Things we know, and *don't* know, about biological vision

Bruno A. Olshausen
Helen Wills Neuroscience Institute
School of Optometry
and Redwood Center for Theoretical Neuroscience
UC Berkeley

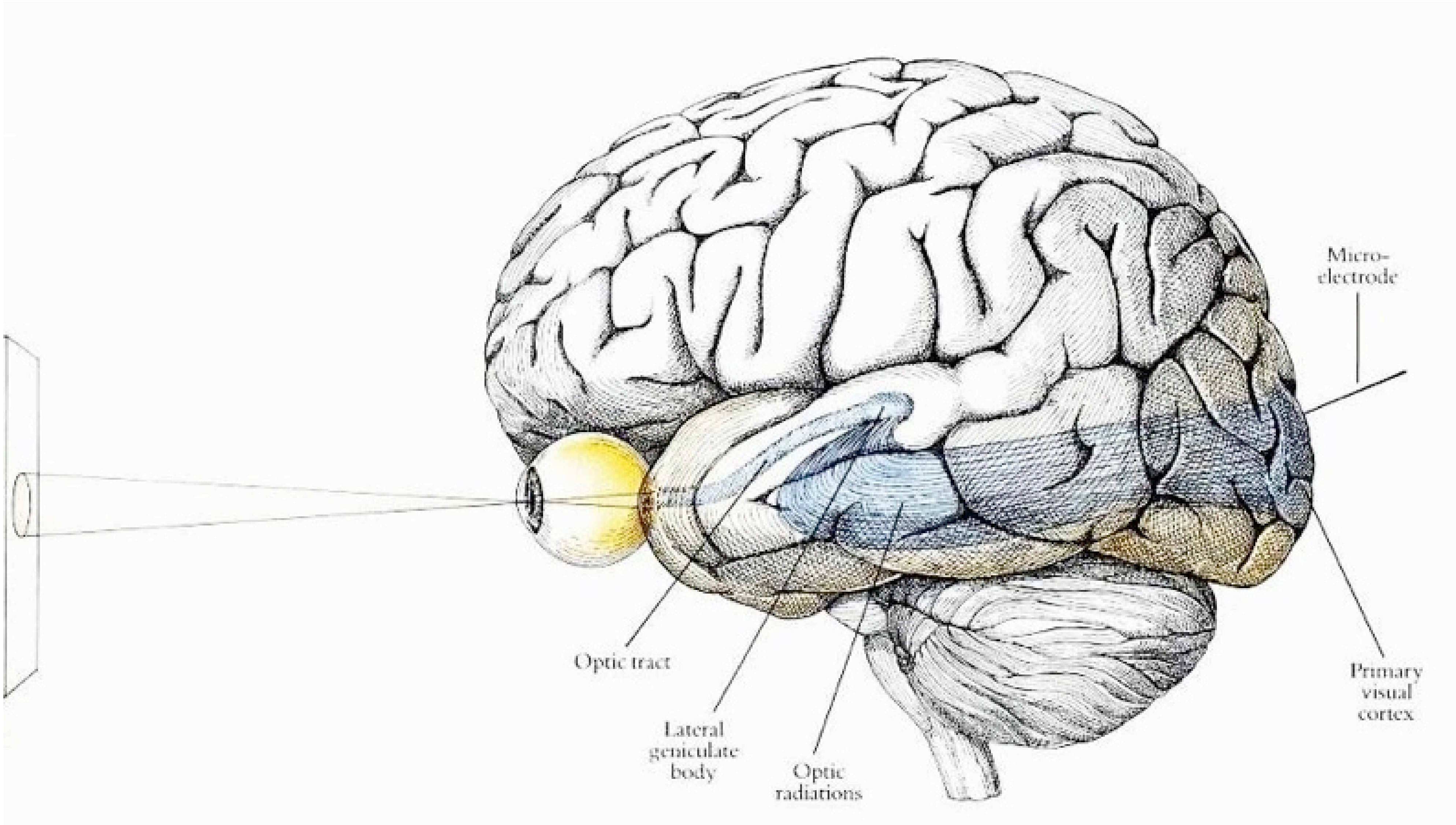
REDWOOD CENTER
for Theoretical Neuroscience

The Unknown

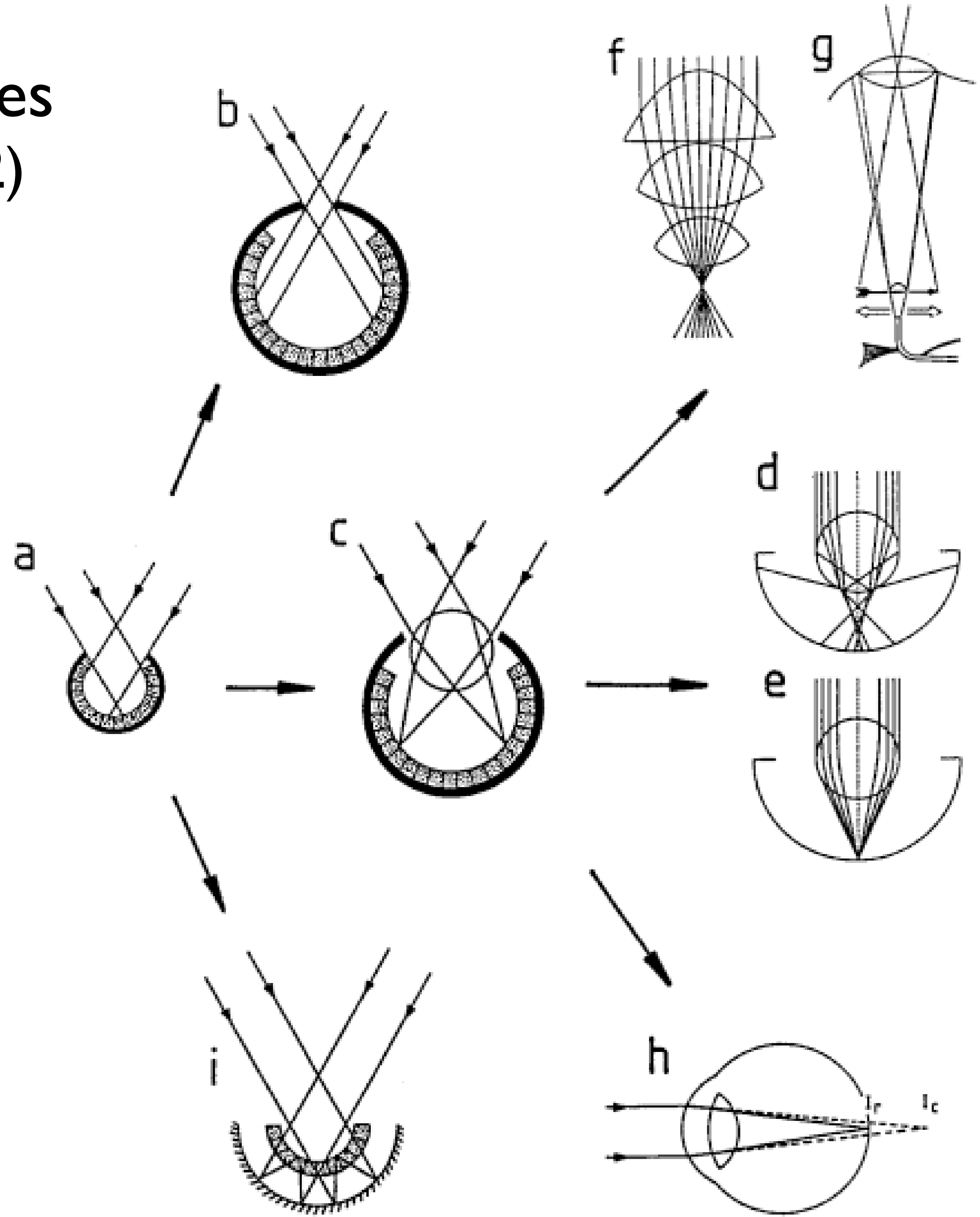
As we know,
There are known knowns.
There are things we know we know.
We also know
There are known unknowns.
That is to say
We know there are some things
We do not know.
But there are also unknown unknowns,
The ones we don't know
We don't know.

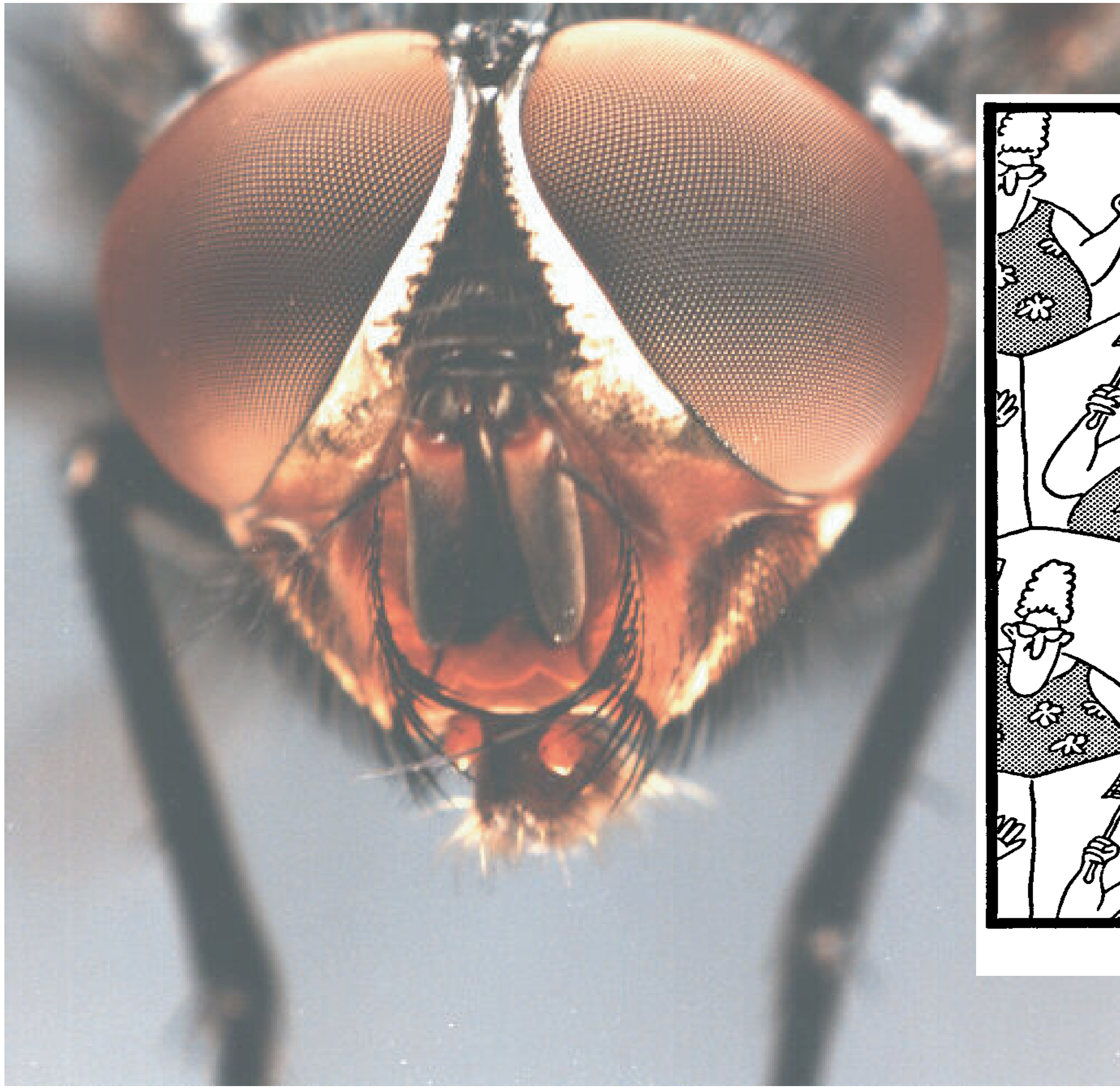
Feb. 12, 2002, Department of Defense news briefing

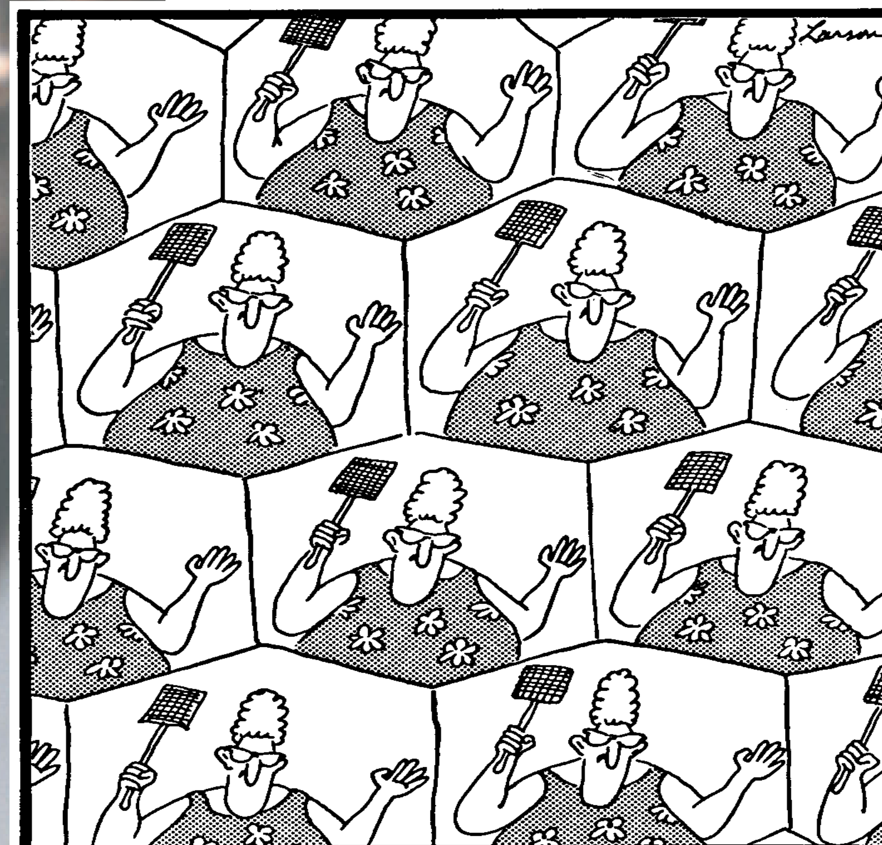
From: *The Poetry of Donald Rumsfeld*
Hart Seeley, Slate Magazine


Micro-
electrode
Optic tract
Lateral
geniculate
body
Optic
radiations
Primary
visual
cortex

The evolution of eyes
Land & Fernald (1992)

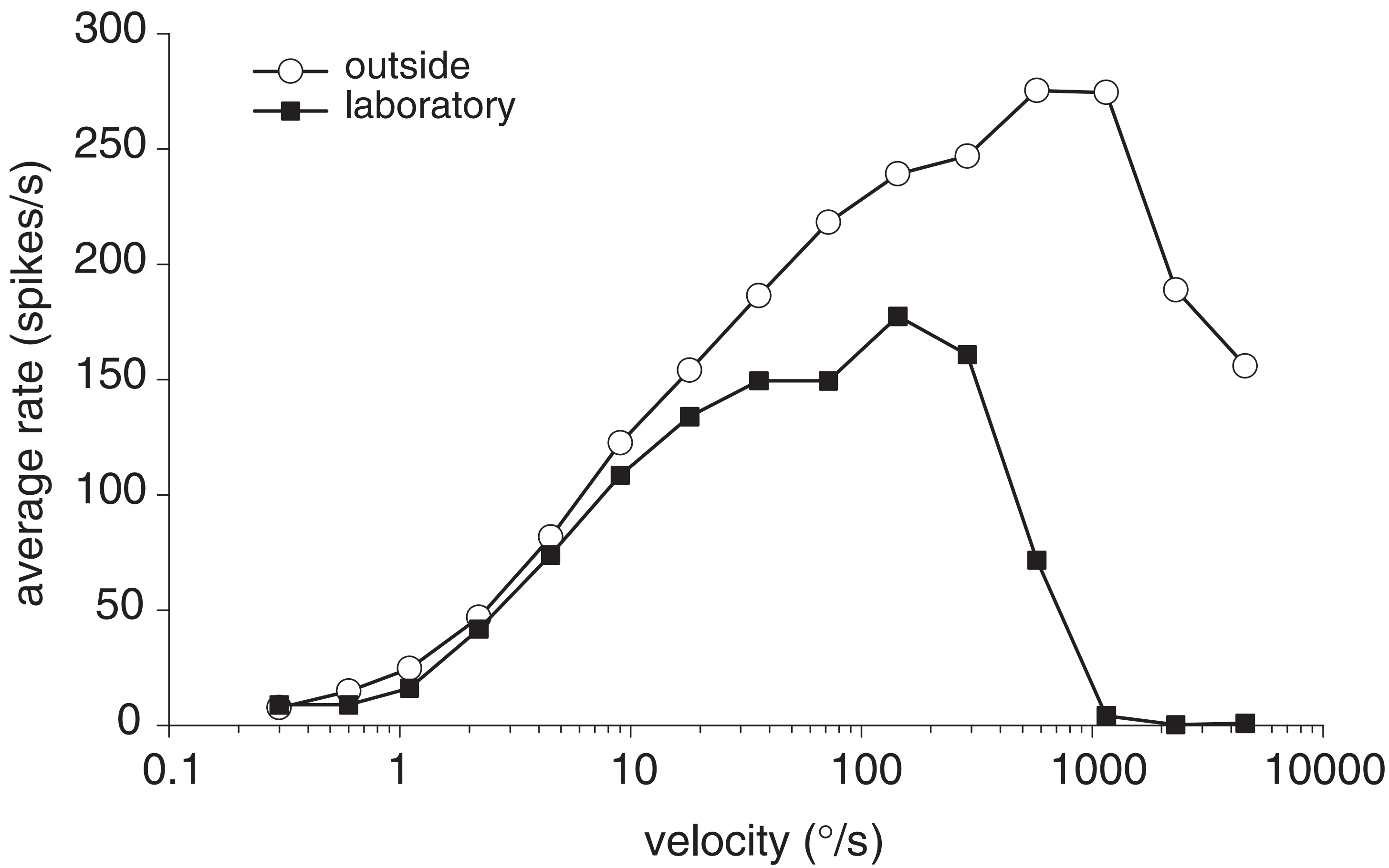






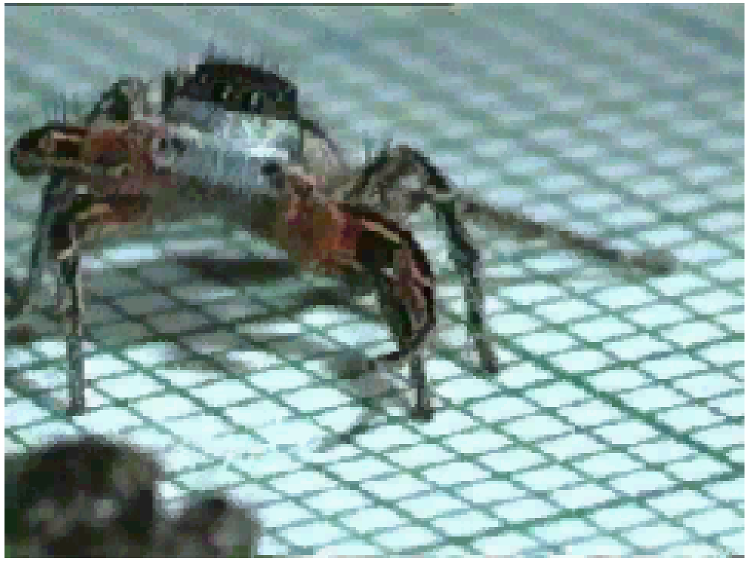
The last thing a fly ever sees

Fly H1 neuron - dynamic range of speed sensitivity
Lewen, Bialek & de Ruyter van Steveninck (2001)



