



RUB

RUHR-UNIVERSITÄT BOCHUM

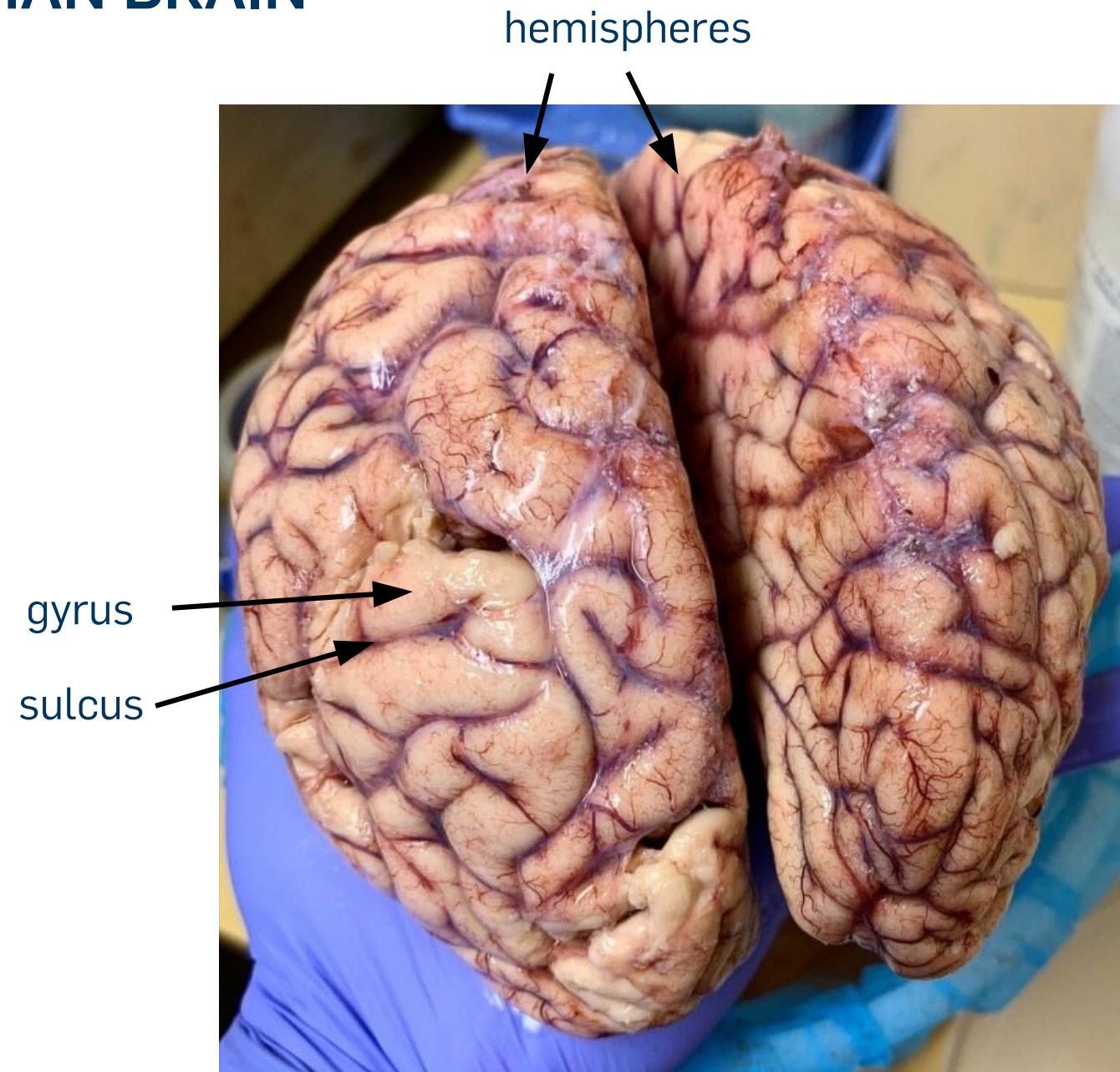
Biological Neural Networks

Sen Cheng

Institute for Neural Computation

BASICS

HUMAN BRAIN



ANCIENT HISTORY

earliest recorded
reference to the brain

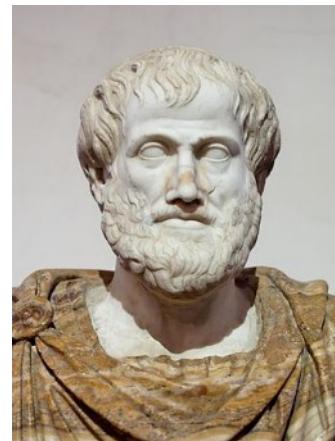


17th century BC

heart: intelligence
brain: who cares?

→ “learning by heart”

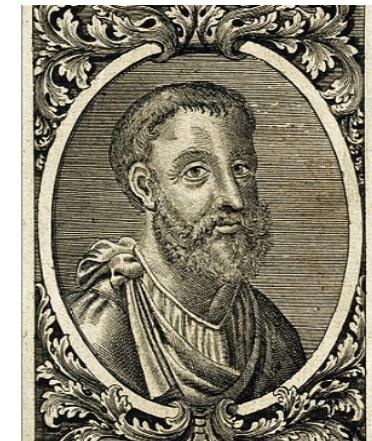
Aristotle



384 BC - 322 BC

heart: intelligence
brain: cooling the blood

Galen



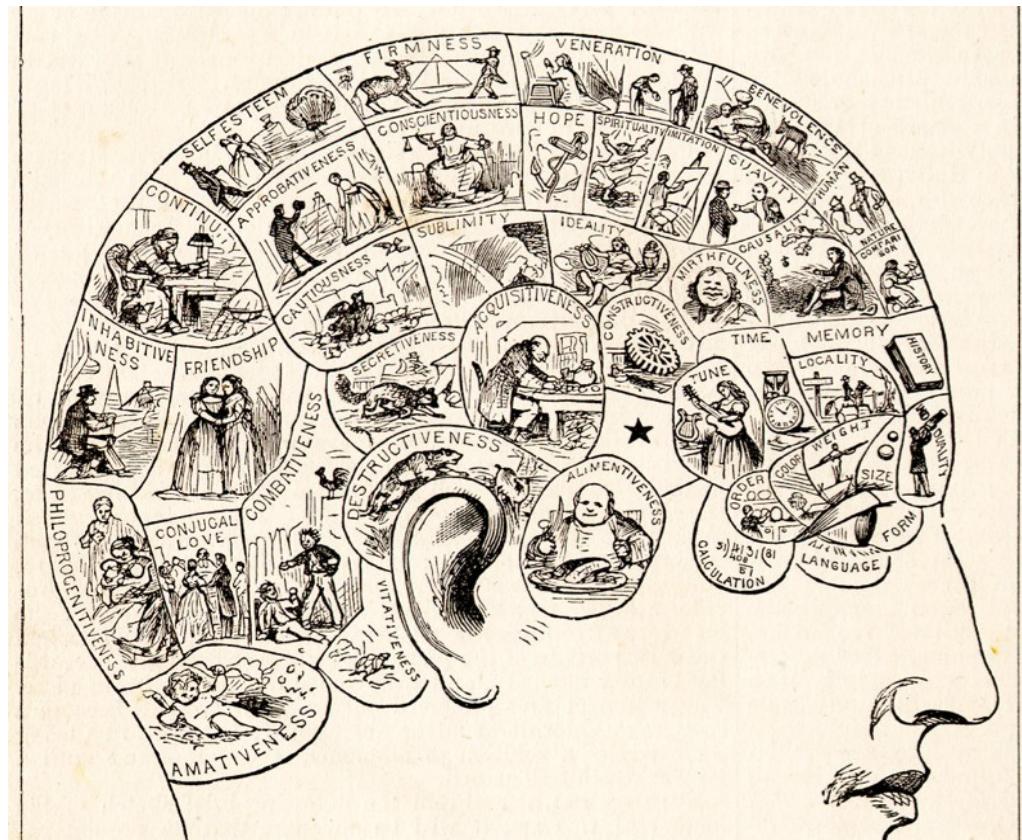
129 AD - 210 AD

brain: senses, control
muscles

PHRENOLOGY

- Developed by Franz Joseph Gall (1796)
- Functions are localized in the brain
- Specialization leads to variation in size of regions
- Specializations are visible on the skull

