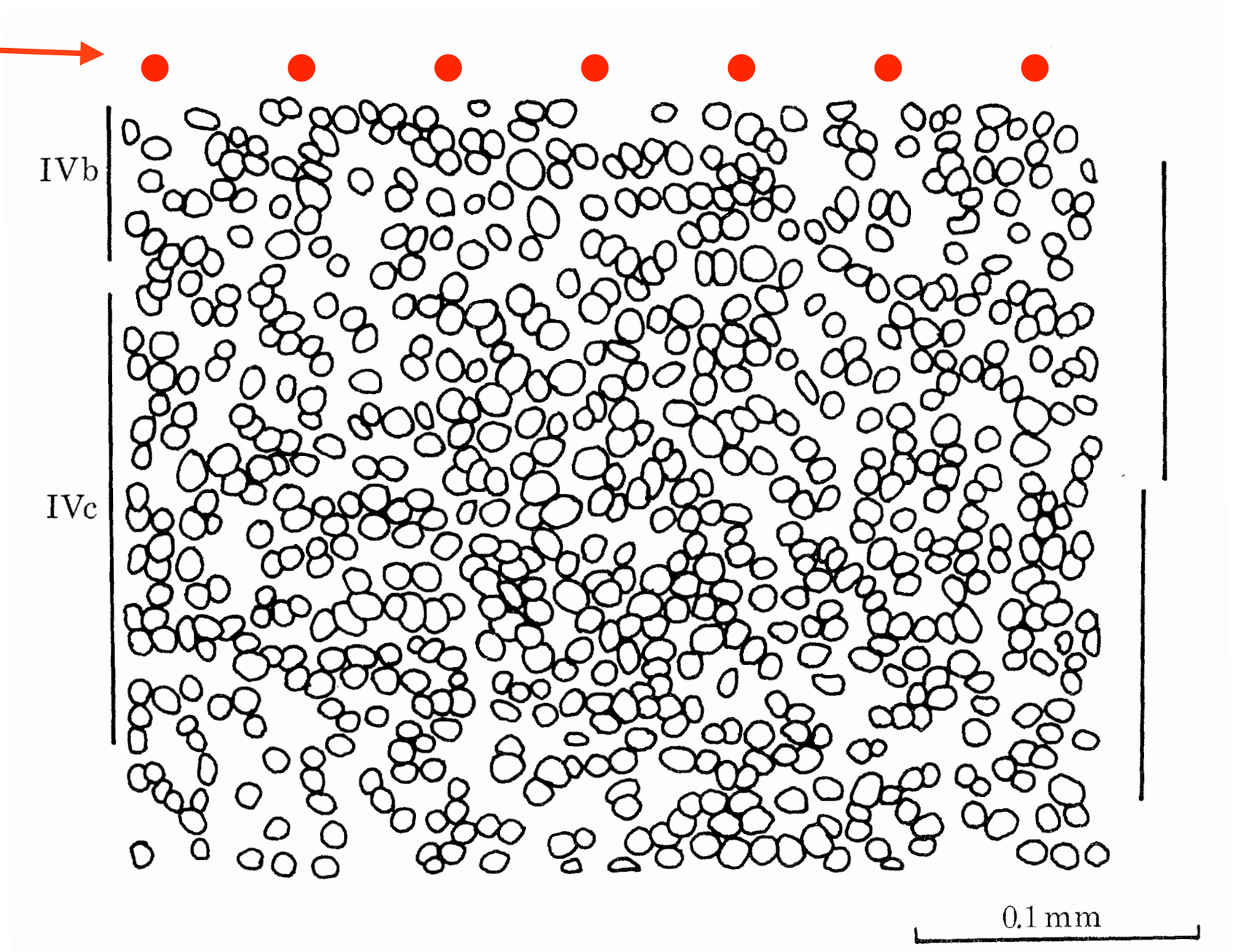




V1 is highly overcomplete

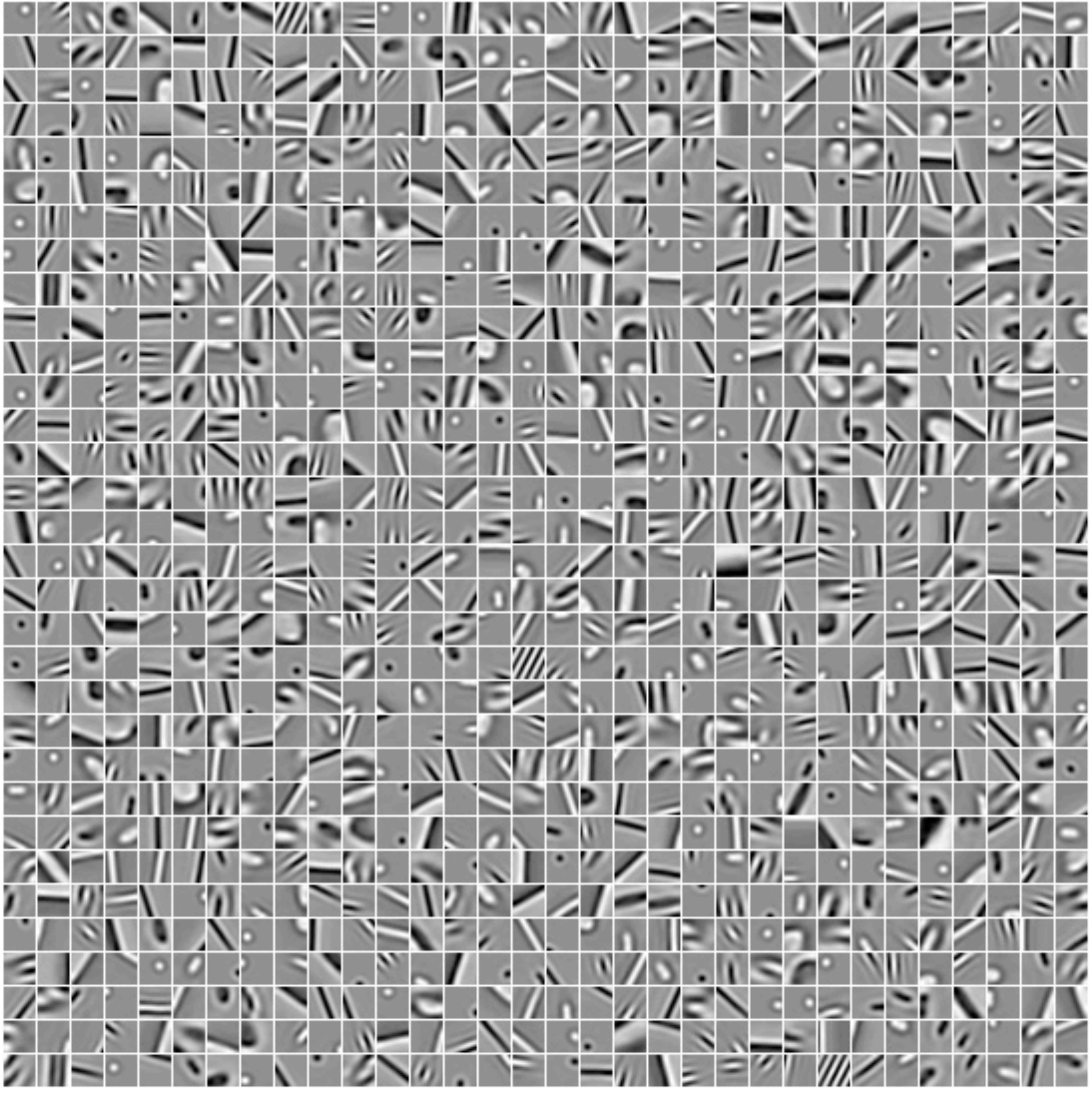
LGN afferents

layer 4 cortex

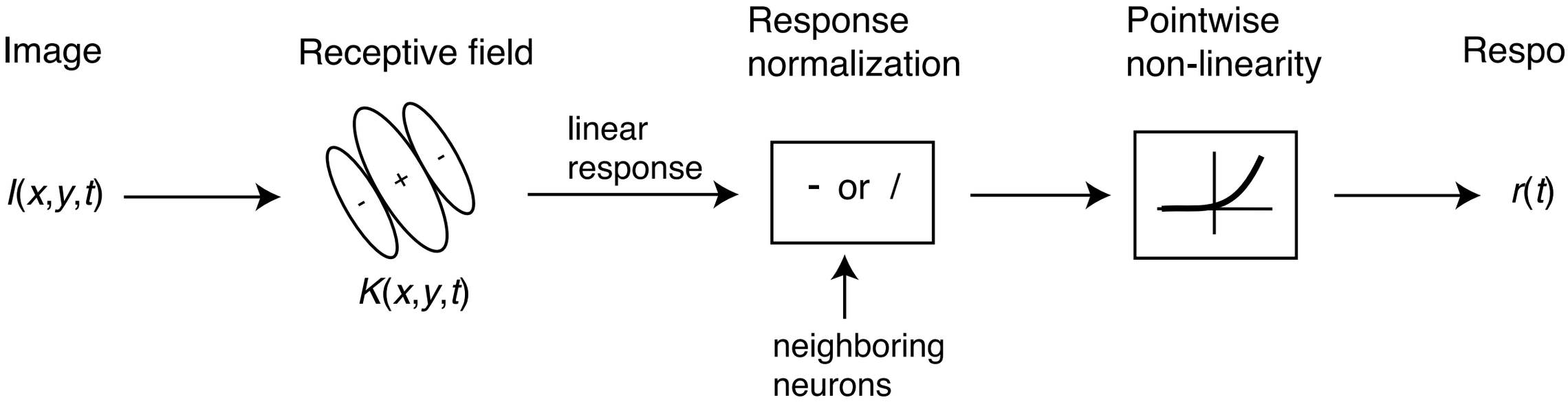


Barlow (1981)