Philanthus triangulum

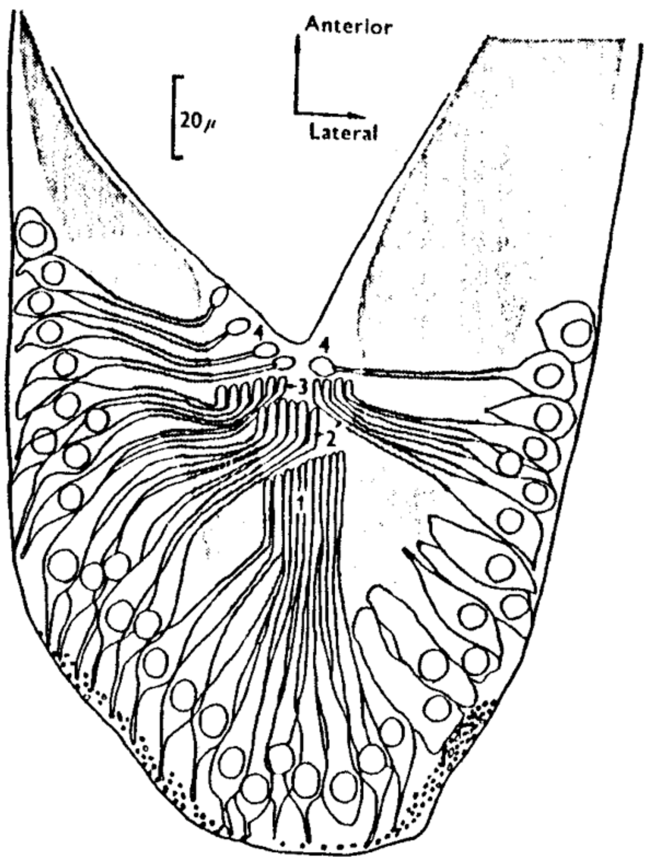
Jumping spiders



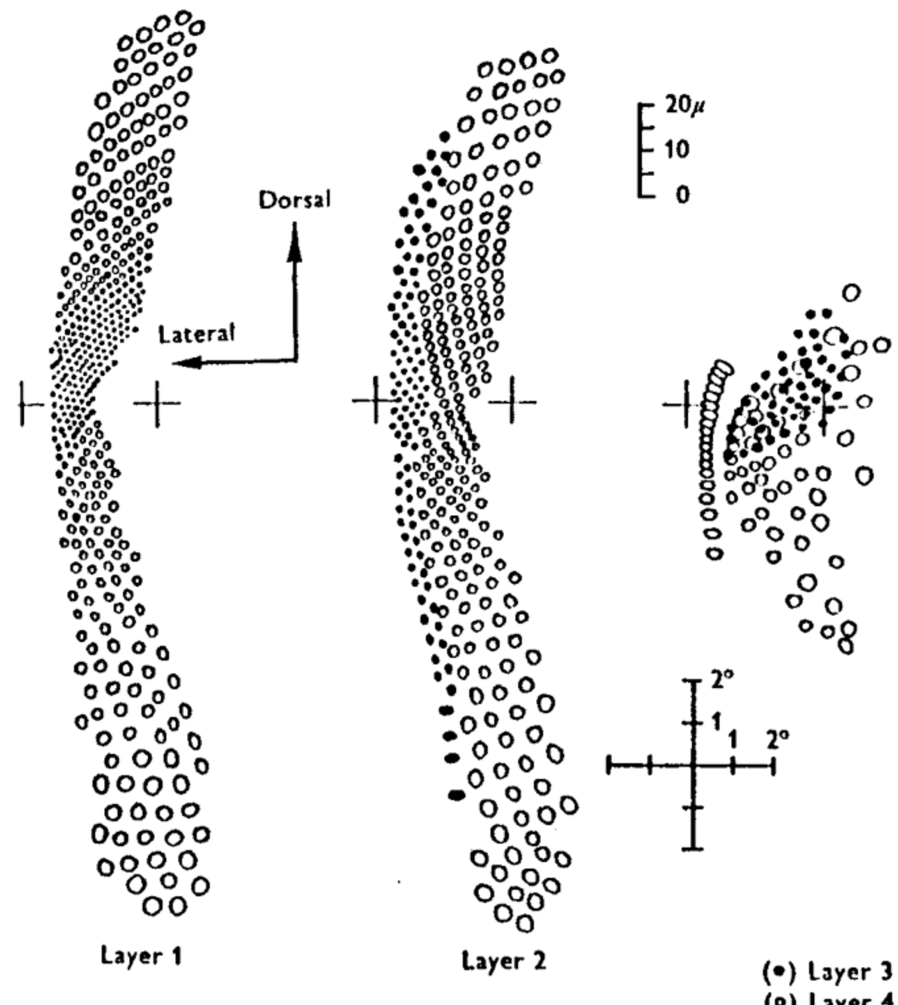
Jumping spiders

Jumping spider retina

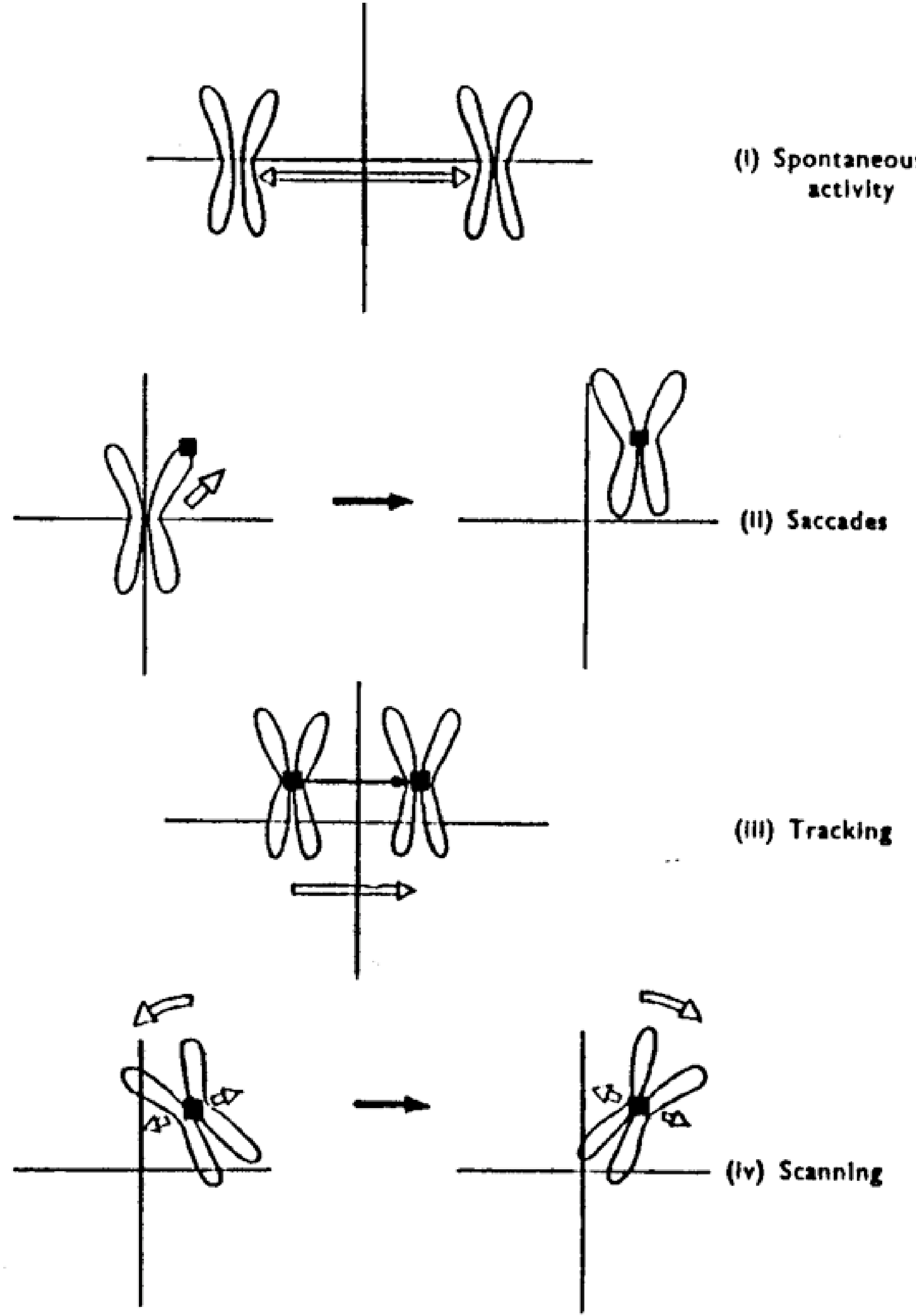
horizontal section



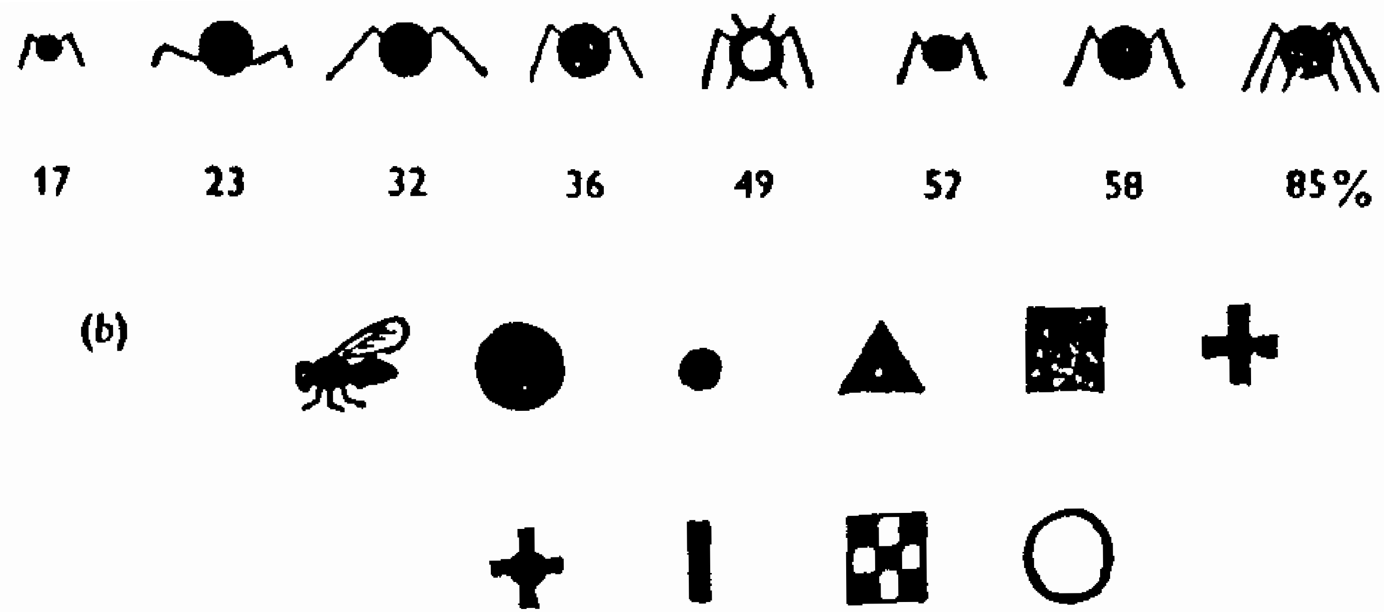
photoreceptor array



Jumping spider eye movements



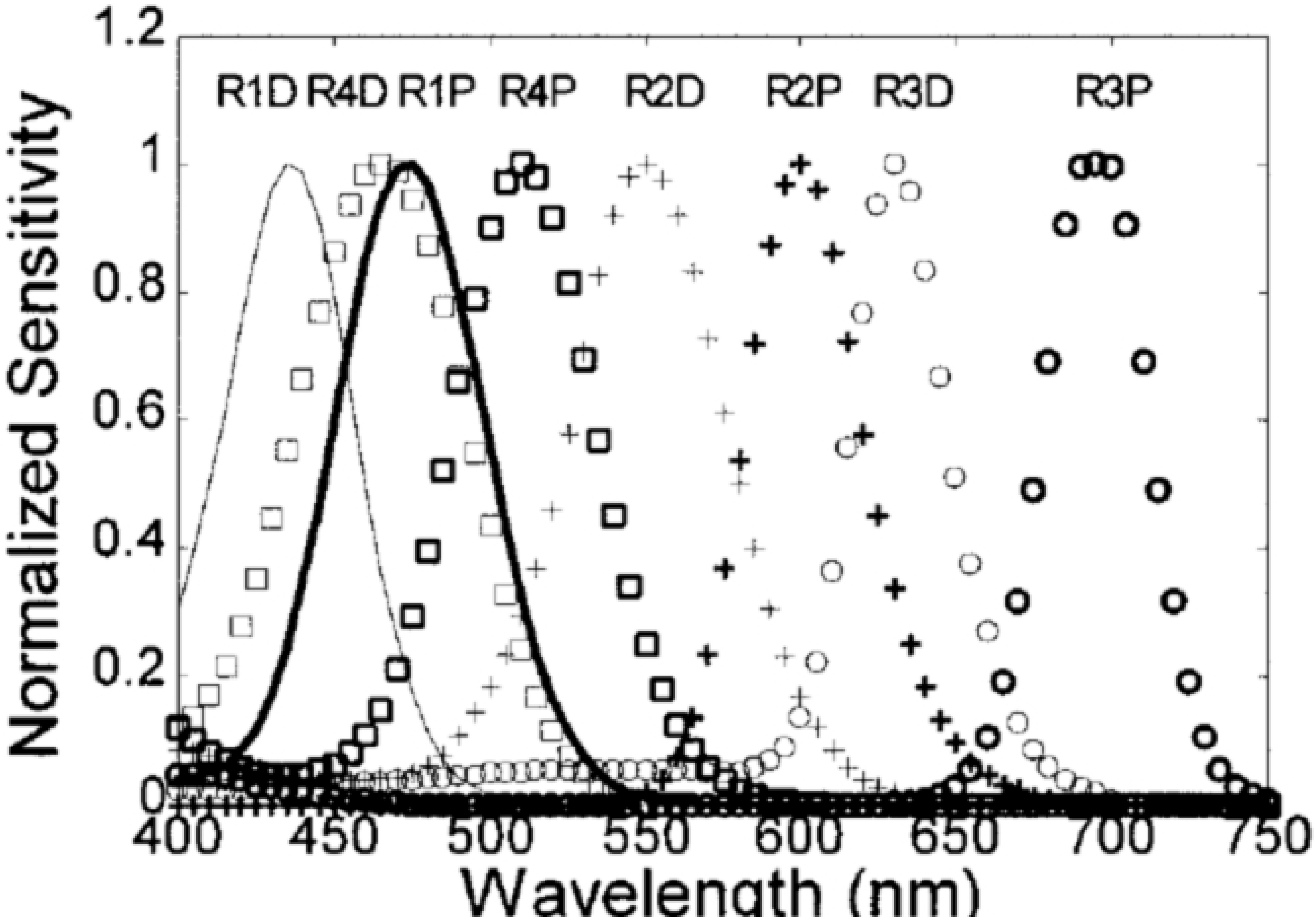
Jumping spiders do 'object recognition'



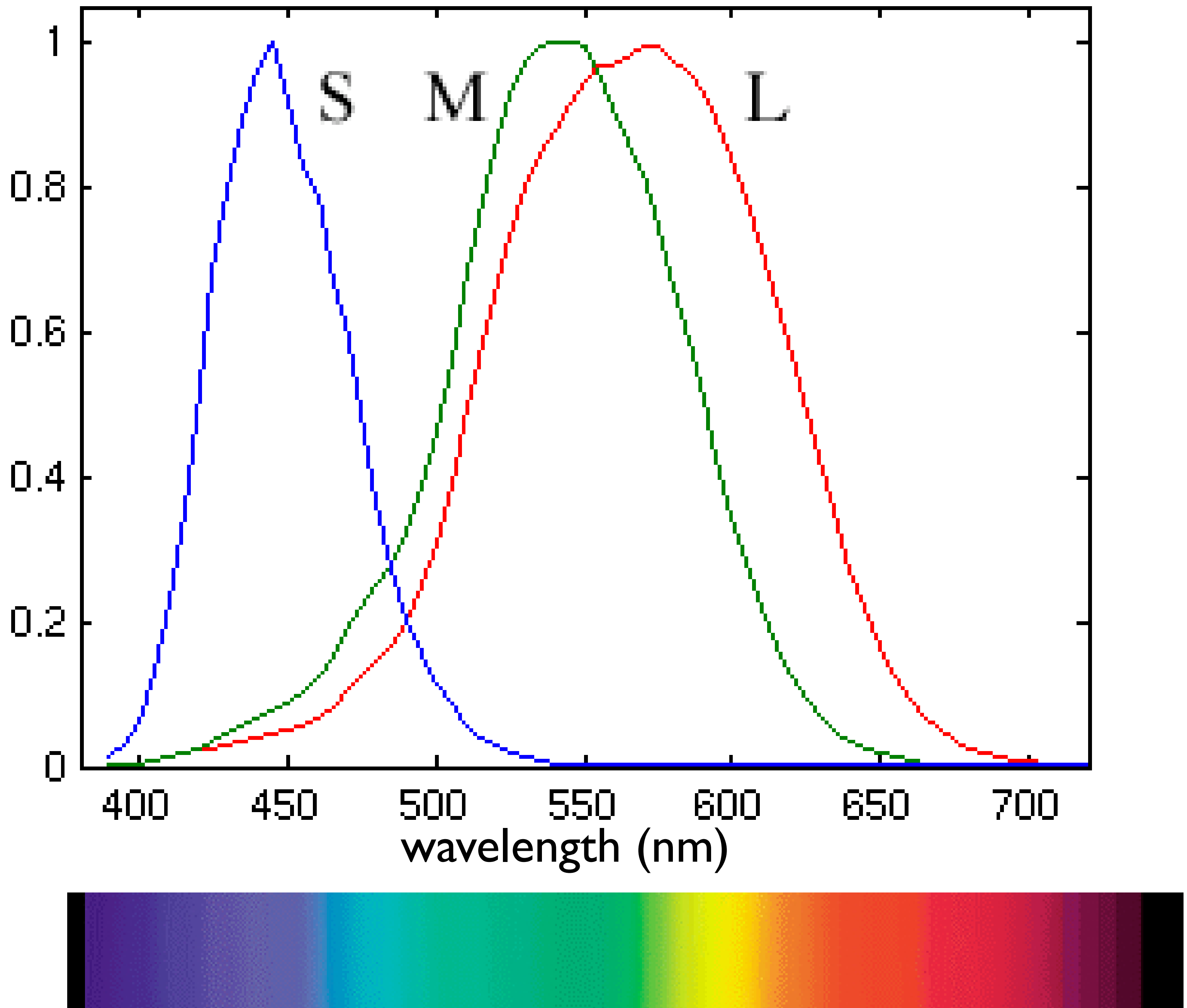
Text-fig. 12. Stimuli found by Drees to evoke courtship (*a*) and prey capture (*b*) in male jumping spiders (*Epiblemum scenicum*). The numbers beneath each figure in (*a*) are the percentage of trials on which courtship was evoked. After Drees (1952).

Mantis shrimp

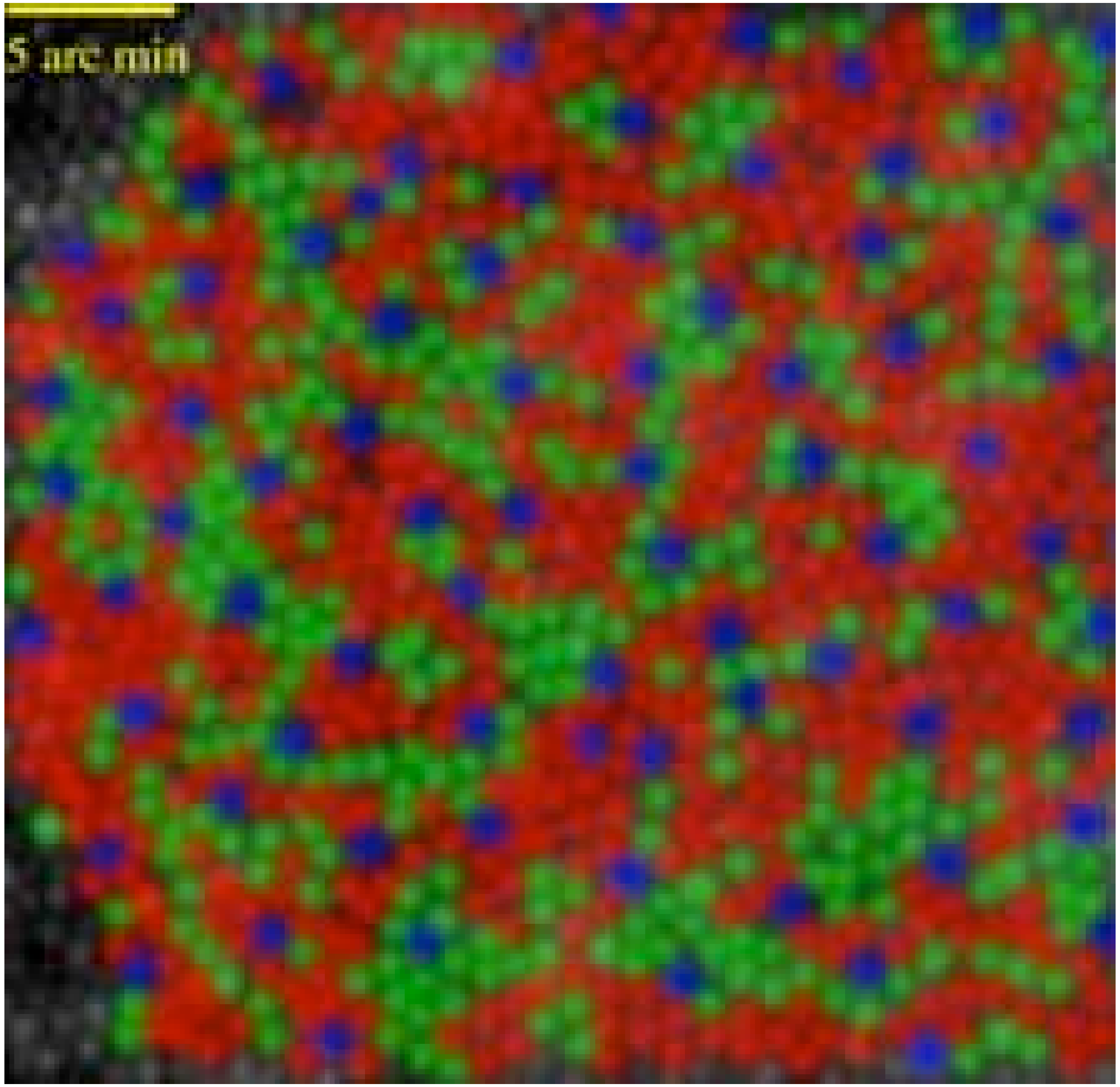
Mantis shrimp - photoreceptor spectral sensitivities



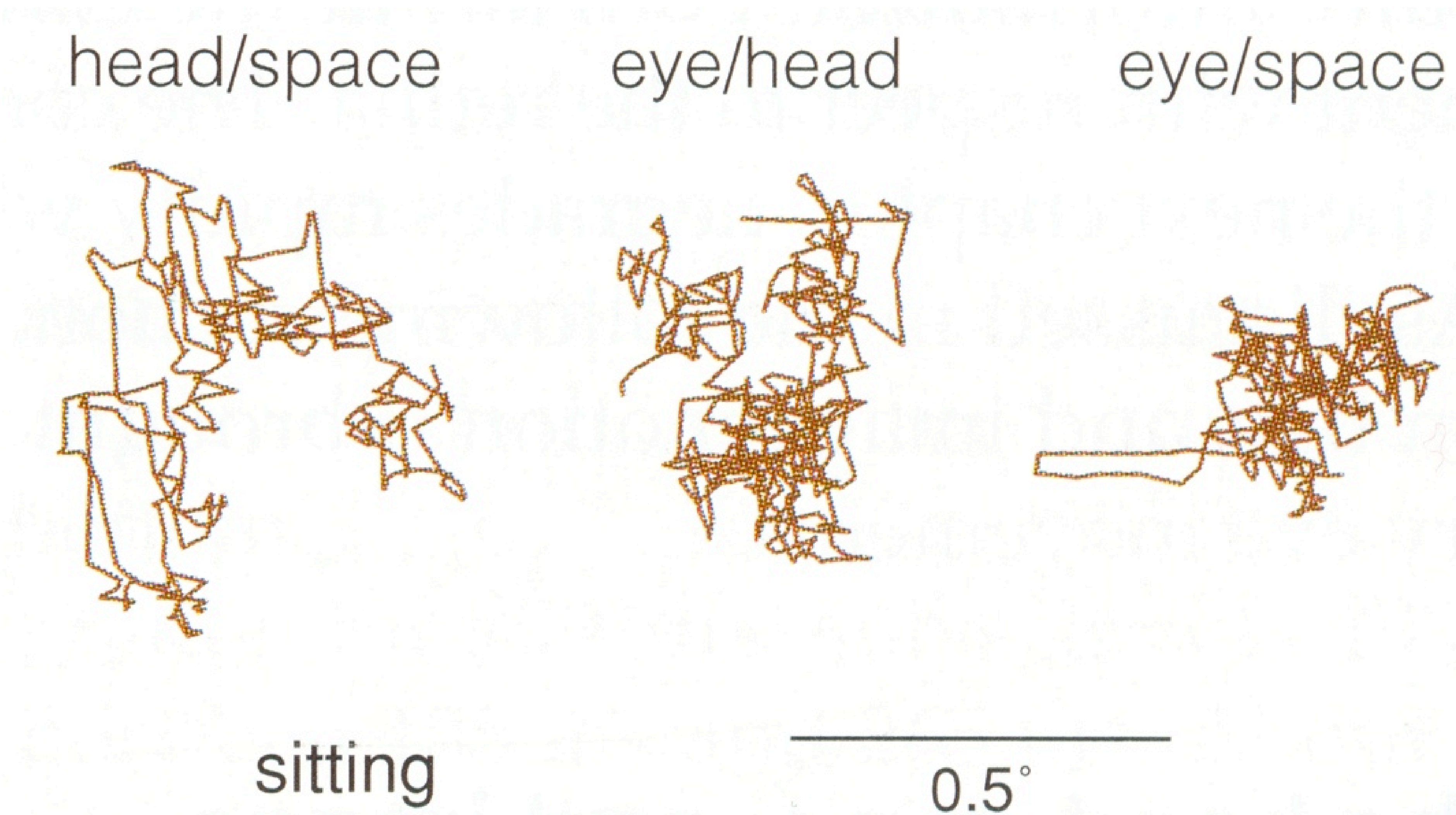
Human - photoreceptor spectral sensitivities



