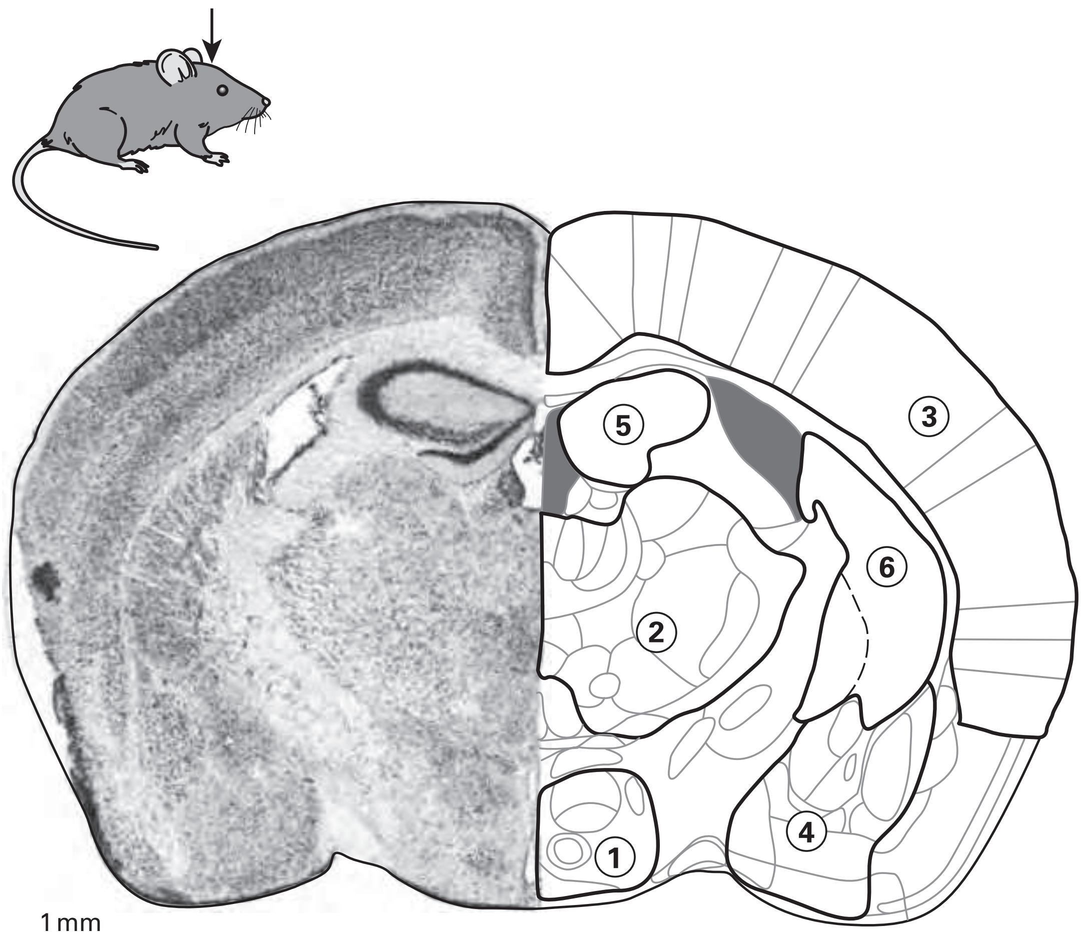
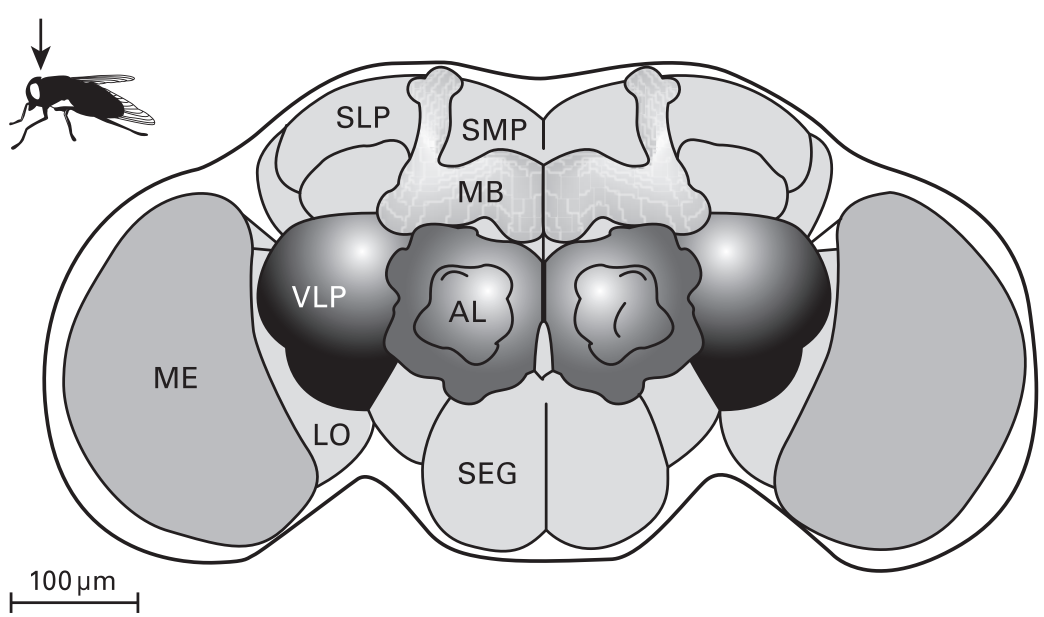
Why does an animal need a brain?

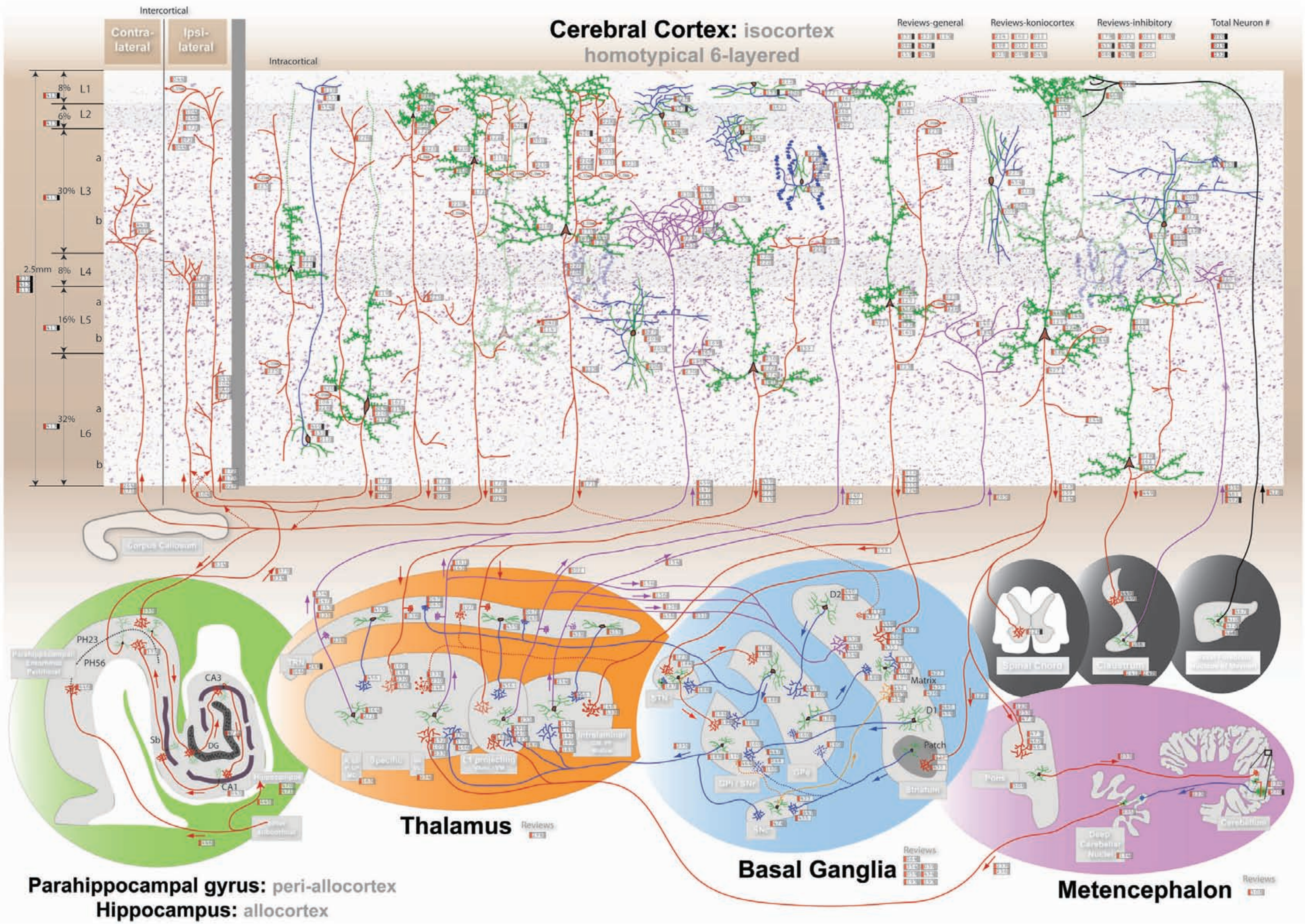


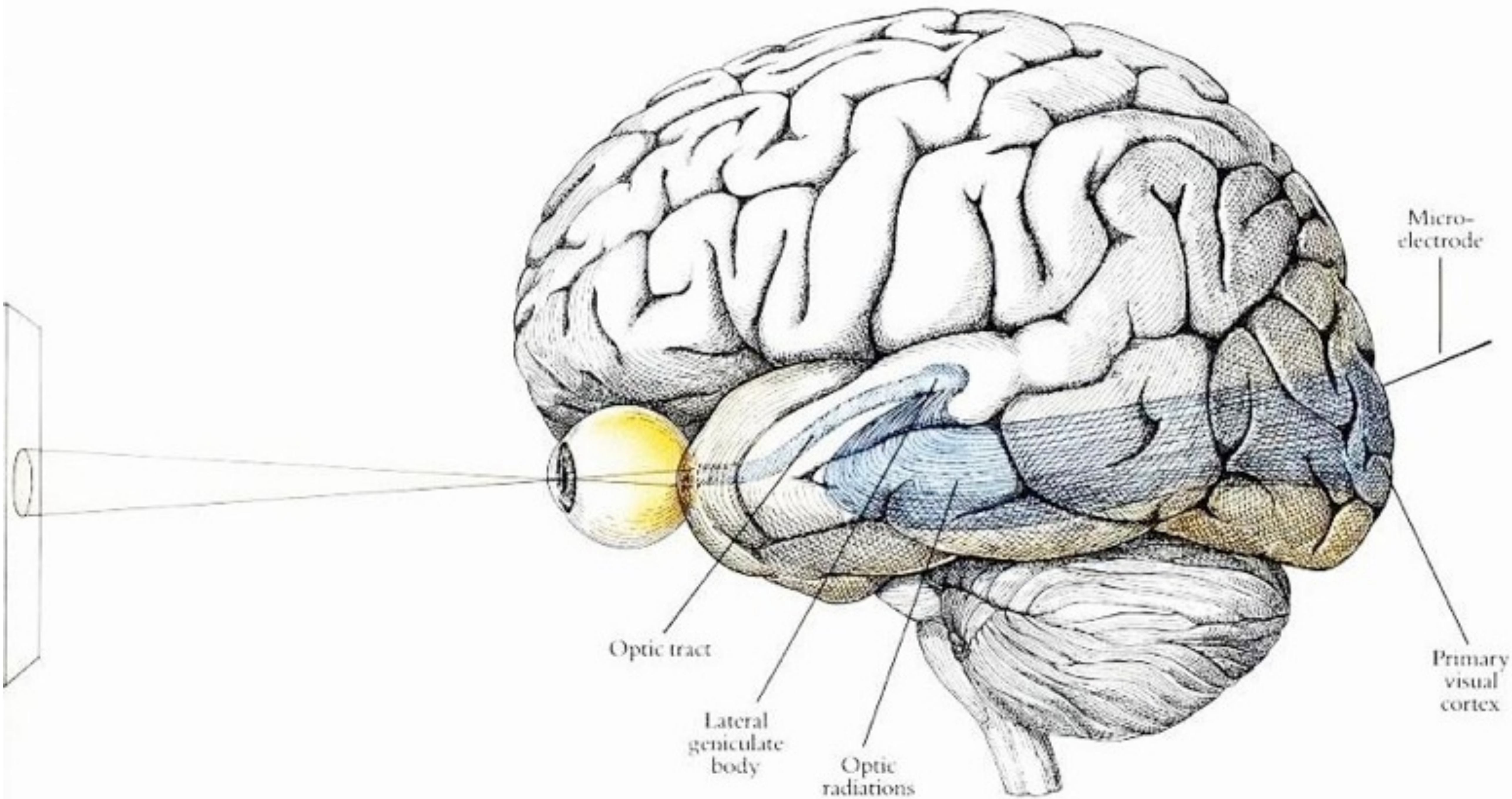
(1) Generate patterns for wireless signaling and appetitive behaviors. (hypothalamus)
(2) "Preprocessing" to shape signals for higher processing. (thalamus)
(3) High-level processing: assemble larger patterns, choose behaviors. (cerebral cortex)
(4) "Tag" high-level patterns for emotional significance. (amygdaloid complex)
(5) Store and recall. (hippocampus)
(6) Evaluate reward predictions. (striatum - basal ganglia)

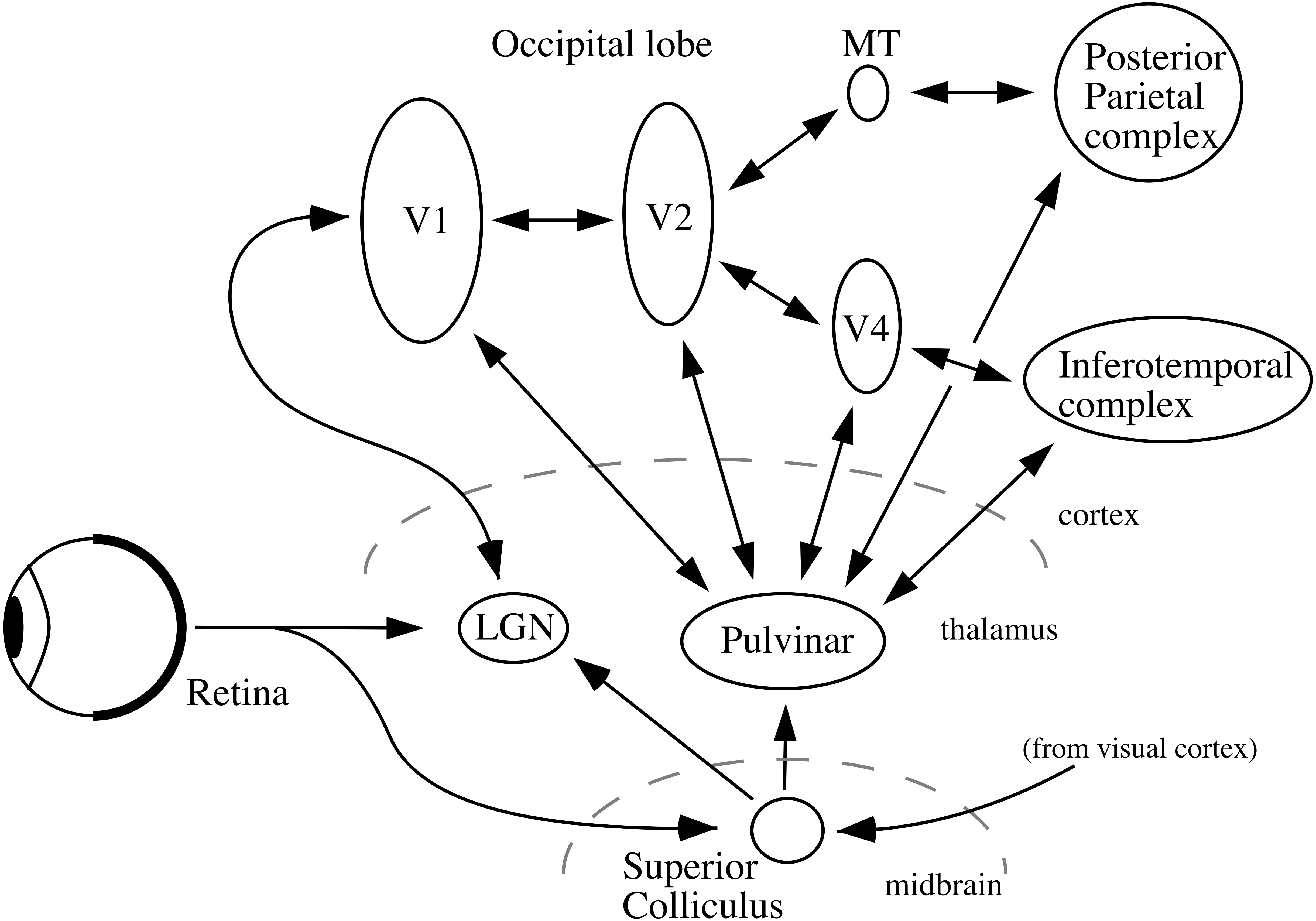


ME, medulla - detect and map local visual patterns
LO, lobula - assemble local visual patterns into larger patterns
AL, antennal lobe - preprocess olfactory signals for pattern recognition
VLP, ventrolateral protocerebrum - high-level integration
SLP, superior lateral protocerebrum - high-level integration
SMP, superior medial protocerebrum - high-level integration
MB, mushroom body - store and recall
SEG, subesophageal ganglion - integrate information for wired and wireless output to body