Learned dictionary 10x overcomplete

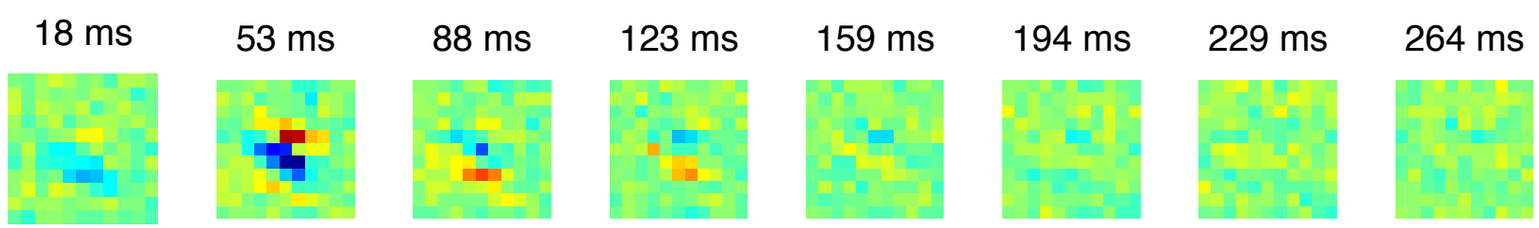


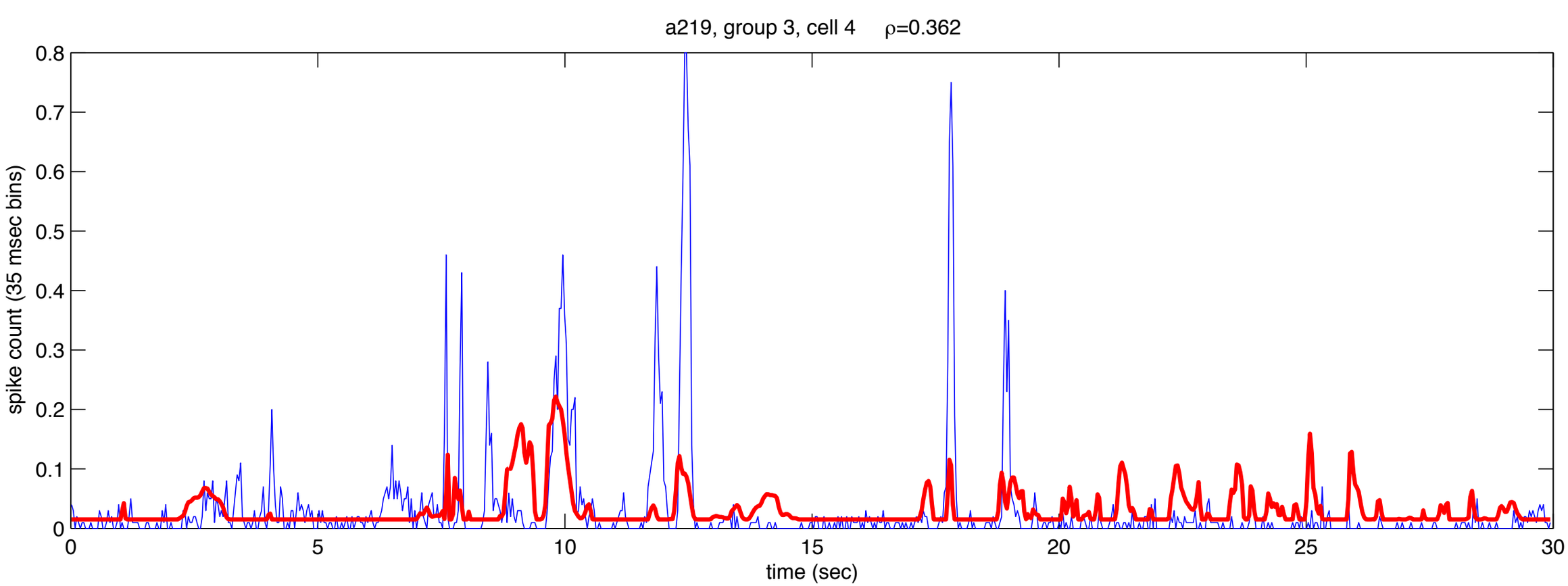
The "standard model" of V1



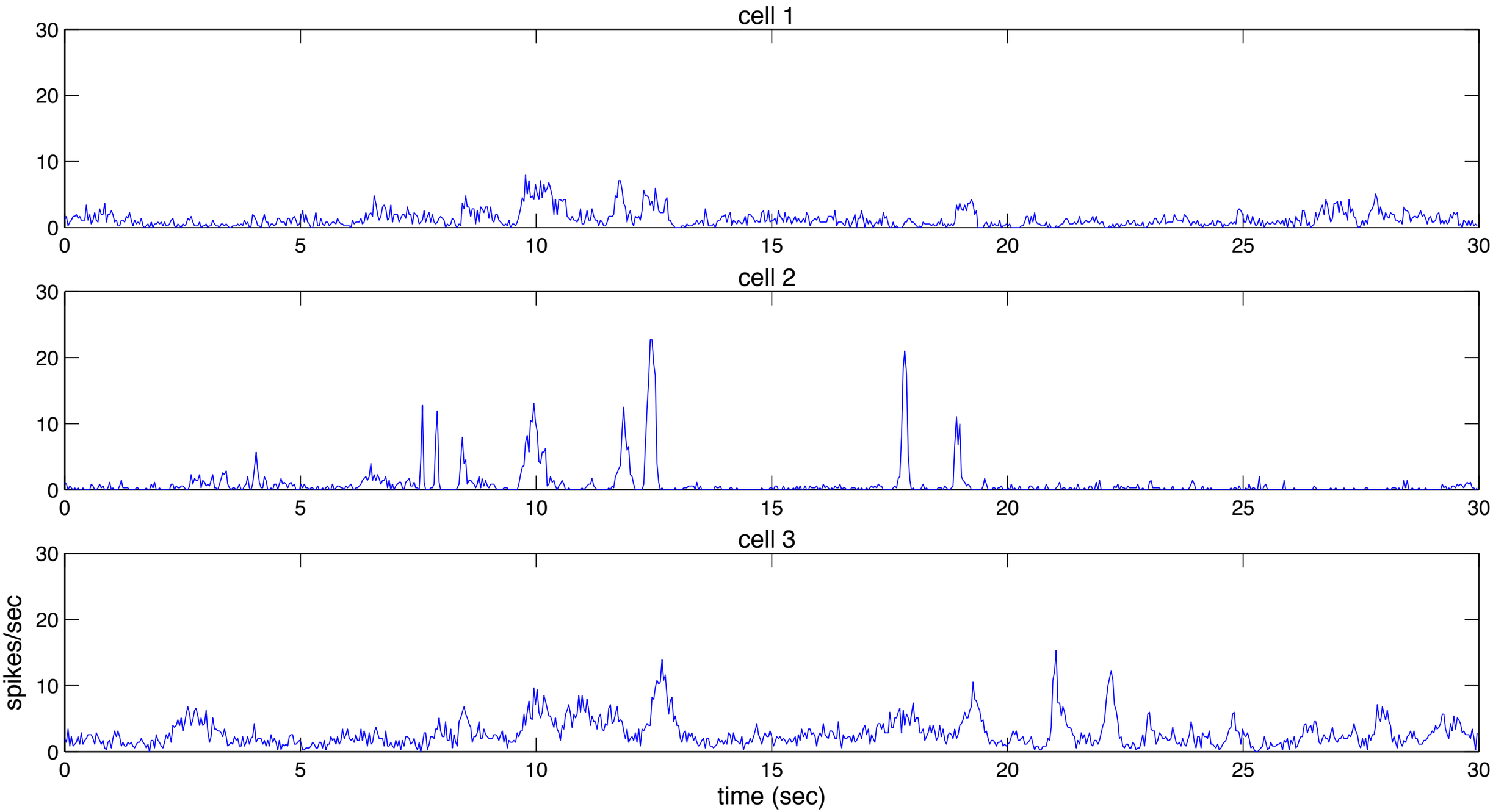
Responses of V1 neurons are not well predicted by RF models

receptive field:

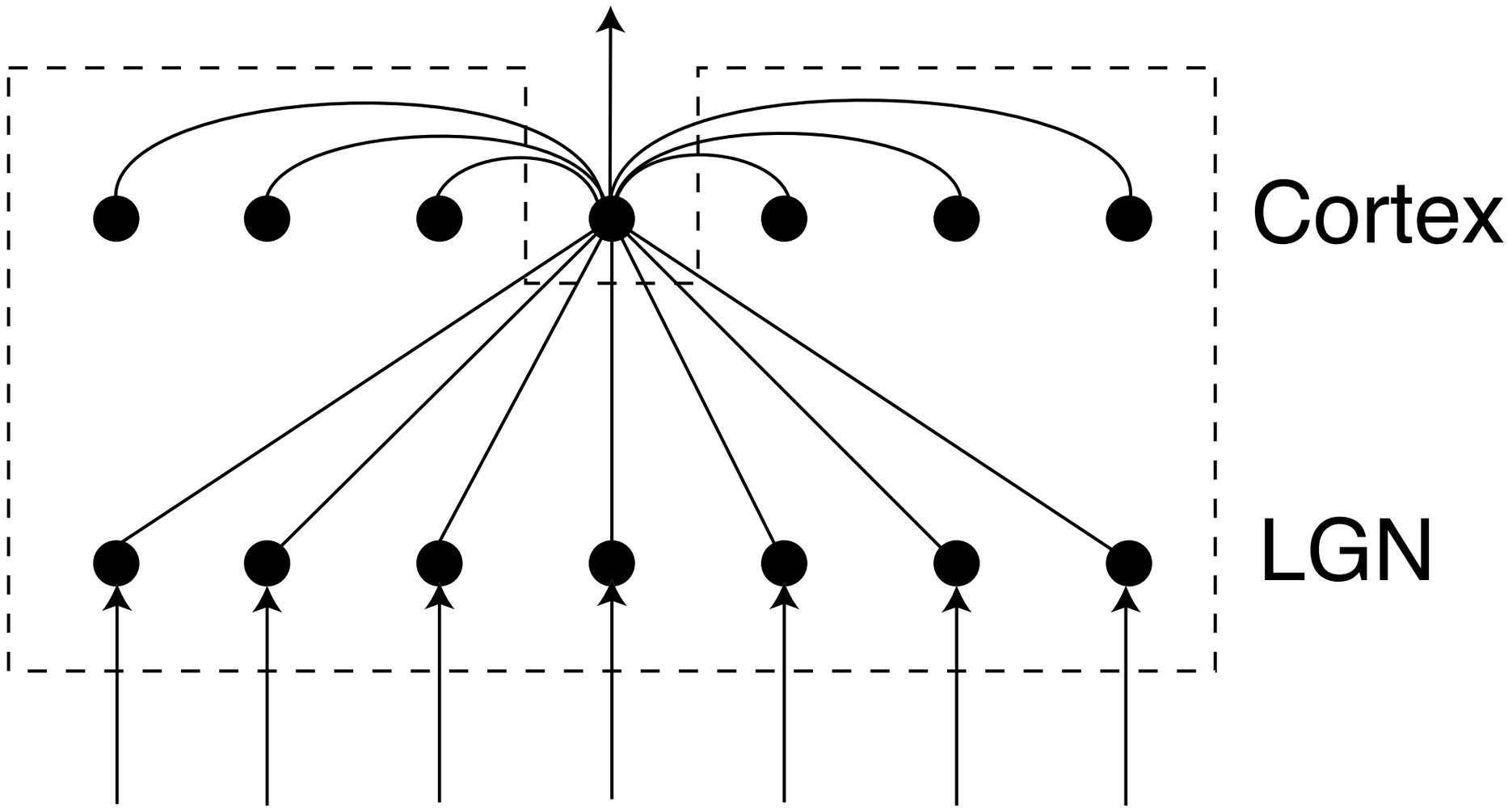




Responses of neighboring cells are heterogeneous



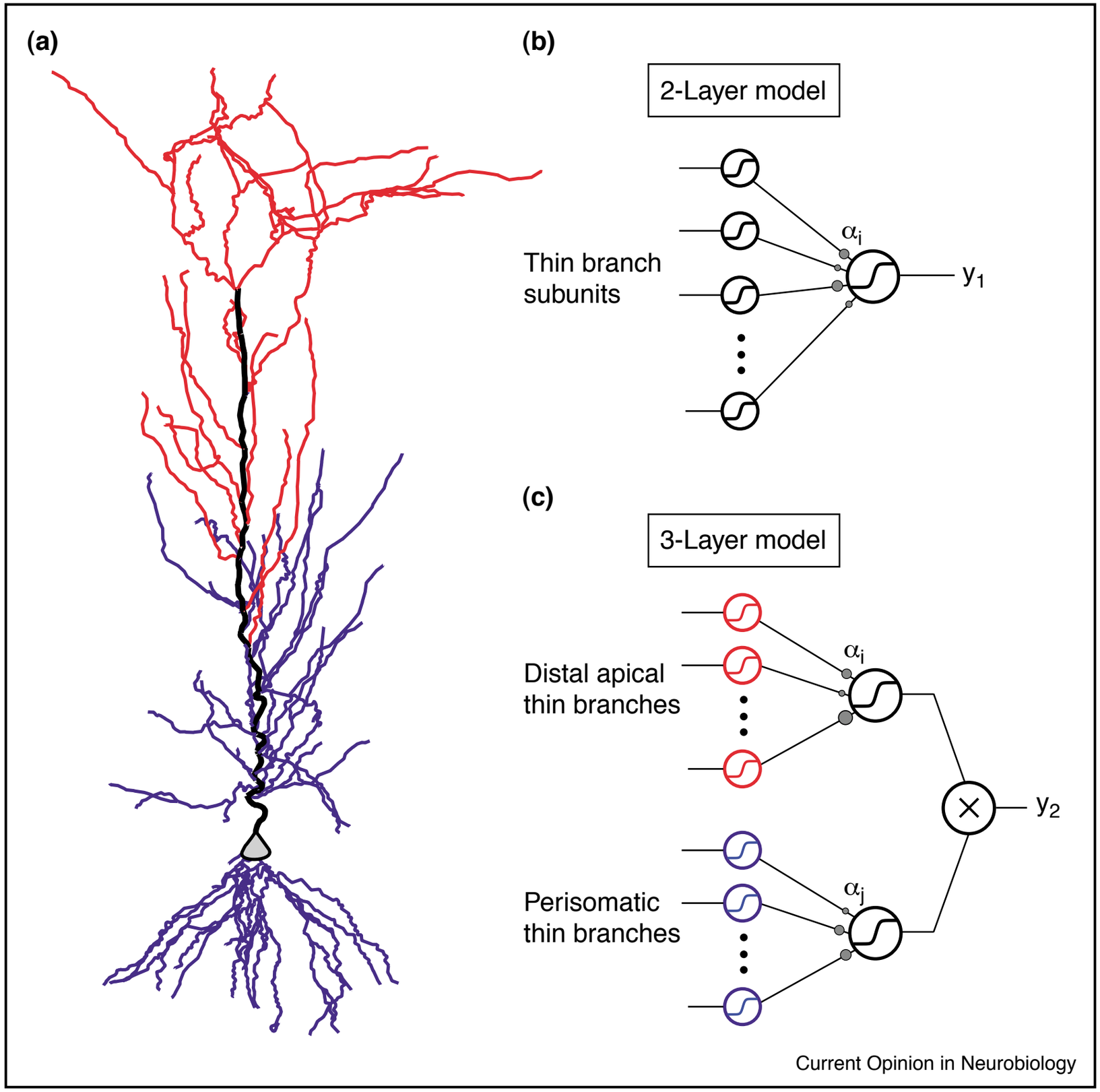
Single unit recording is blind to neuronal interactions