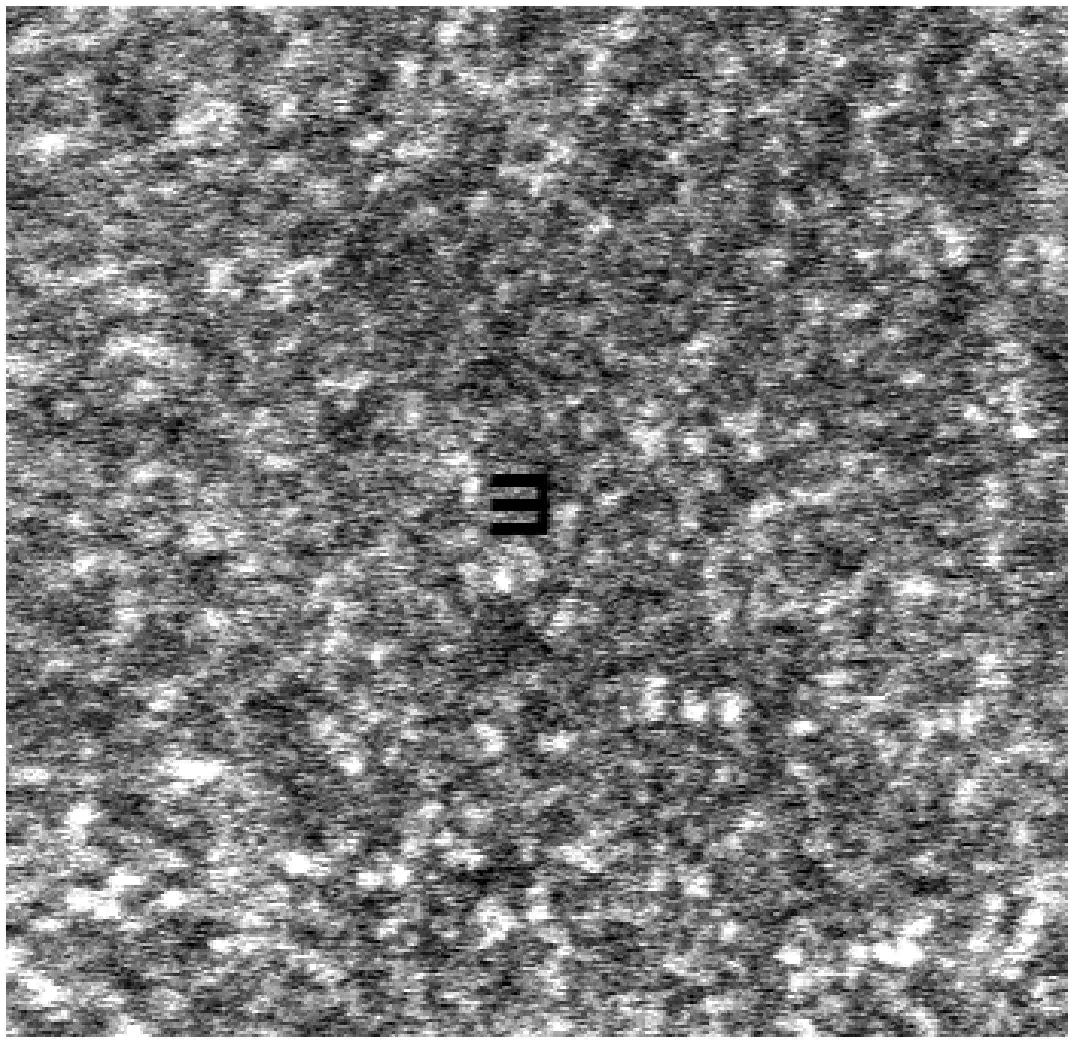
Human retina - cone mosaic

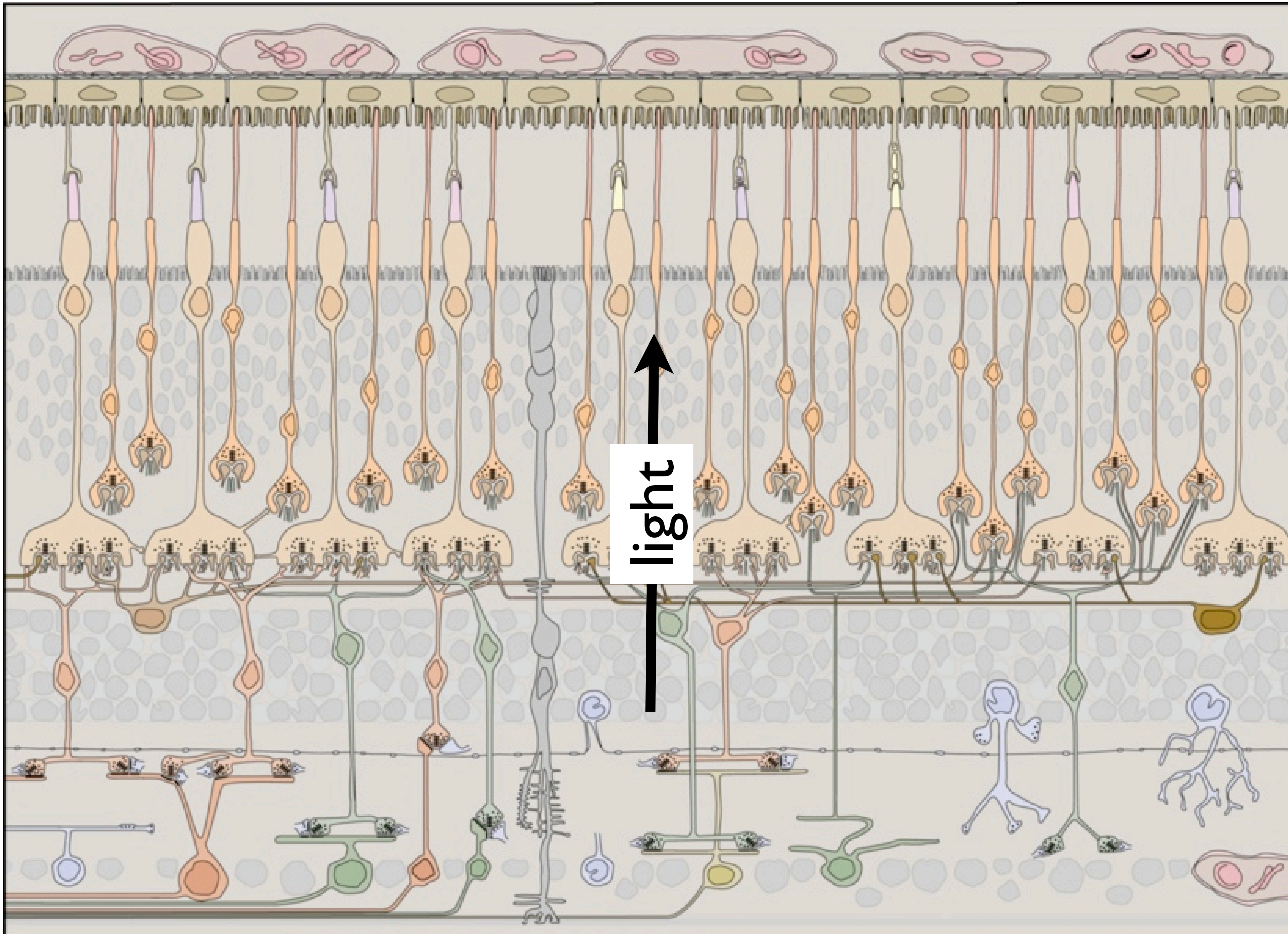


Fixational eye movements

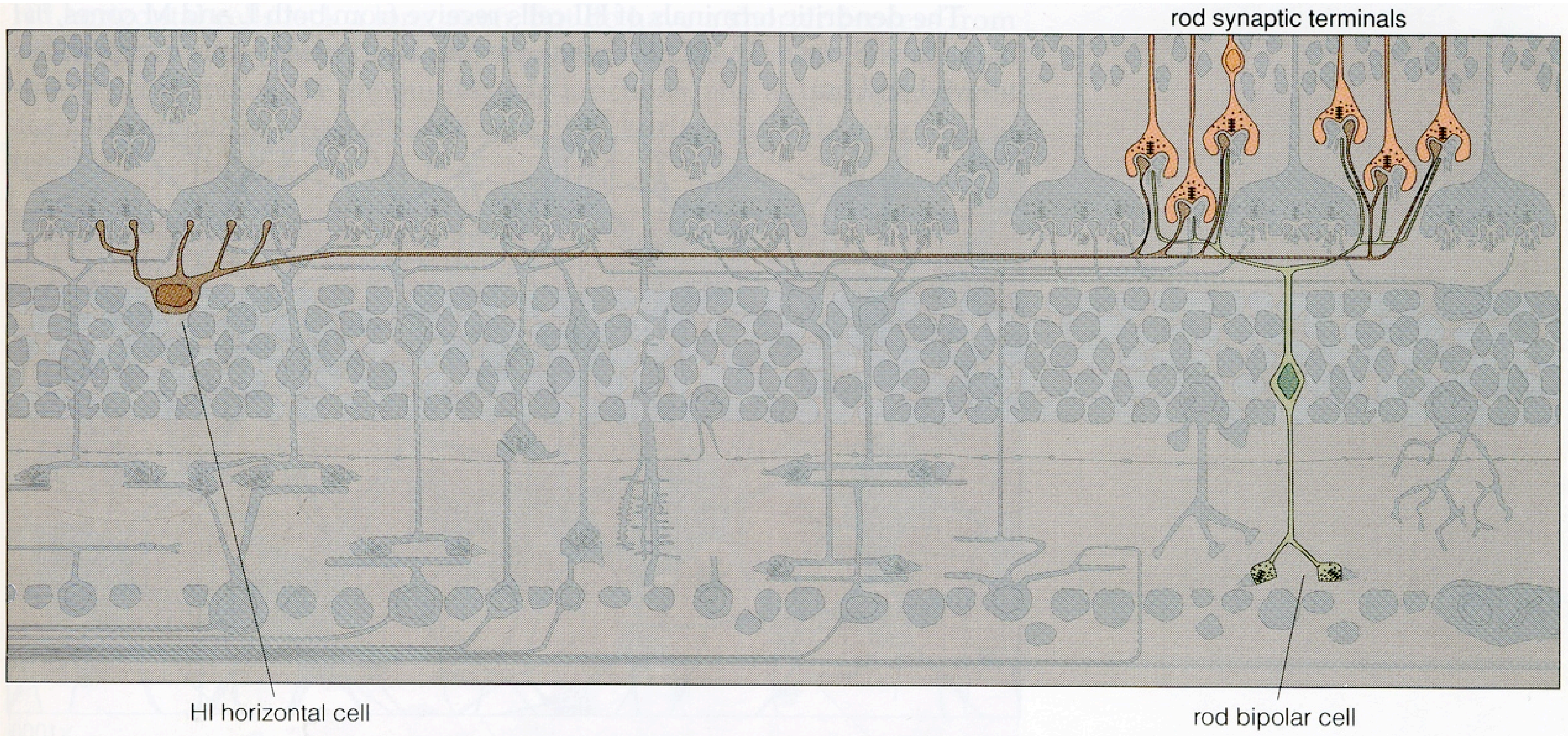


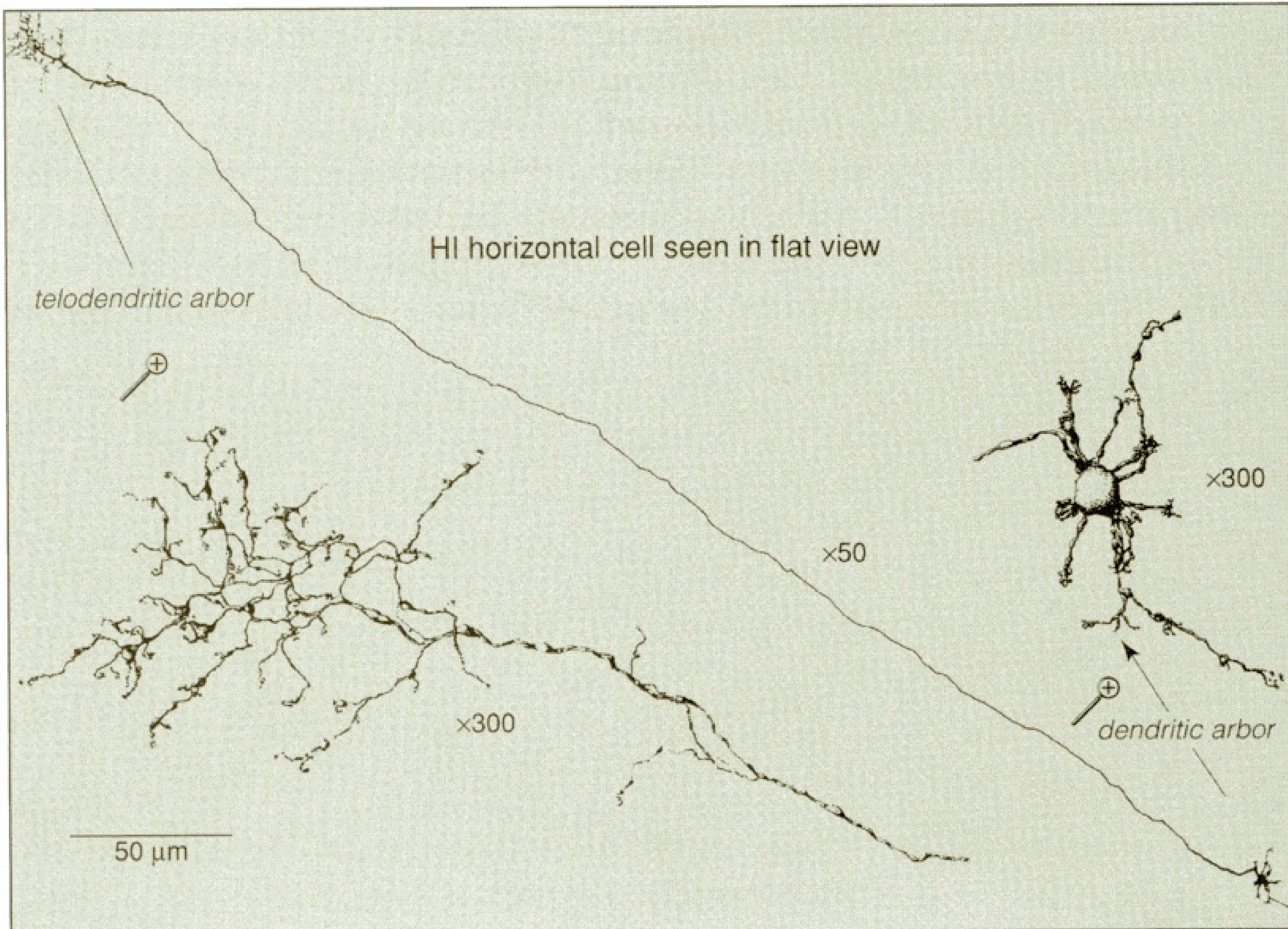
Human fixational eye movements
(Austin Roorda, UCB)



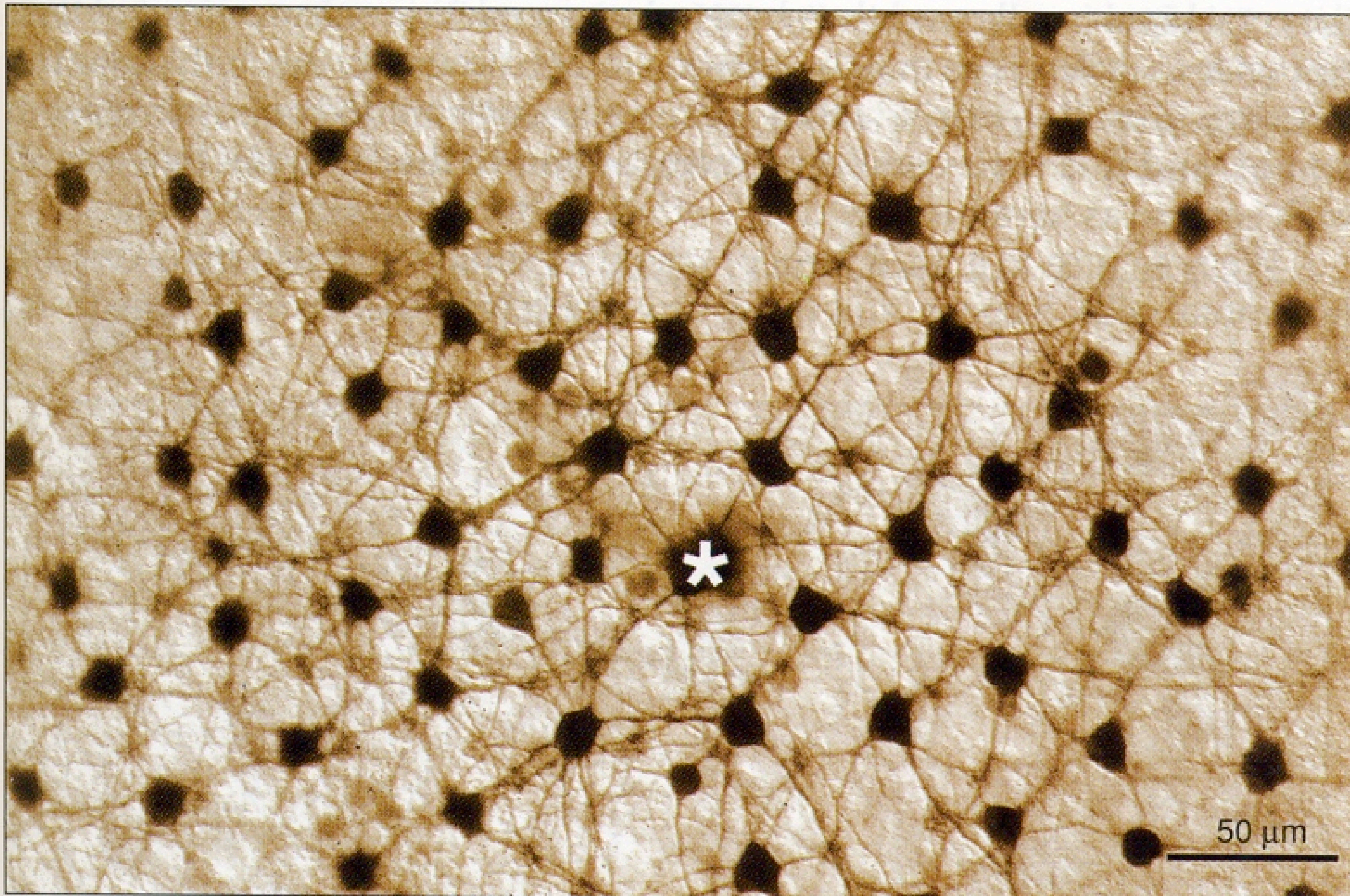

light

HI horizontal cell




HI horizontal cell seen in flat view
telodendritic arbor
×300
×50
×300
dendritic arbor
50 µm

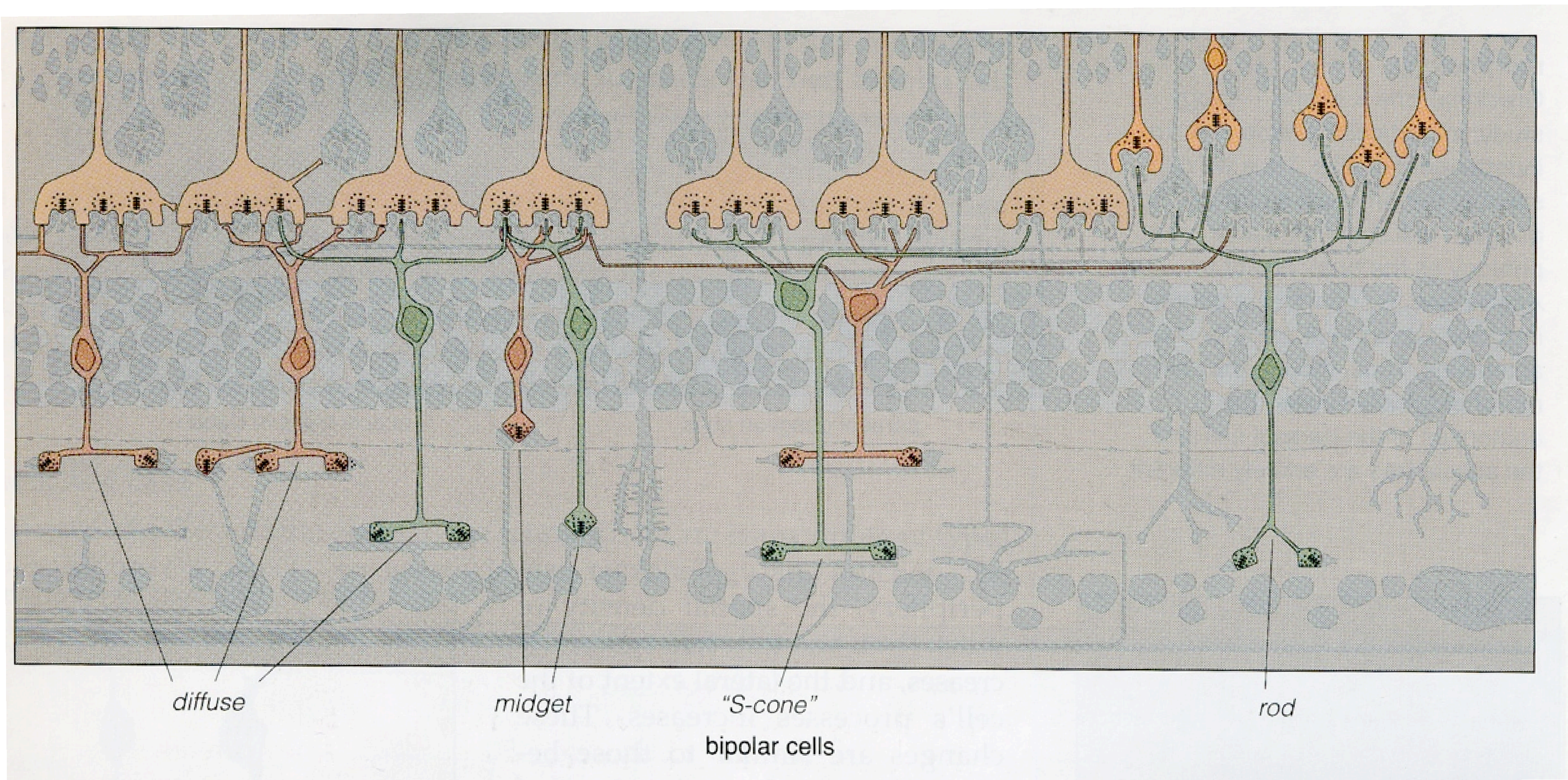
HI horizontal cells connected via gap junctions



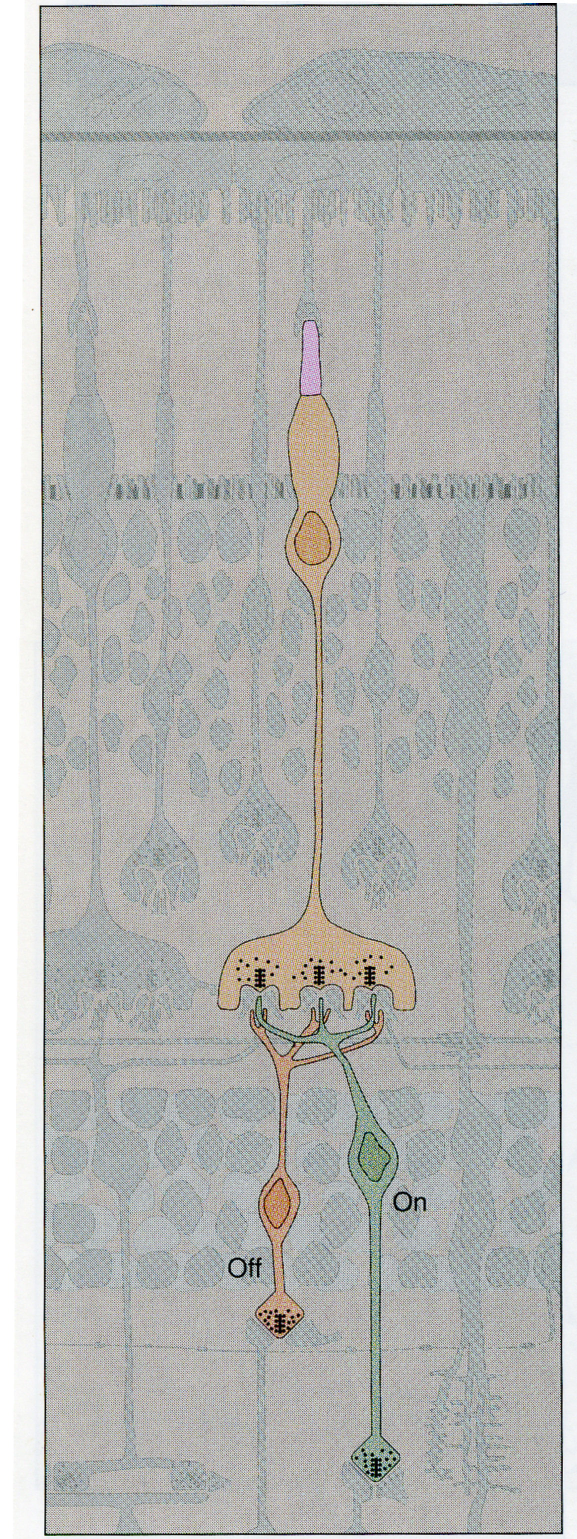
HI horizontal cells labeled following injection of one HI cell (*) ×300