“Cognitive Consilience” - Solari & Stoner (2011)

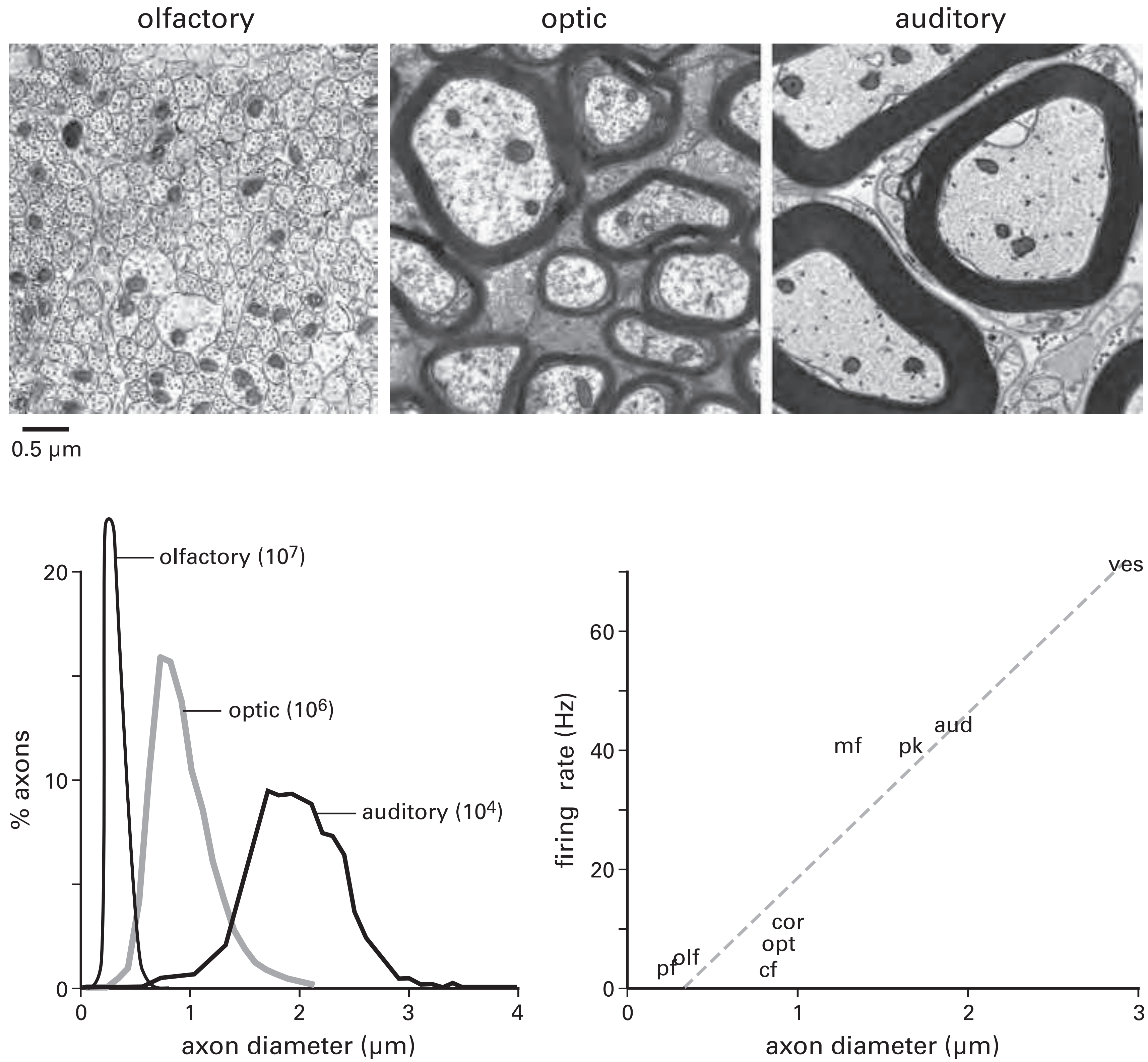



Micro-
electrode
Optic tract
Lateral
geniculate
body
Optic
radiations
Primary
visual
cortex

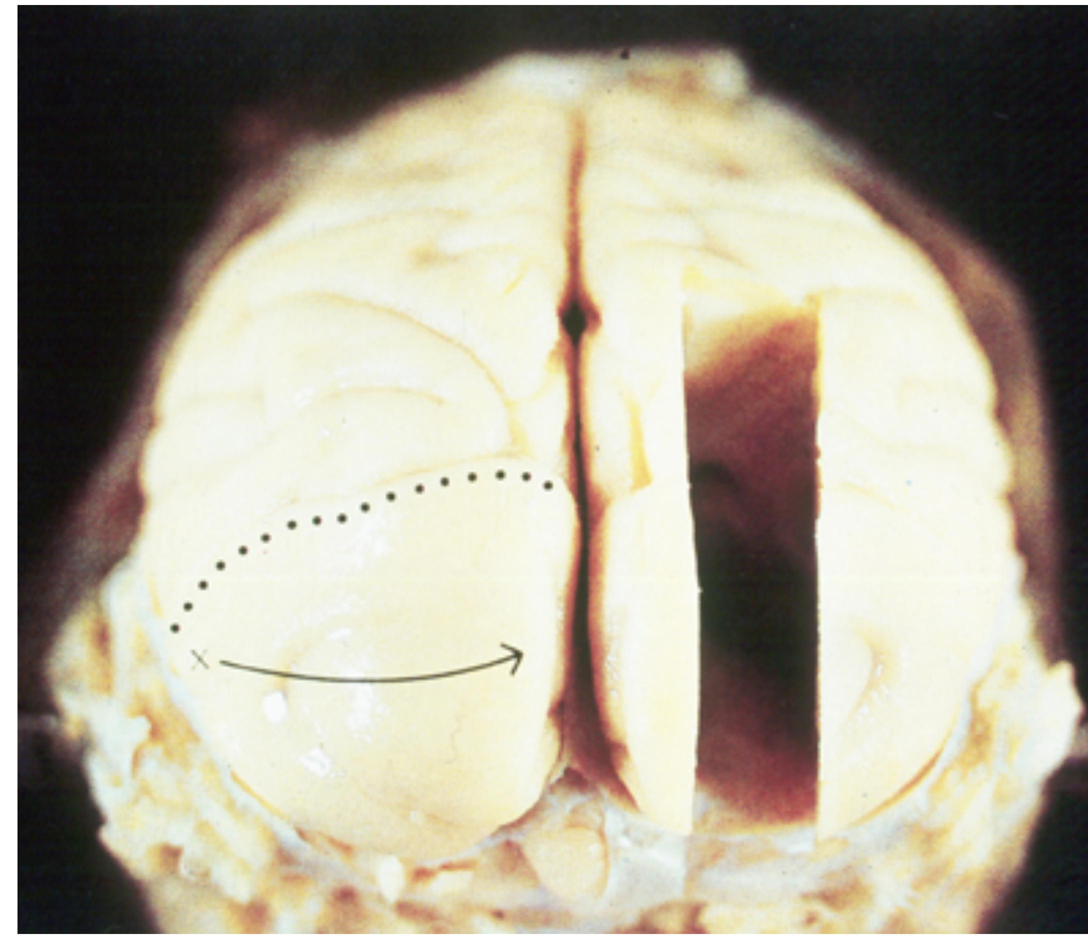


Occipital lobe
MT
Posterior
Parietal
complex
V1
V2
V4
Inferotemporal
complex
cortex
LGN
Pulvinar
thalamus
Retina
(from visual cortex)
Superior
Colliculus
midbrain

Optic nerve fibers: size distribution and myelination
(larger = faster/higher bandwidth)



Cerebral cortex: gray matter & white matter

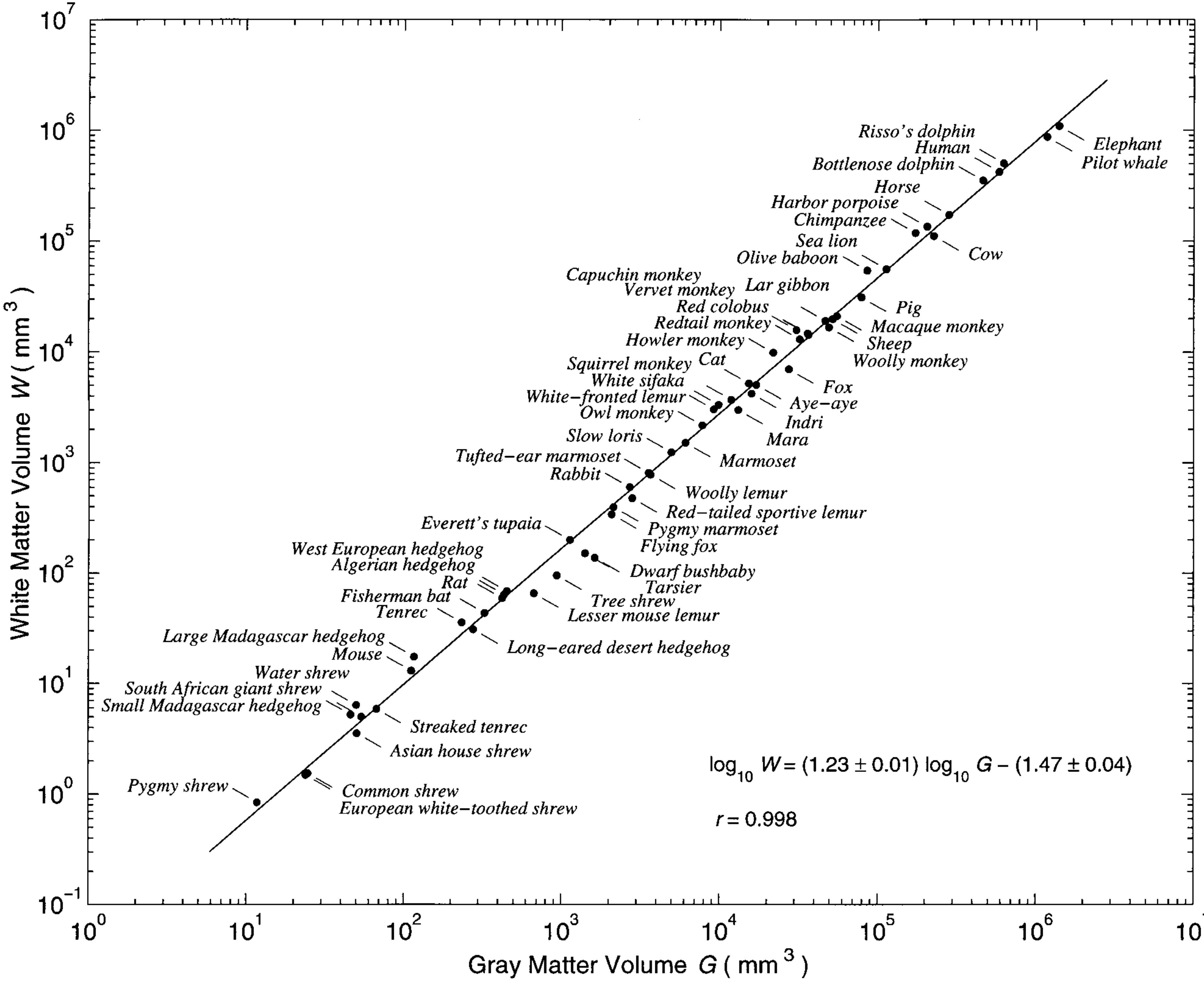


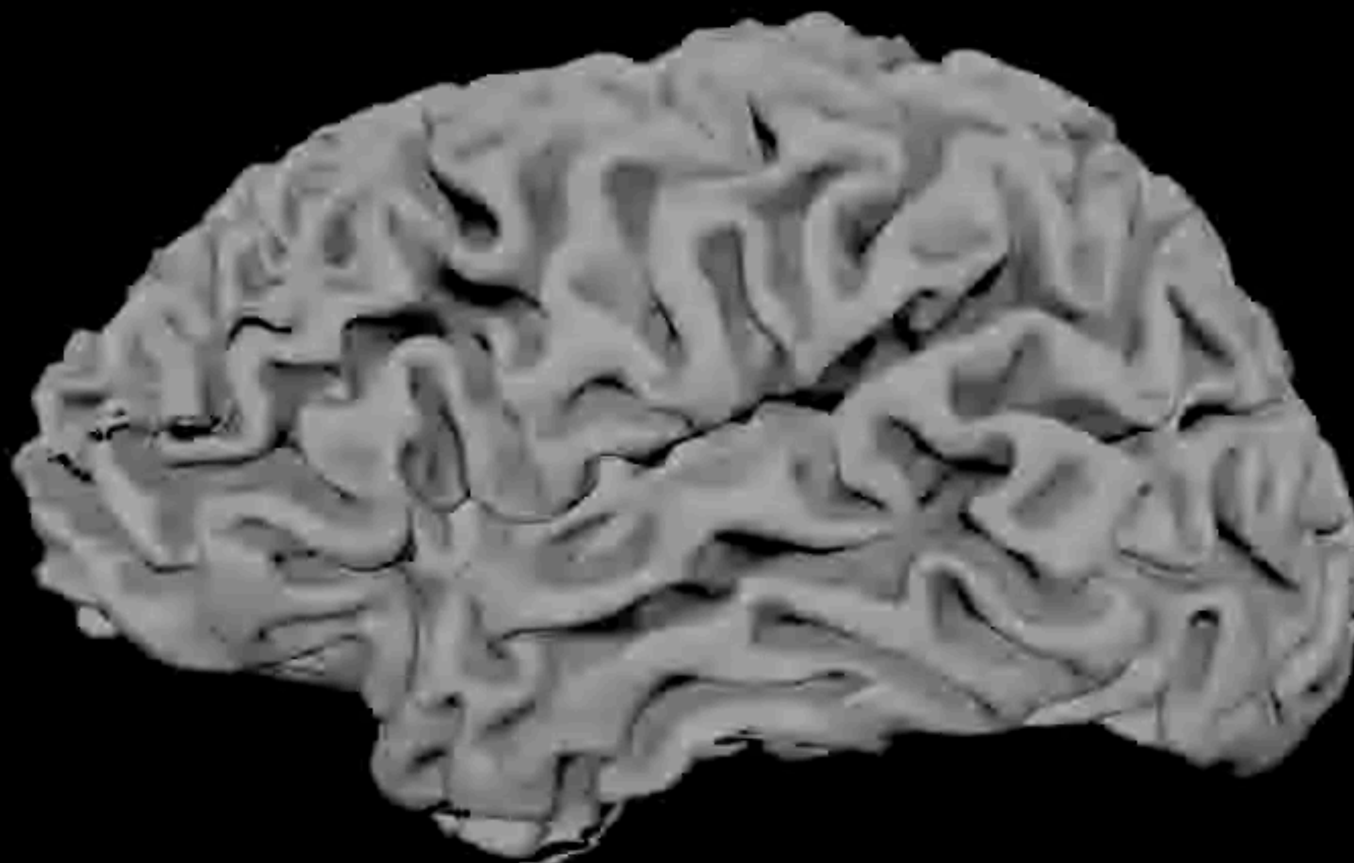
Gray matter (stained purple): folded sheet containing cell bodies (100,000/mm^3), dendrites, local axon branches (3 km/mm^3!).