...their (neurons') apparently erratic behavior was caused by our ignorance, not the neuron's incompetence. -- H.B. Barlow (1972)

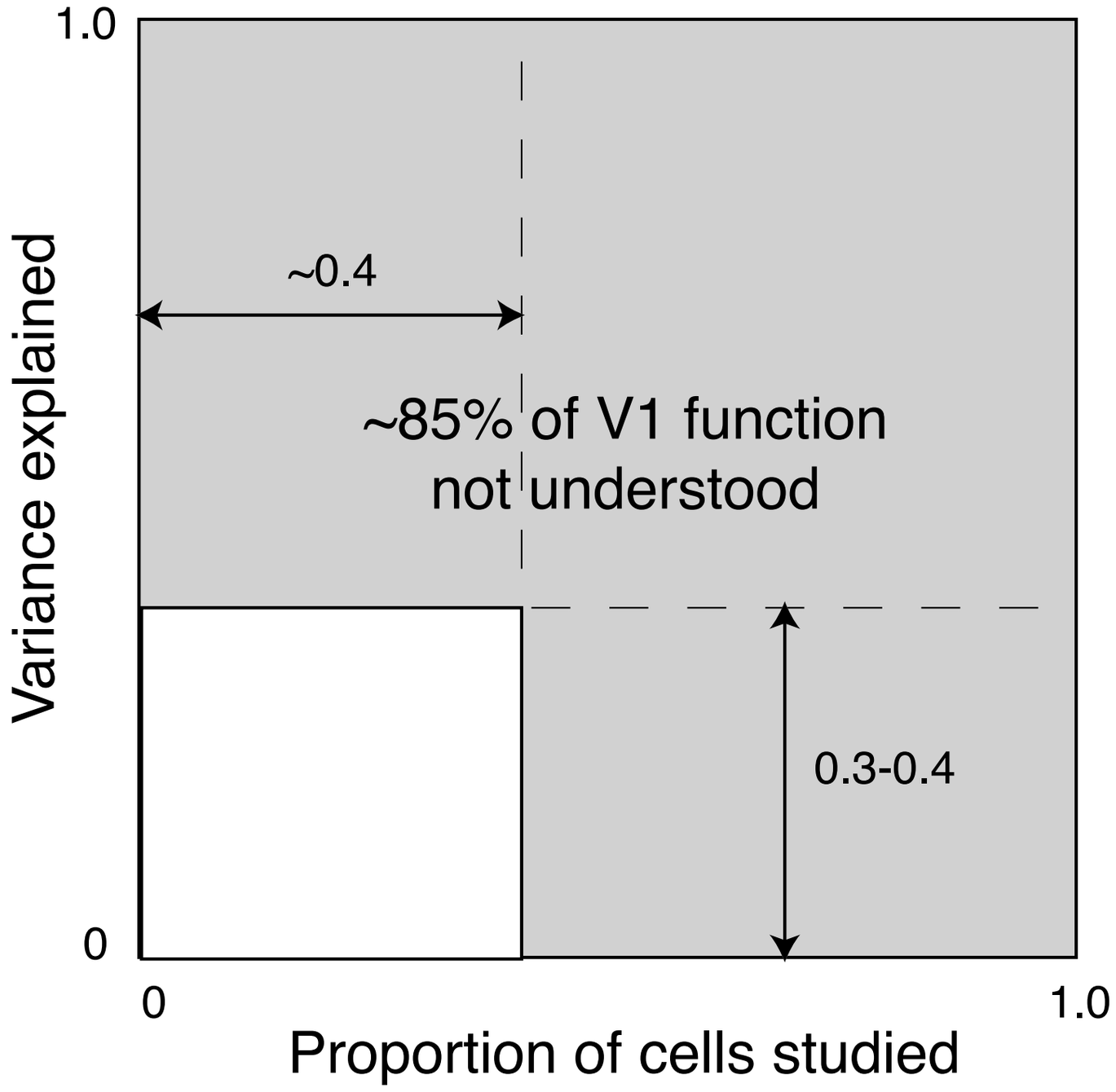
Dendritic nonlinearities

(Hausser & Mel, 2003)