after Dacey, Lee, and Stafford, 1996

Bipolar cells

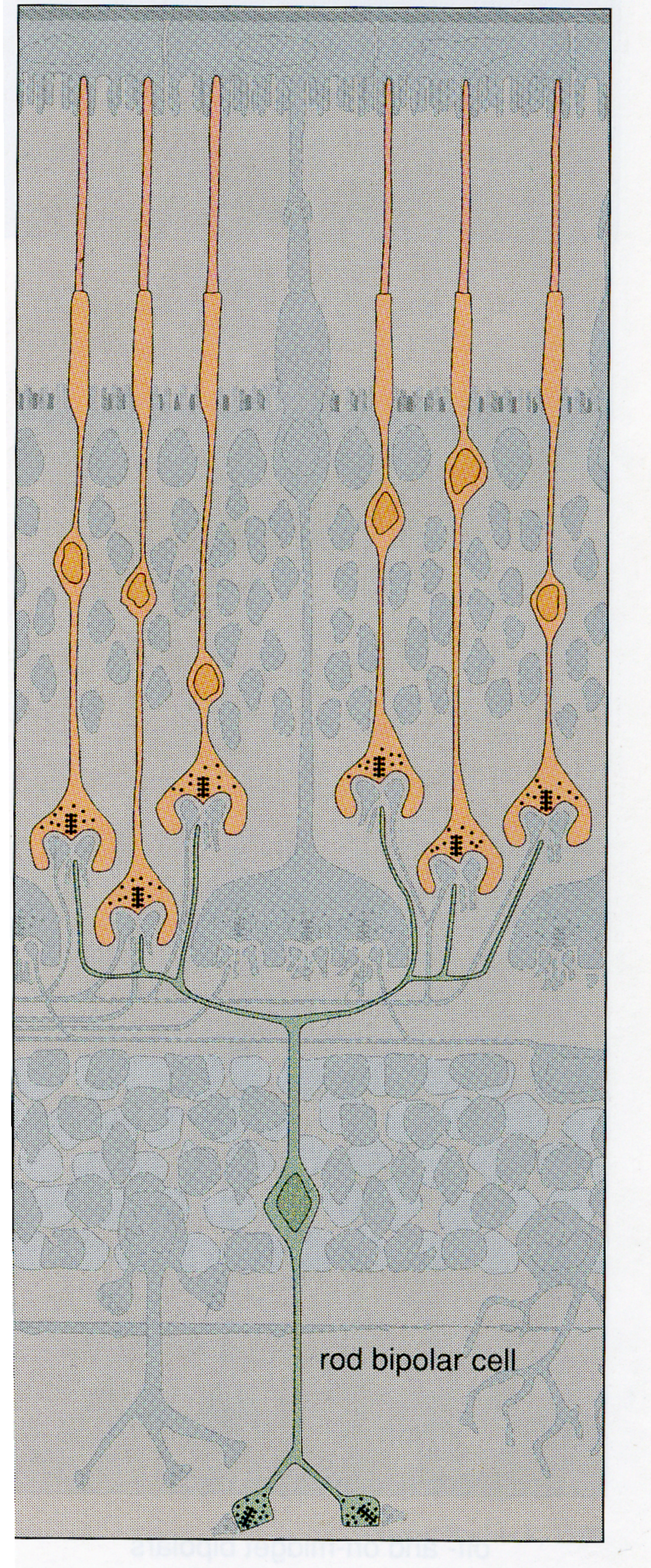


On vs. off cone bipolar cells

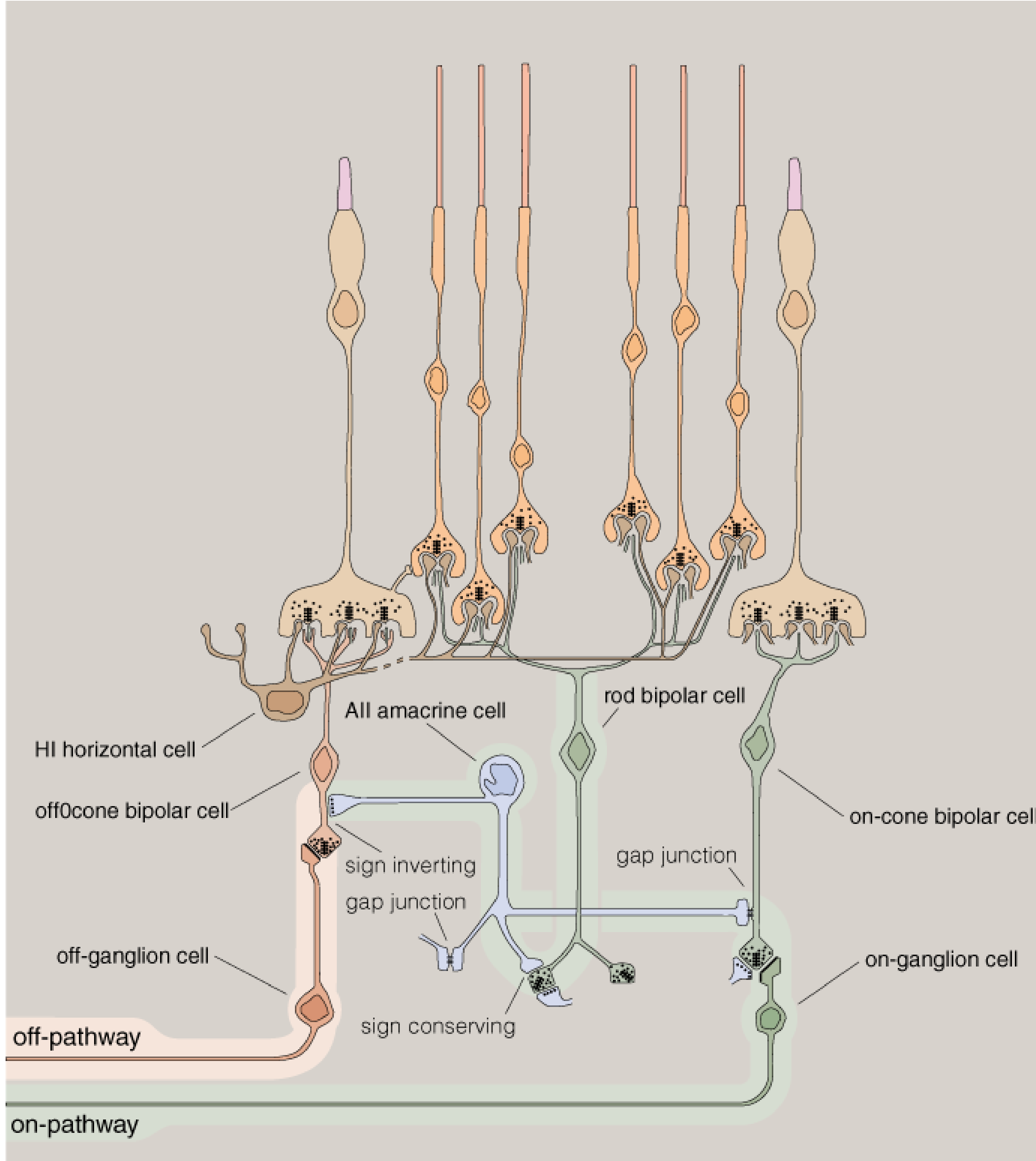


Rod bipolar cell is of on-type only

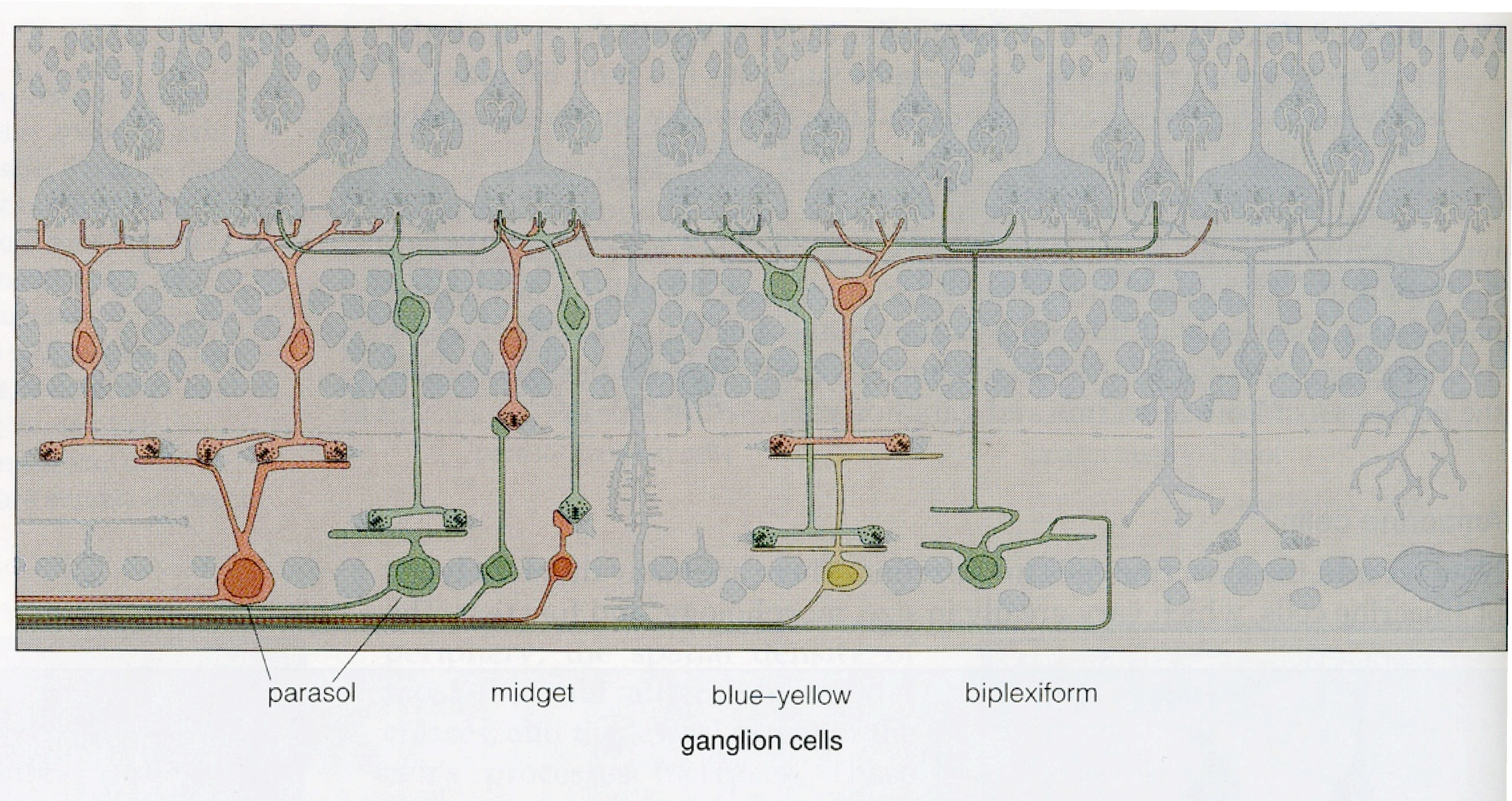
Net convergence of rods to bipolar cells

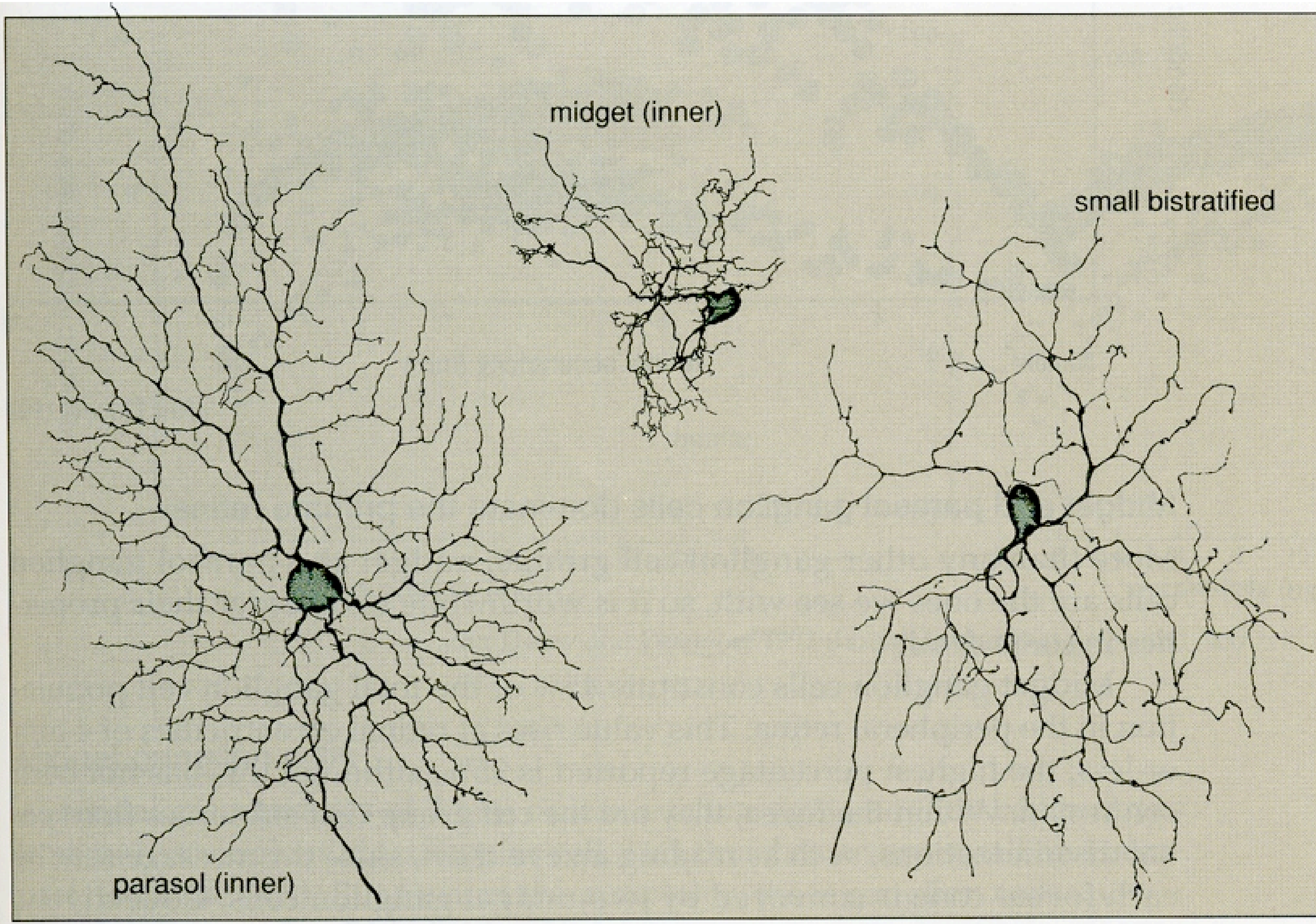


AII amacrine cell links rod bipolar cells to ganglion cells



Ganglion cells



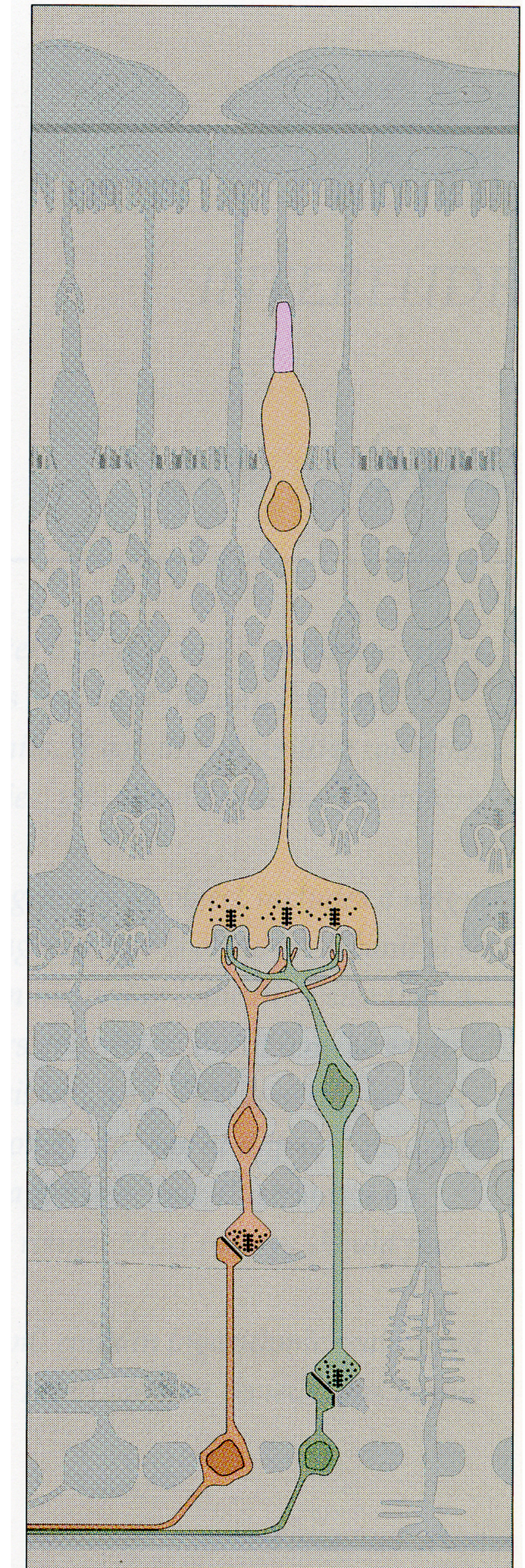


human ×200

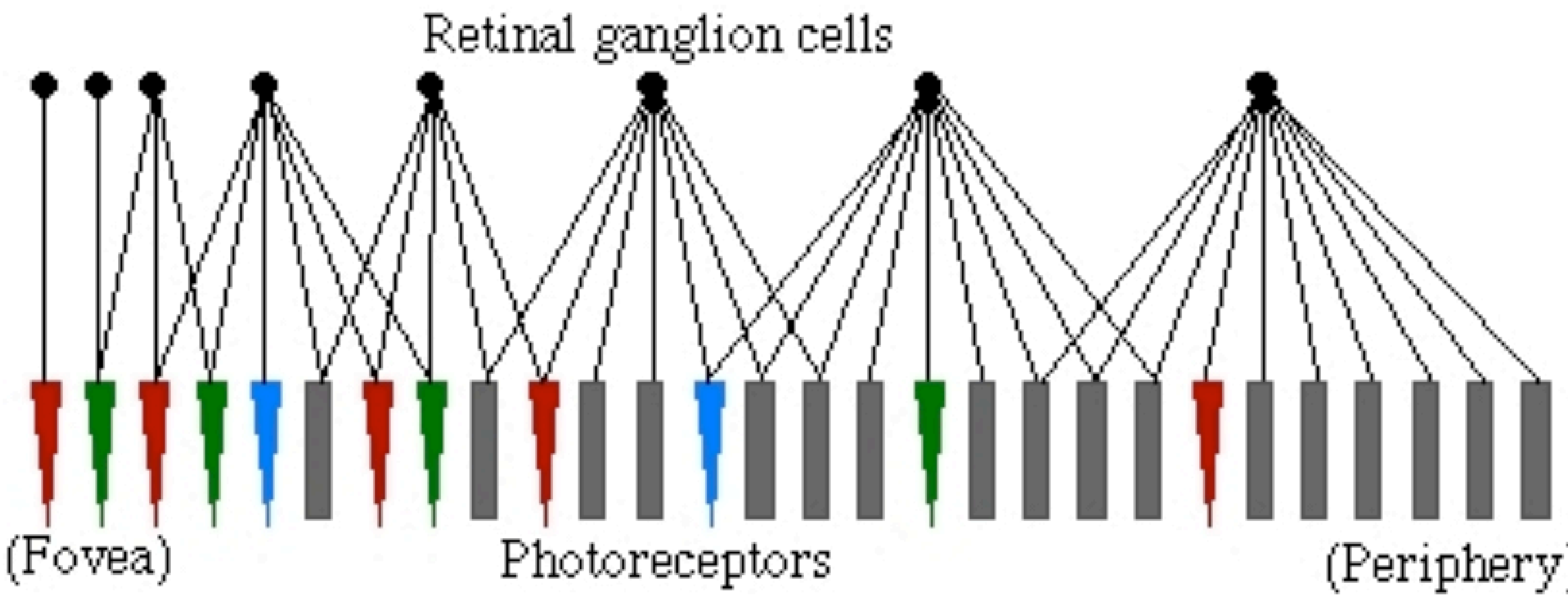
ganglion cells in peripheral retina

Midget ganglion cells receive input from midget bipolar cells.

Ratio is 1:1 in fovea.

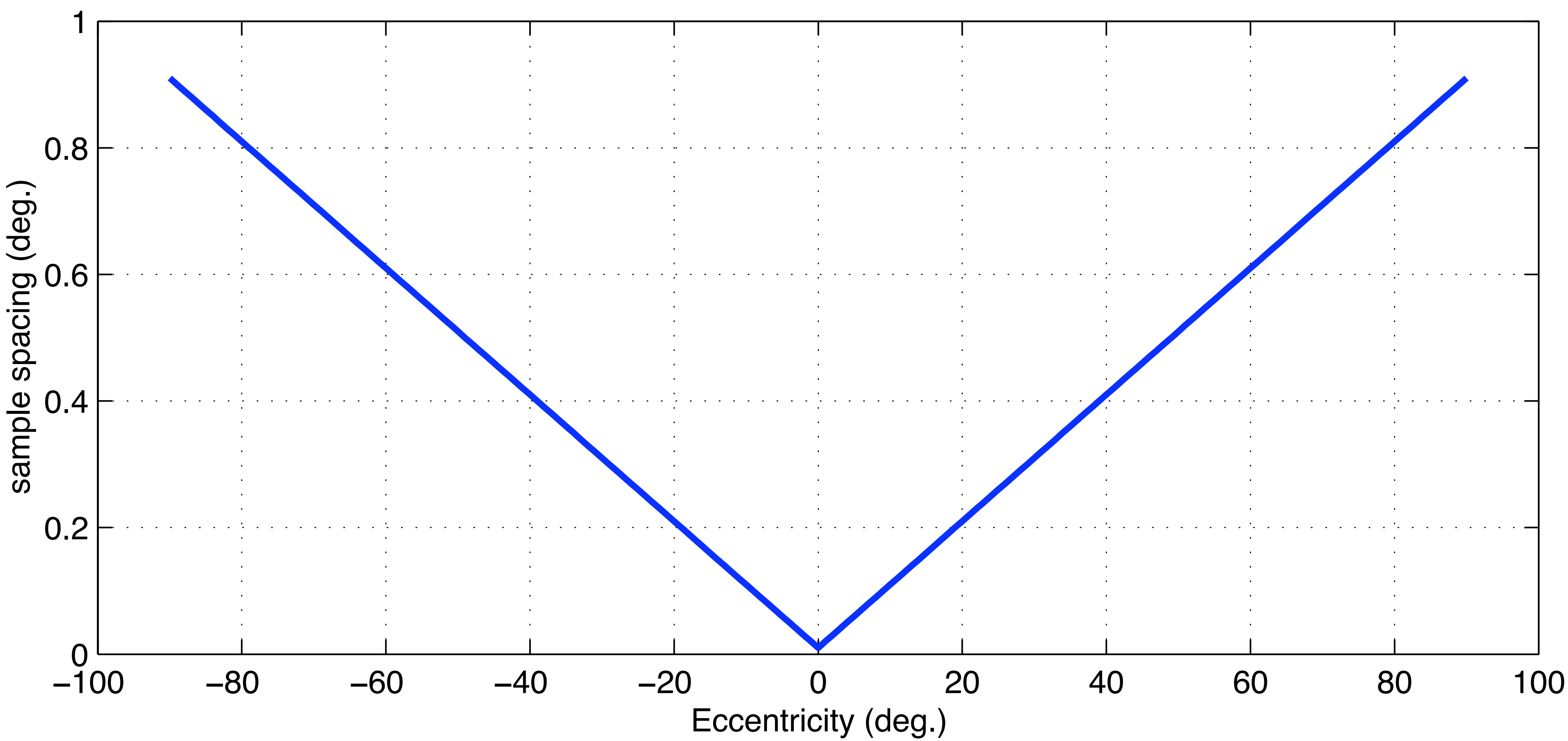


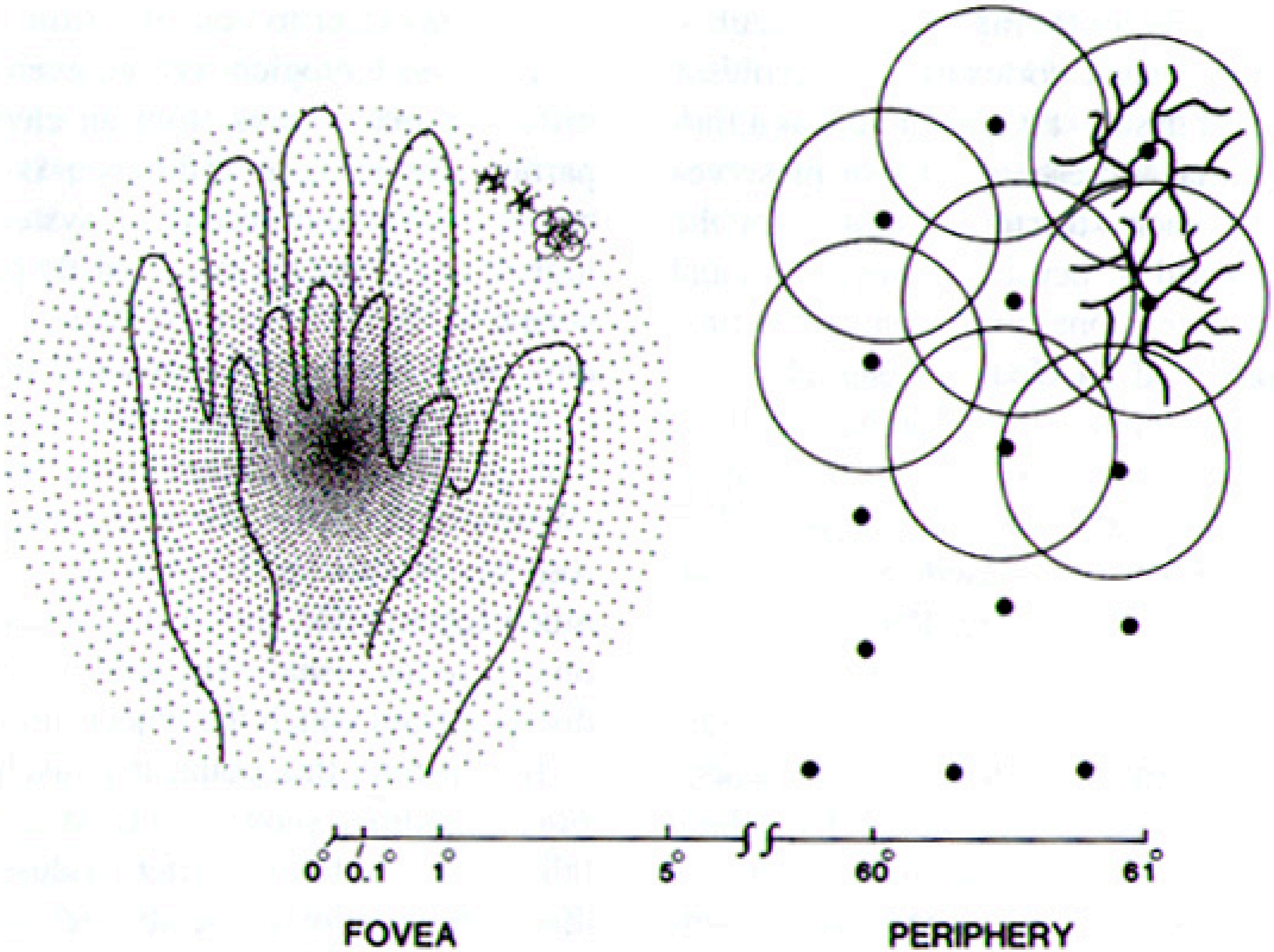
Smoothing and subsampling by retinal ganglion cells



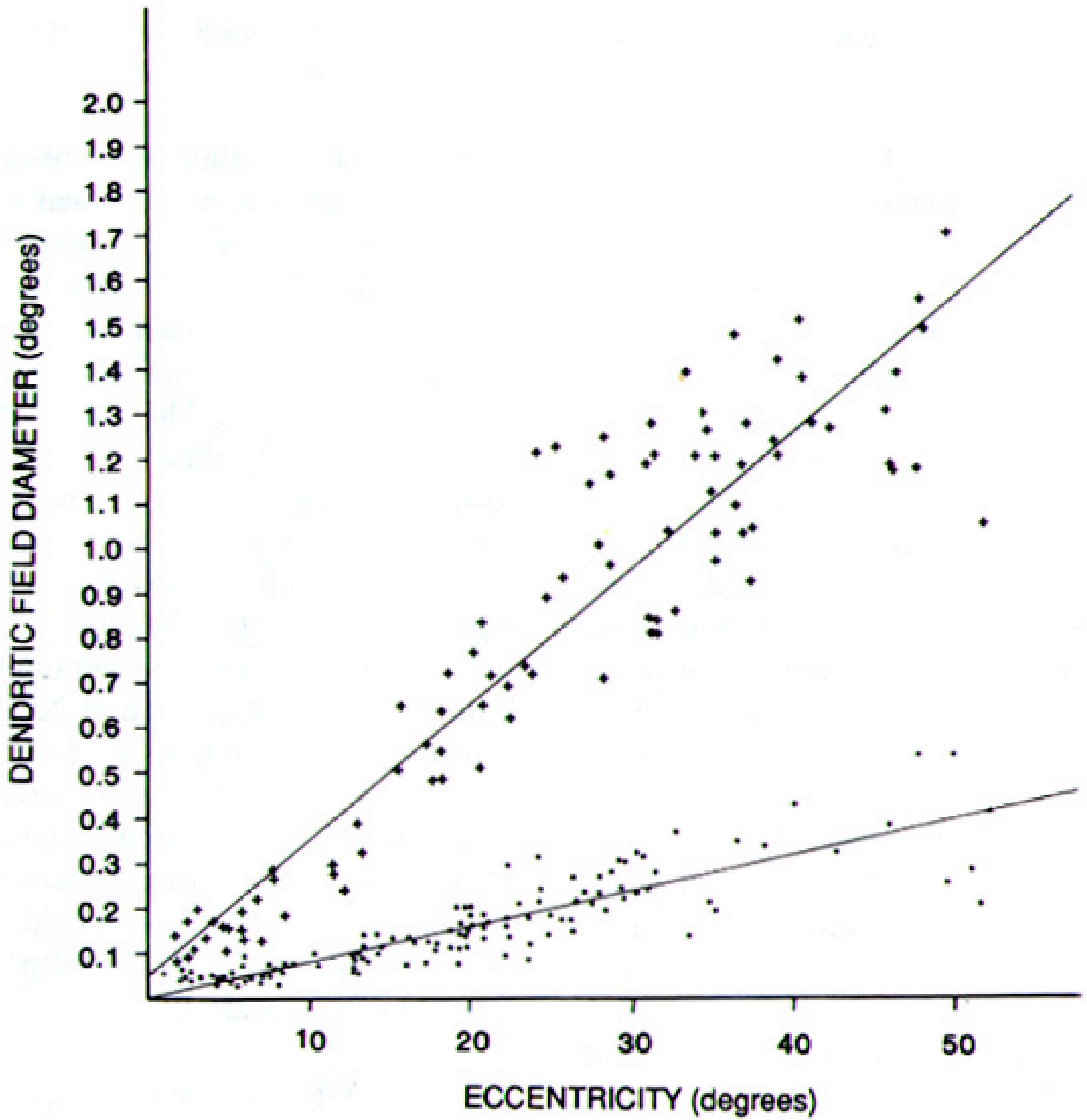
Retinal ganglion cell spacing as a function of eccentricity

$$\Delta E \approx .01(|E| + 1)$$

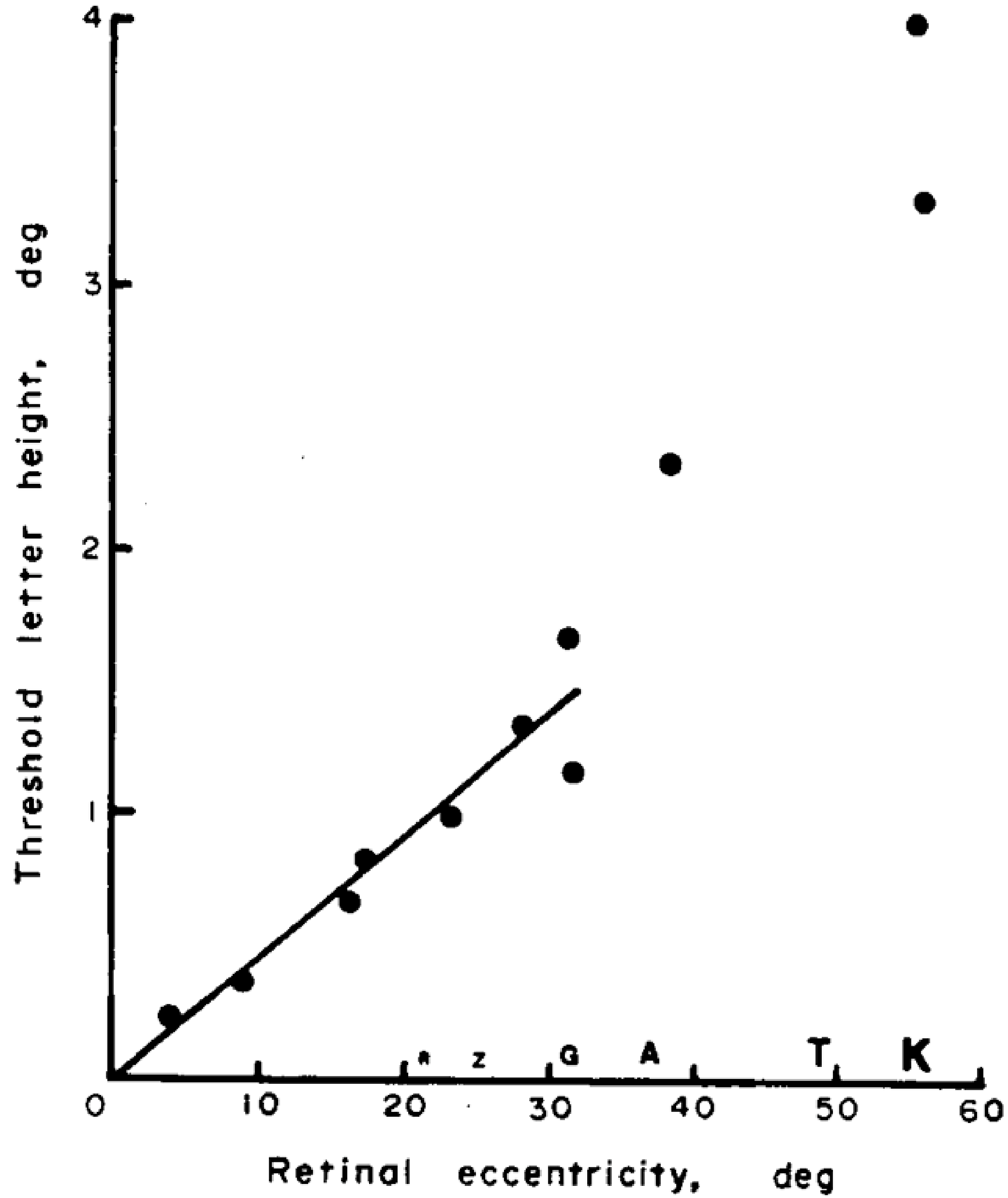



0°
0.1°
1°
5°
60°
61°
FOVEA
PERIPHERY

Dendritic field size as a function of eccentricity



Letter size vs. eccentricity
(Anstis, 1974)