White matter: axons making long-range connections.

Total cortical surface area is about 2500 cm^2.

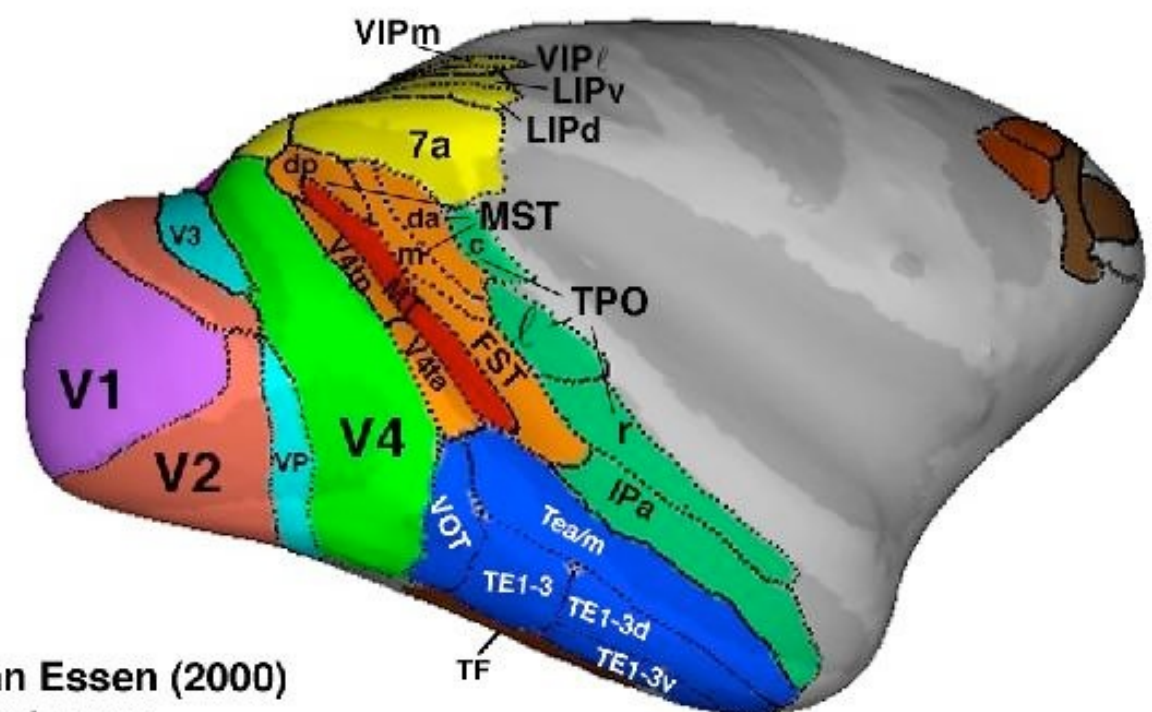
Zhang & Sejnowski (2000)