phrenology chart 1883

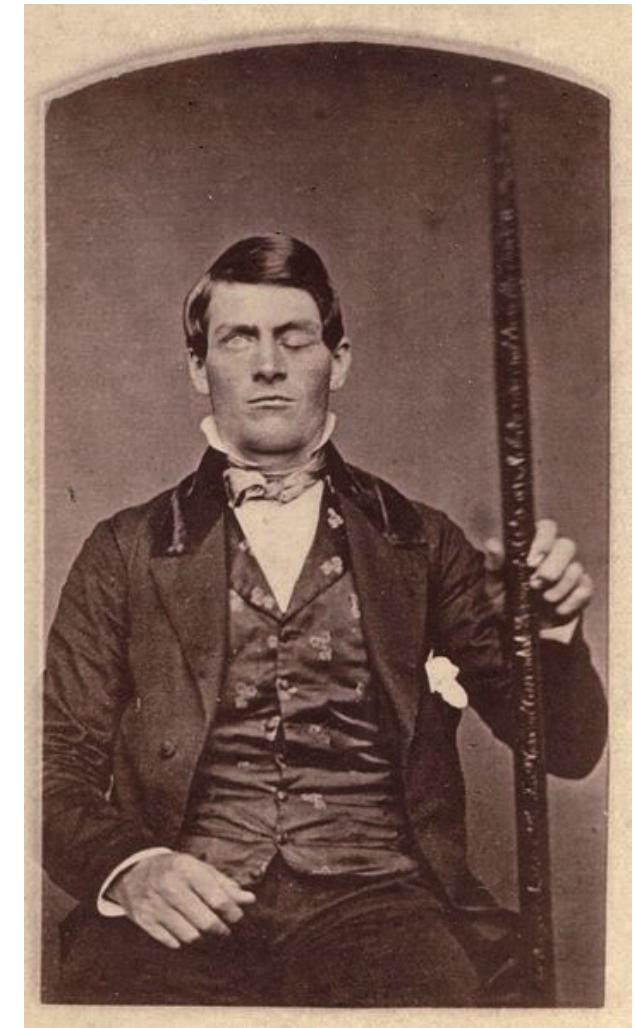


LOCALISATION OF FUNCTIONS

- Accident 1848
- Destroyed left frontal lobe
- Marked change in personality
 - Before: organized, well-tempered, persistent
 - After: impatient, ill-tempered, unsteady



Phineas Gage



RETINOTOPIC ORGANIZATION

Inouye (1909), Holmes (1918)

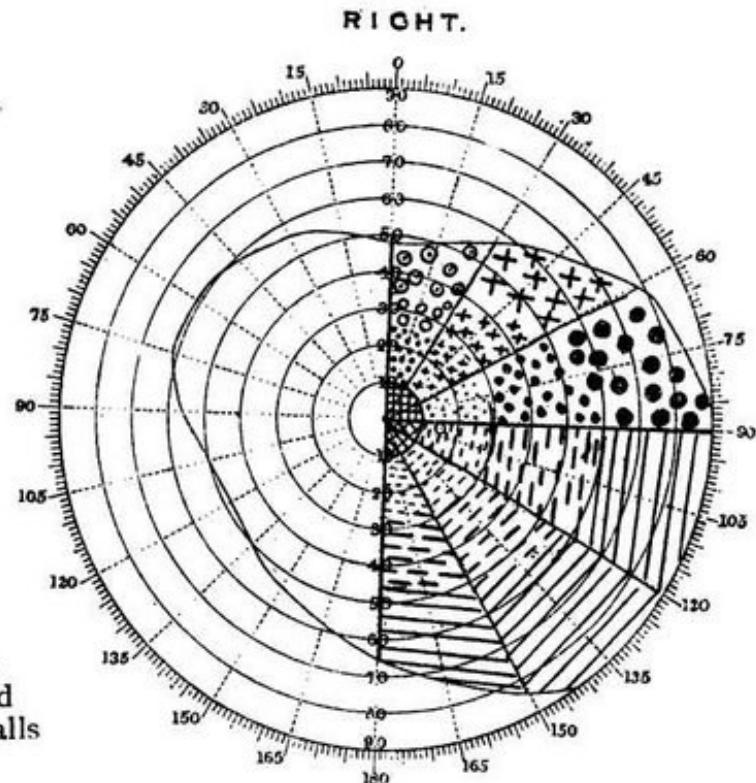
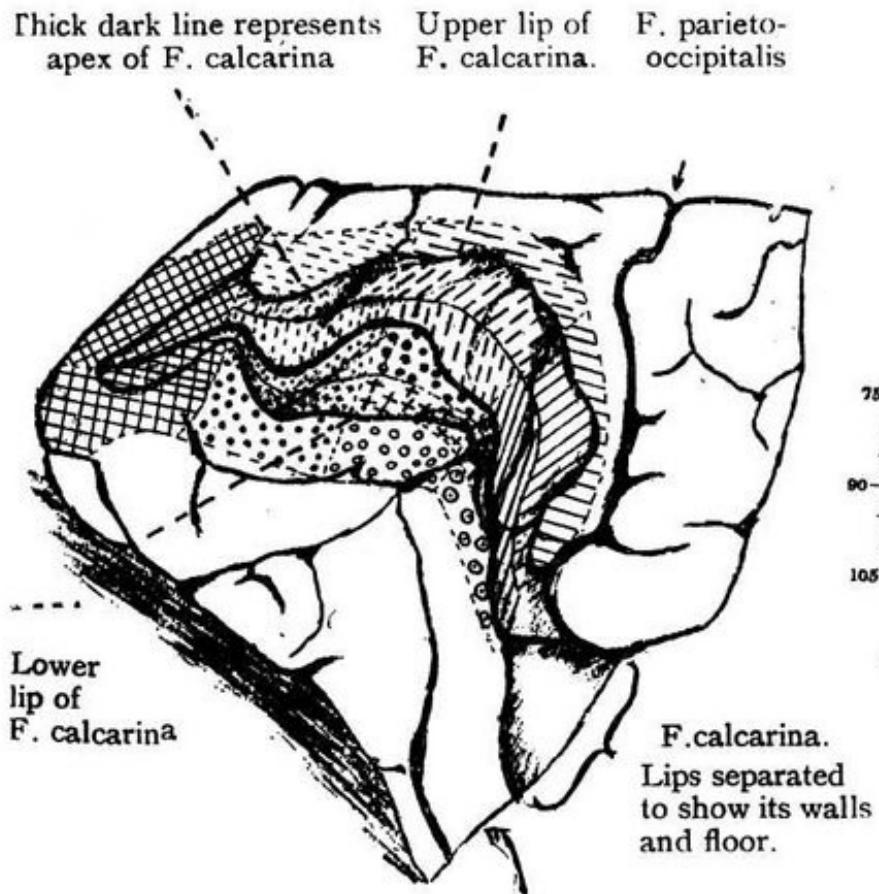


FIG. 16.

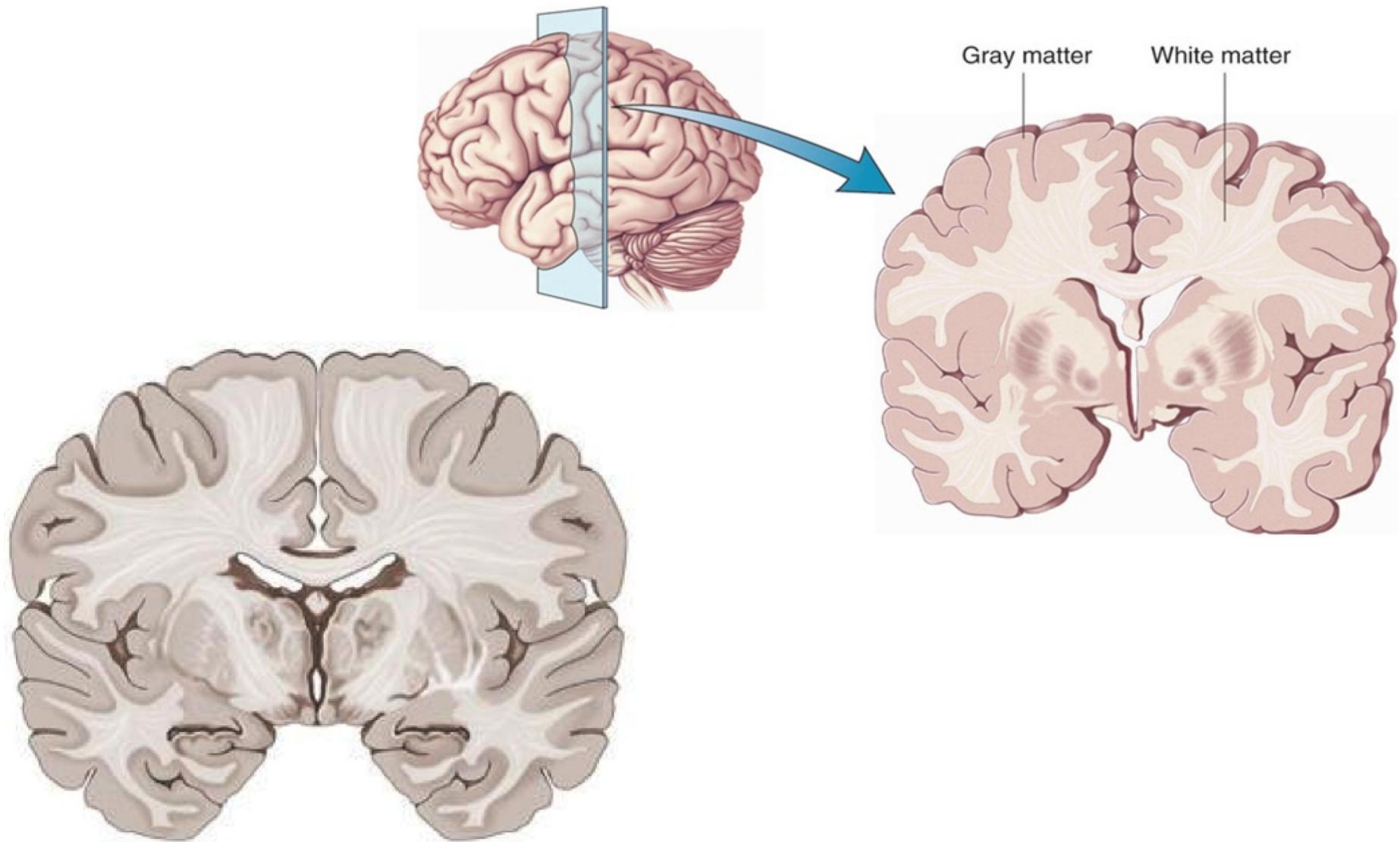
A diagram of the probable representation of the different portions of the visual fields in the calcarine cortex. On the left is a drawing of the mesial surface of the left occipital lobe with the lips of the calcarine fissure separated so that its walls and floor are visible. The markings on the various portions of the visual cortex which is thus exposed correspond with those shown on the chart of the right half of the field of vision.