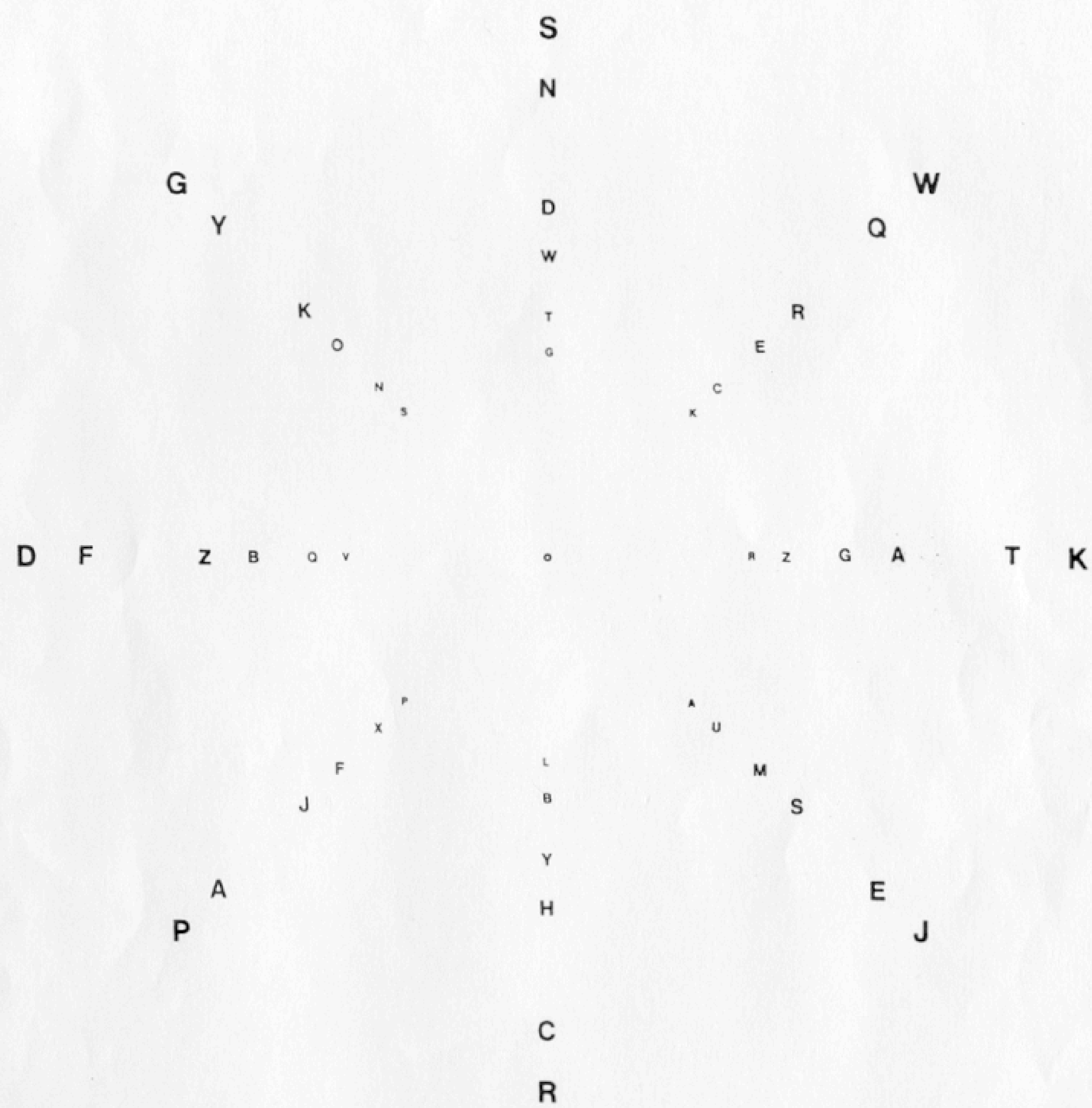


Fig. 2. All letters should lie at threshold when centre of this chart is fixated. Threshold letter size increases linearly with increasing distance from fixation point.

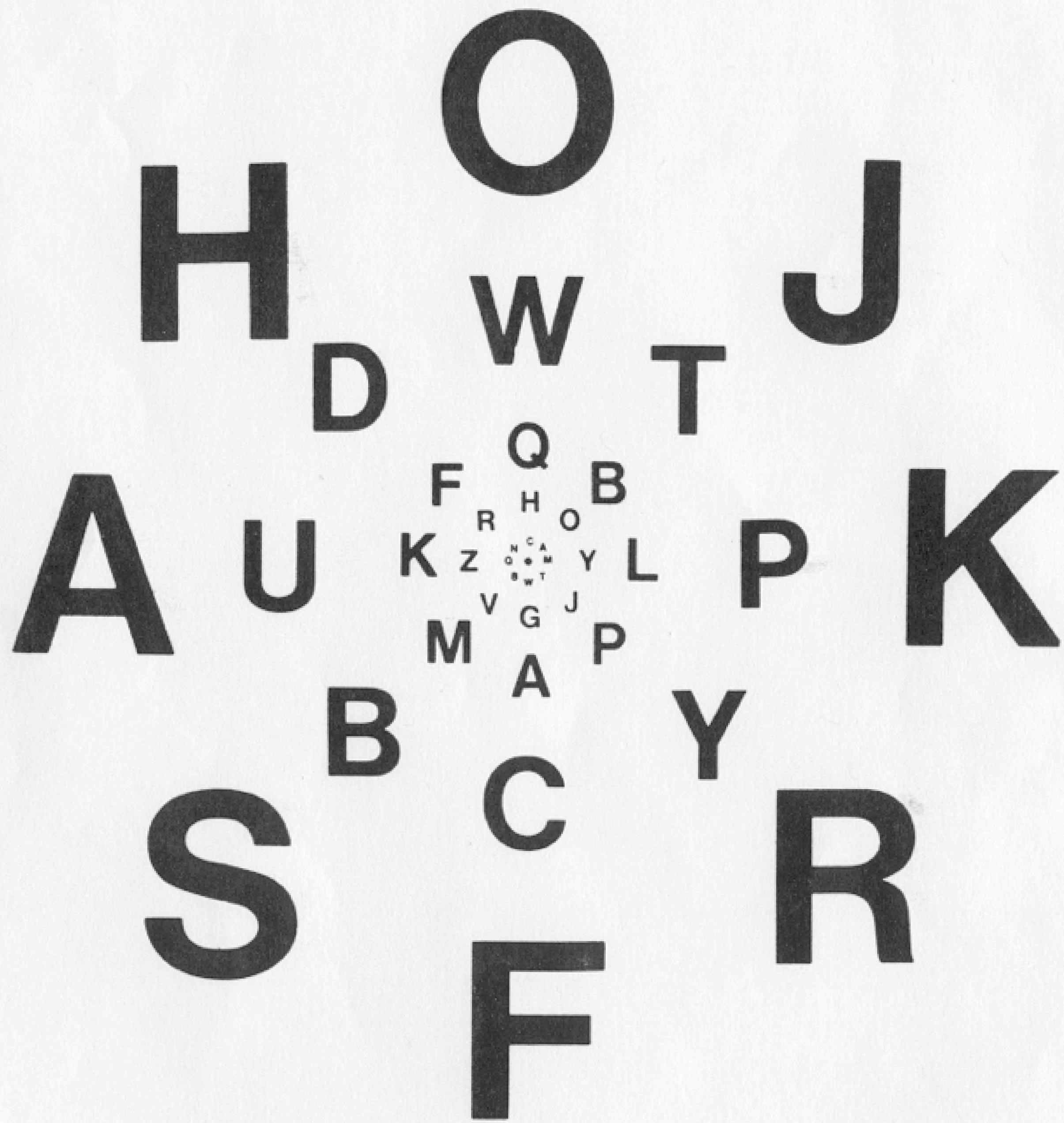
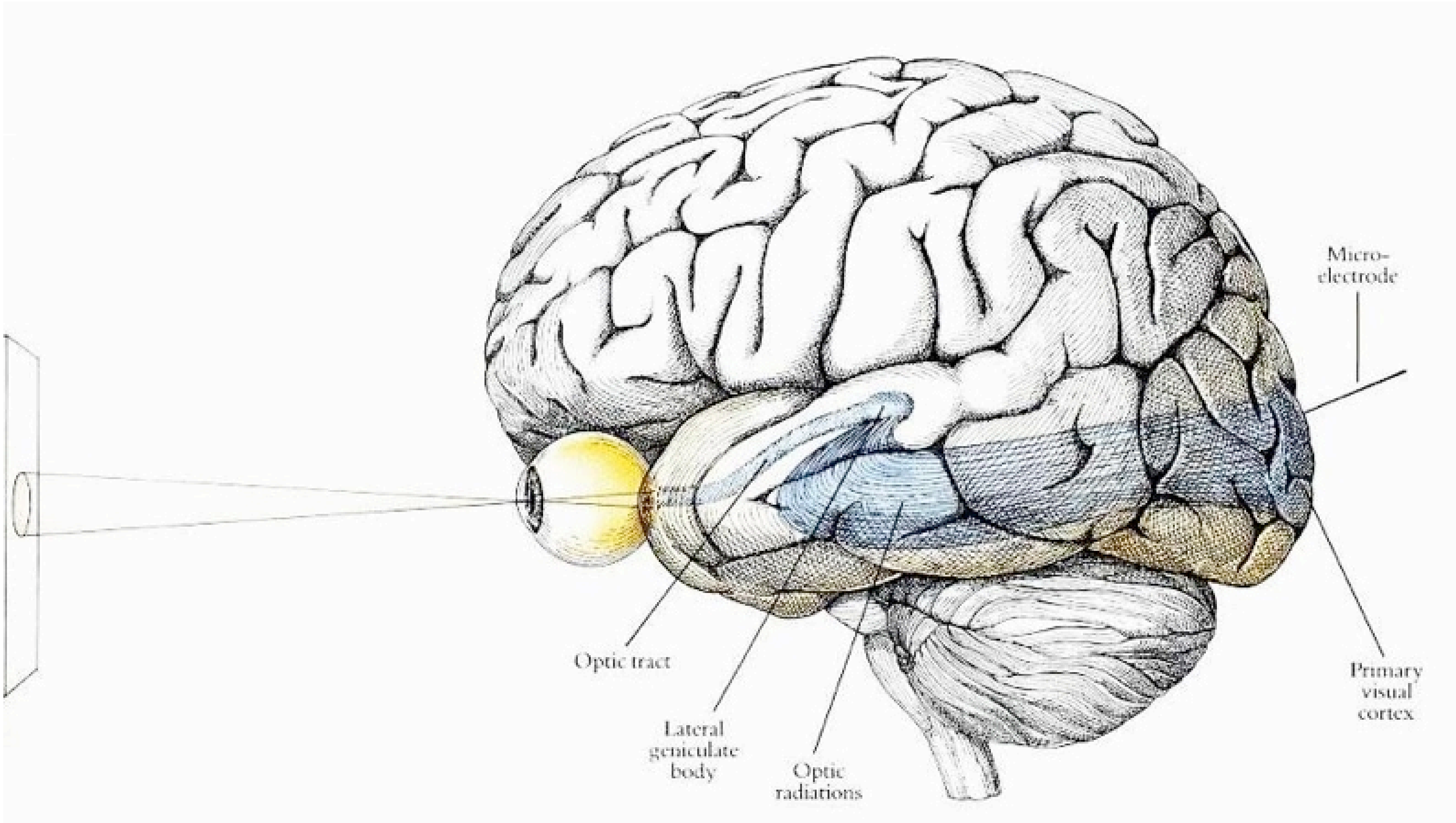
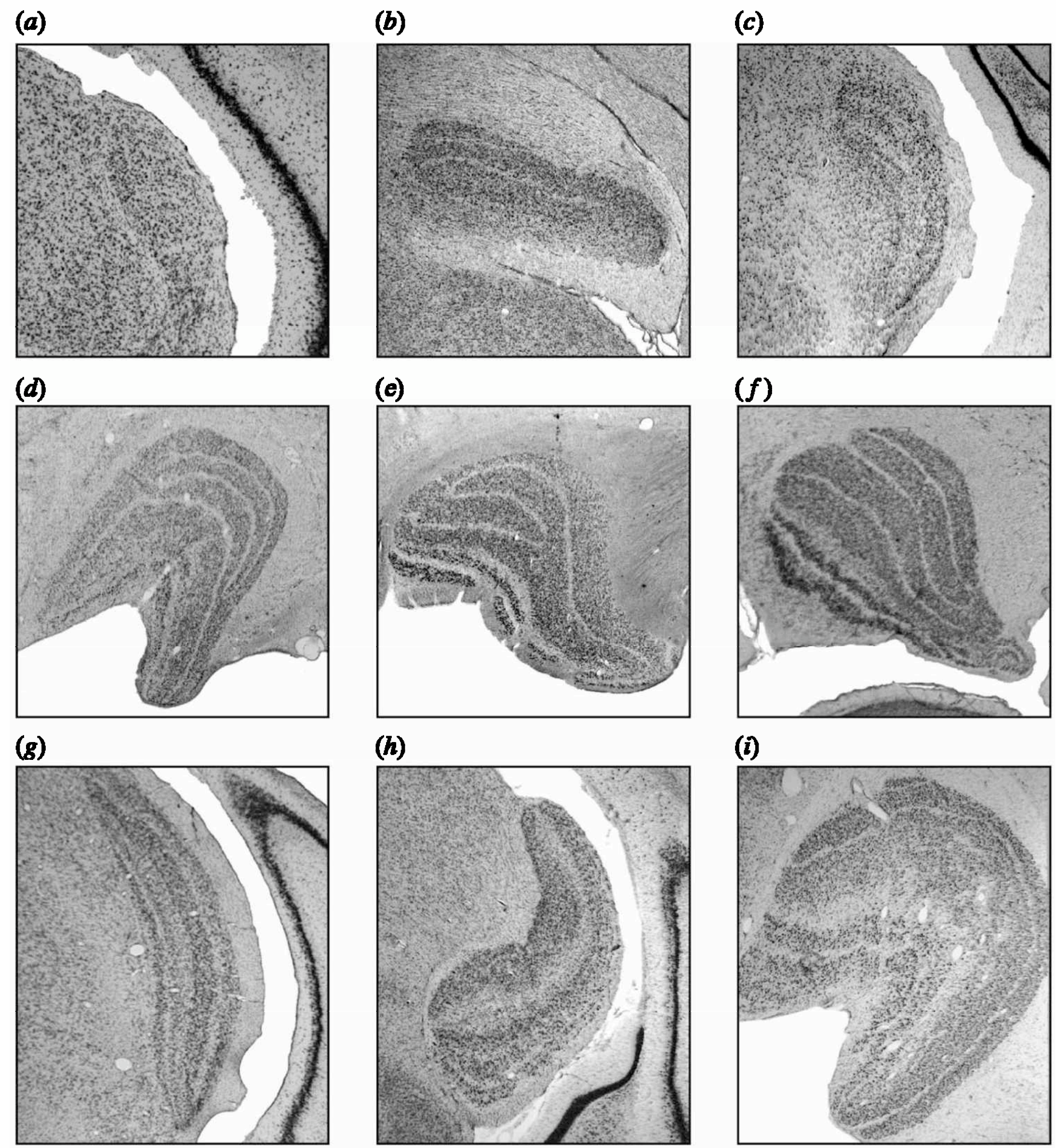


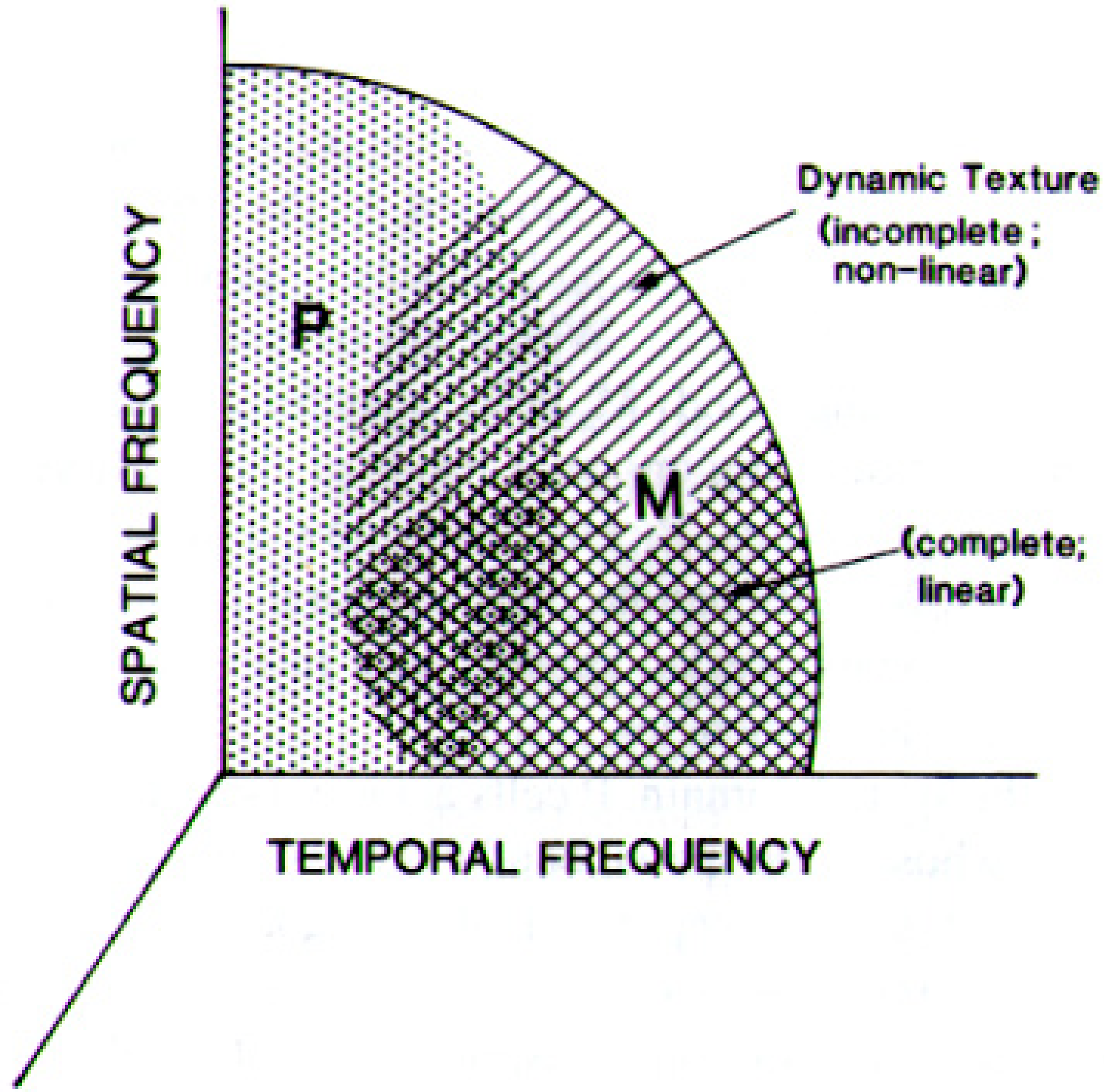
Fig. 3. All letters should be equally readable when centre of this chart is fixated, since each letter is ten times its threshold height.


Micro-
electrode
Optic tract
Lateral
geniculate
body
Optic
radiations
Primary
visual
cortex

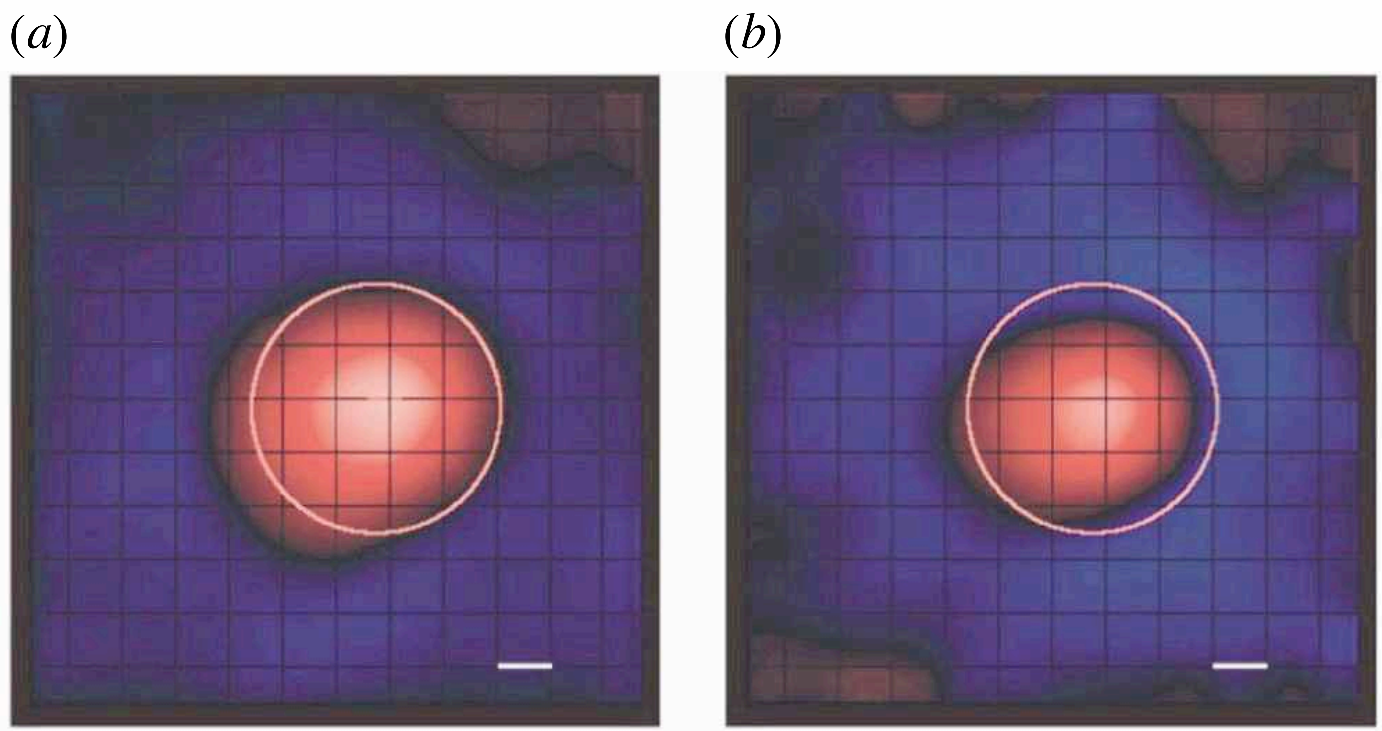
Lateral geniculate nucleus (LGN)