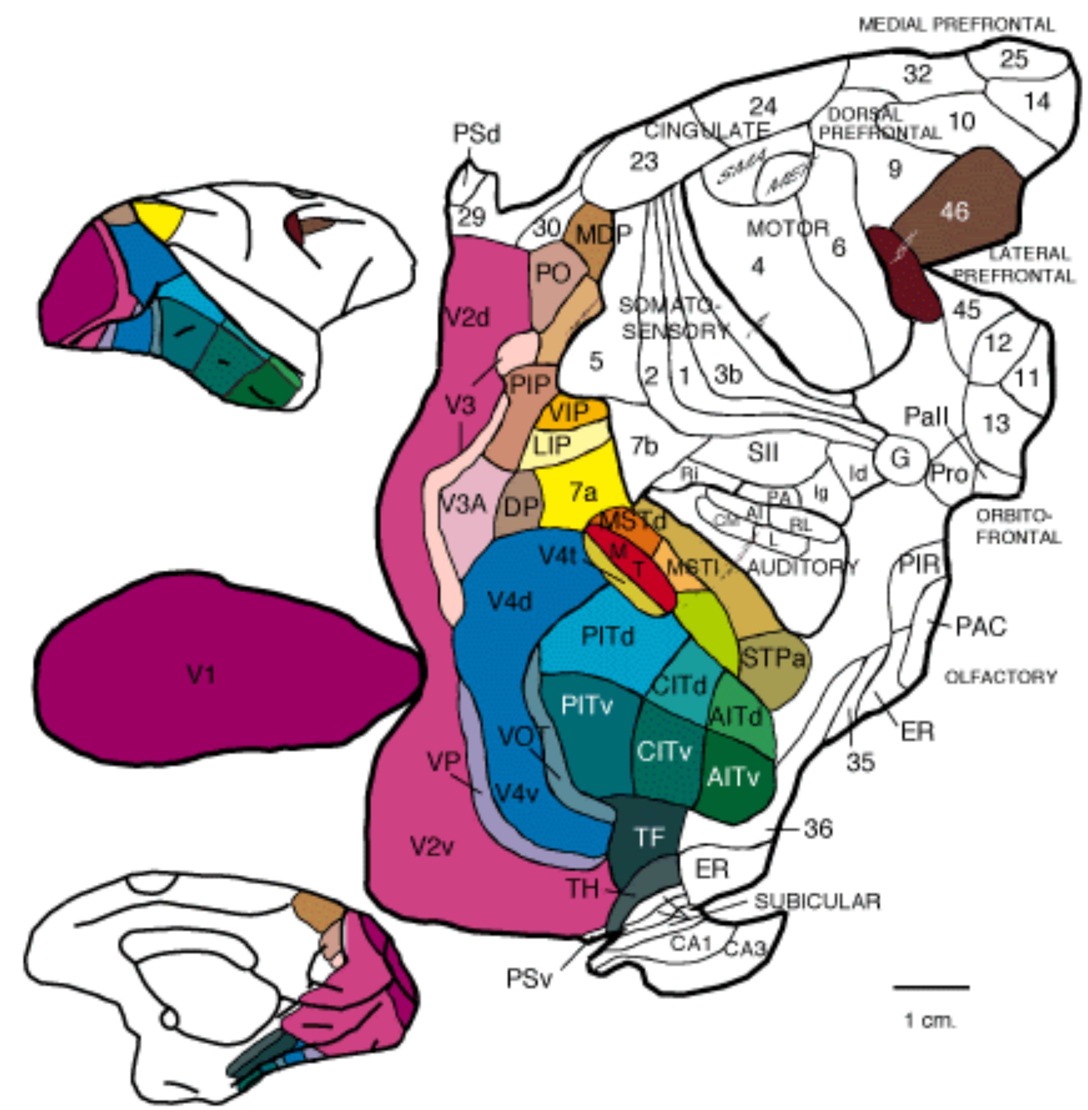


Movie courtesy of Mark Lescroart

Macaque visual cortex

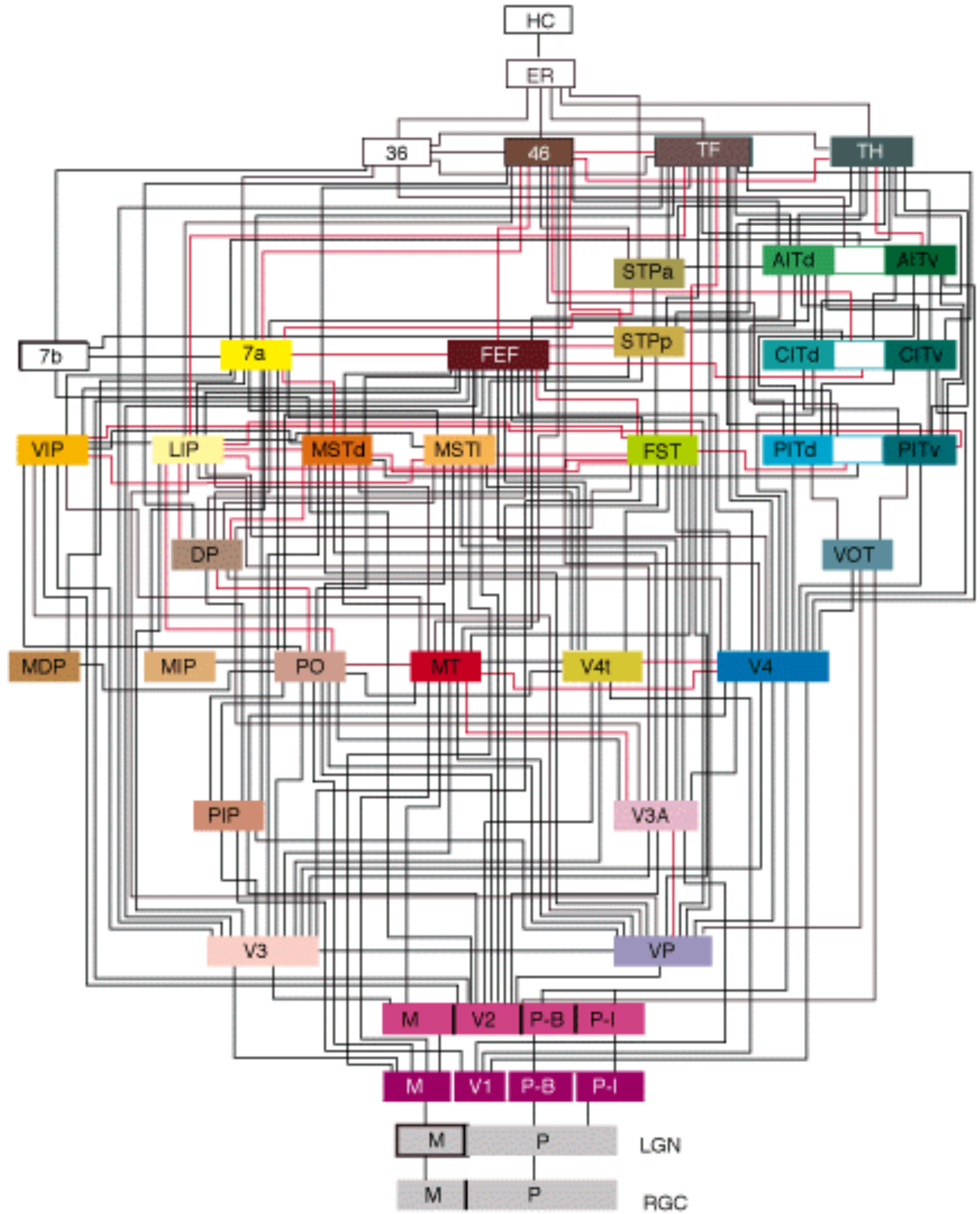


Lewis & Van Essen (2000)
Visual areas



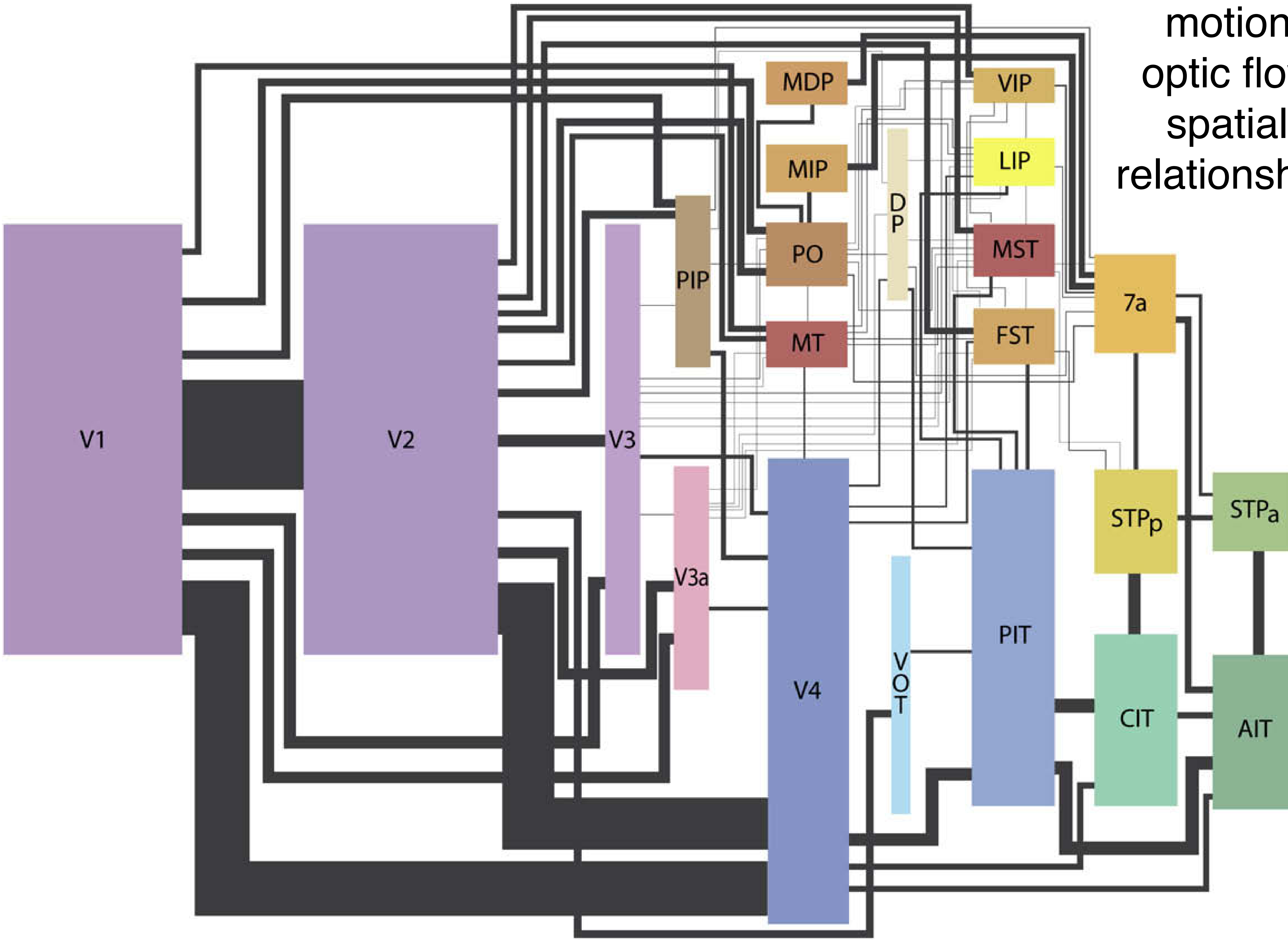
inflated

flattened



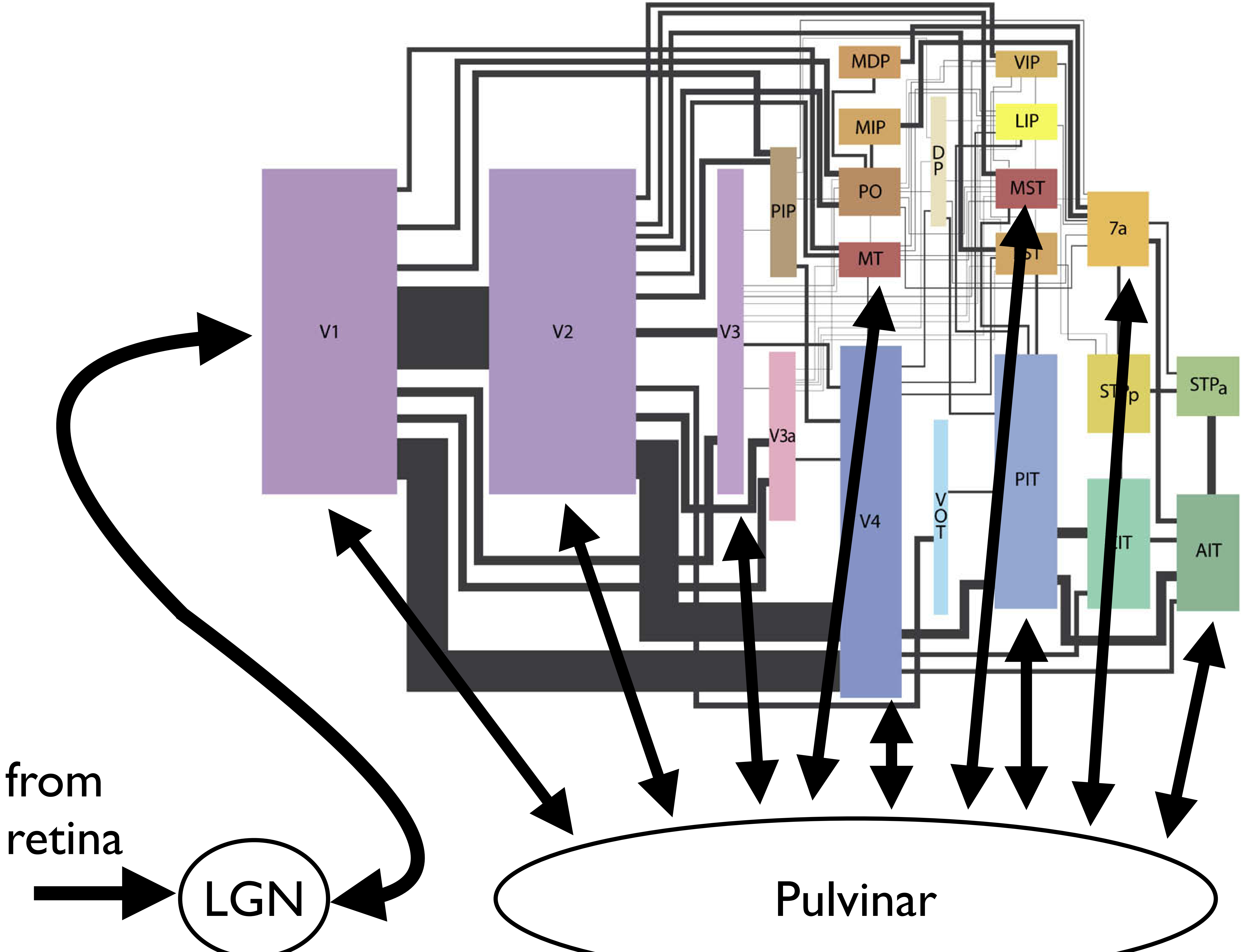
From Van Essen & Felleman (1991)
(for entire macaque brain see papers of Nikola Markov, 2013-14)

Wallisch & Movshon (2008)

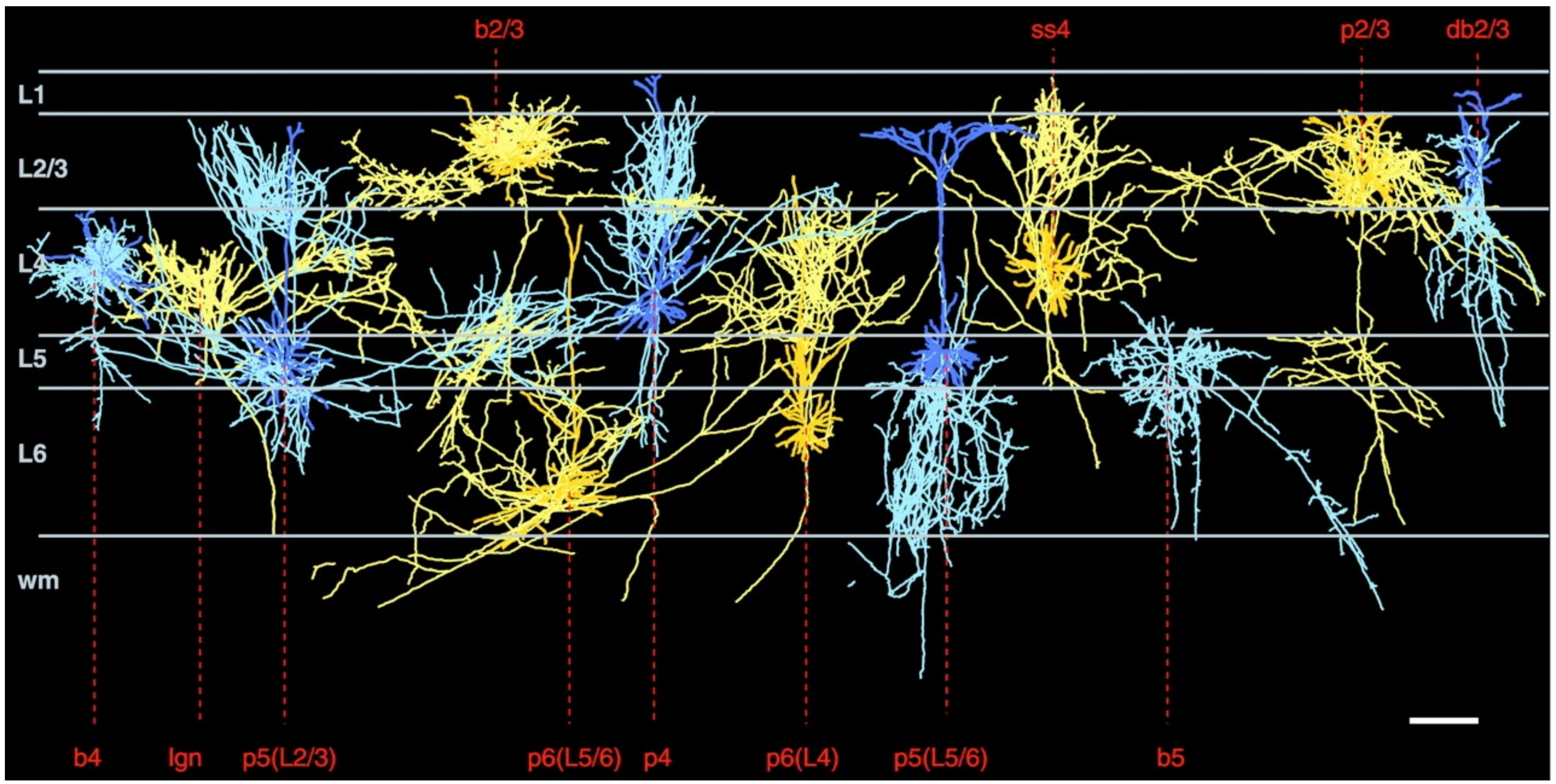


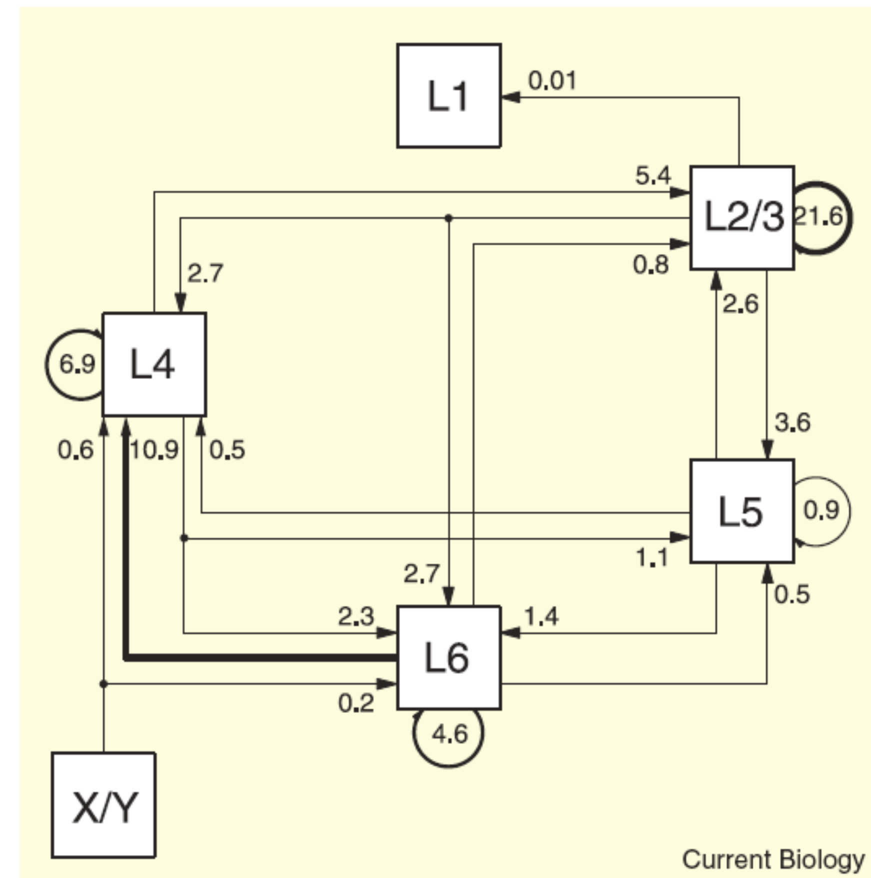
motion, optic flow, spatial-relationships

lines, edges   surface boundaries   ?   objects   faces

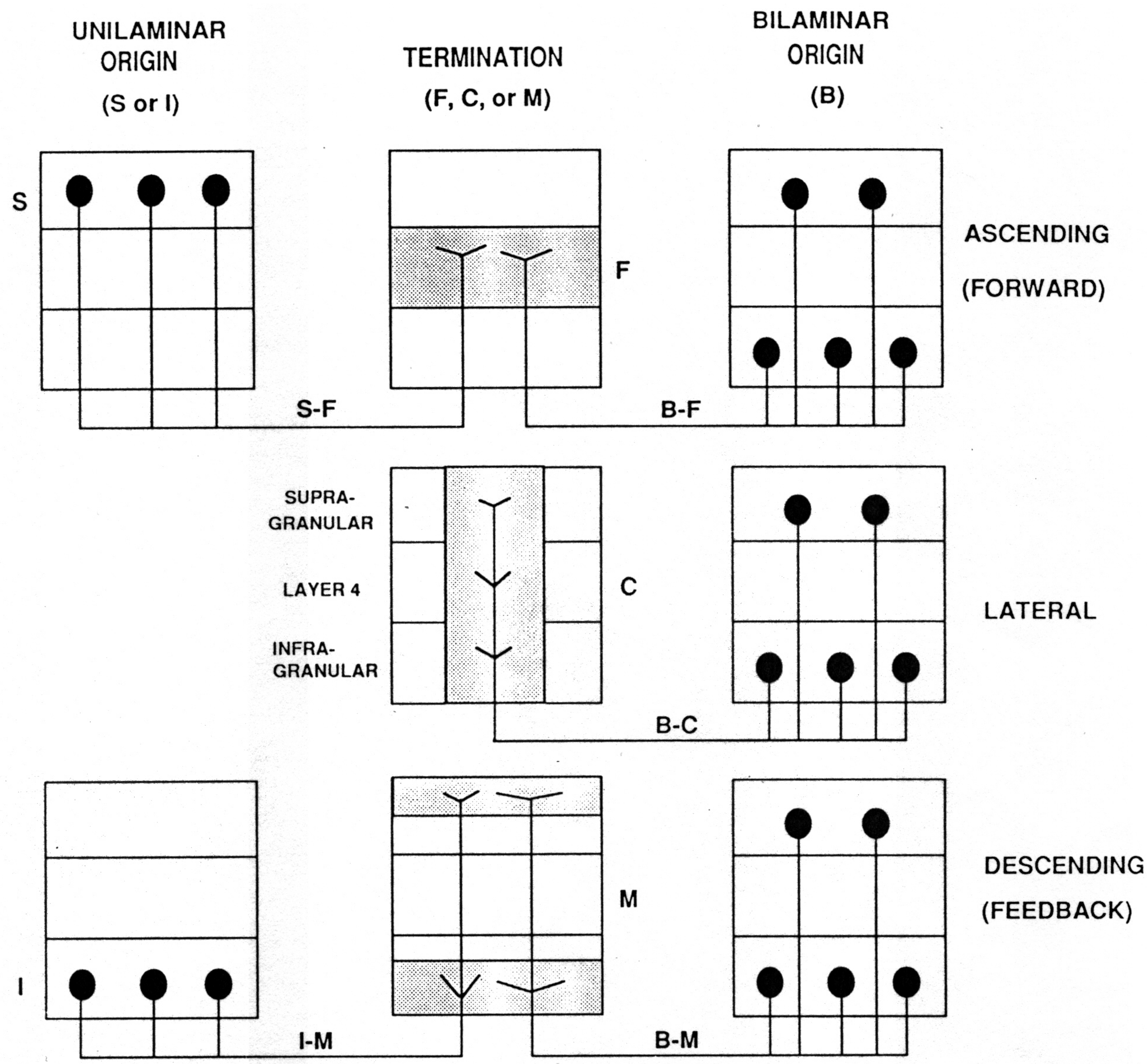

MDP
VIP
MIP
LIP
DP
PO
MST
PIP
7a
MT
V1
V2
V3
STPa
V3a
V4
VOT
PIT
AIT
from retina
LGN
Pulvinar

Laminar organization and ‘canonical microcircuit’

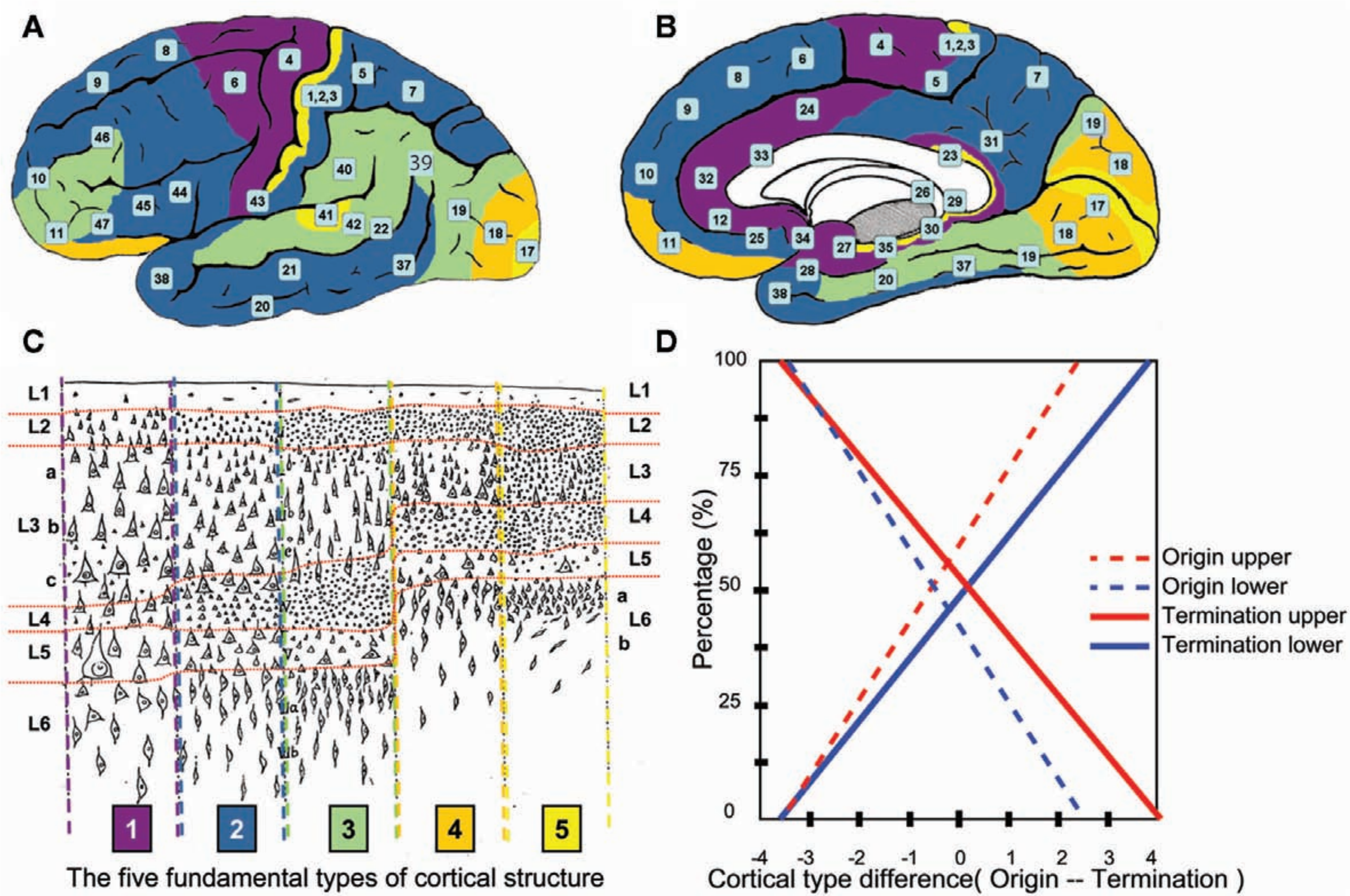




(Douglas and Martin, 2007)