This diagram does not claim to be in any respect accurate ; it is merely a schema.

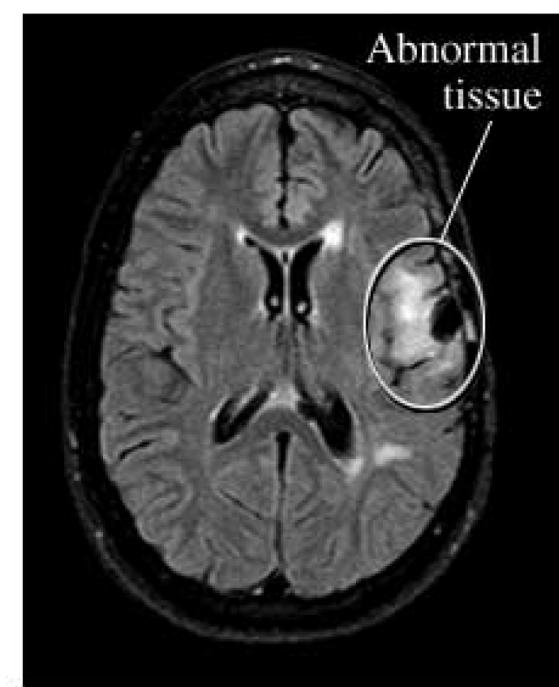
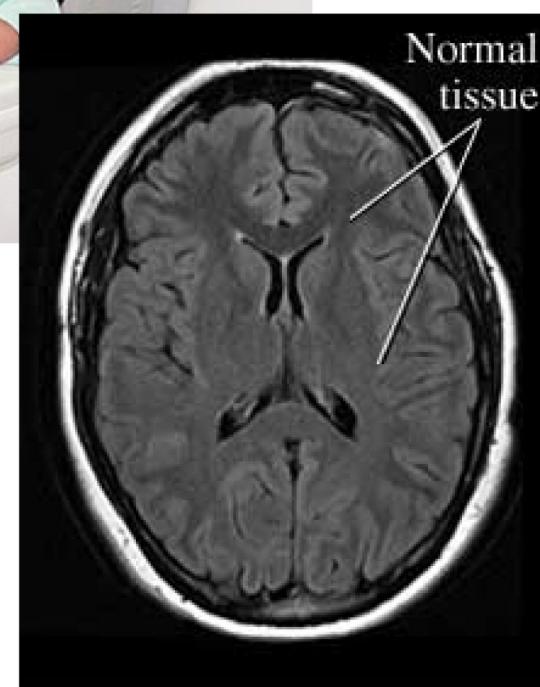
Clive Wearing



STRUCTURES



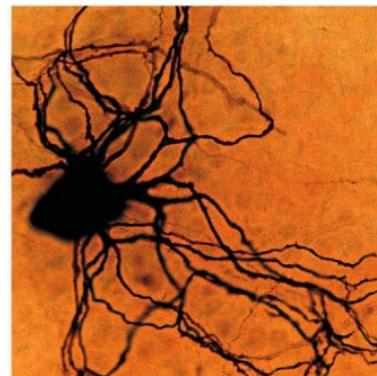
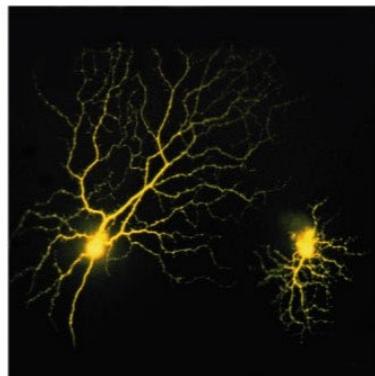
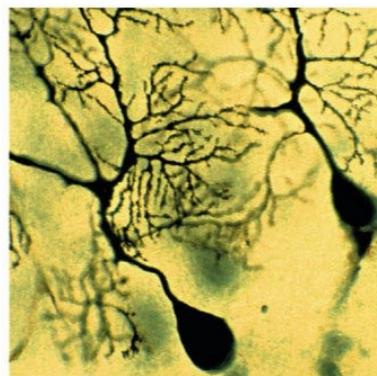
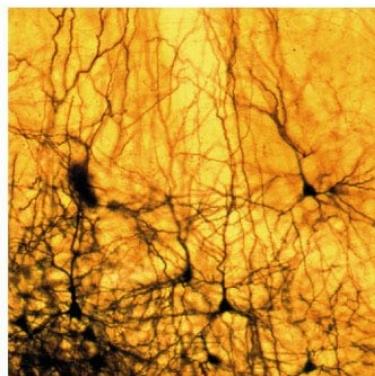
MAGNETIC RESONANCE IMAGING (MRI)