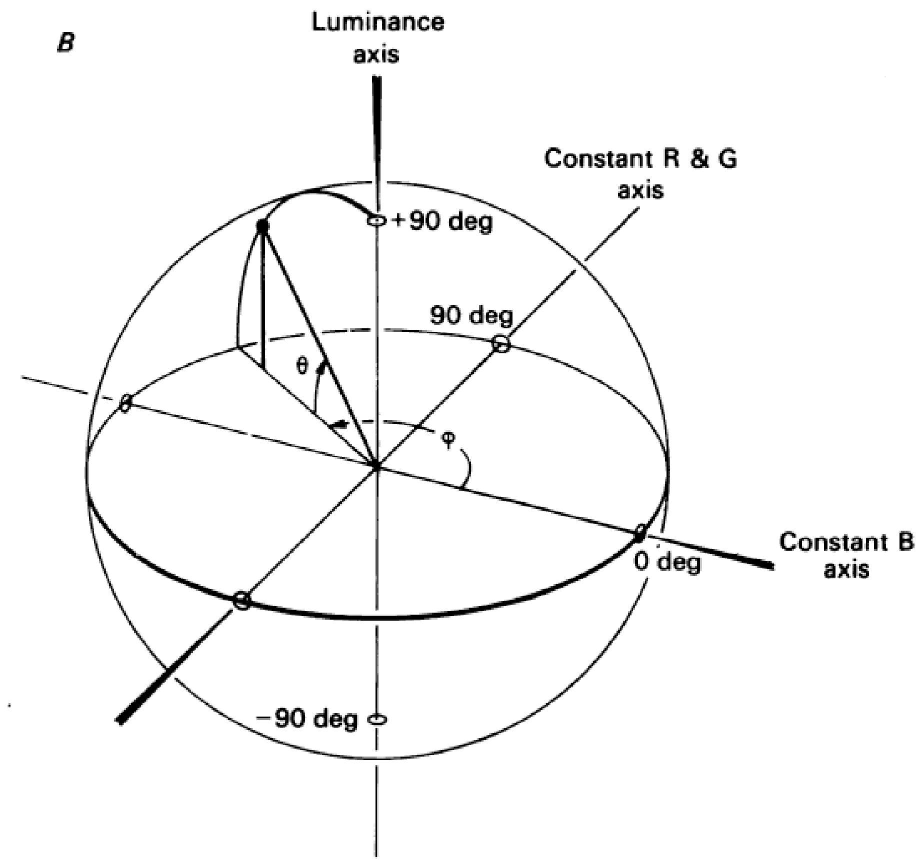
Space-time tiling by parvo- and magno-cells

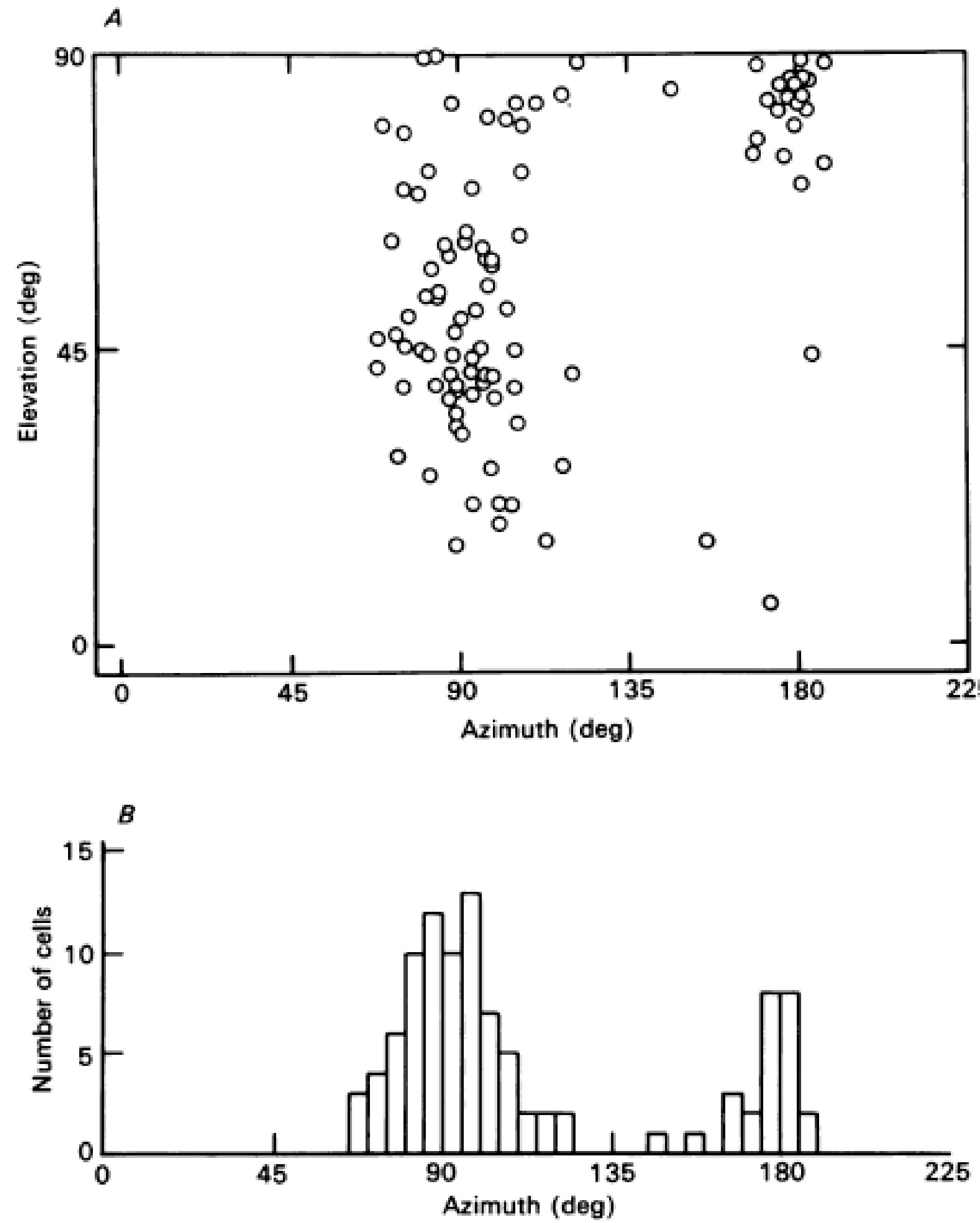


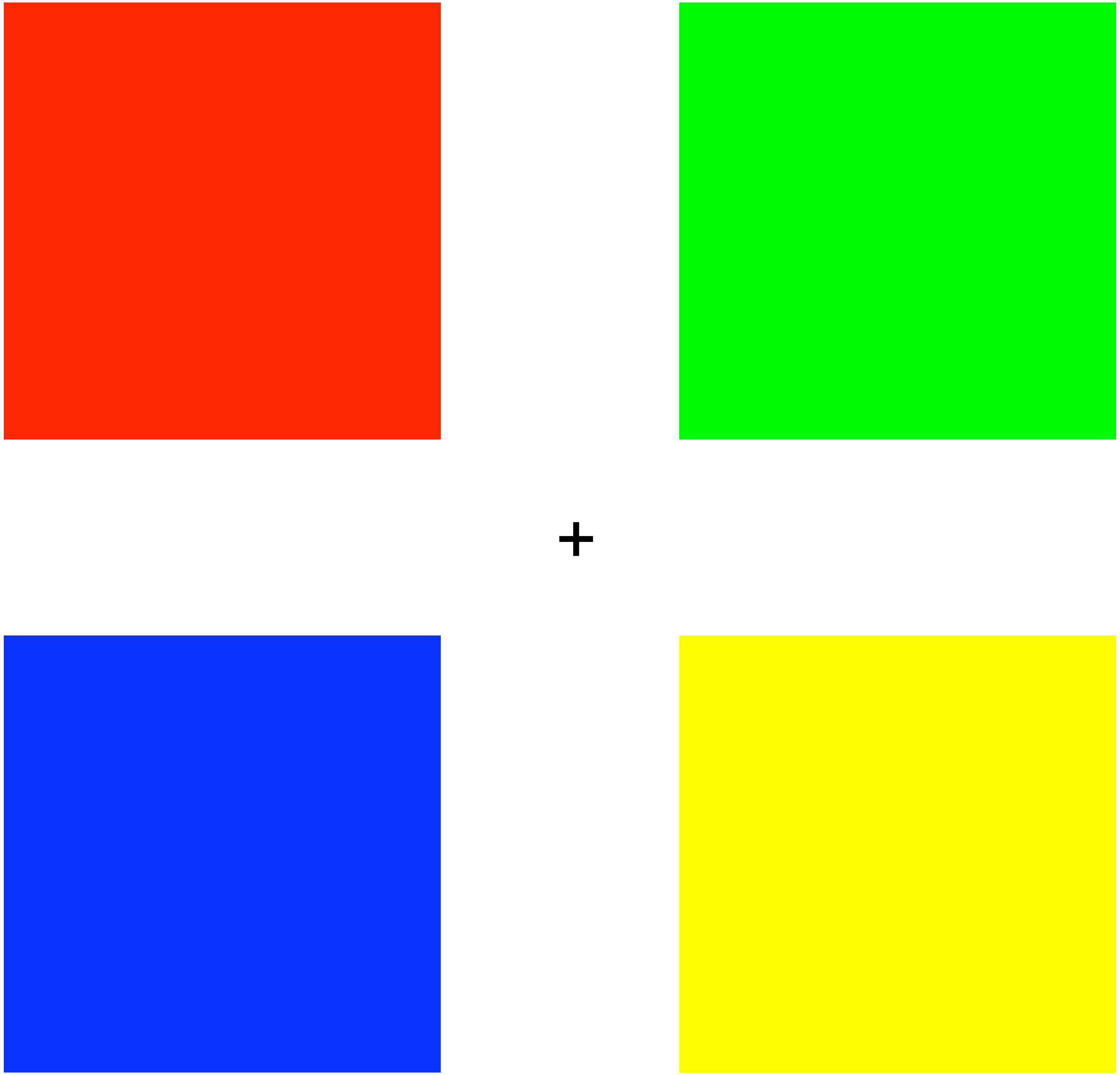
Receptive fields of monosynaptically connected cells in retina (a) and LGN (b) (from Marty Usrey)

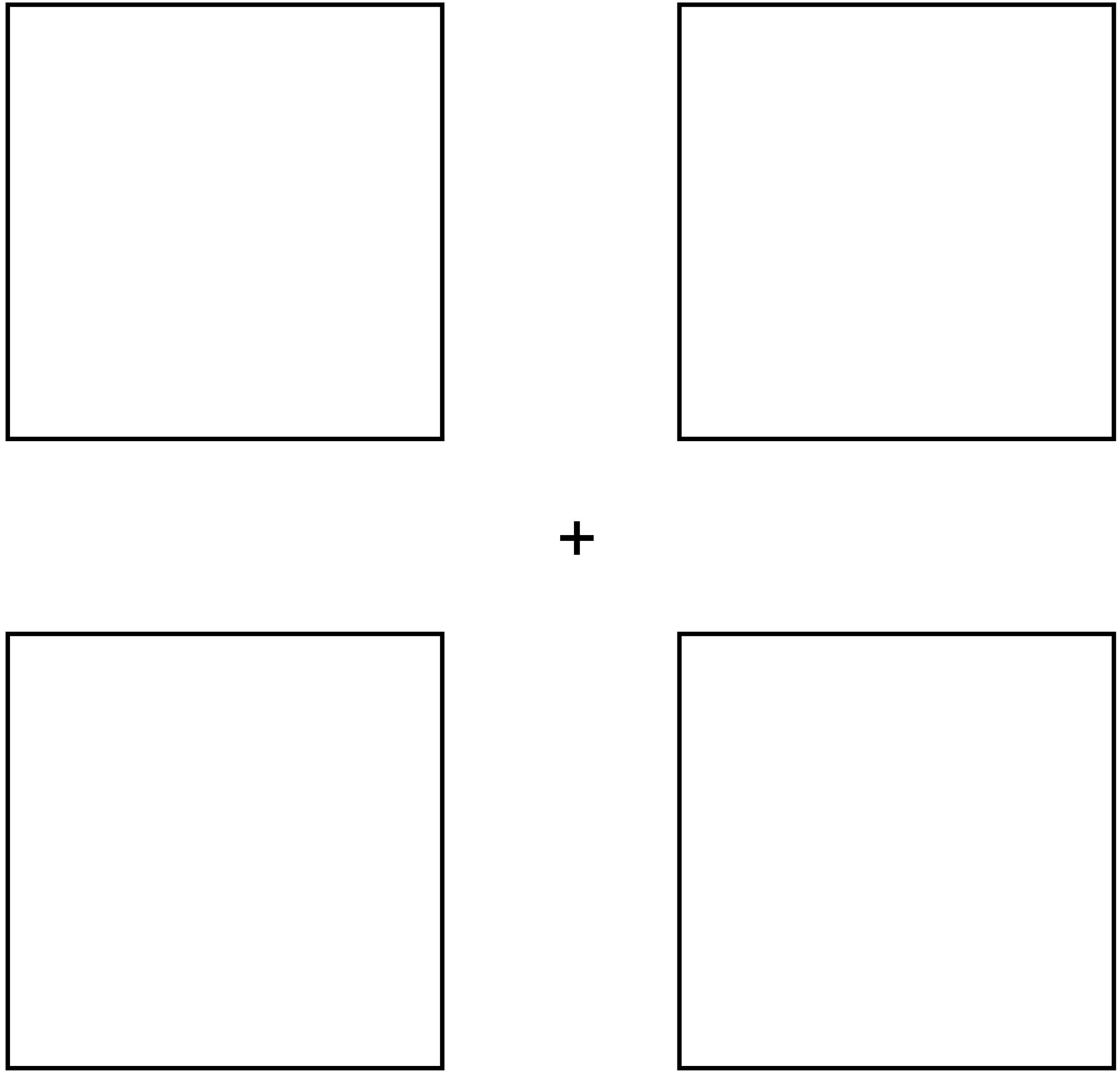


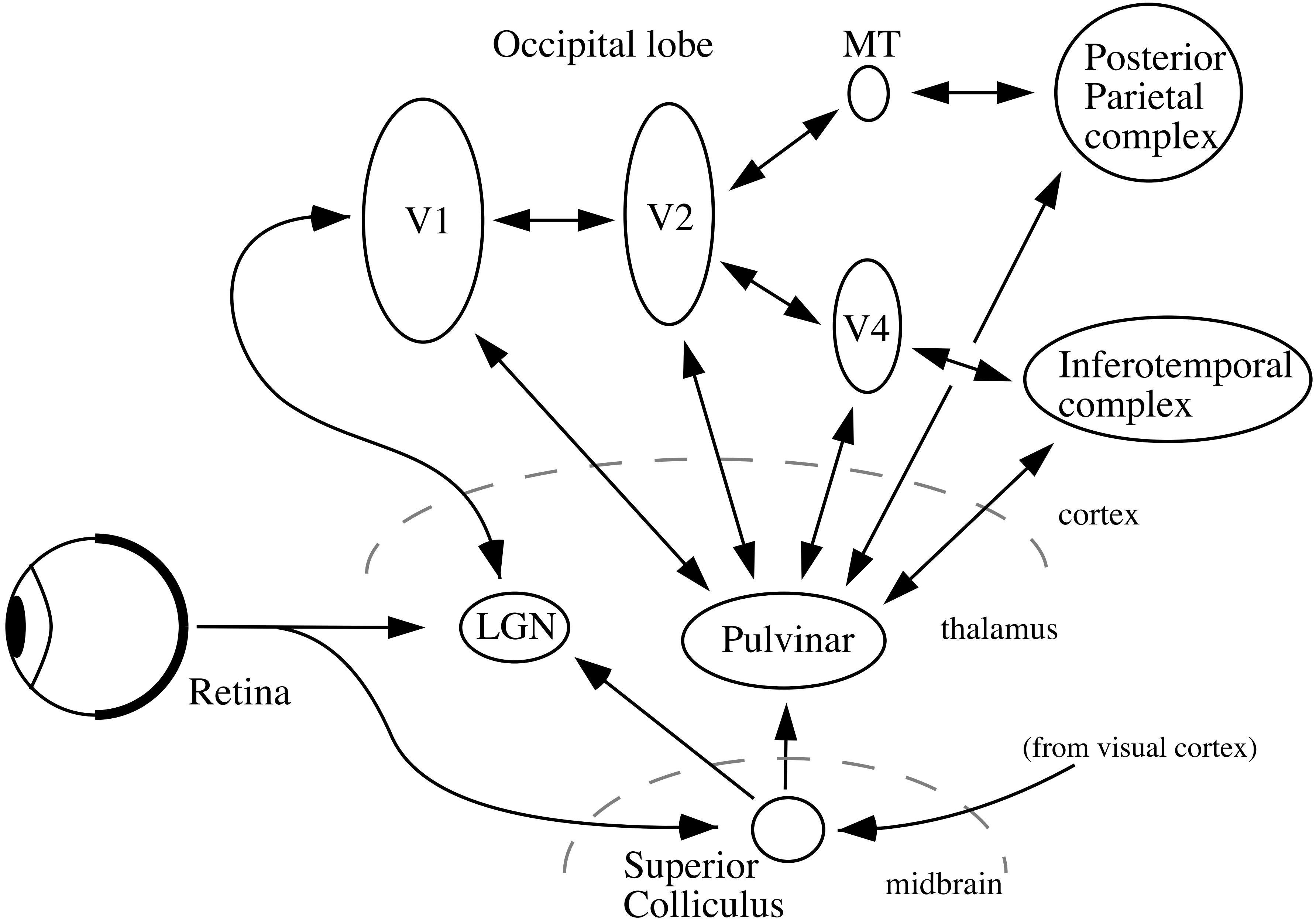
Color opponency in LGN
(Derrington, Krauskopf & Lennie, 1984)





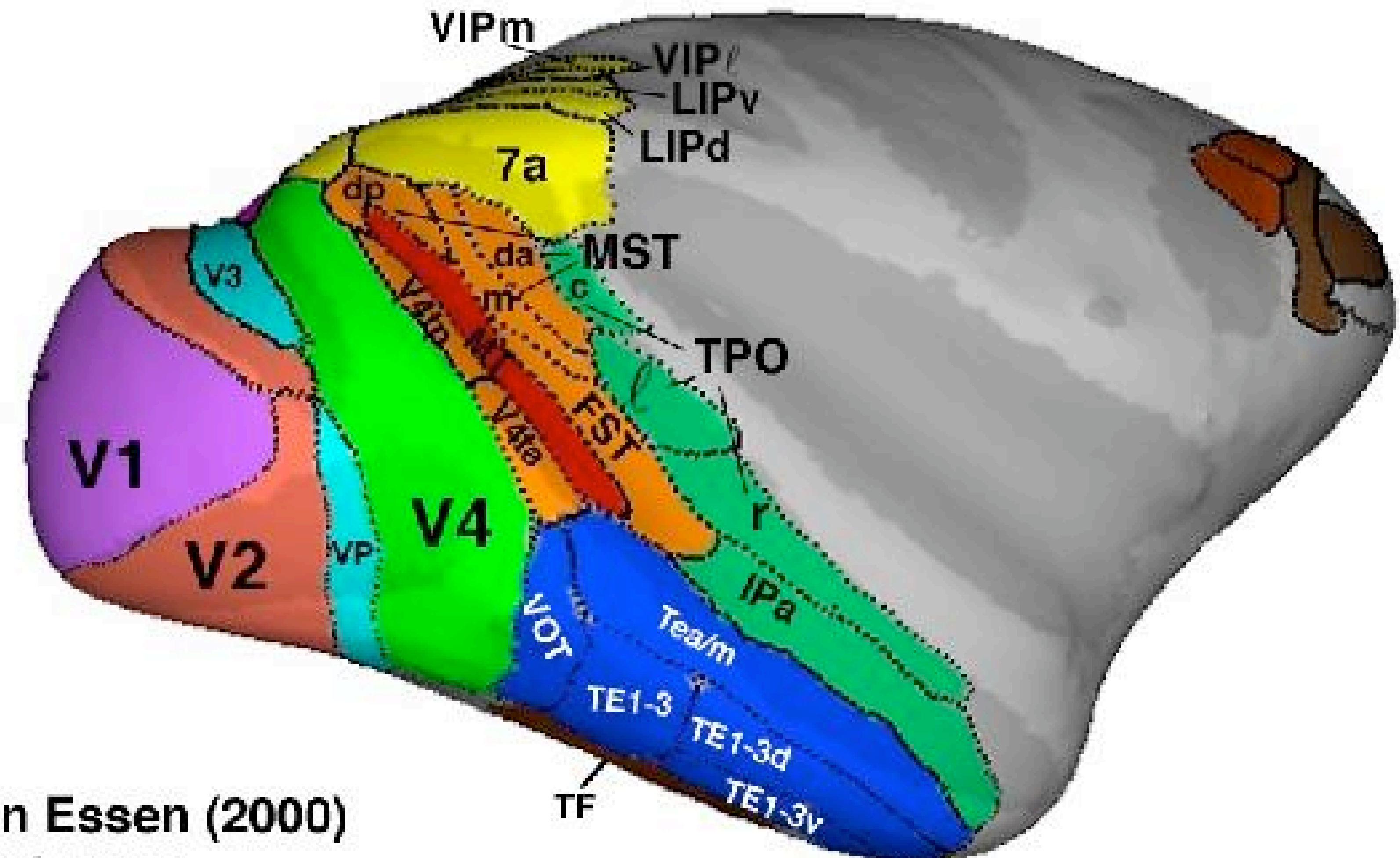






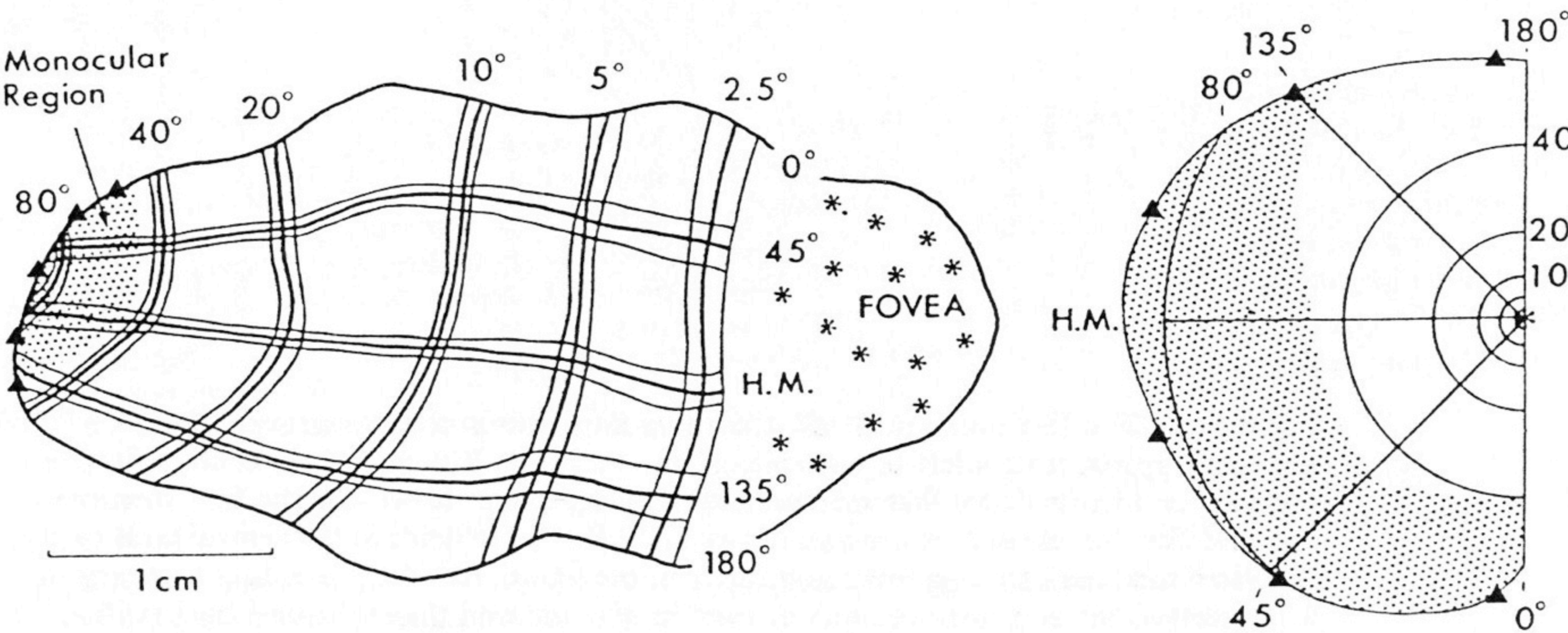
Occipital lobe
MT
Posterior
Parietal
complex
V1
V2
V4
Inferotemporal
complex
cortex
LGN
Pulvinar
thalamus
Retina
(from visual cortex)
Superior
Colliculus
midbrain