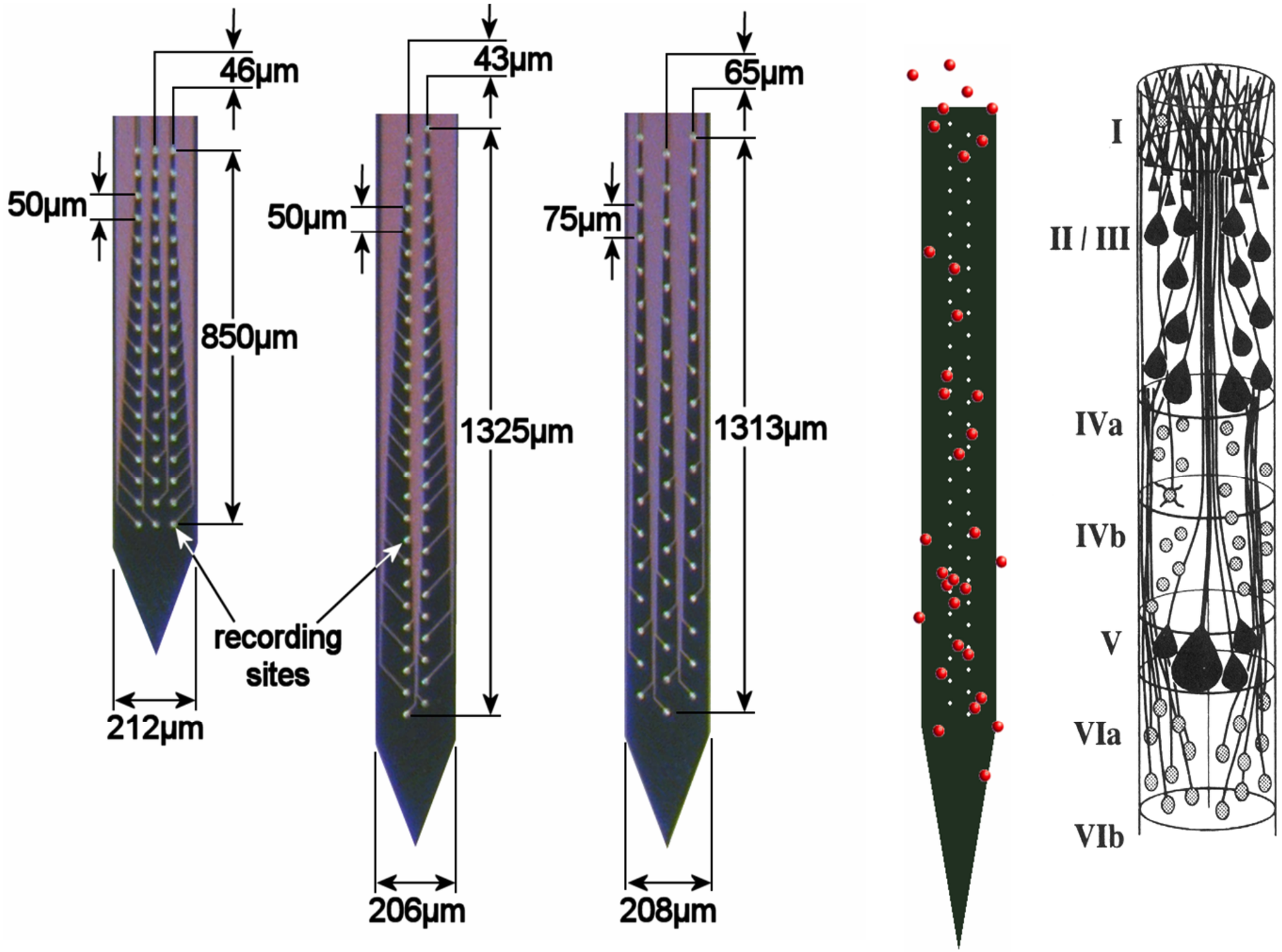


What is the other 85% doing?

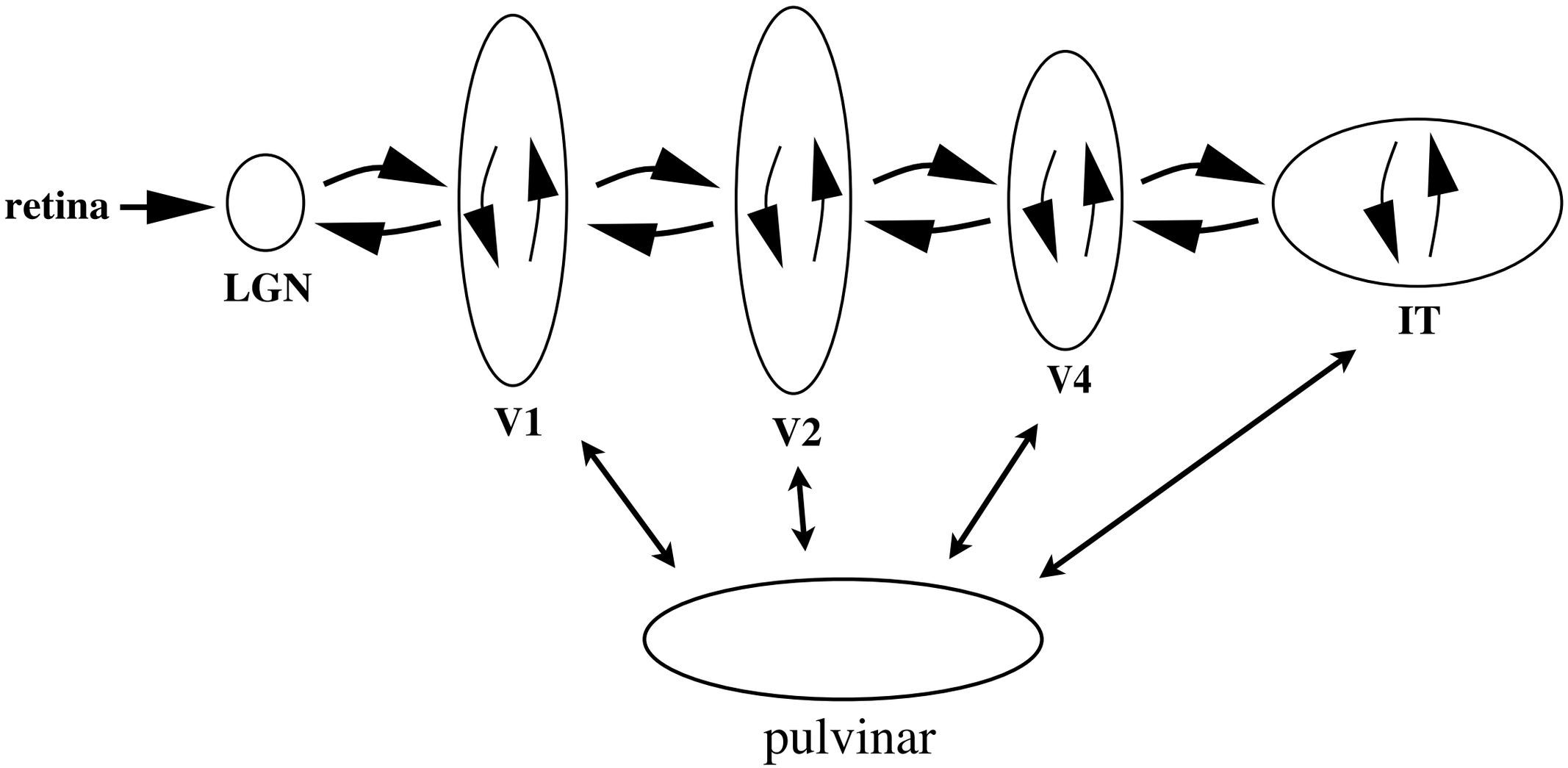
(Olshausen & Field, *Neural Computation*, 2005)