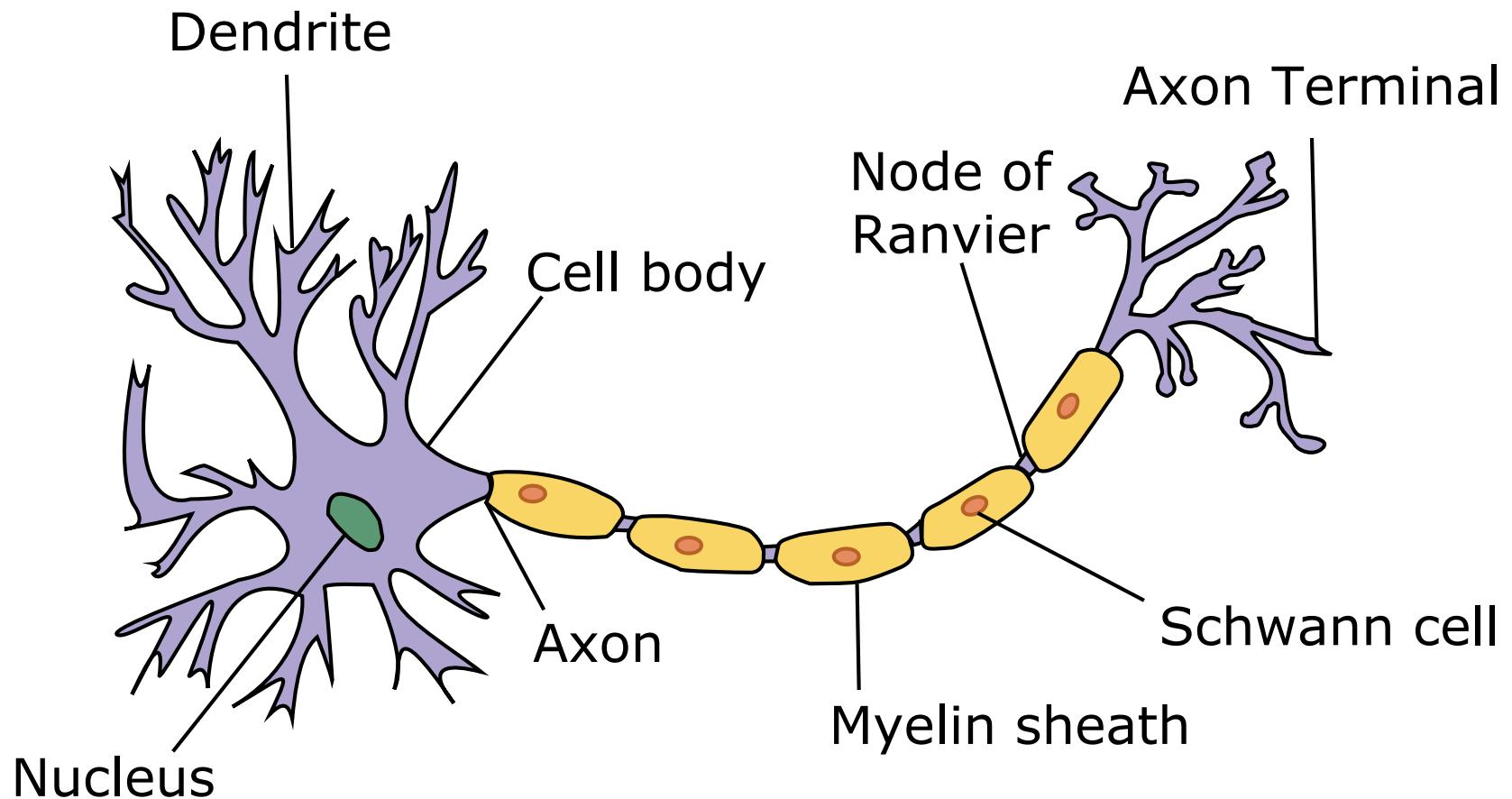
NEURON DOCTRINE

- Brain matter is transparent and dense
- Camillo Golgi (1843–1926)
 - Golgi Stain 1873
 - potassium dichromate, 2 days
 - silver nitrate, 2 days
- Santiago Ramón y Cajal (1852–1934)
- Neuron doctrine 1891