Felleman & Van Essen 1991



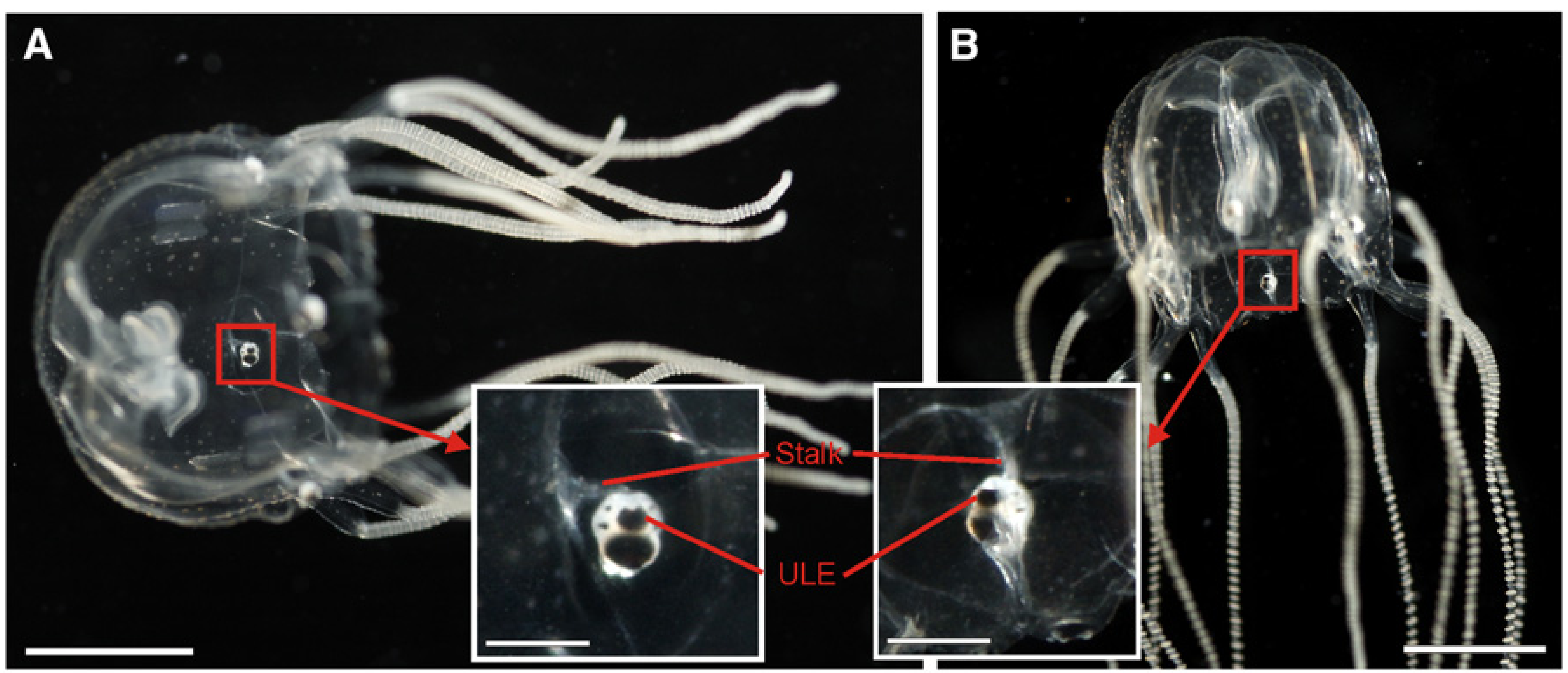
von Economo (1929)

From: Solari & Stoner (2011) "Cognitive Consilience"

Where did this come from?

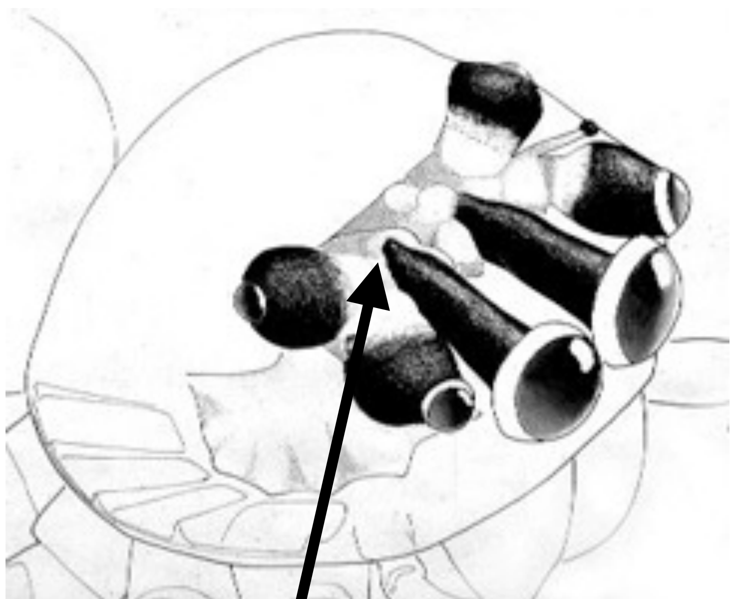
jumping spider

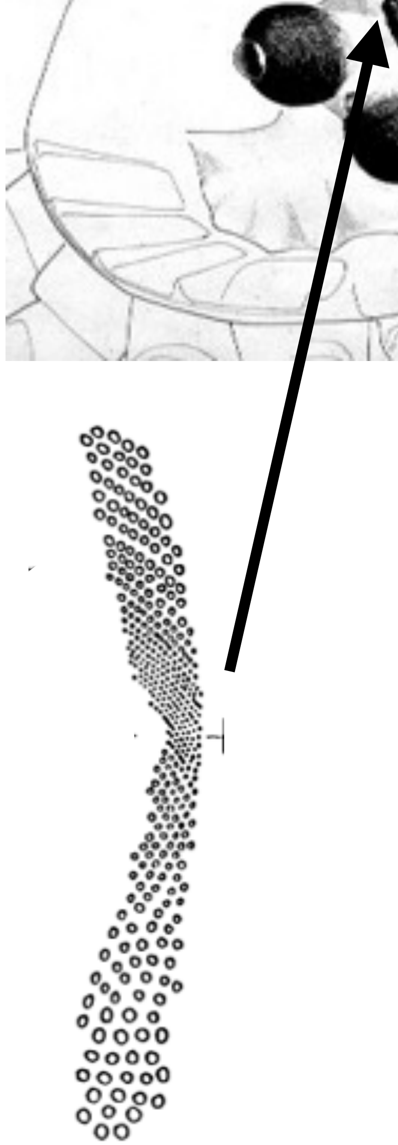
sand wasp



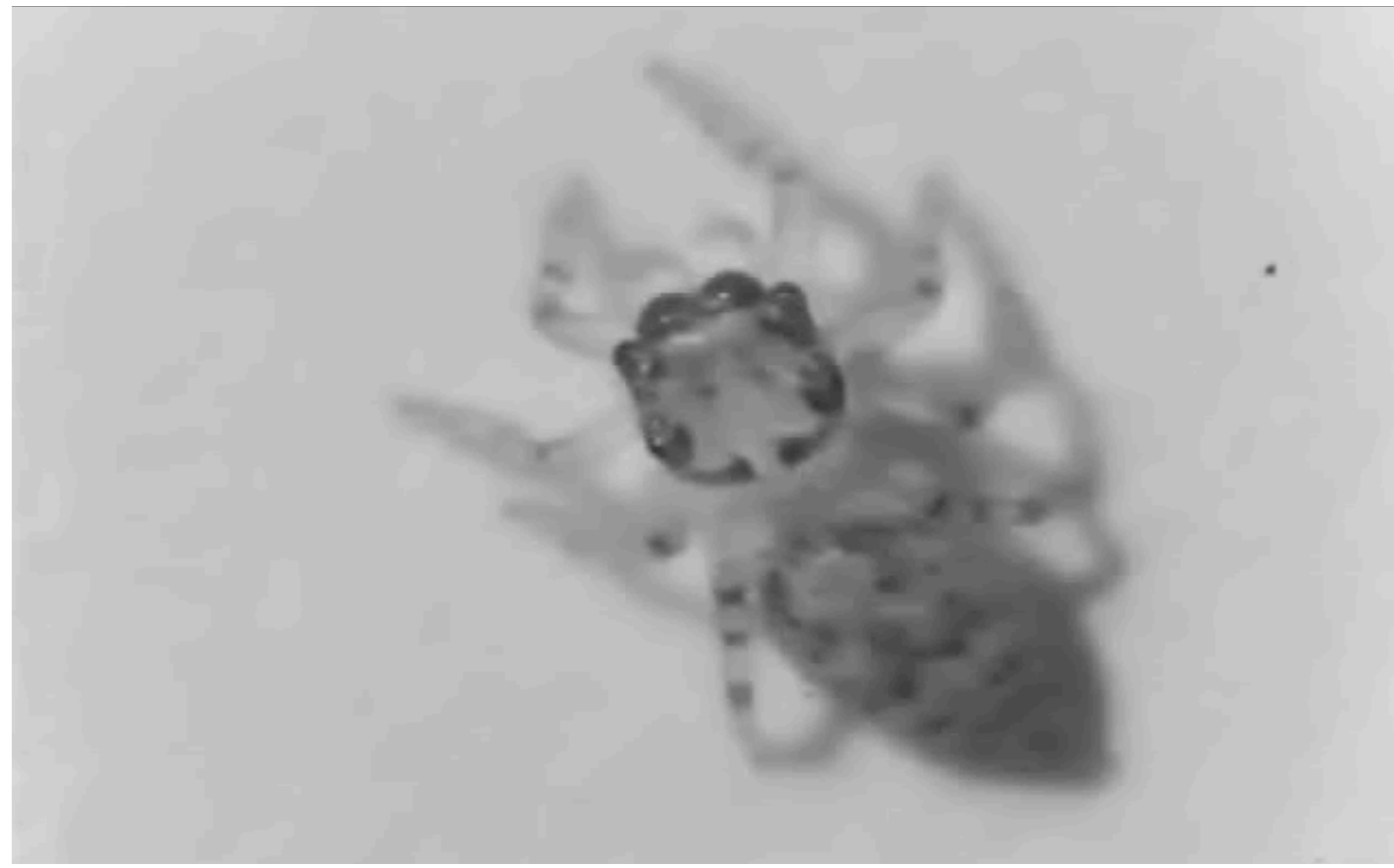
box jellyfish

Vision in jumping spiders





(Wayne Maddison)



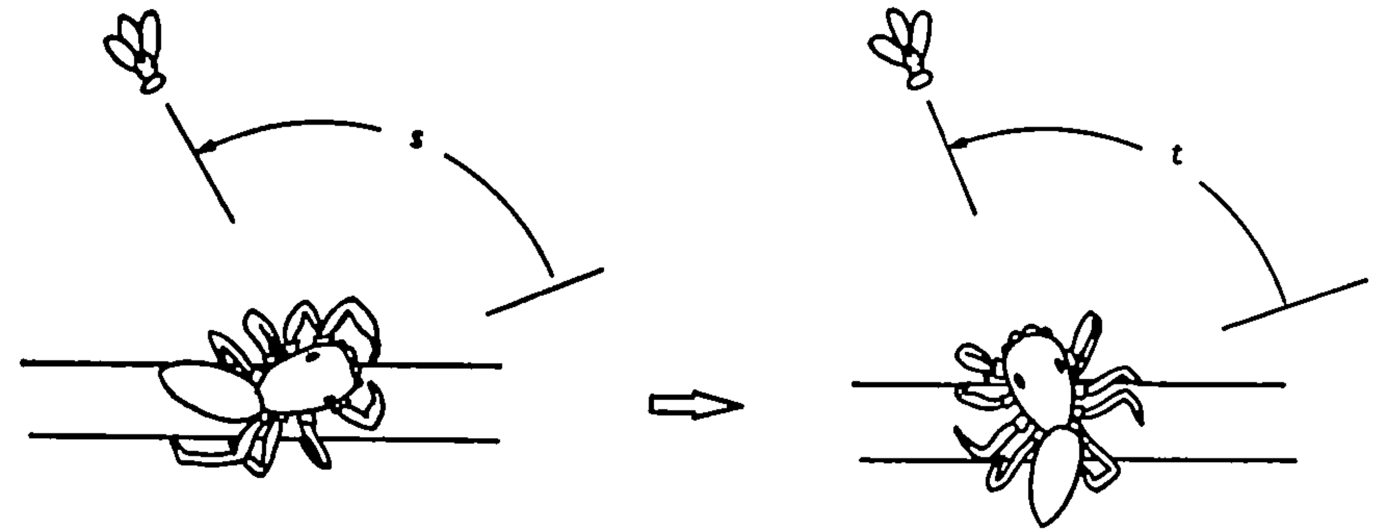
(Bair & Olshausen, 1991)

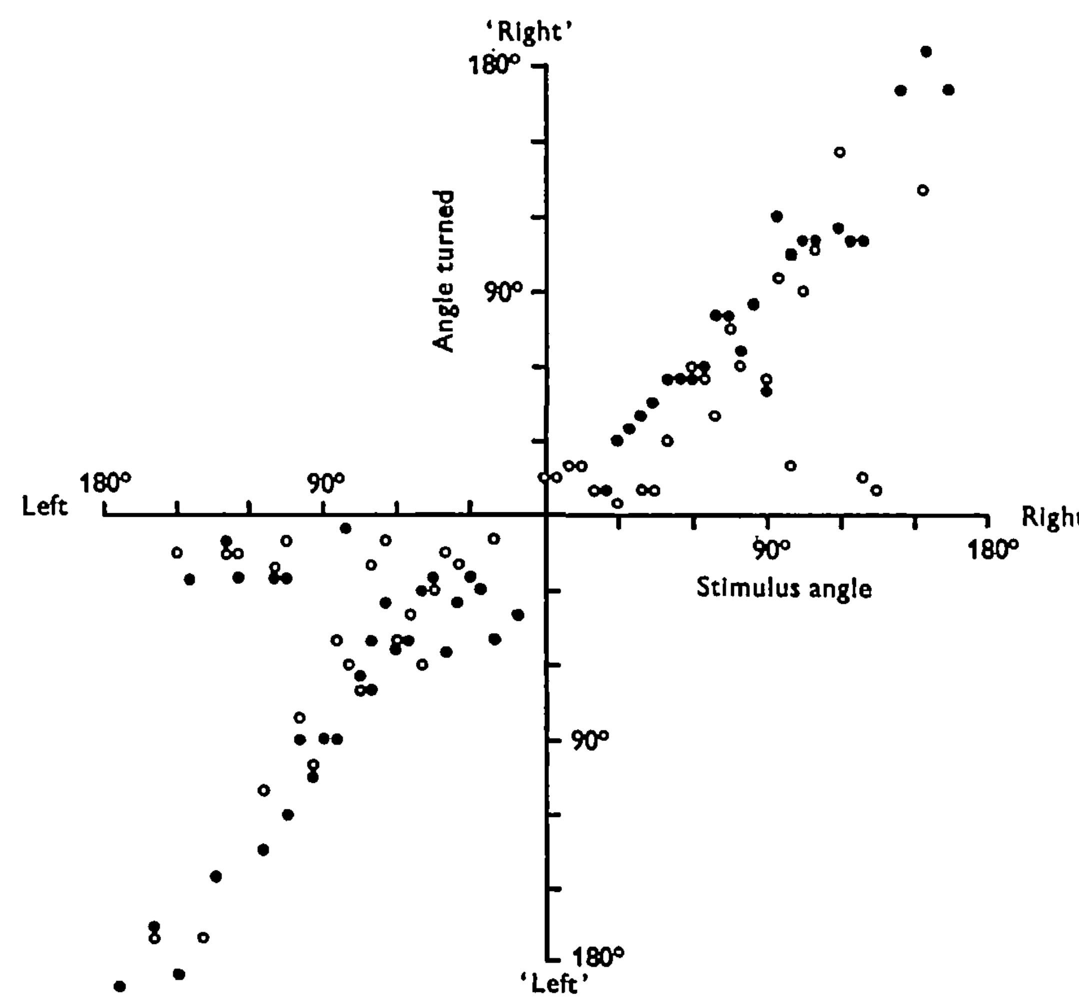
One-day old jumping spider
(filmed in the Bower lab, Caltech)