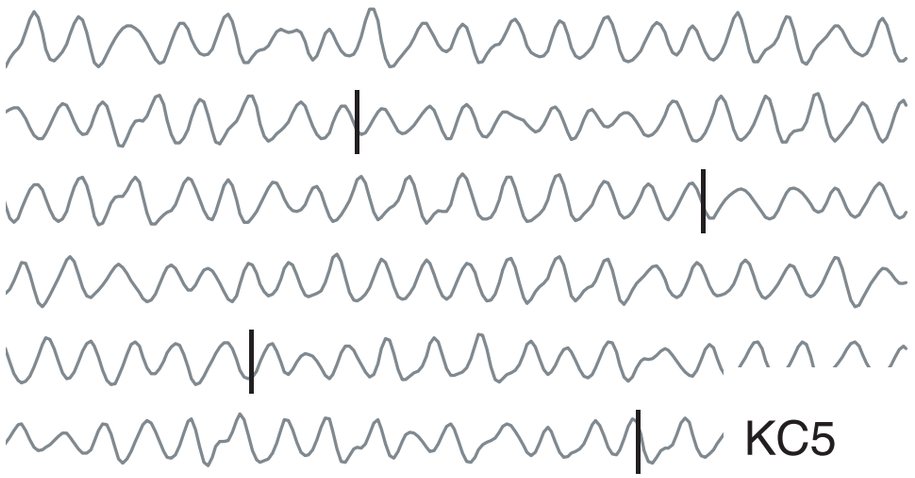
Silicon polytrodes



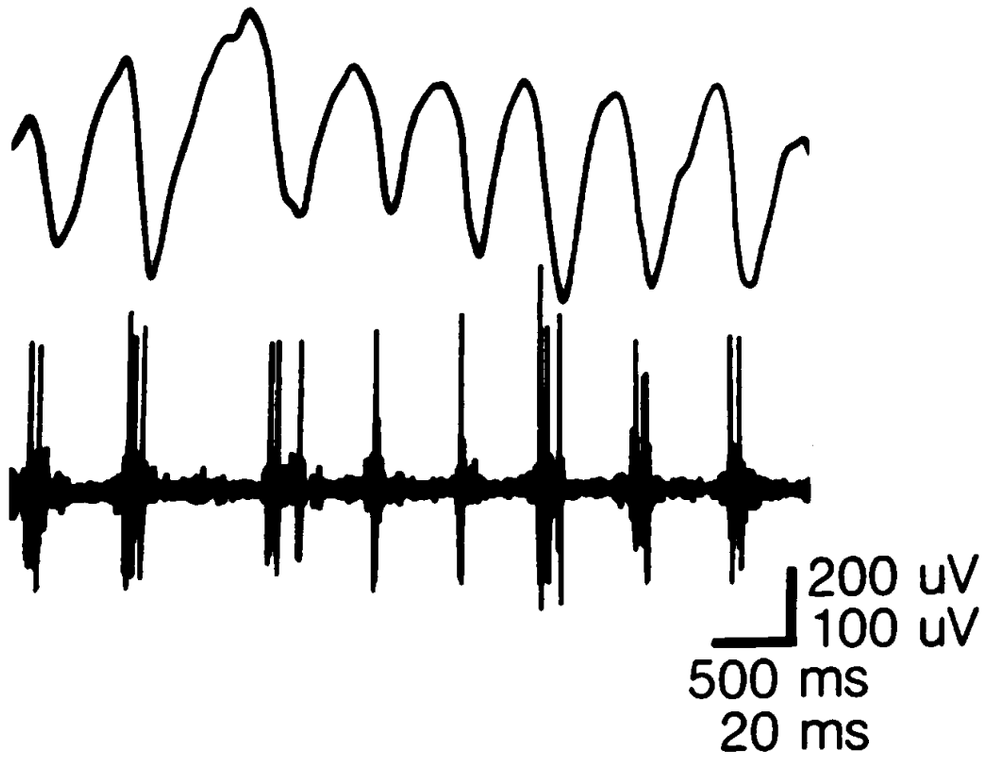
What is the role of cortico-cortical and thalamo-cortical feedback?



Neuronal oscillations are prevalent in sensory systems throughout the animal kingdom