Primate visual cortex

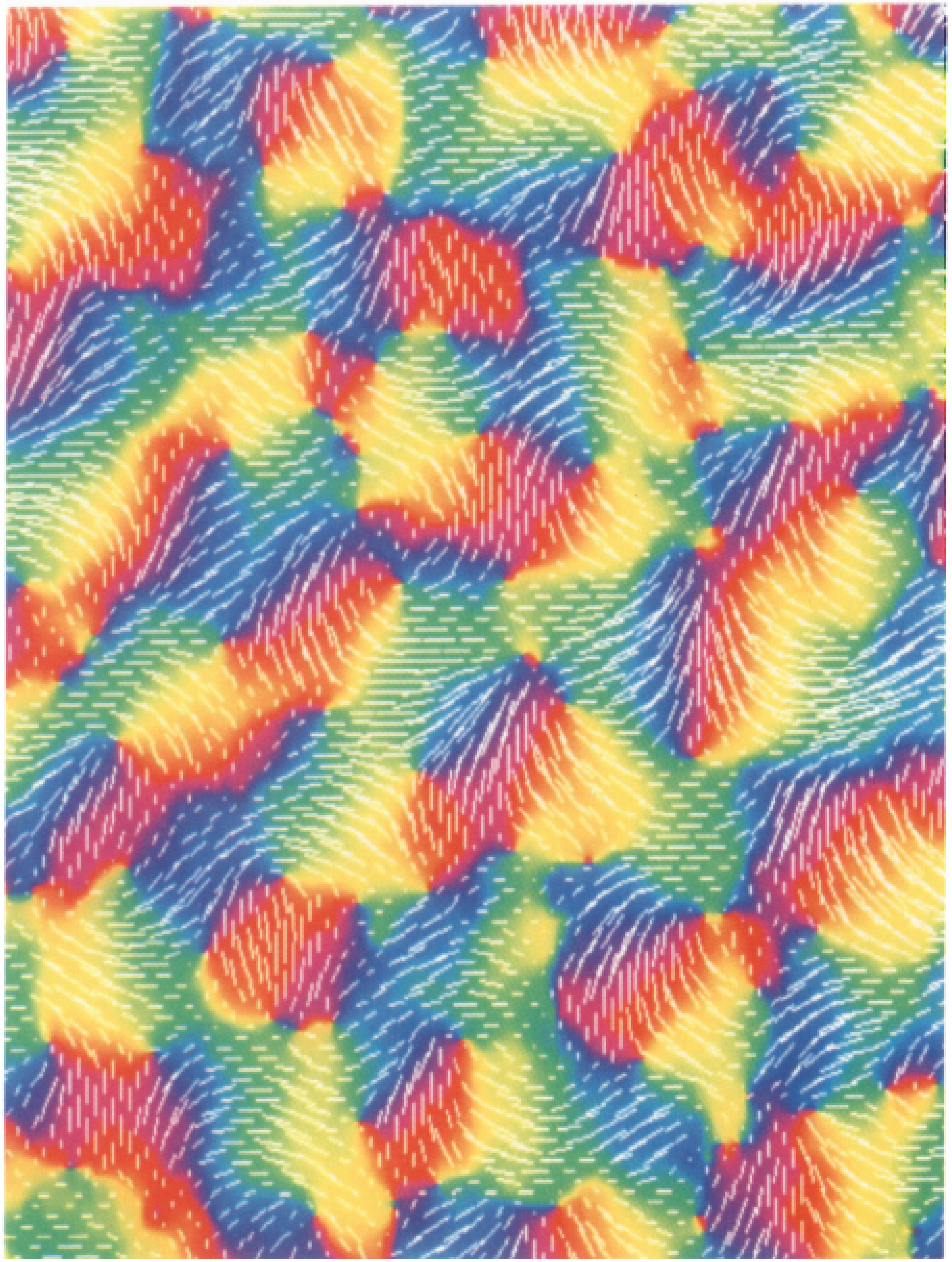


Lewis & Van Essen (2000)
Visual areas

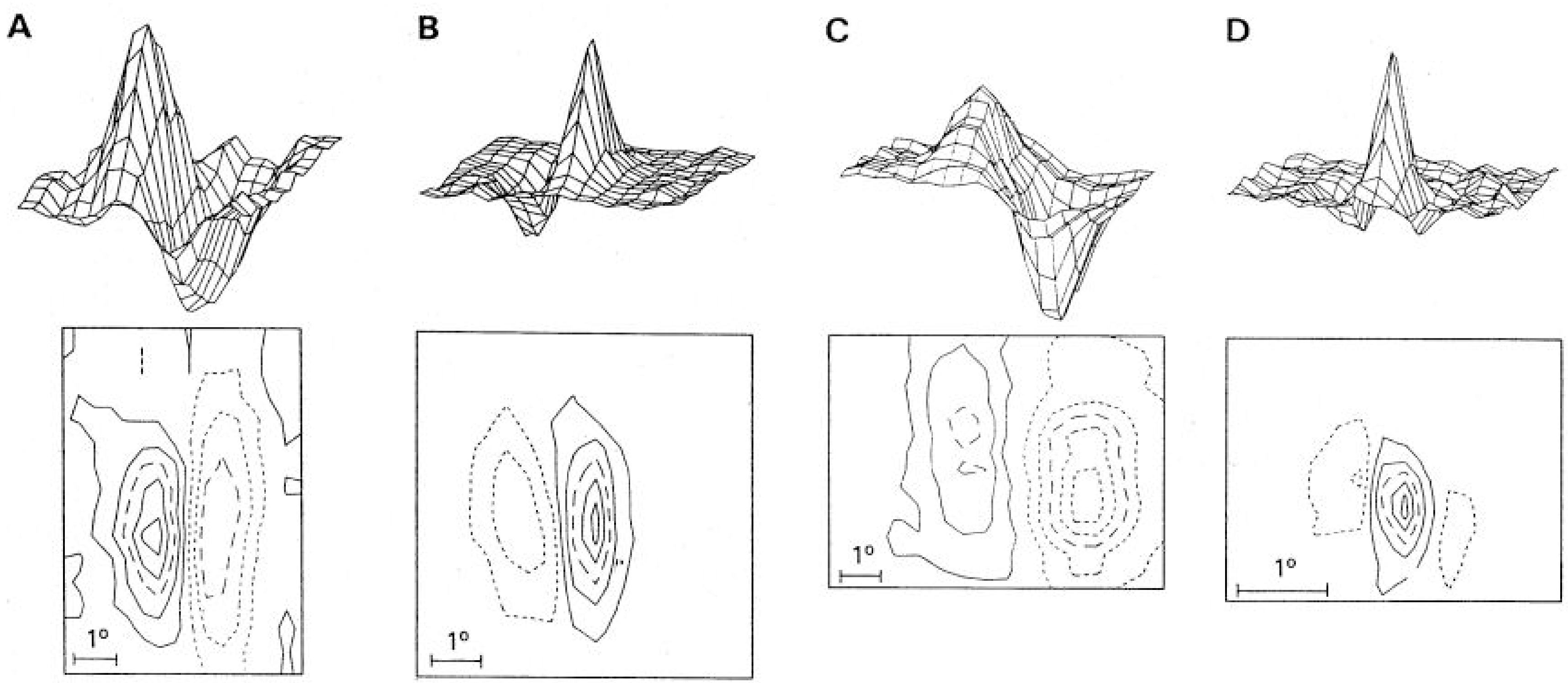
V1 - topographic representation



Orientation columns

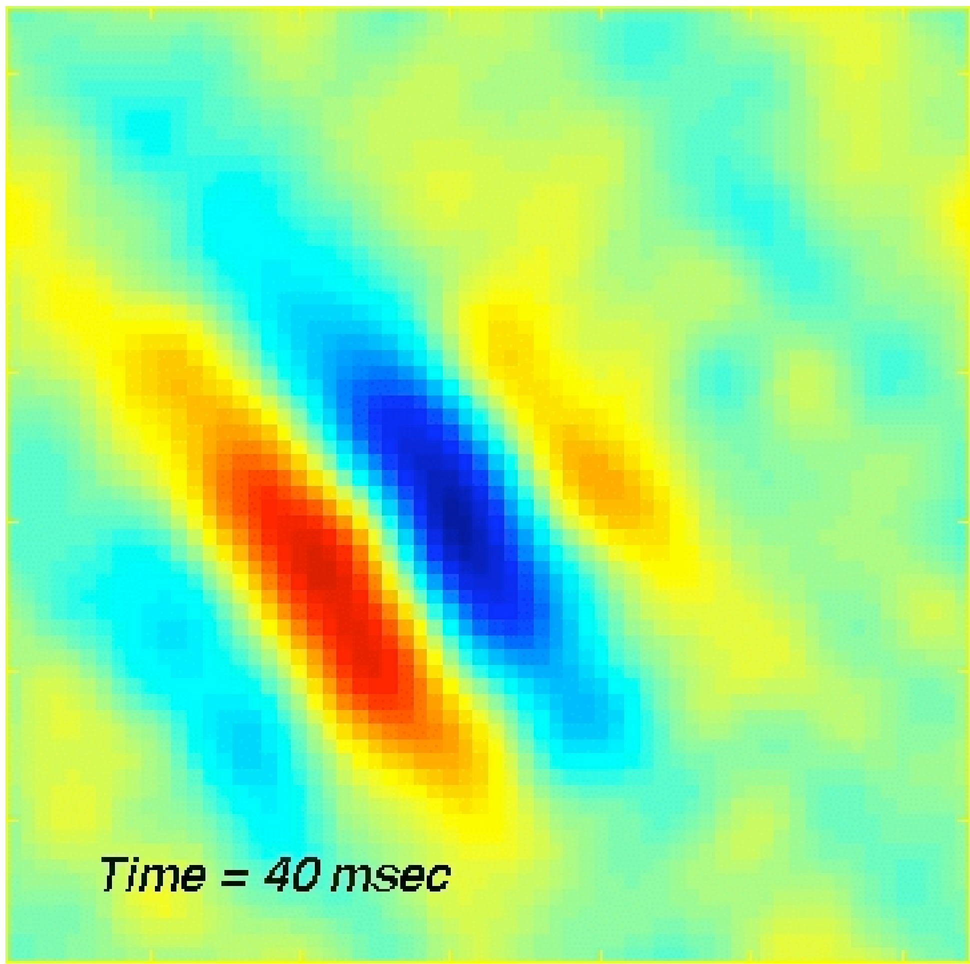


V1 receptive fields - 'simple cells'

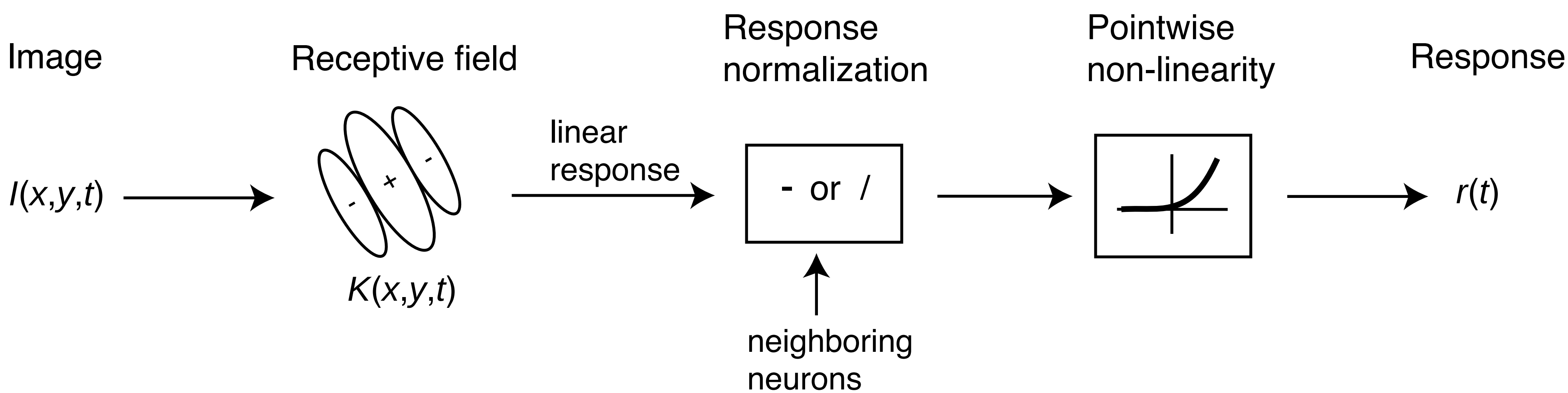


Jones & Palmer (1987)

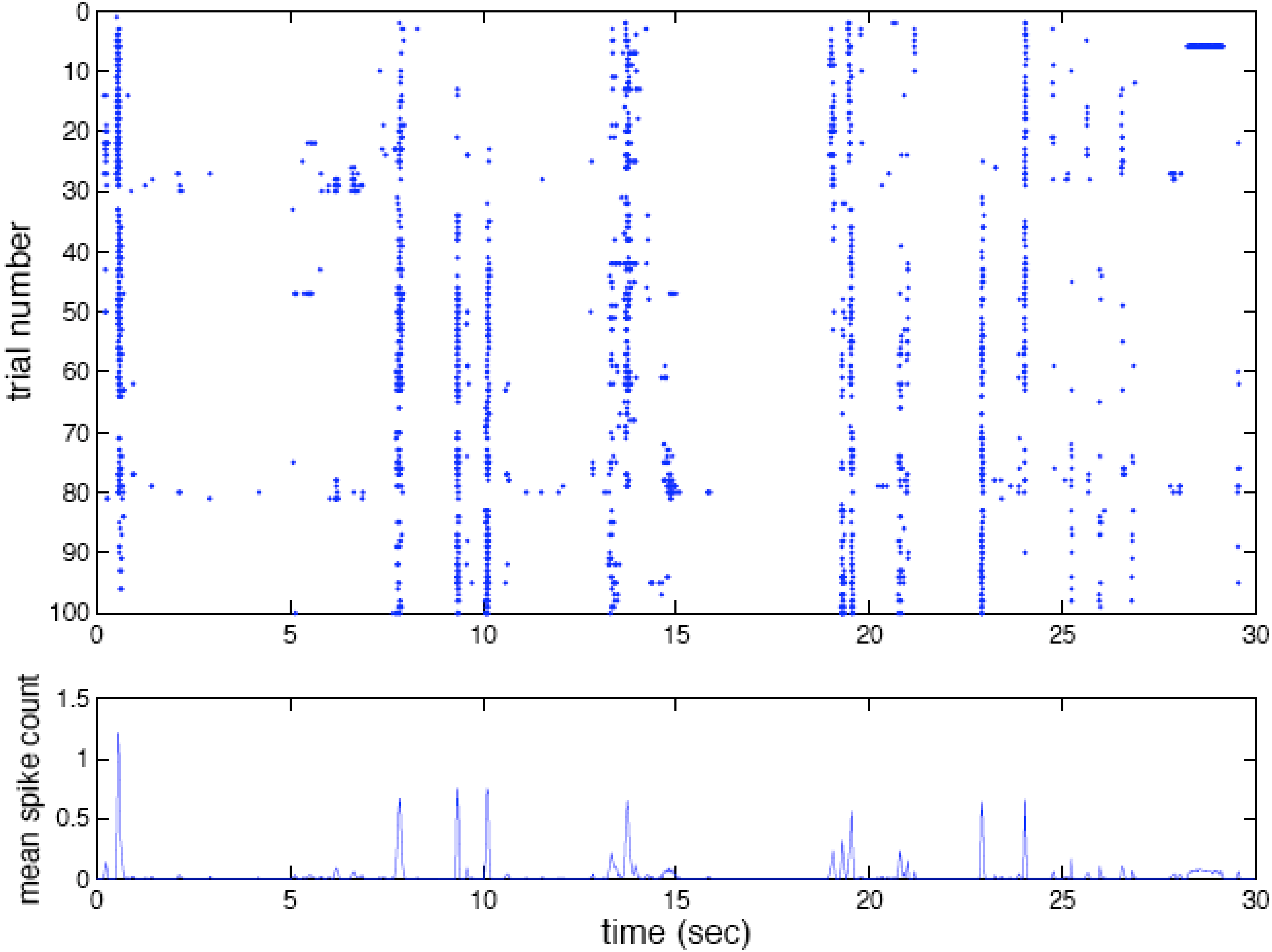
V1 space-time receptive field
(Courtesy of Dario Ringach, UCLA)



The "standard model" of V1

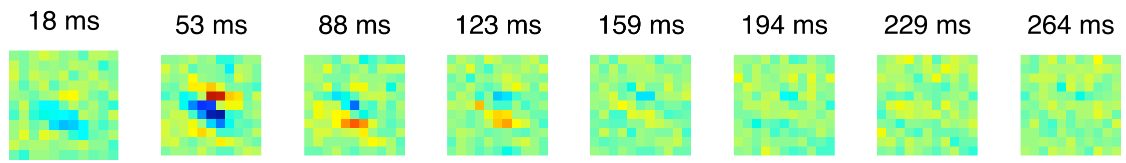


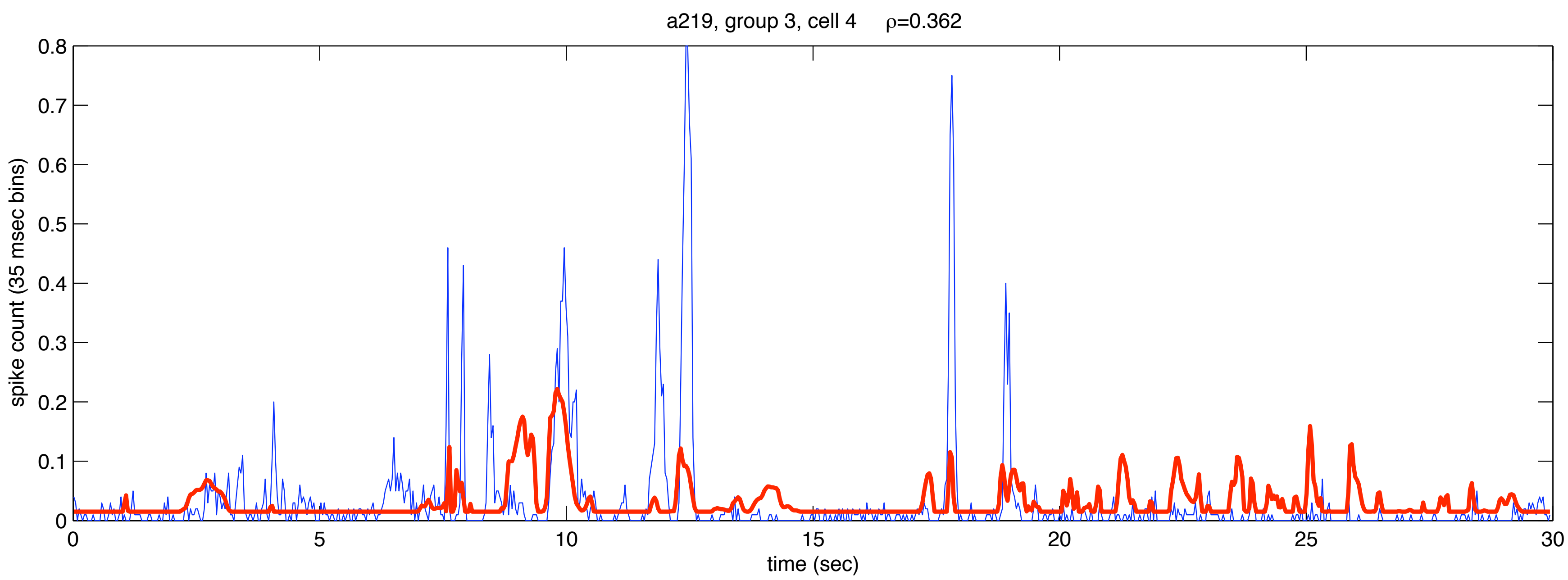
Cat V1 - natural movies (J. Baker, S.C. Yen, C.M. Gray, MSU Bozeman)



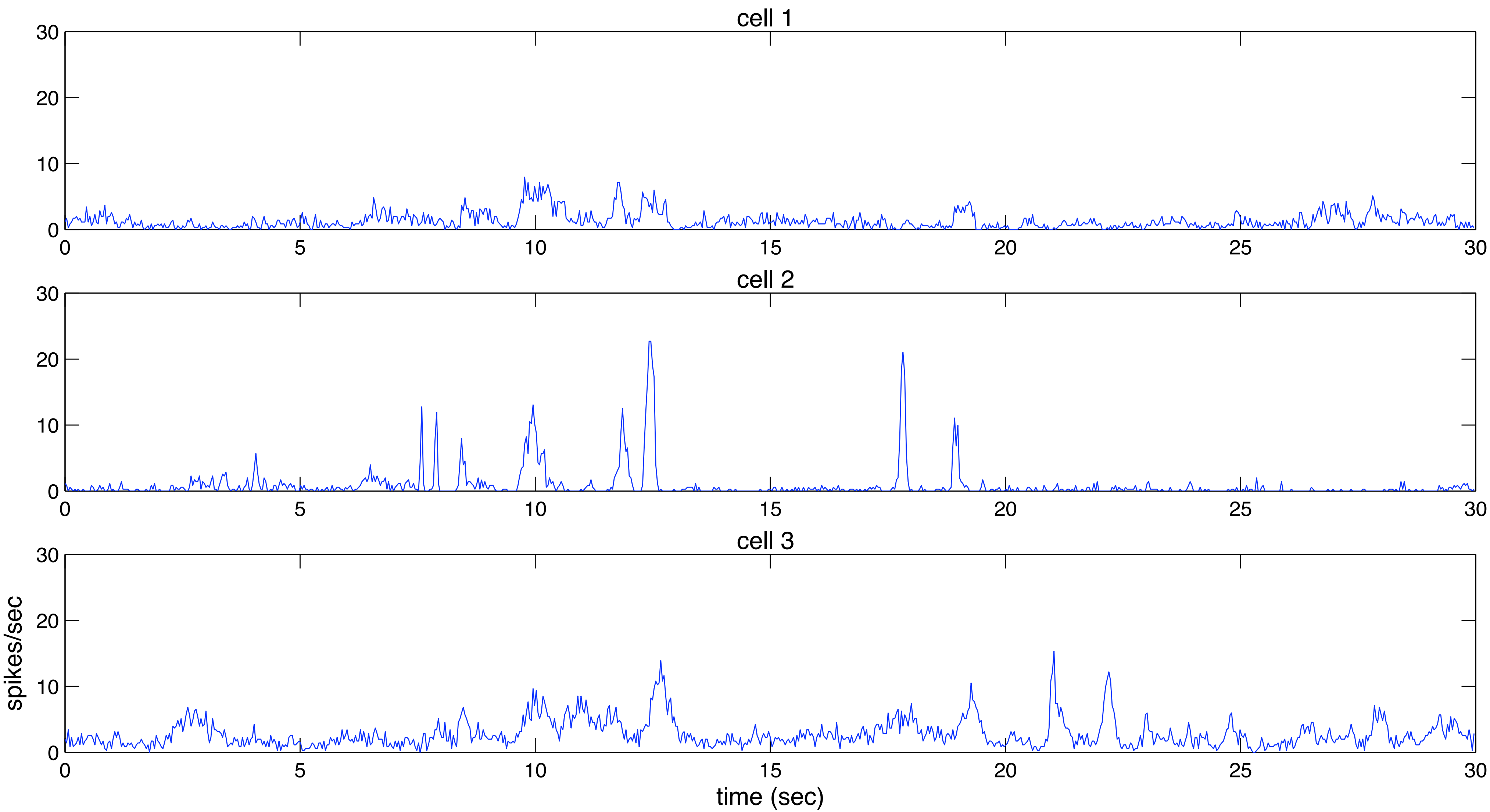
Responses of V1 neurons are not well predicted by RF models

receptive field:





Responses of neighboring cells are heterogeneous

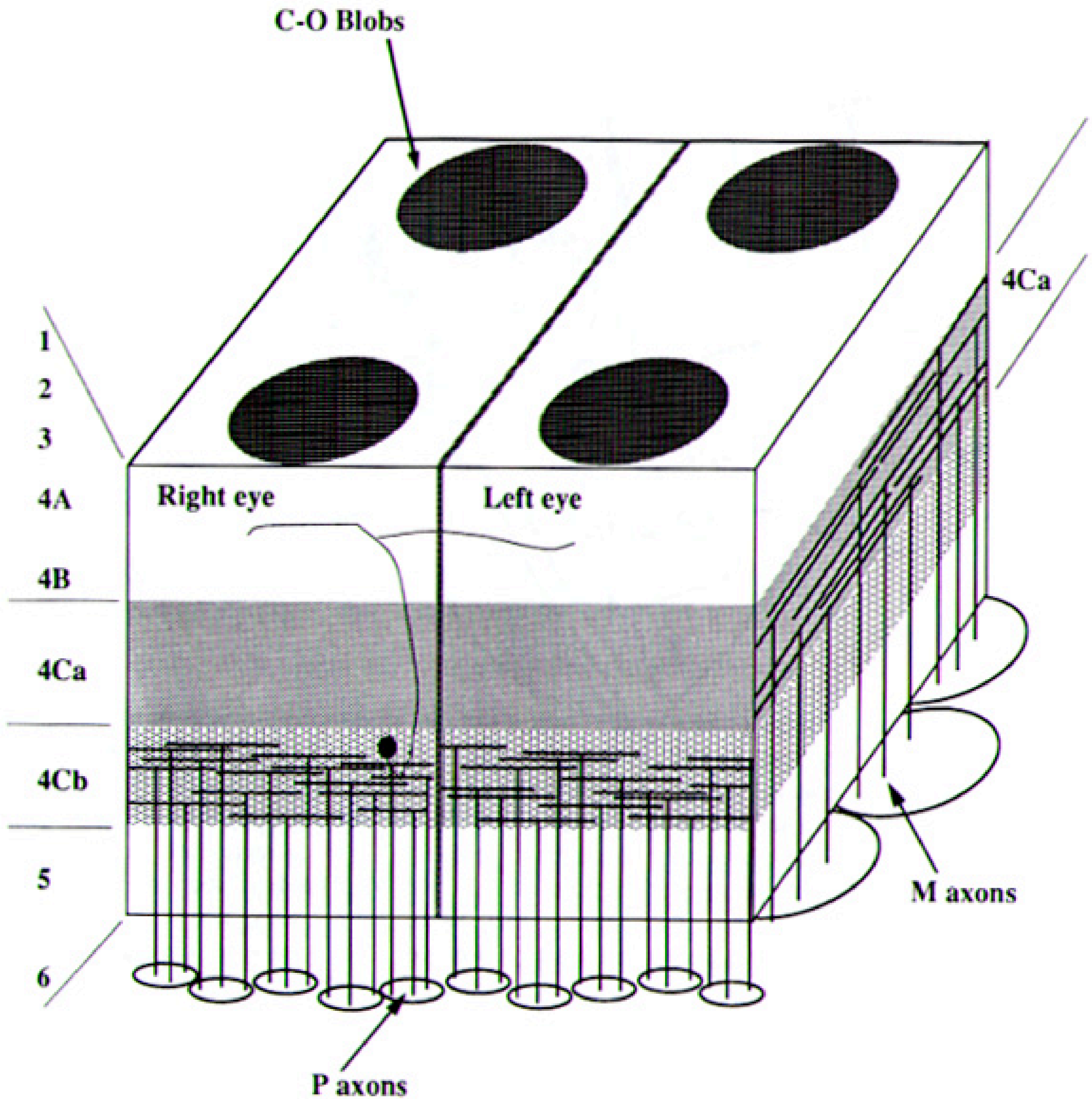


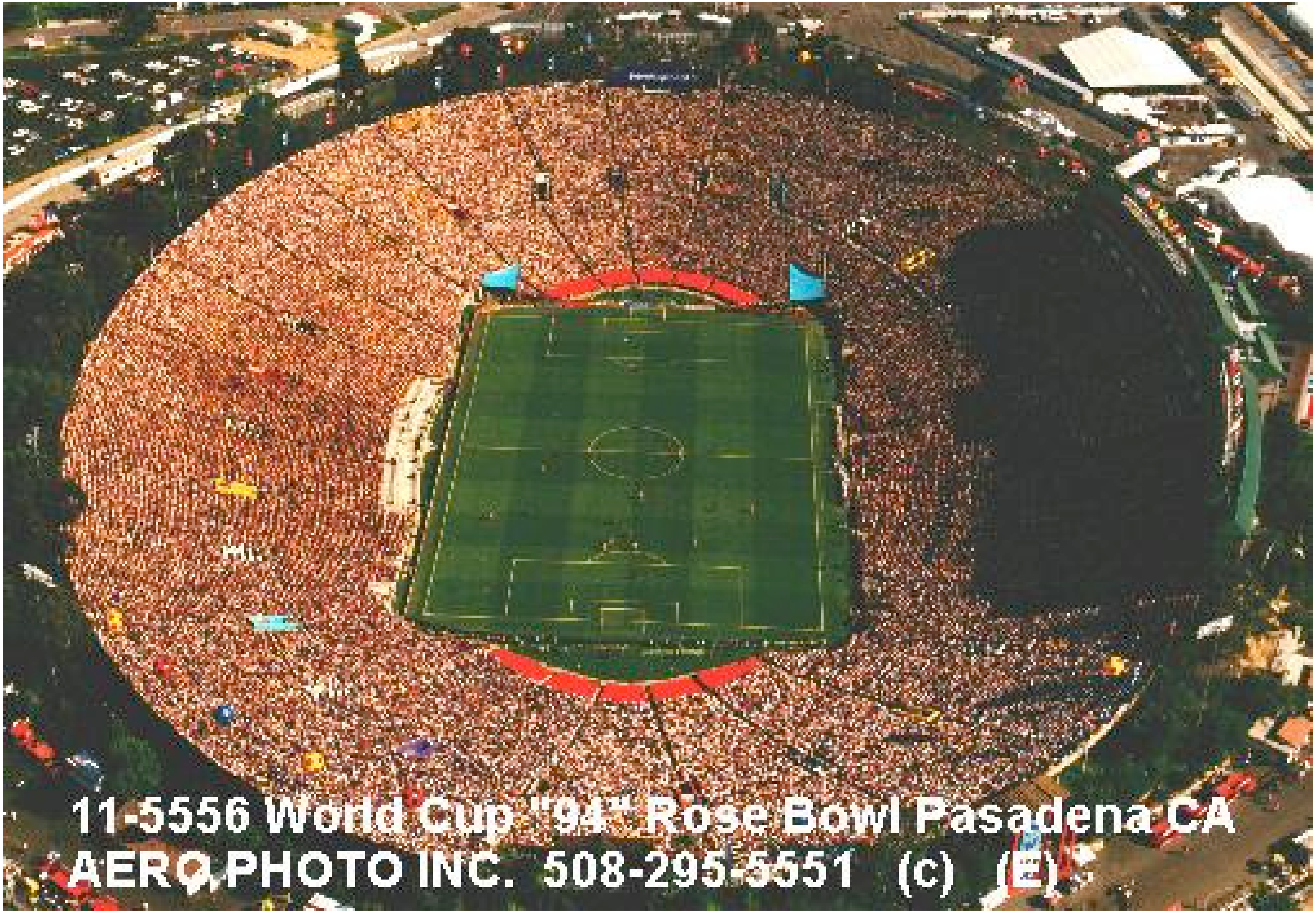
Five problems with the current view of V1