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

Prey capture

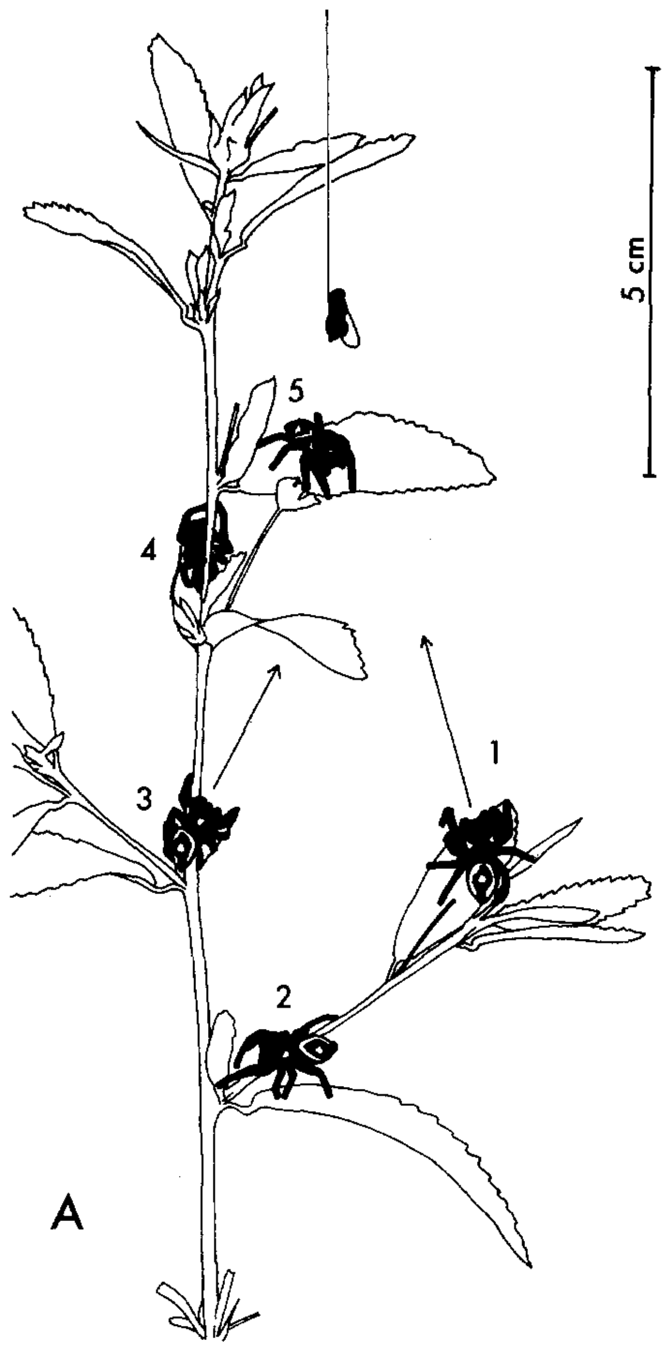
- attention
- orienting
- tracking

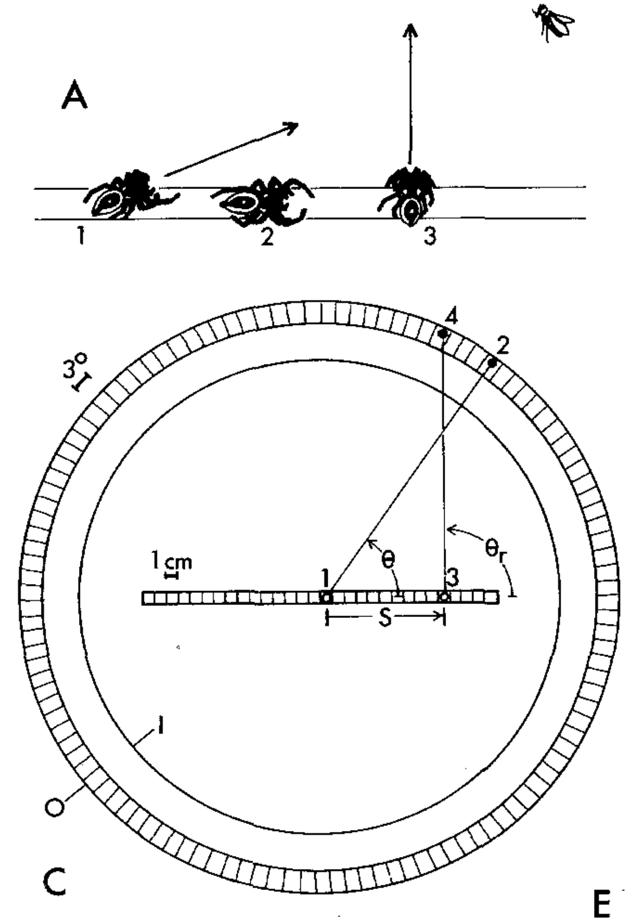


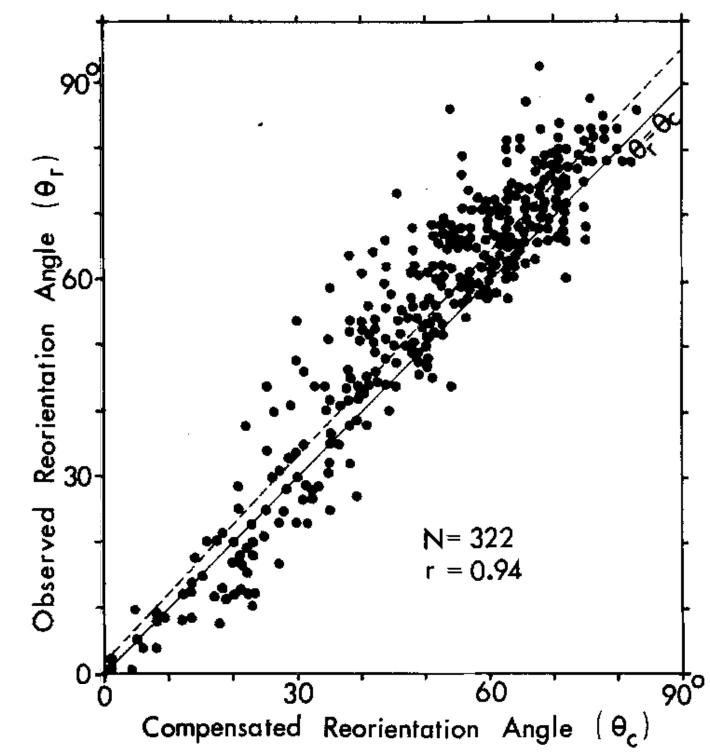


Orientation by Jumping Spiders During the Pursuit of Prey

(D.E. Hill, 1979)







Navigation

(Tarsitano & Jackson 1997)

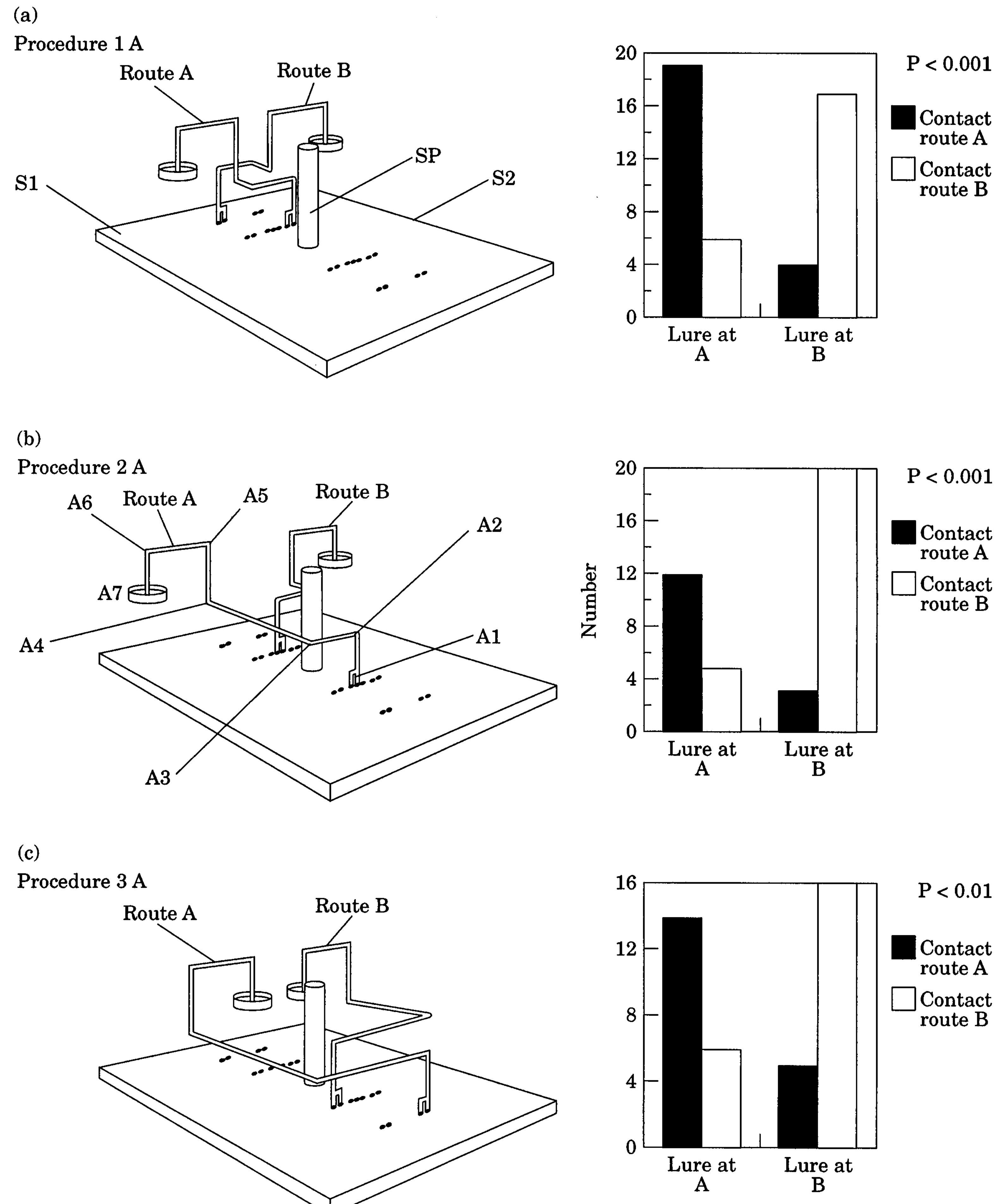
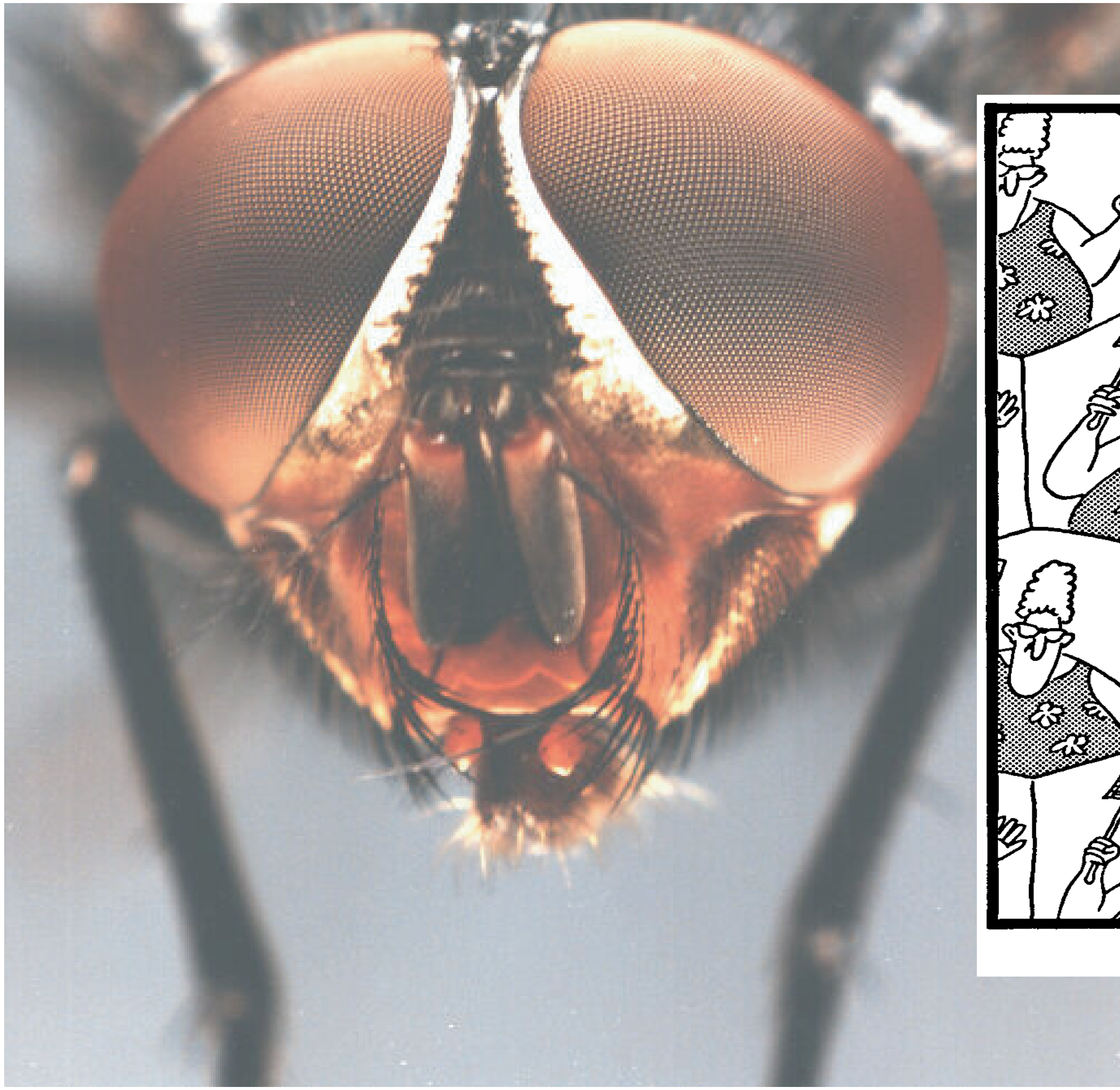
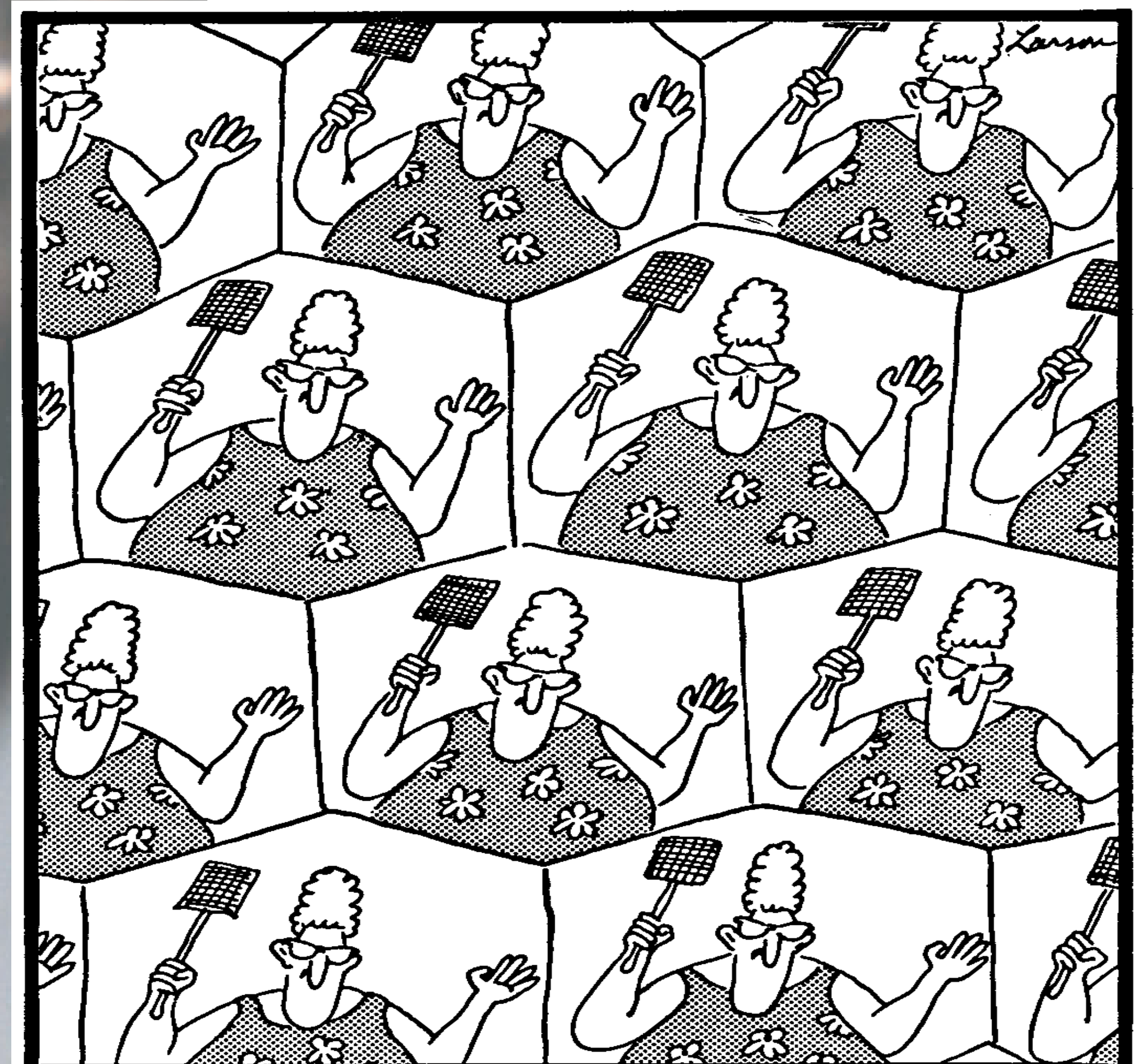