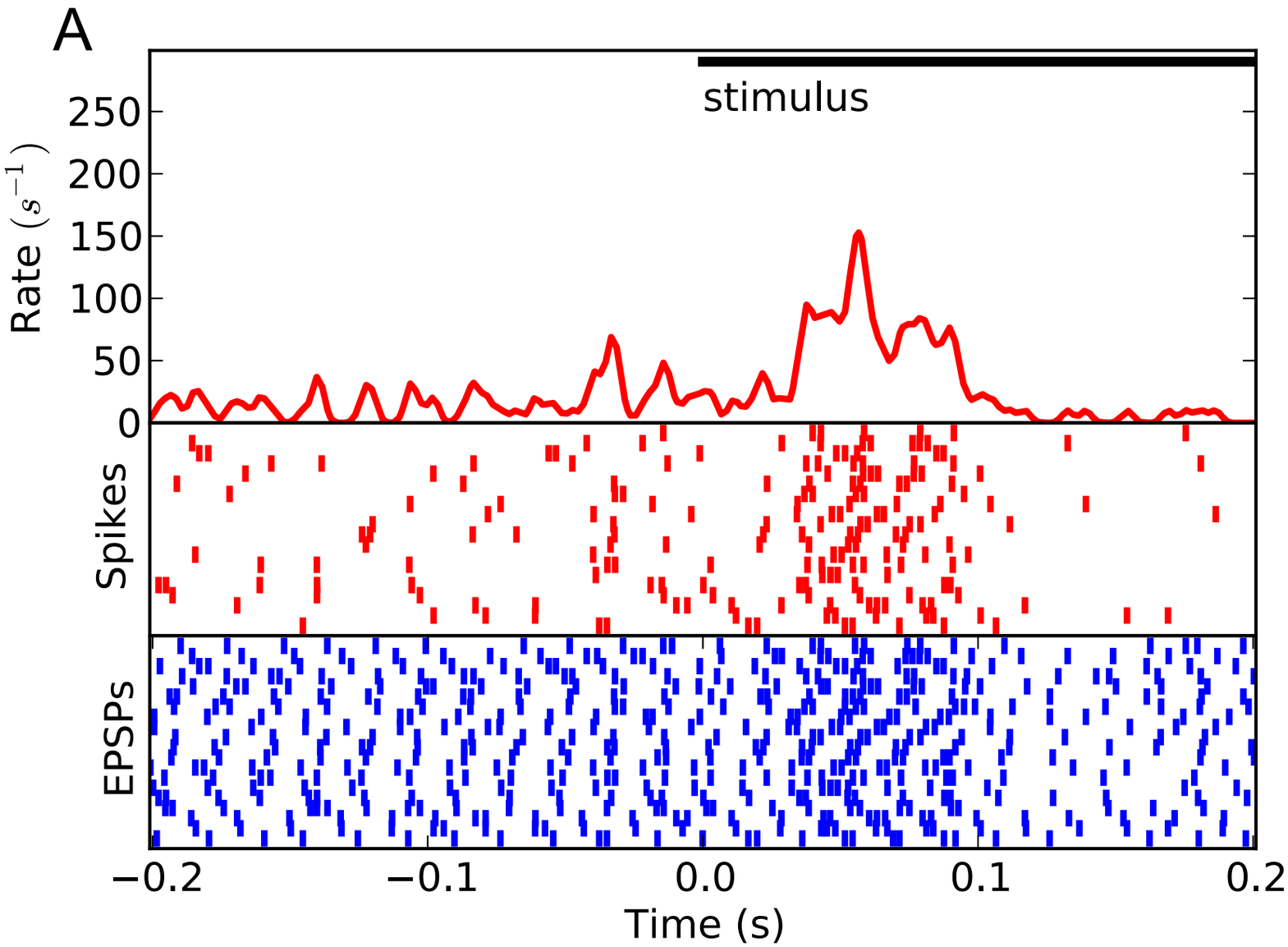


Locust olfactory system
(Laurent lab)

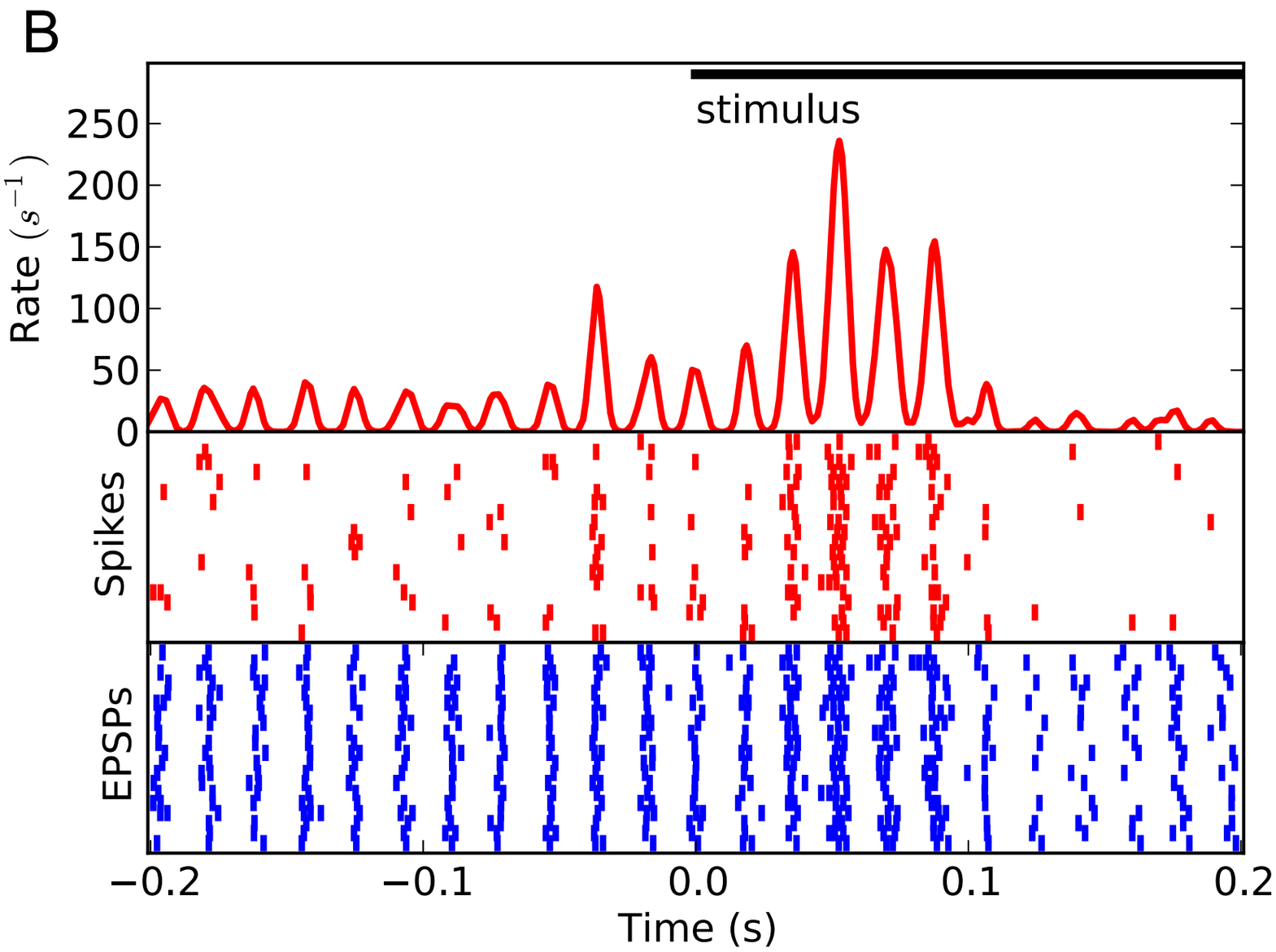


Cat V1
(Gray & Singer)

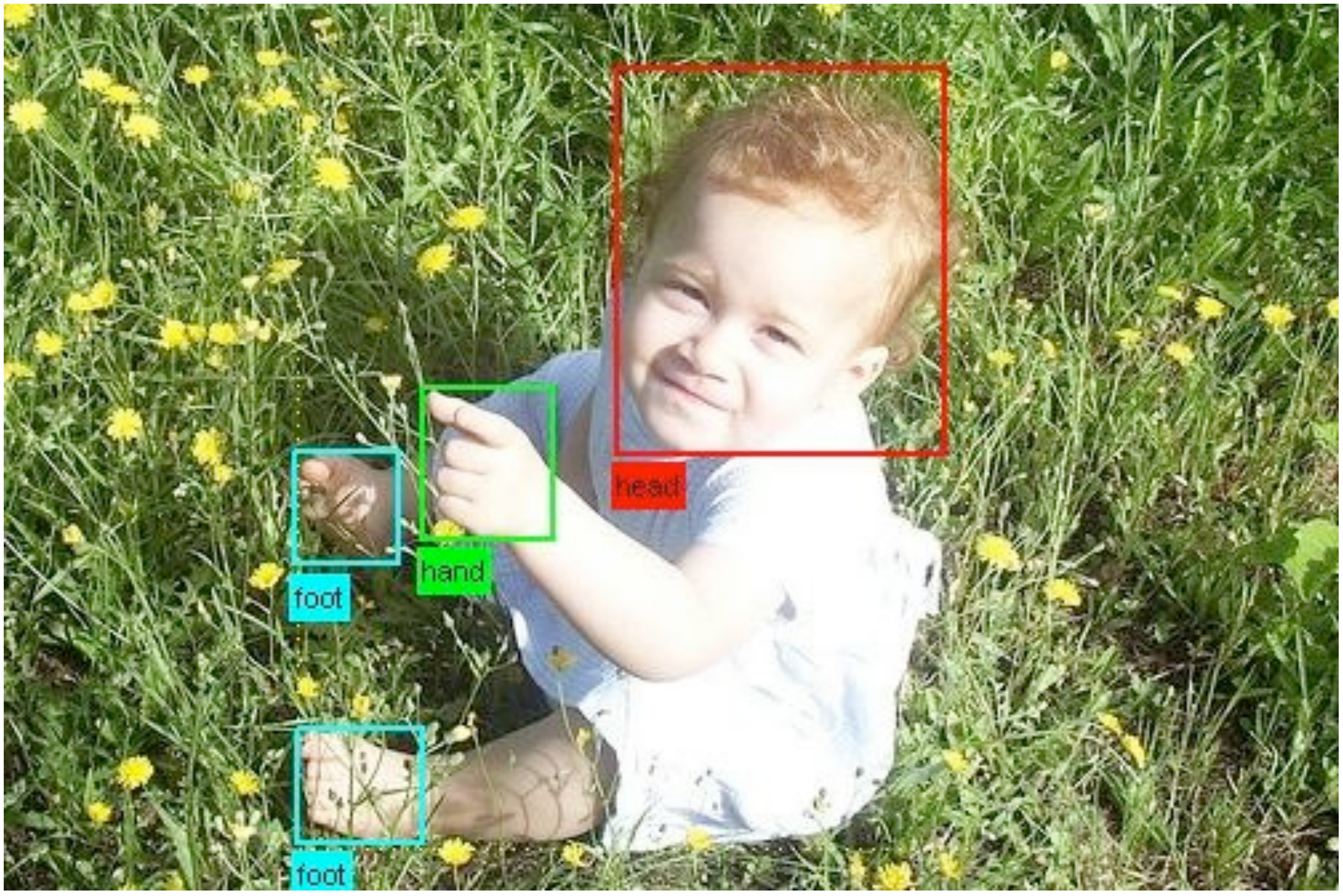
LGN neurons phase-lock to retinal oscillations (recordings from Hirsch lab, USC)