- Biased sampling (single unit recording)
- Biased stimuli (bars, spots, gratings)
- Biased theories (data-driven vs. functional theories)
- Interdependence and context (effect of intra-cortical inputs)
- Ecological deviance

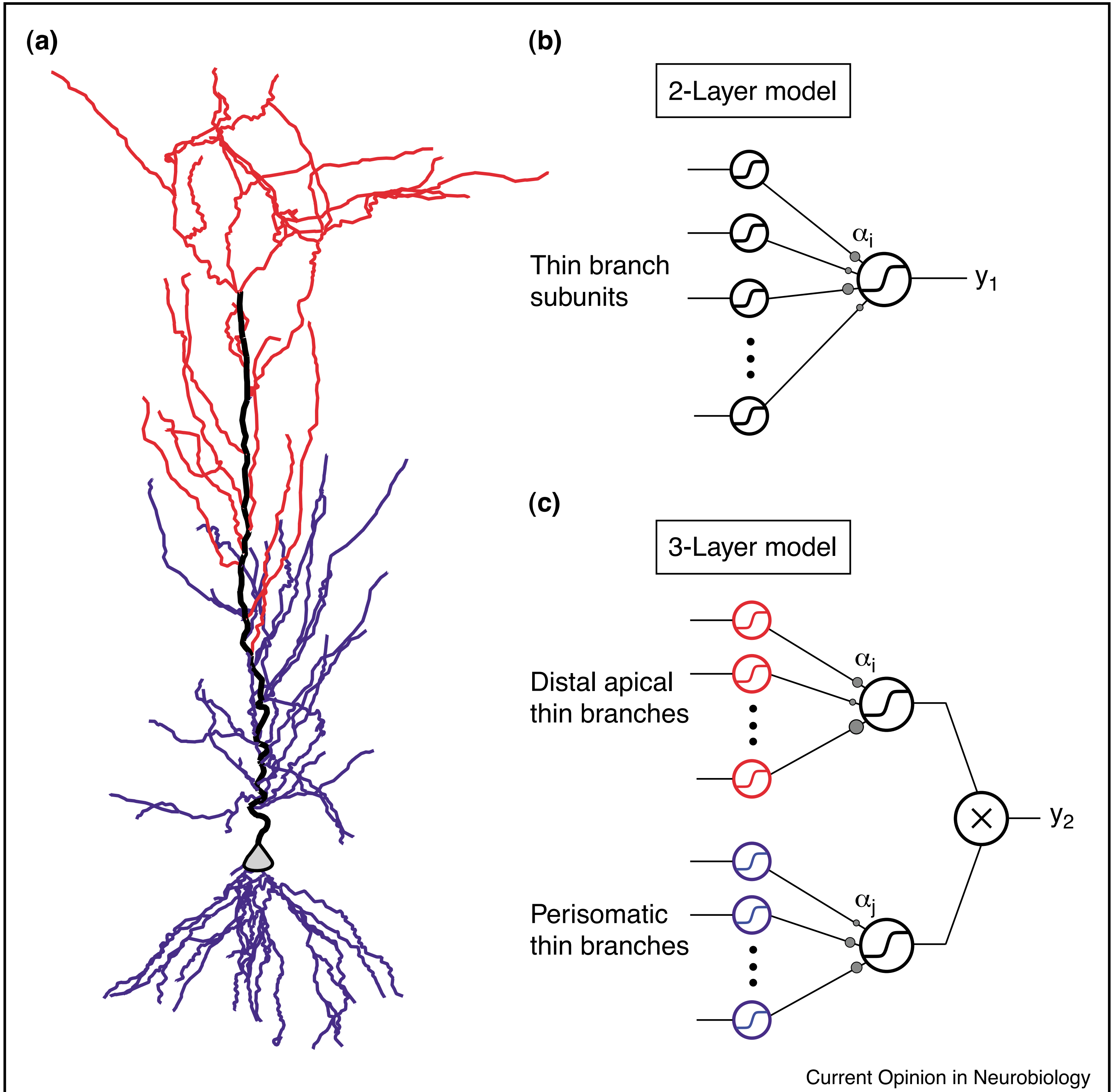
See: Olshausen BA, Field DJ (2005) How close are we to understanding V1? *Neural Computation, 17*, 1665-1699.

1 mm^2 of cortex analyzes ca. 14 x 14 array of retinal sample nodes and contains 100,000 neurons

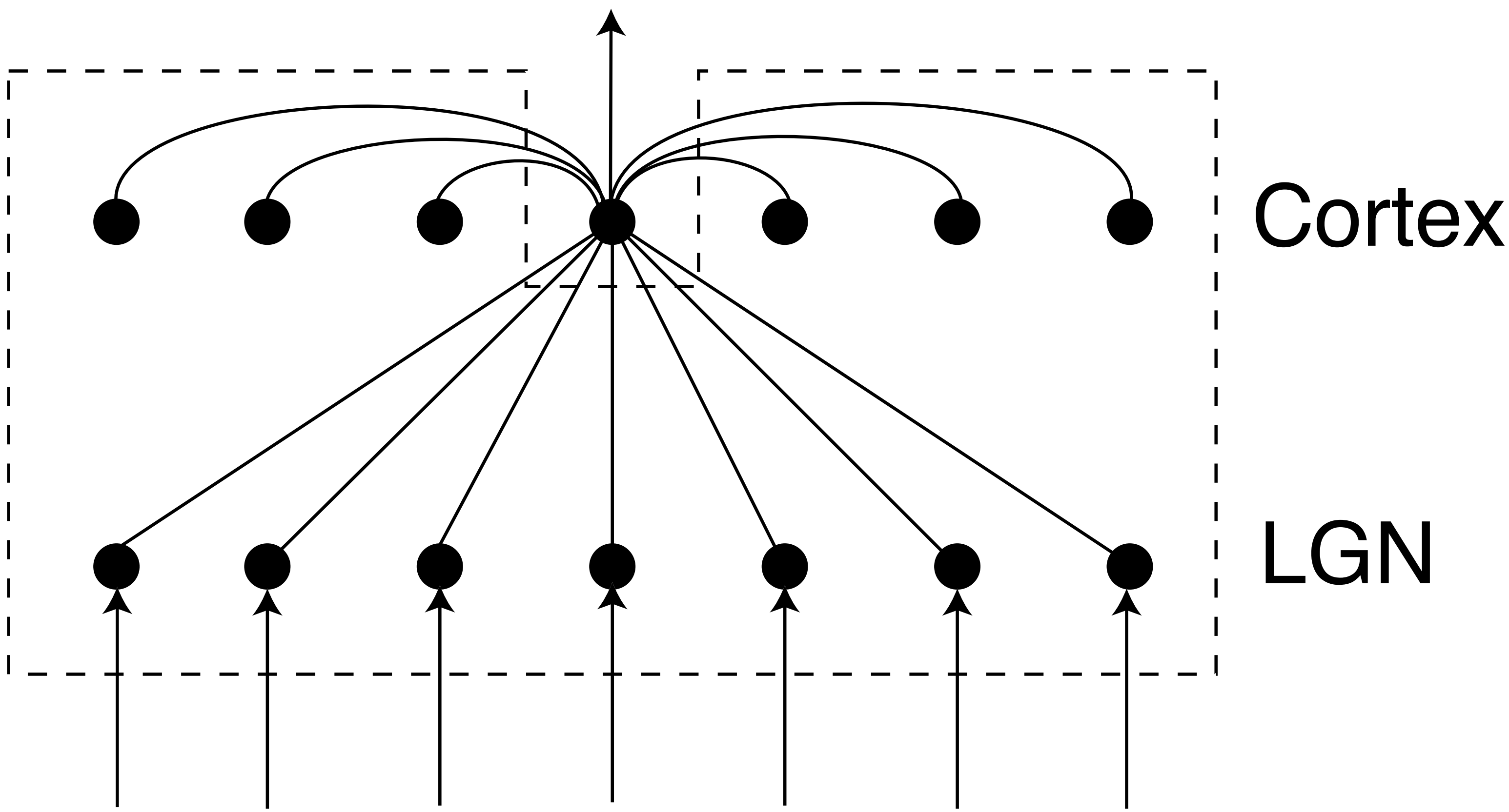



11-5556 World Cup "94" Rose Bowl Pasadena CA
AERO PHOTO INC. 508-295-5551 (c) (E)

Hausser & Mel (2003)

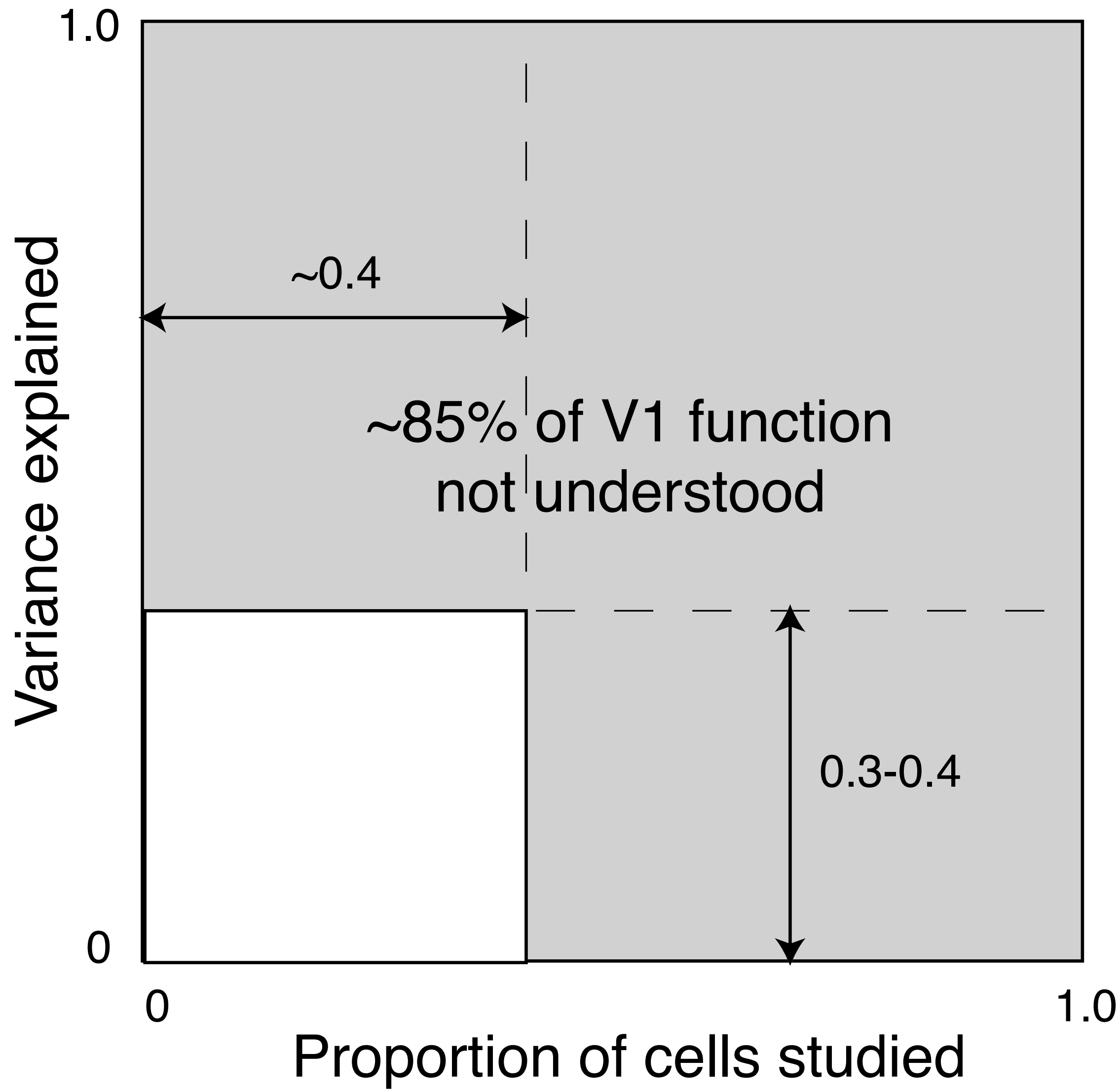


Single unit recording is blind to neuronal interactions



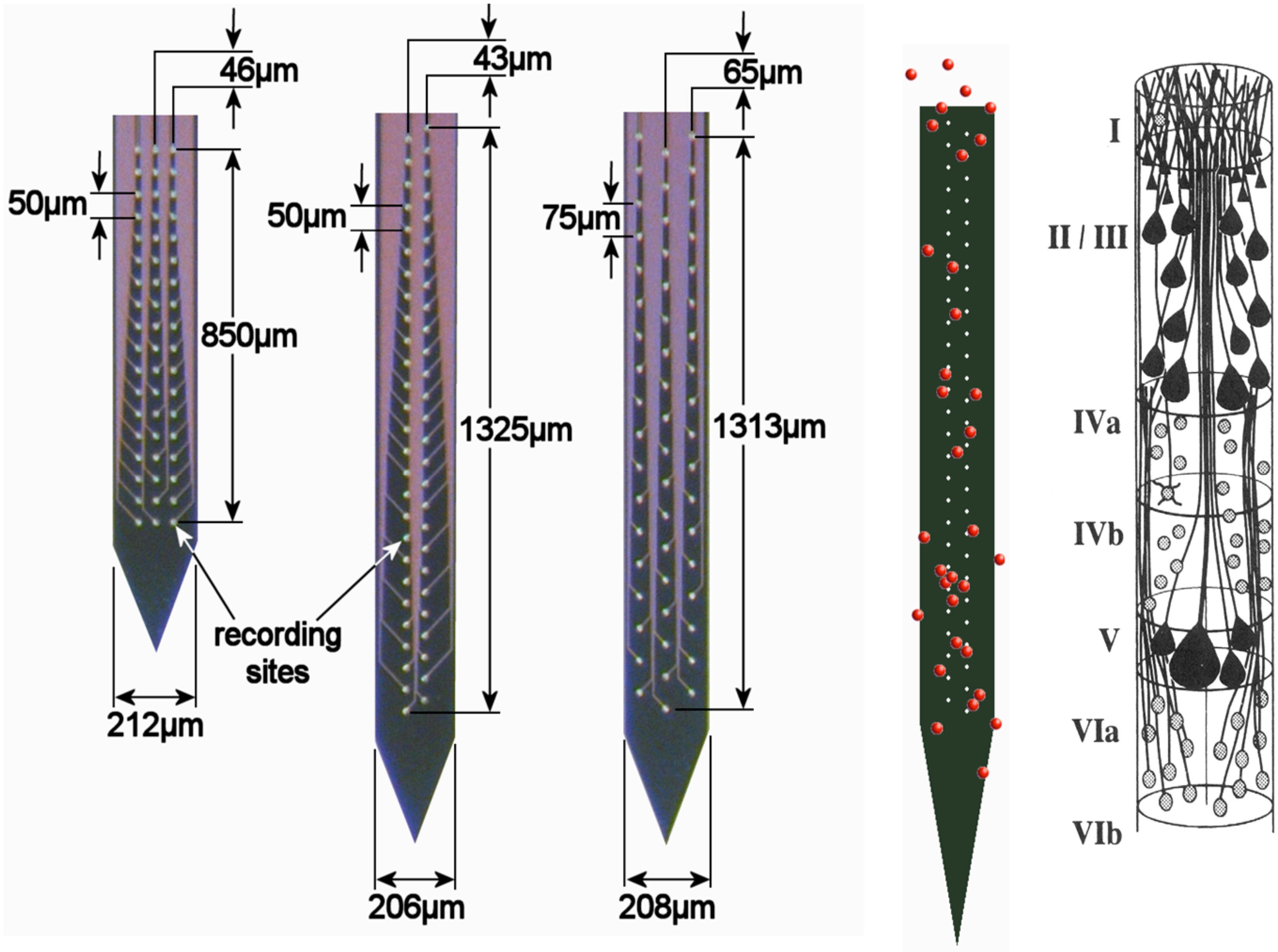
...their (neurons') apparently erratic behavior was caused by our ignorance, not the neuron's incompetence. -- H.B. Barlow (1972)

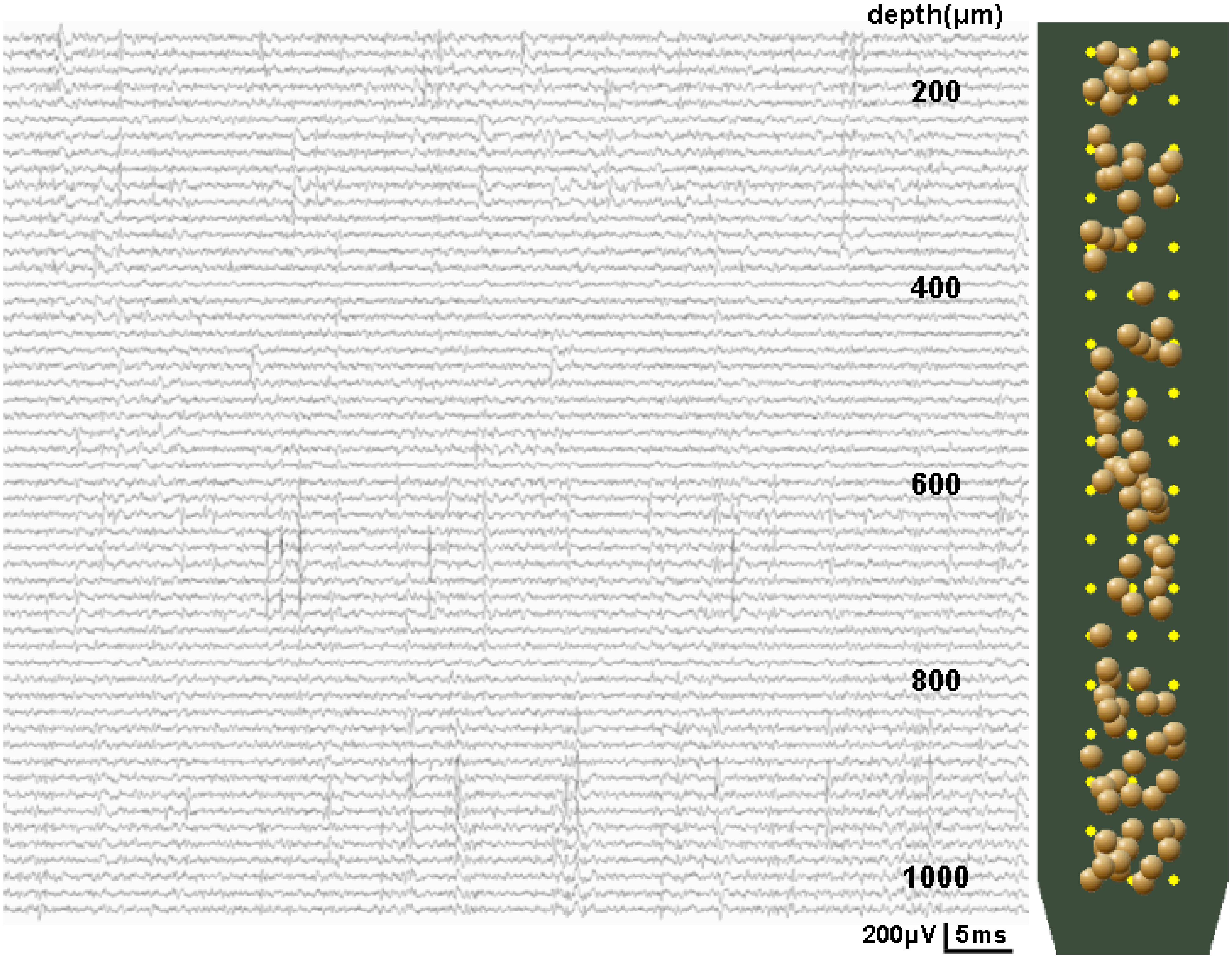
What is the other 85% doing?

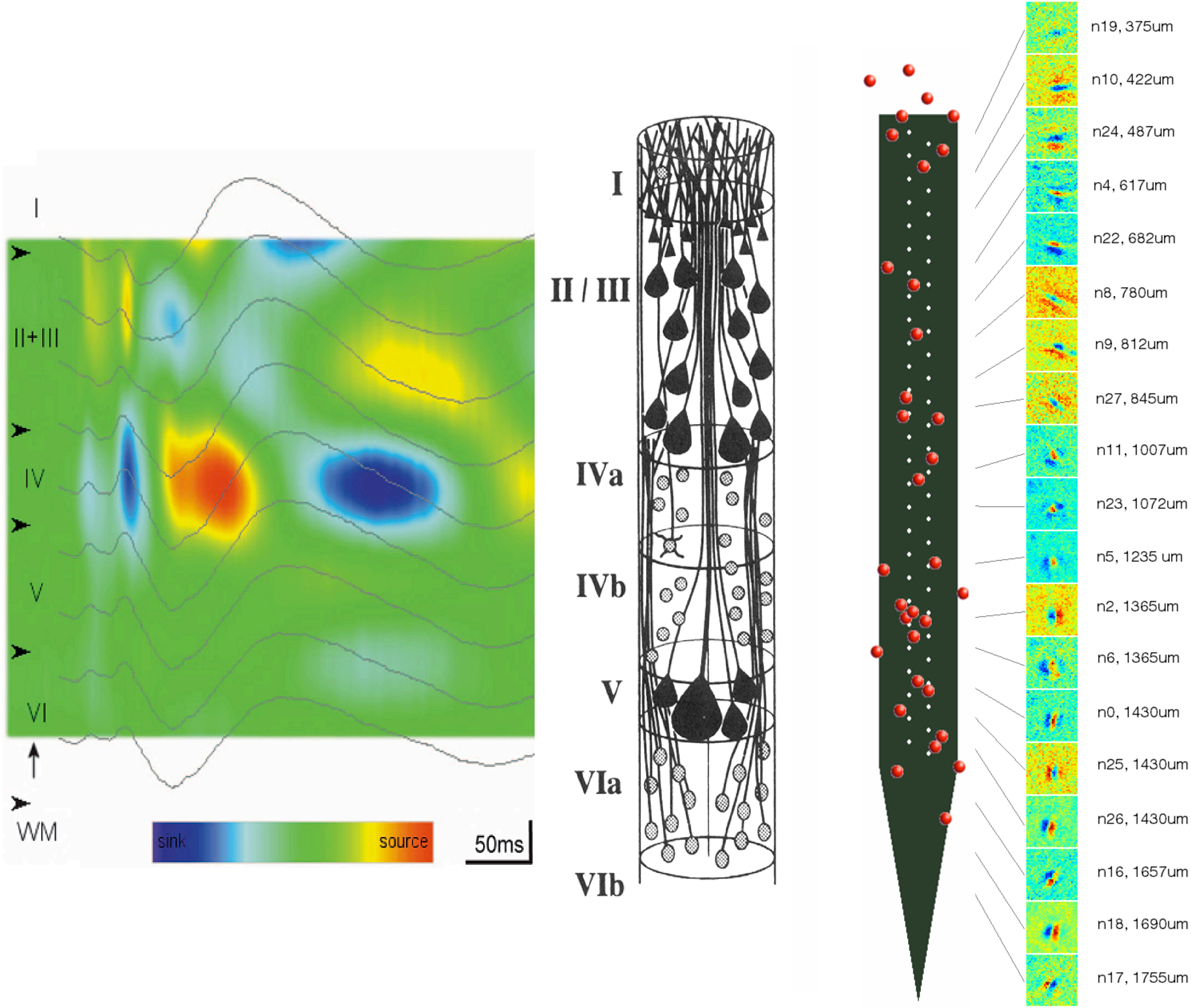


There's hope.

Silicon polytrodes




depth(μm)
200
400
600
800
1000
200μV
5ms


I
II+III
IV
V
VI
WM
sink
source
50ms
I
II / III
IVa
IVb
V
VIa
VIb
n19, 375um
n10, 422um
n24, 487um
n4, 617um
n22, 682um
n8, 780um
n9, 812um
n27, 845um
n11, 1007um
n23, 1072um
n5, 1235 um
n2, 1365um
n6, 1365um
n0, 1430um
n25, 1430um
n26, 1430um
n16, 1657um
n18, 1690um
n17, 1755um