Figure 1 a-c.

Philanthus triangulum
(sand wasp)

From: *Curious Naturalists* by Niko Tinbergen





The last thing a fly ever sees

Land & Collett (1973)

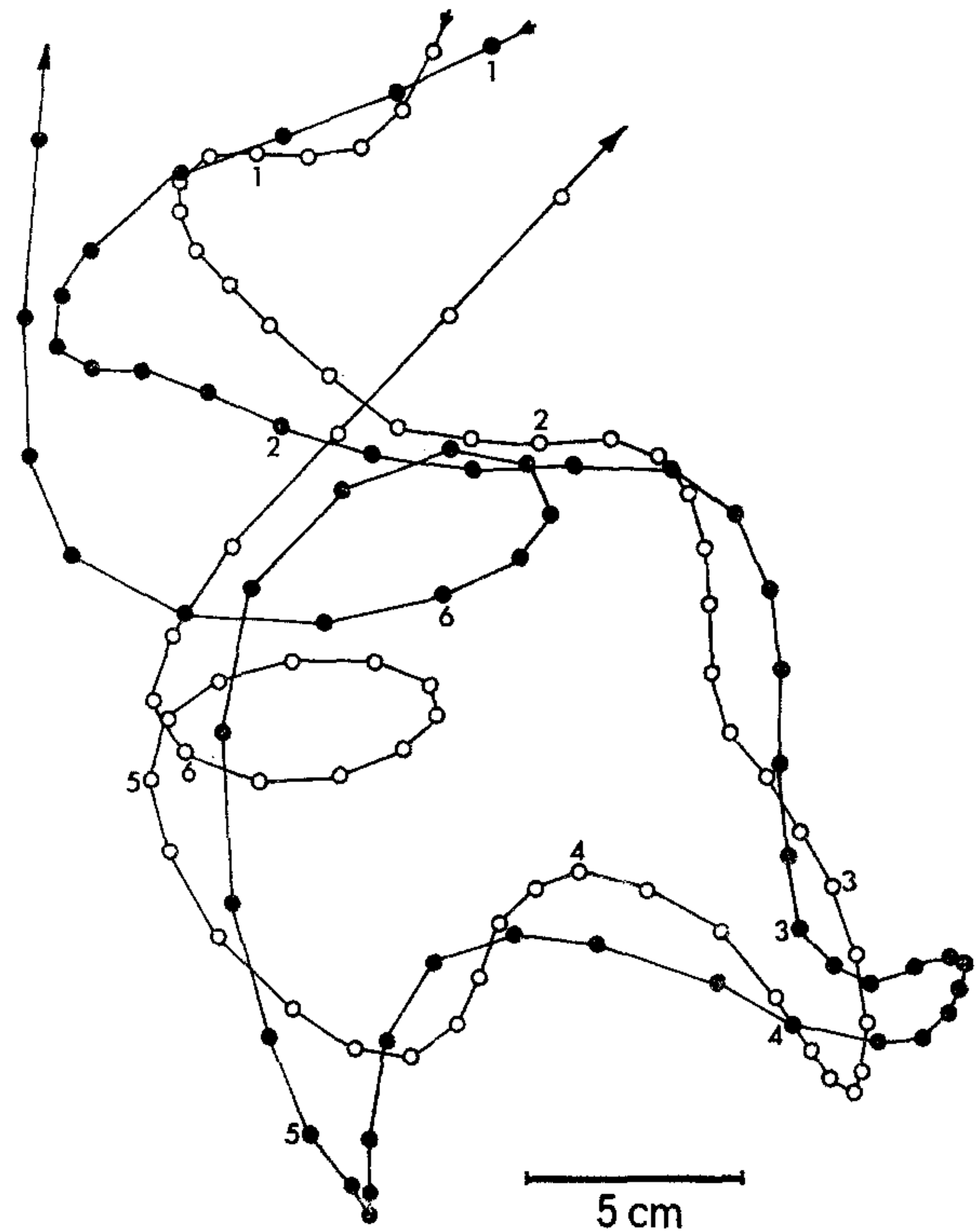
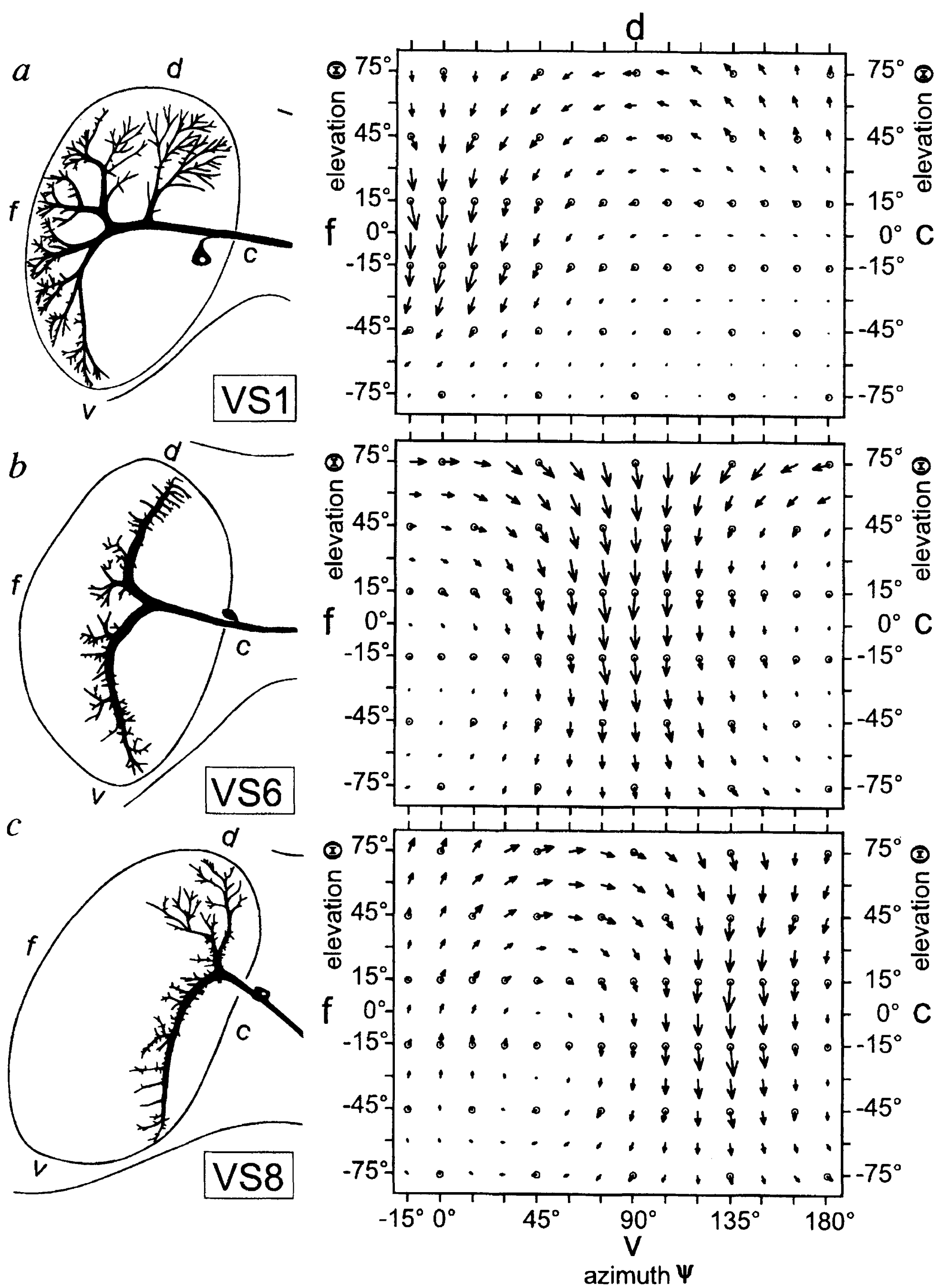
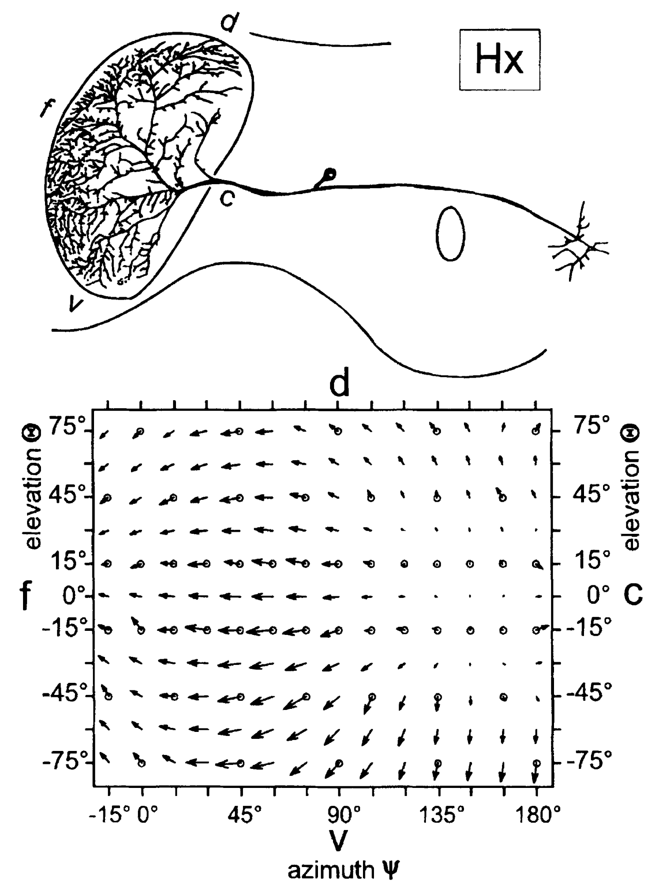
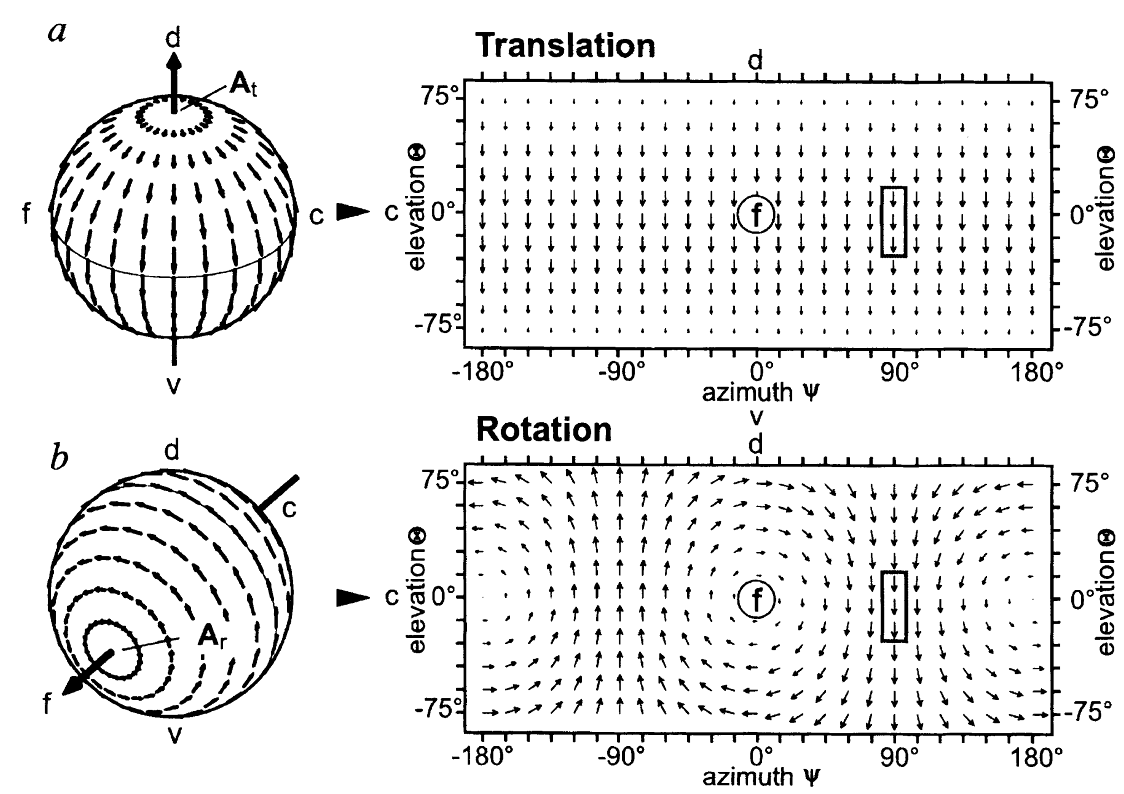


Fig. 4. Flight paths of chasing (●) and leading (○) flies during the longest recorded chase. Points at 20 ms intervals. Corresponding instants on the two paths numbered at 200 ms intervals