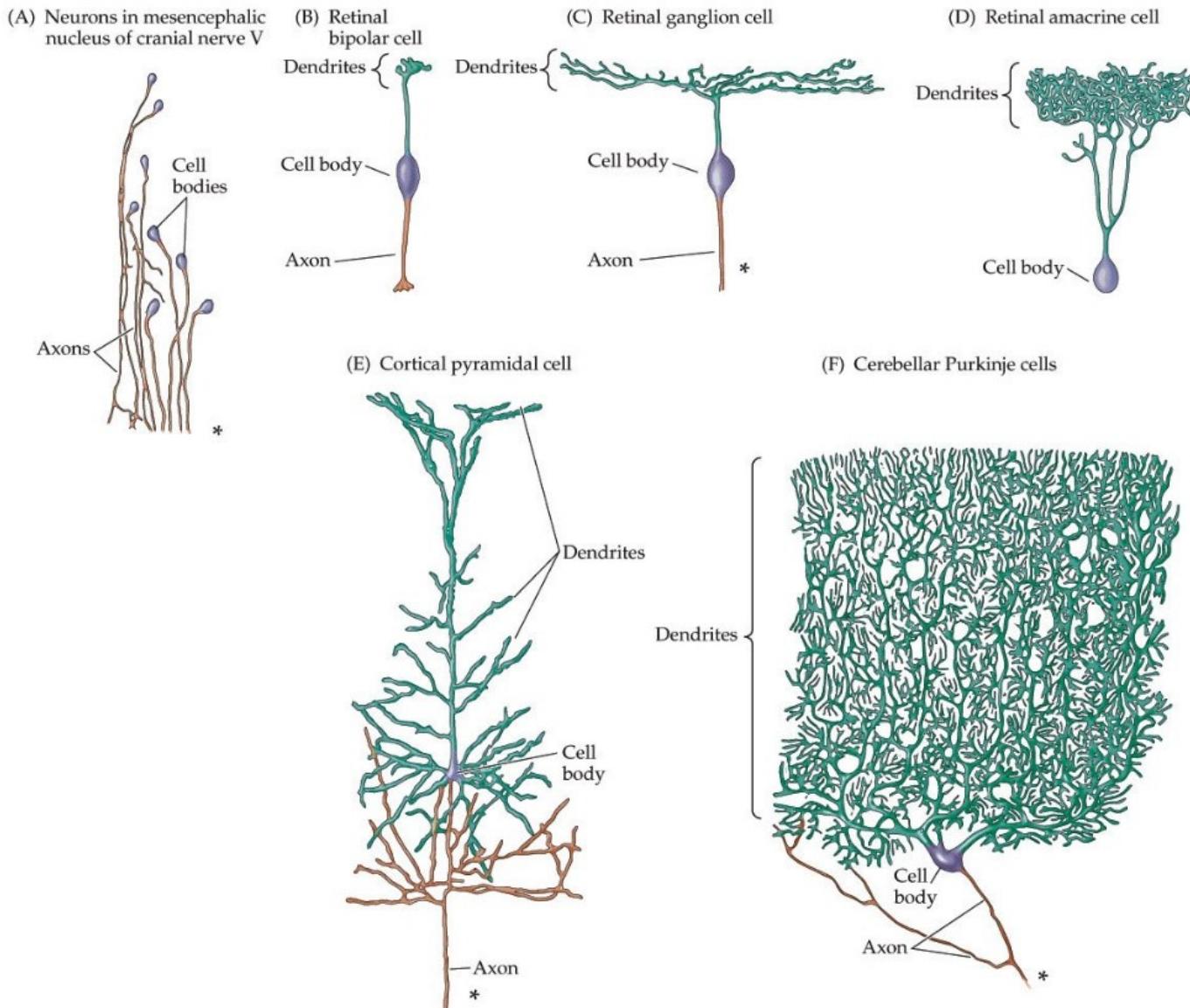
Golgi staining



NEURONS



VARIOUS NEURON MORPHOLOGIES

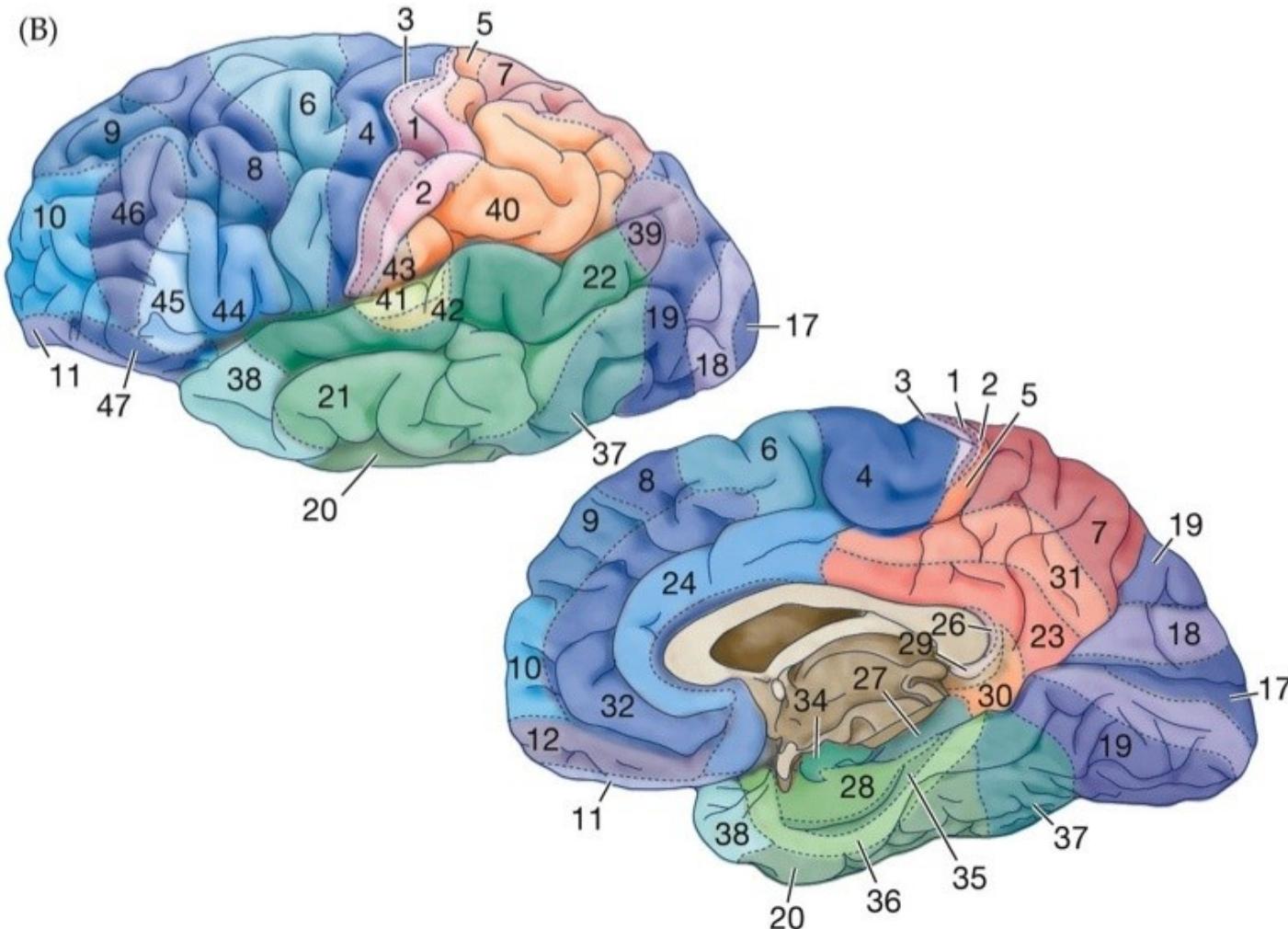


NEUROSCIENCE, Fourth Edition, Figure 1.2

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BRODMANN AREAS

Korbinian Brodmann, 1909

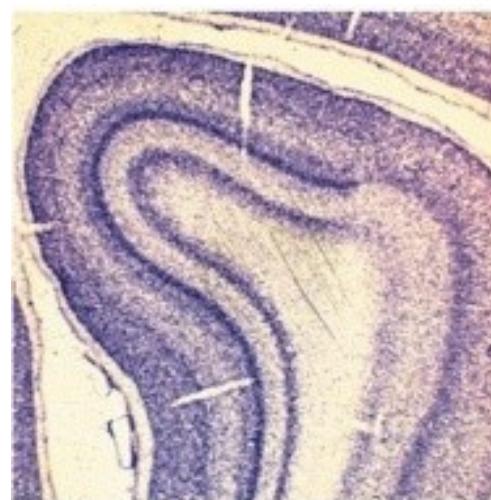
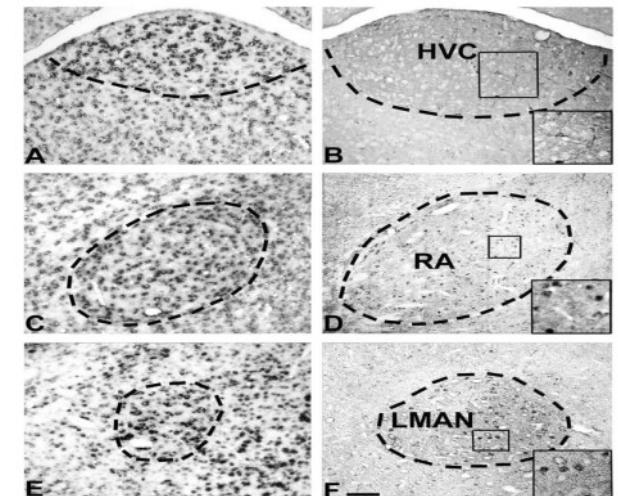
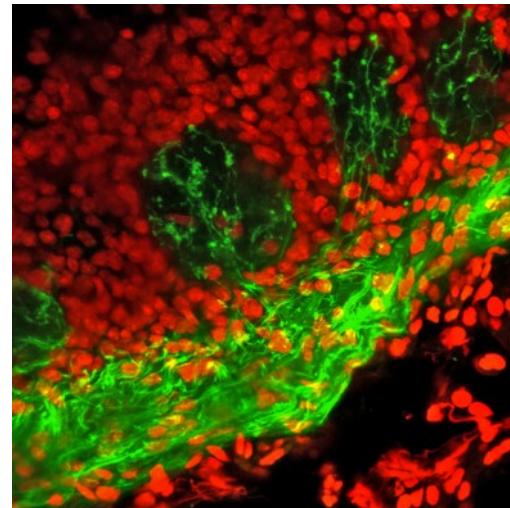


NEUROSCIENCE, Fourth Edition, Figure 26.2 (Part 2)

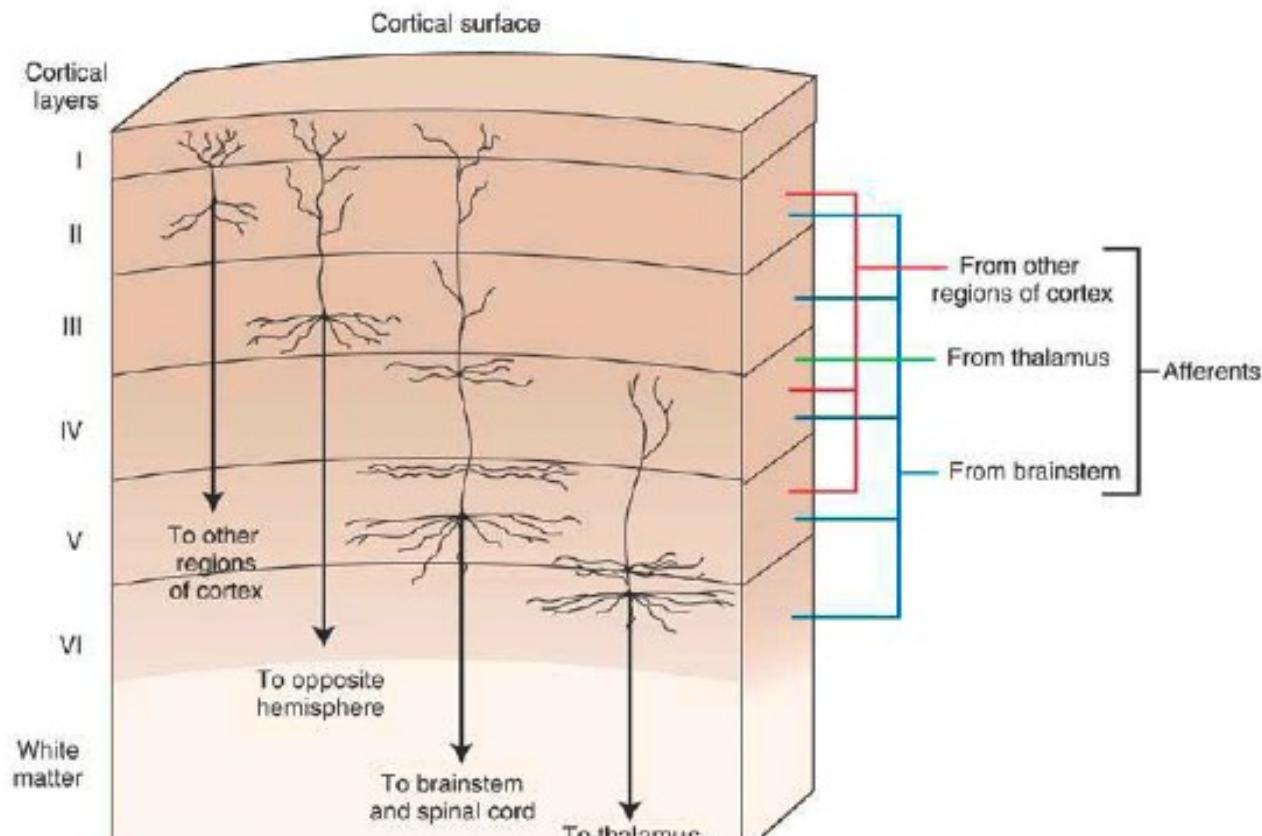
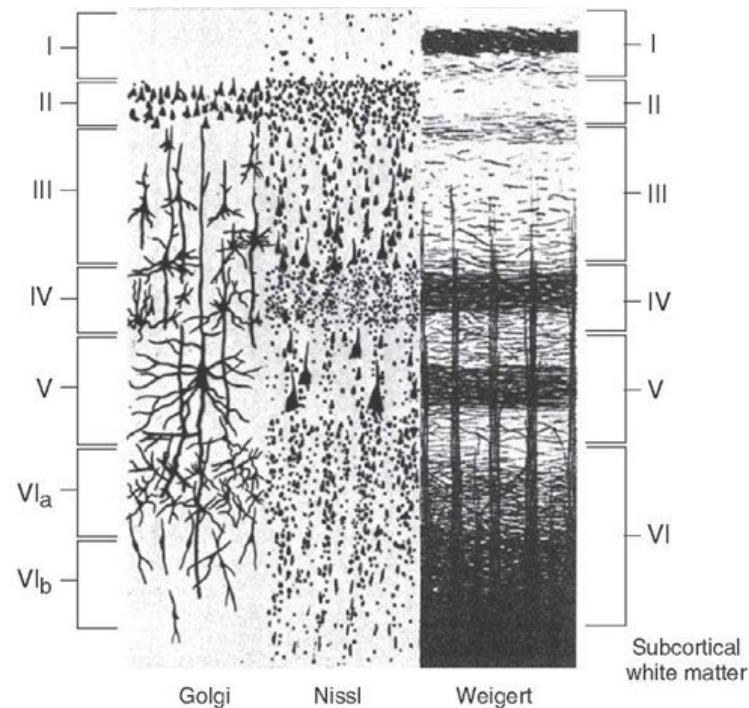
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ORGANIZATIONAL STRUCTURES