Same activity corrected for phase of ongoing retinal oscillations



Computer vision: is this the right task?



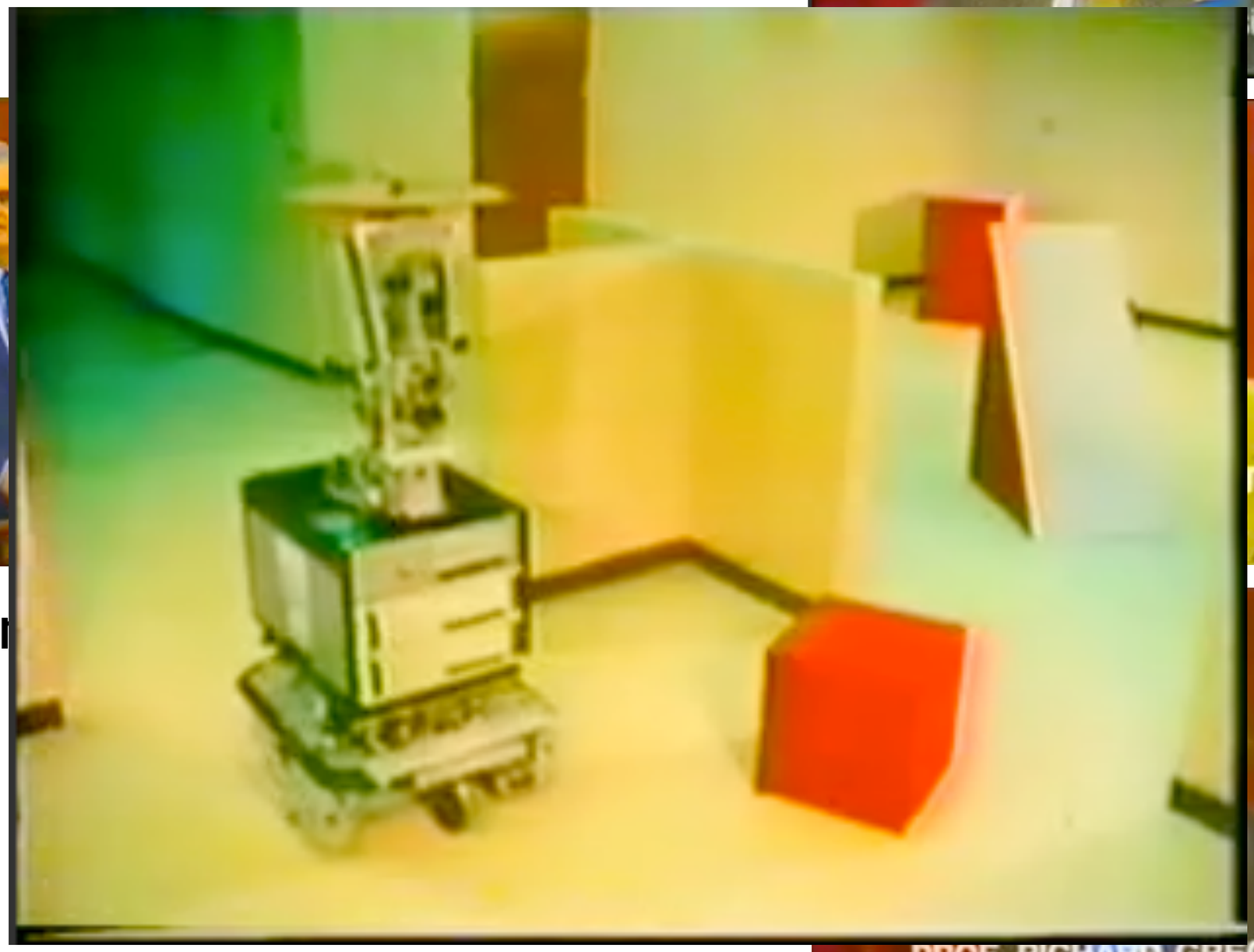
The towel folding robot

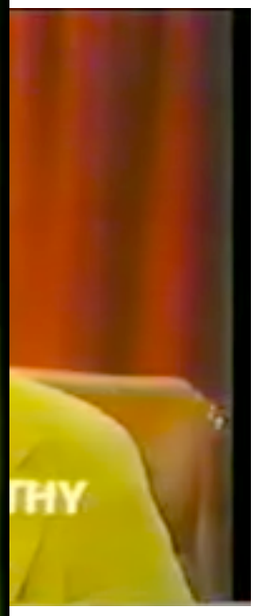
(Maitin-Shepard & Abbeel, UC Berkeley)

http://berkeley.edu/news/media/releases/2010/04/02_robot%20.shtml

The Lighthill debate (1973)

http://www.aiai.ed.ac.uk/events/lighthill1973/





Sir Ja

Questions we haven't yet asked

Scientists by their nature are eager to test hypotheses, or to “tell a story” about how a given set of facts or findings fit together and explain perception.

But most of these hypotheses and stories are far too simple-minded, and ultimately they turn out to be wrong.

We may be better served by taking an exploratory approach.

The frontiers

Surface representation

Large-scale neural dynamics

Perception-action loops

(See Noe & O'regan, "A sensorimotor account of vision and visual consciousness," BBS, 2001)

Santa Fe Institute workshop on action and perception

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Organizers: Murray Sherman, Ray Guillery, Nihat Ay, Bruno Olshausen, Fritz Sommer

Speakers:

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Andy Clark
Ralf Der
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Jeff Hawkins
Yasuo Kuniyoshi
Chris Moore
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