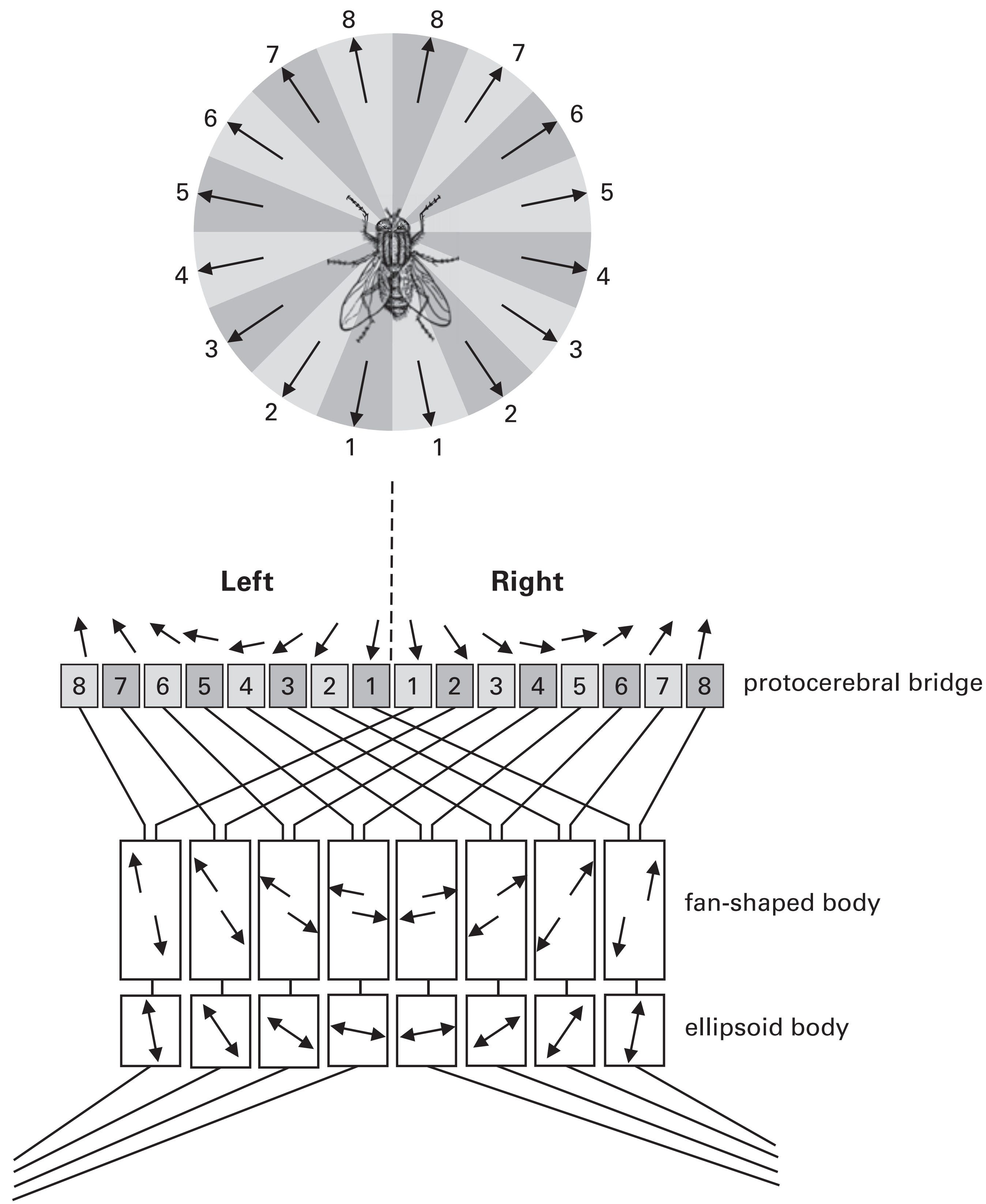
Fly lobula neurons selective to optic flow
(Krapp & Hengstenberg, 1996)

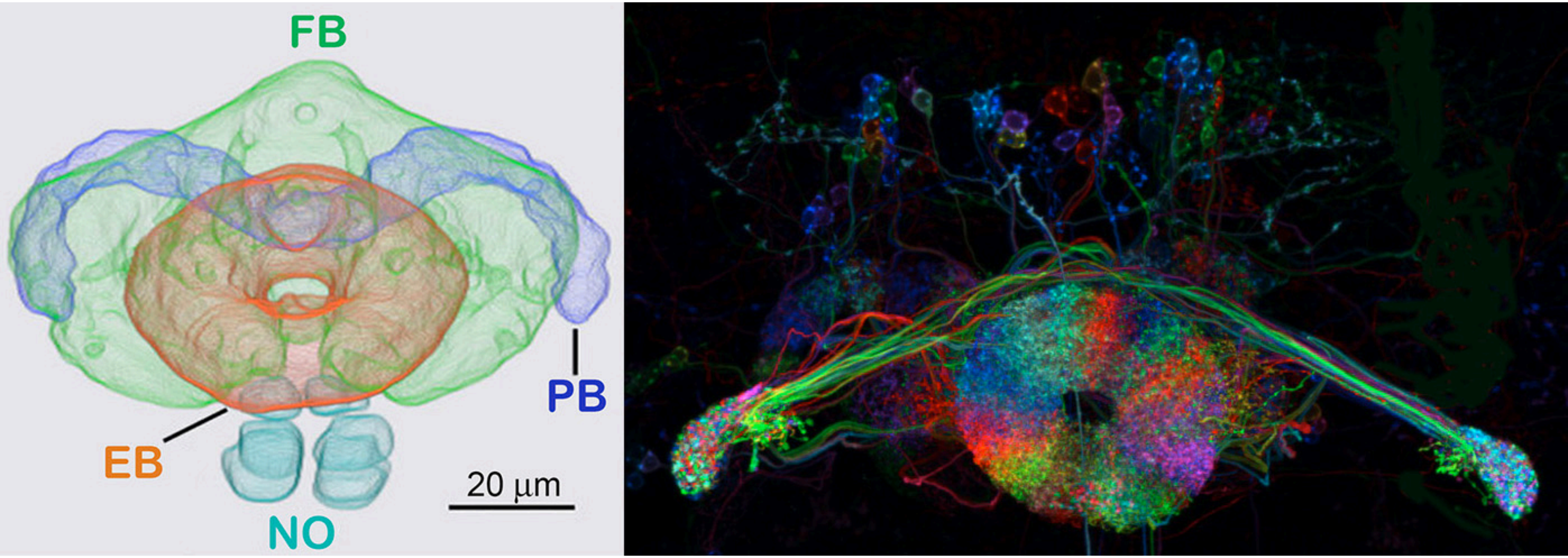






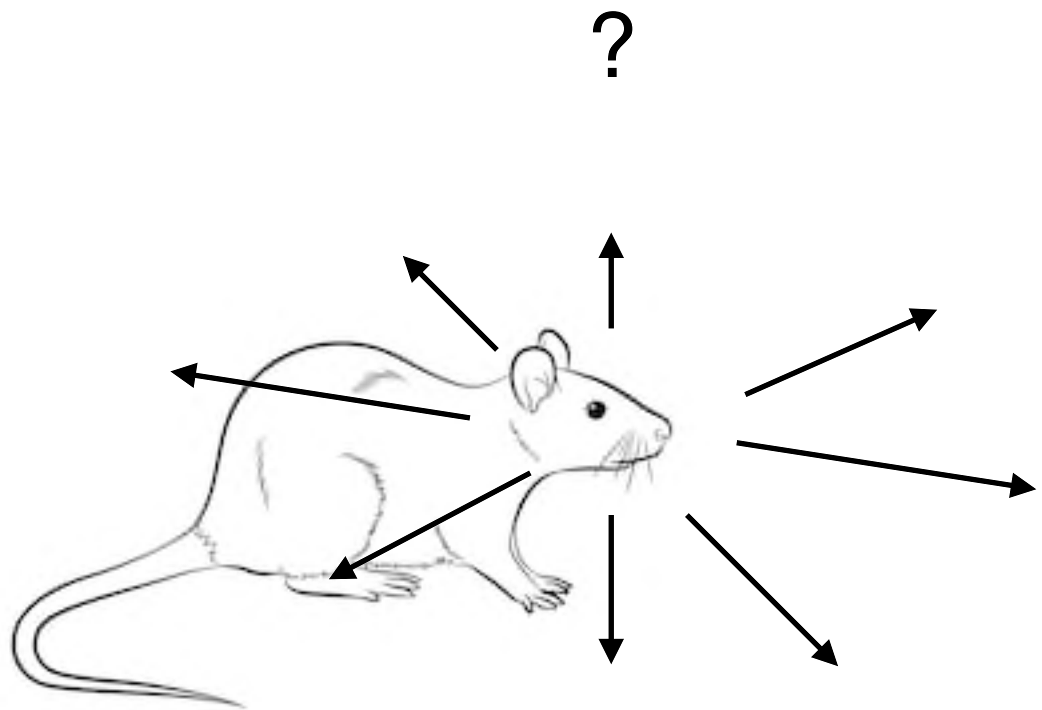
Fly central complex maps horizontal lines of sight

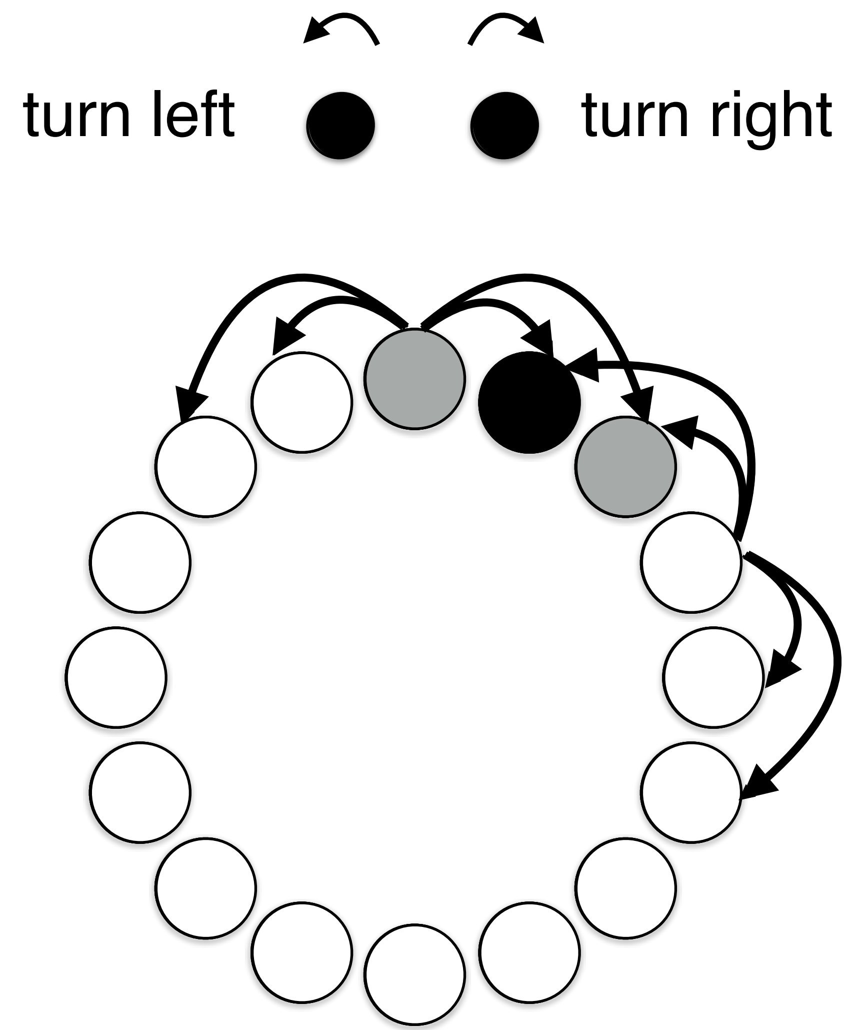




From Rubin lab, HHMI/Janelia

Head-direction cells
(Ranck 1985; Taube et al. 1990)

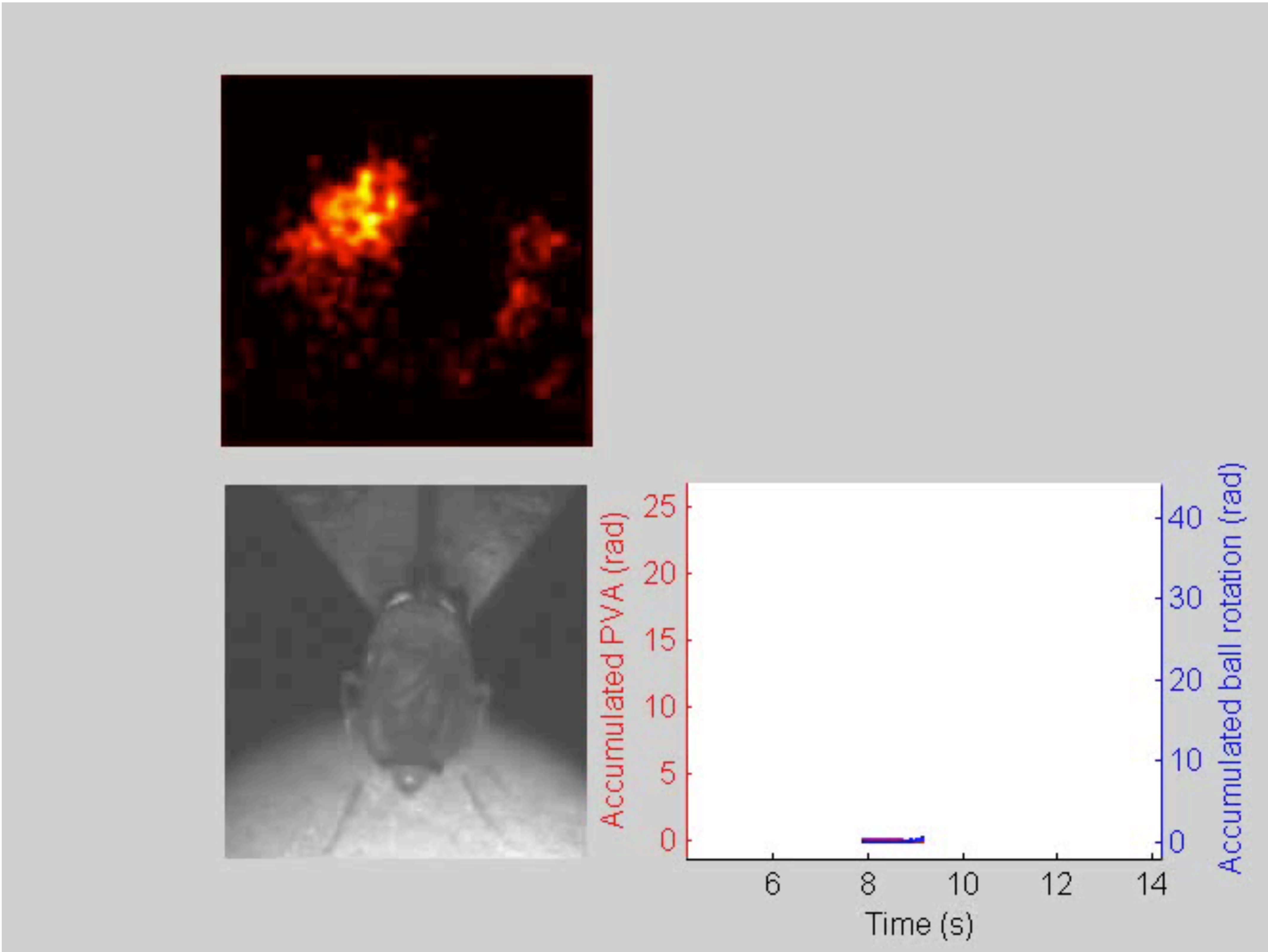




Ring attractor model
(Zhang 1996)

Head-direction cells in ellipsoid body of Drosophila

(Seelig & Jayaraman 2015)



Main points

- Why have a brain?
  - to act, speed, make predictions, memory, coordination

- Core functions and modularity appear to be shared among many different brains, from fly to mammal.

- Basic components of mammalian brain
  - cerebral cortex, hippocampus, thalamus, basal ganglia, cerebellum
  - cortex: 2D sheet of neurons, intrinsically flat.
  - visual cortex subdivided into ~30 different areas with different functions, organized hierarchically.
  - laminar organization and canonical microcircuit, but is there a canonical algorithm?

- Origins of intelligence
  - fly and spider brains produce of rich, autonomous behavior, ability to navigate and reason about 3D world.
  - fly brain builds internal representation of head direction with respect to external environment.