- random
- glomeruli
- nuclei
- layered structures
 - hippocampus - archicortex
 - neocortex

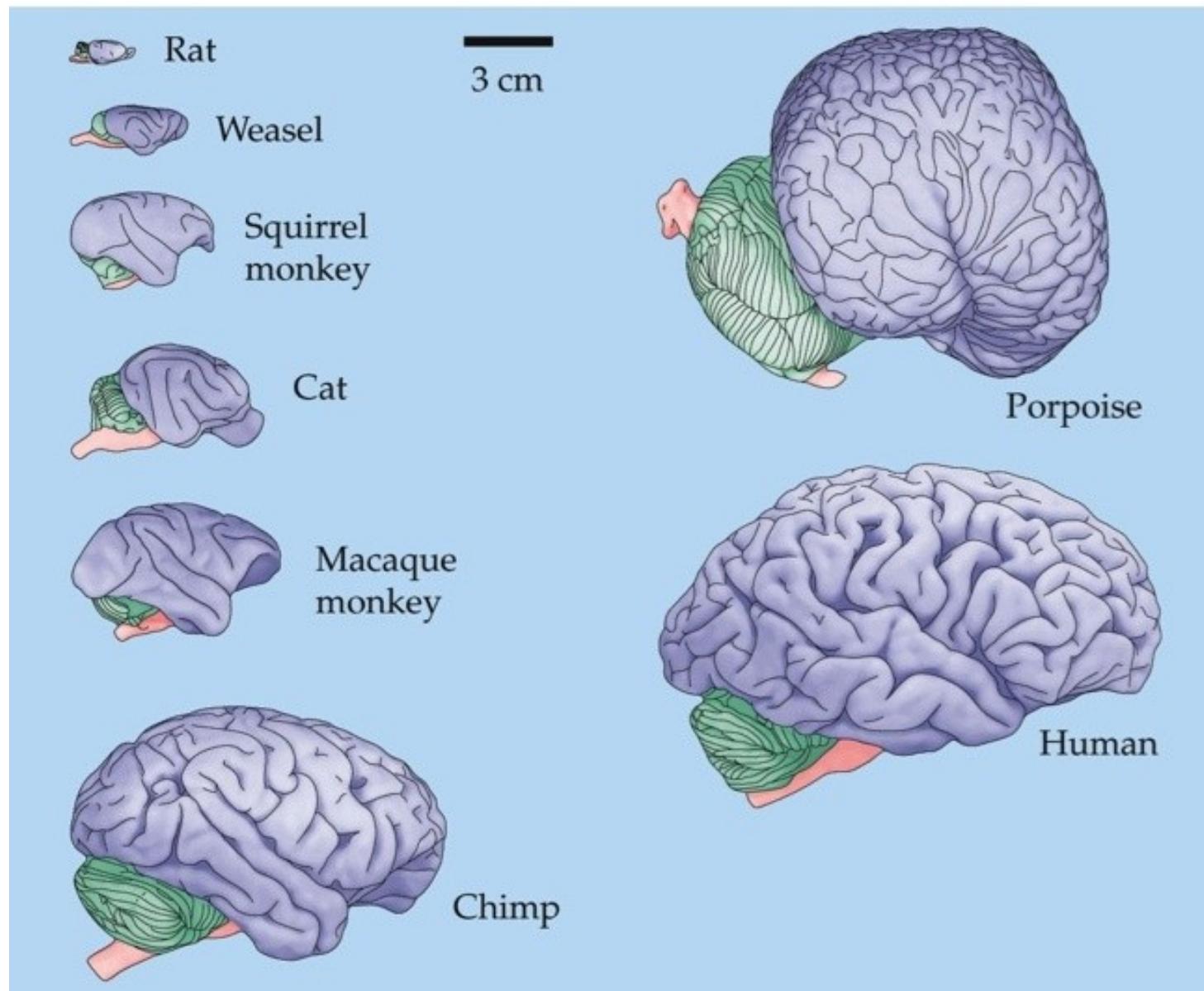


LAYERED NEOCORTEX



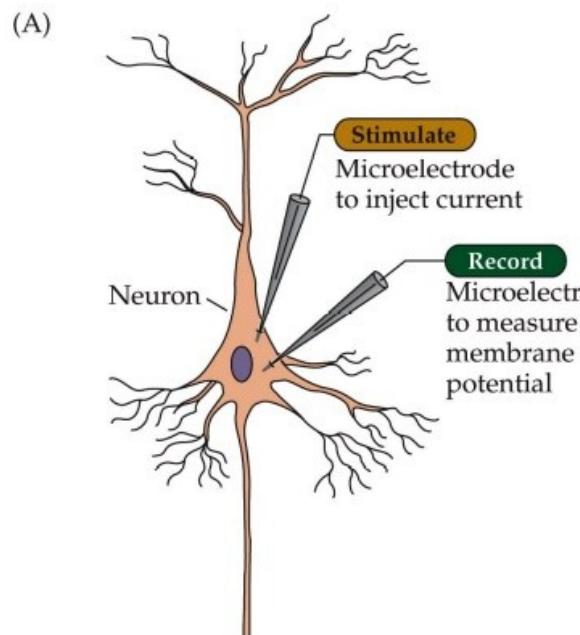
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GYRIFICATION AND HOMOLOGY

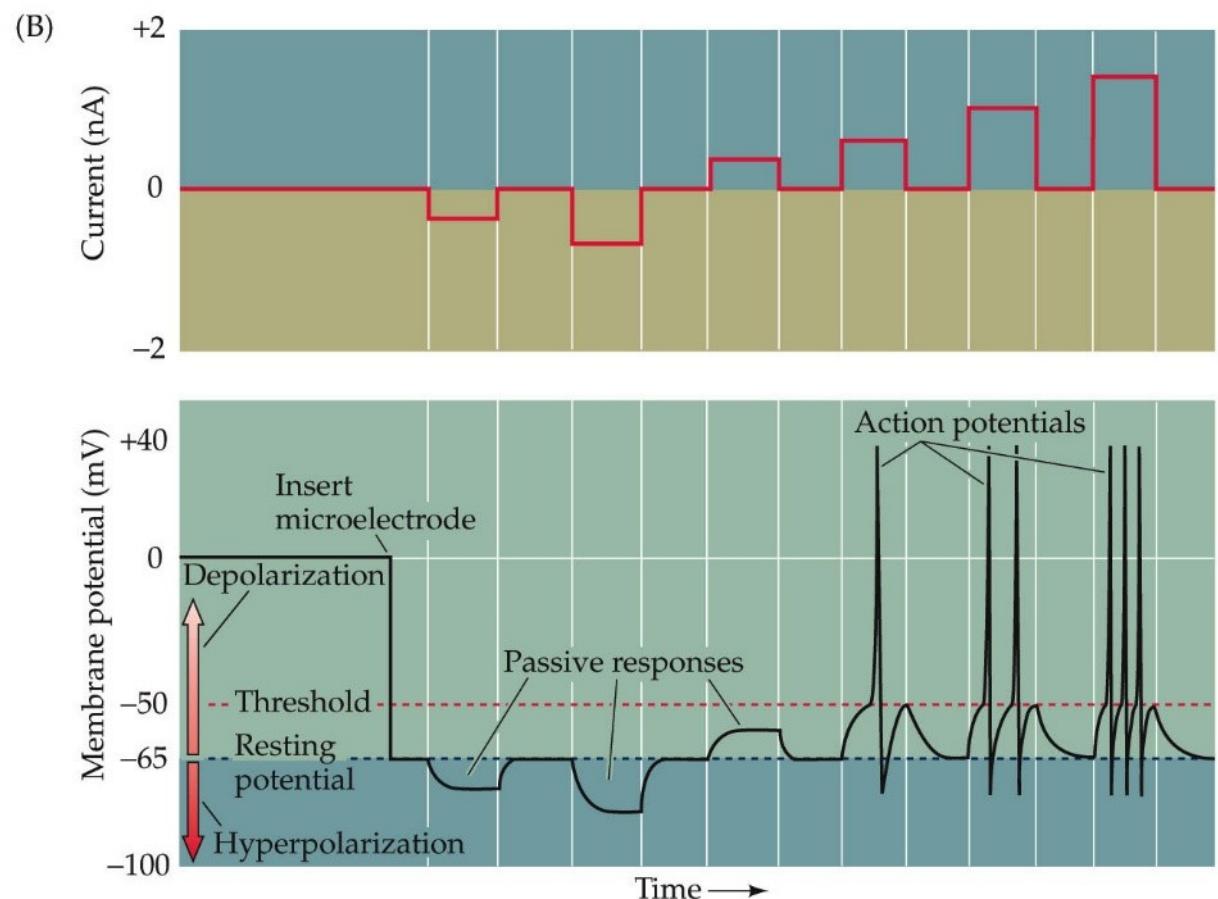


ELECTRICAL SIGNALS IN THE BRAIN

- Electricity (Luigi Galvani, 1791-1797)
- Action potentials (Emil du Bois-Reymond, 1848)
- Spiking threshold



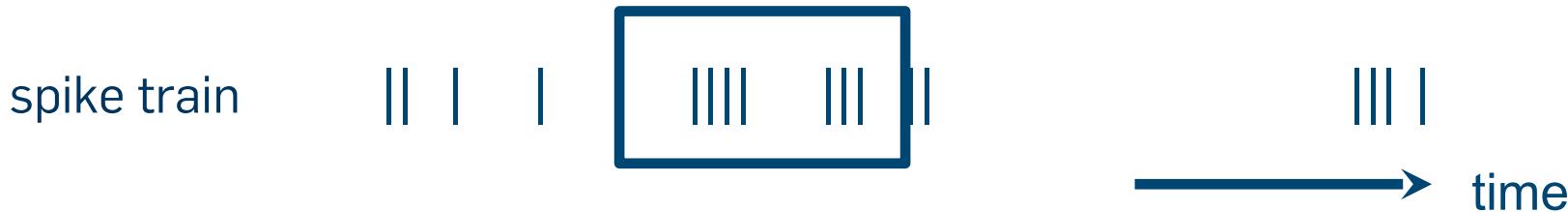
NEUROSCIENCE, Fourth Edition, Figure 2.2 (Part 1)



NEUROSCIENCE, Fourth Edition, Figure 2.2 (Part 2)

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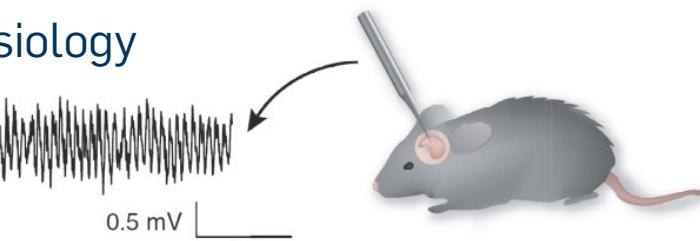
CODING WITH NEURAL ACTIVITY



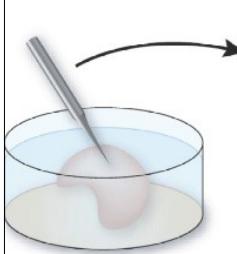
$$\text{firing rate} = \frac{\text{number of spikes}}{\text{length of time window}}$$

electrophysiology

Behaving rat



Whole hippocampus *in vitro*

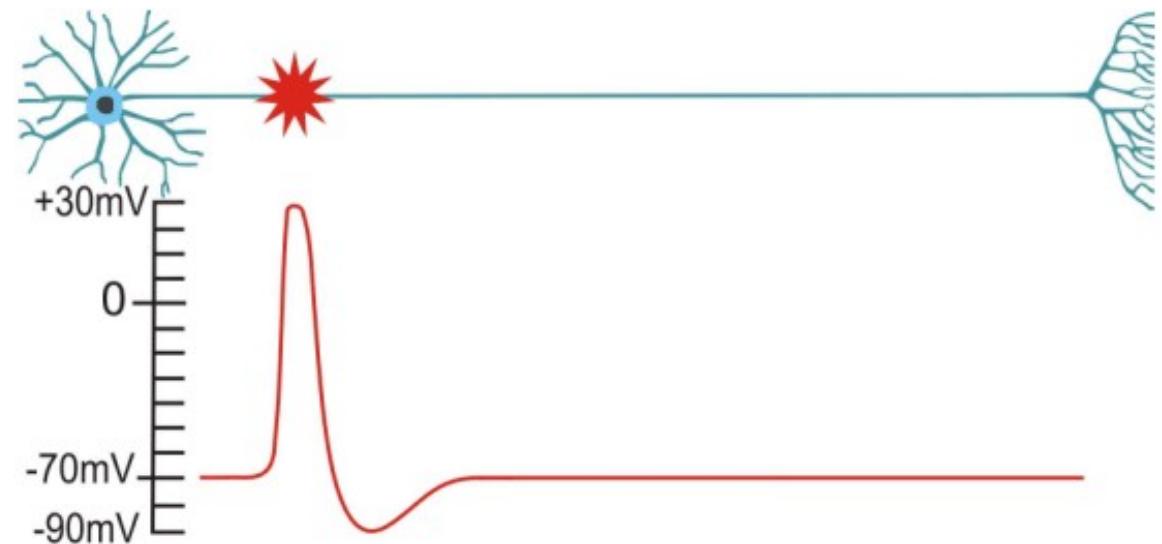


Possible coding schemes

- Rate code
- Temporal code
 - Phase of oscillation
 - Coincidence detection
 - Sequence

PROPAGATION

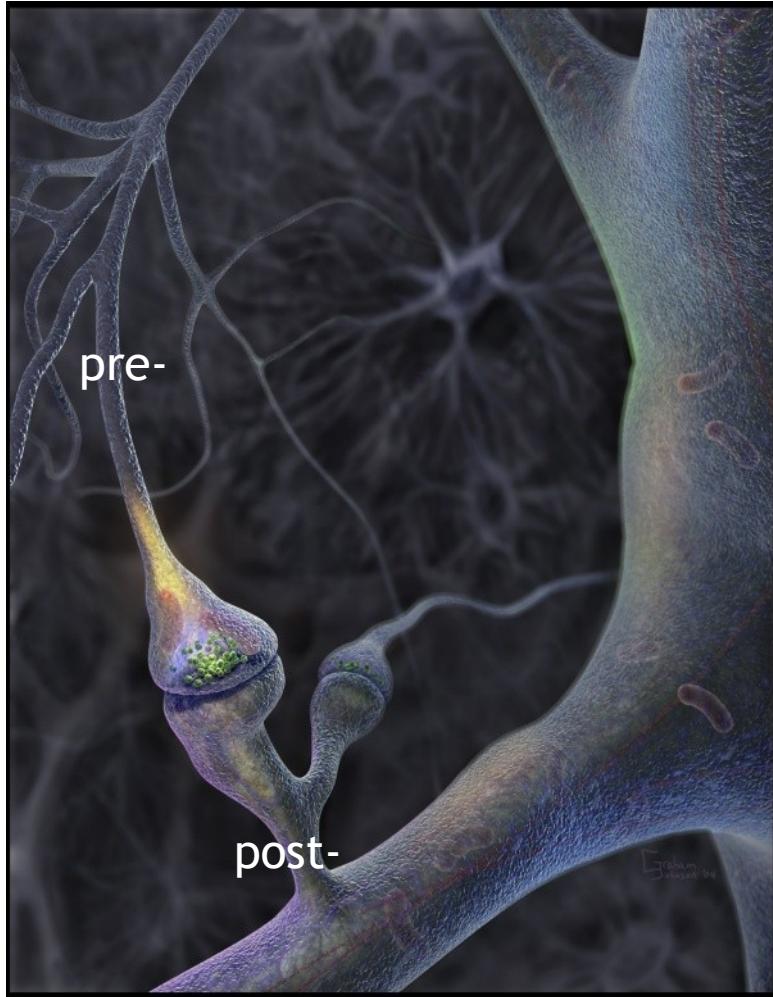
action potential (spikes)



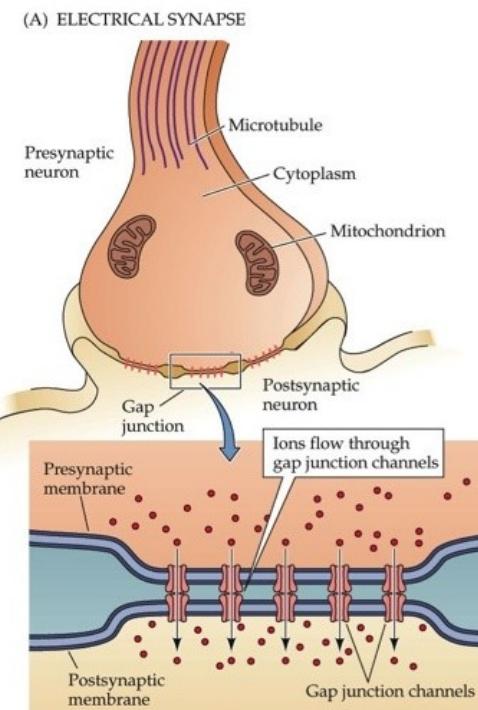
propagation speeds 1-100m/s

SYNAPSES

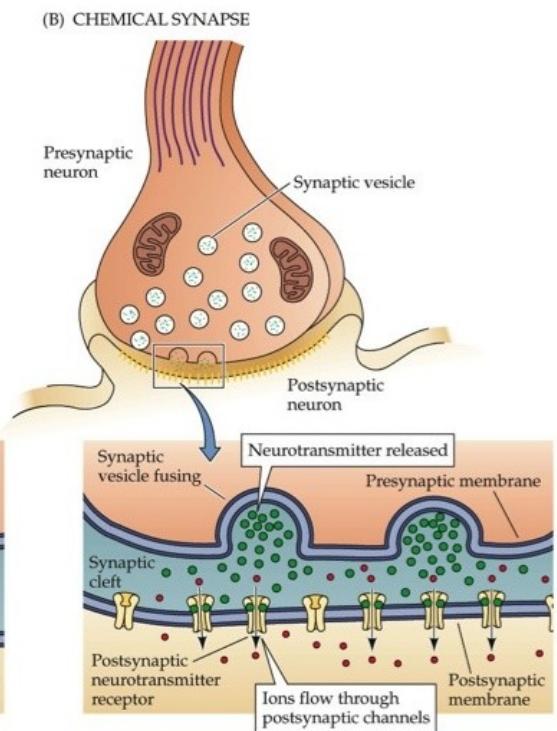
Charles Sherrington (1897)



electrical



chemical

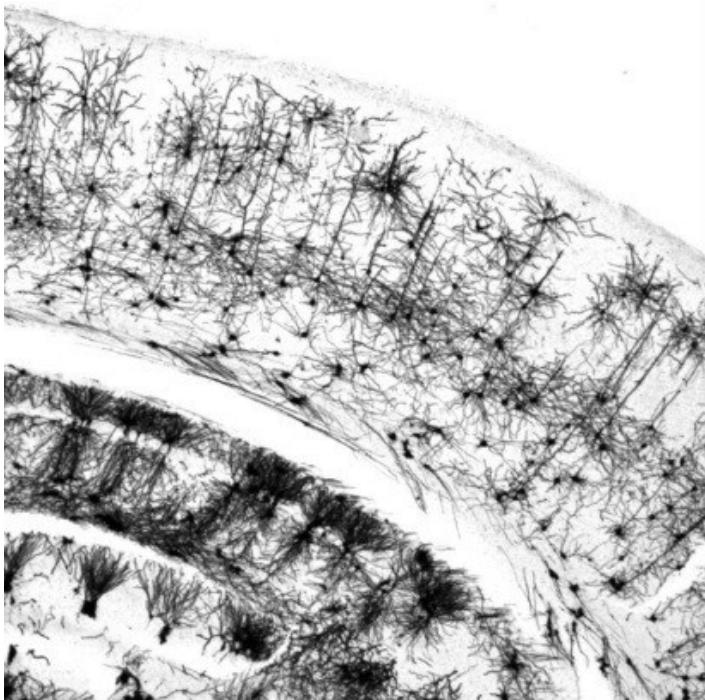


John Eccles

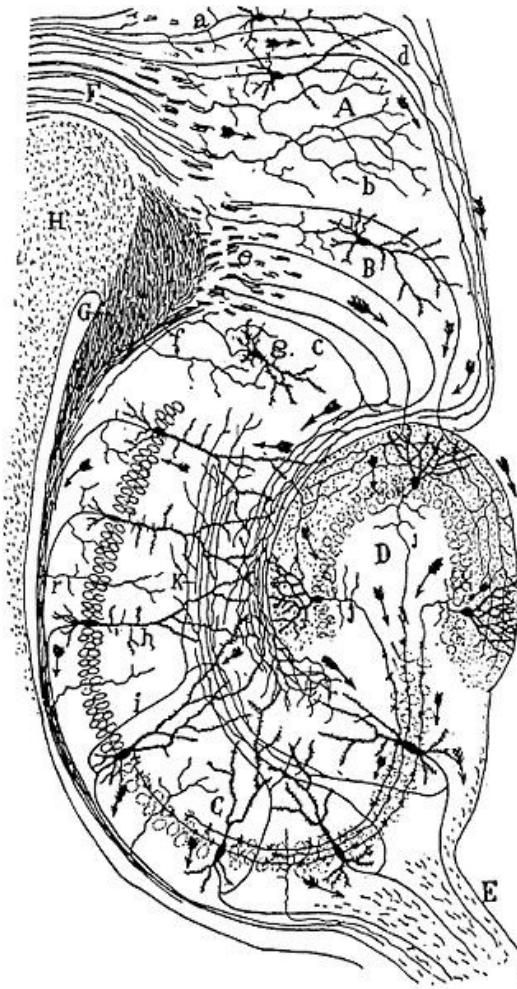
Henry Dale

$\sim 10^{11}$ Neurons
 $\sim 10^{15}$ synapses

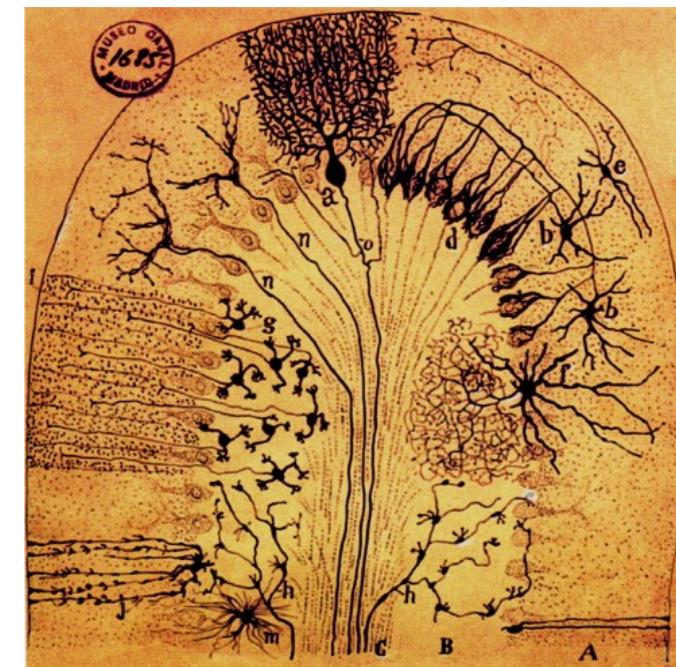
NETWORKS OF NEURONS



neocortex

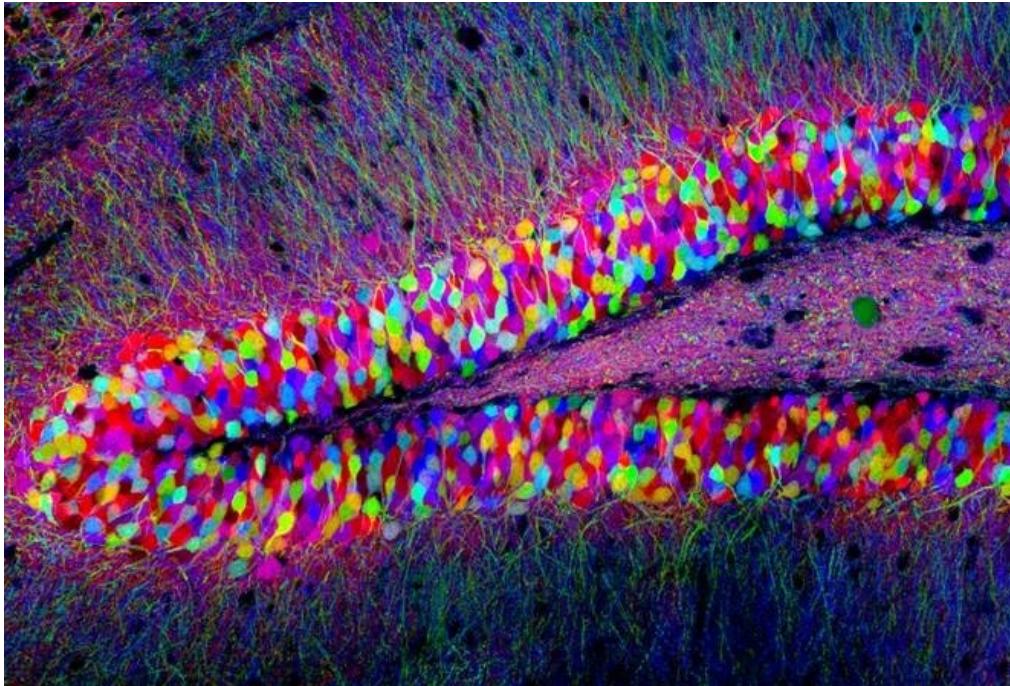


hippocampus

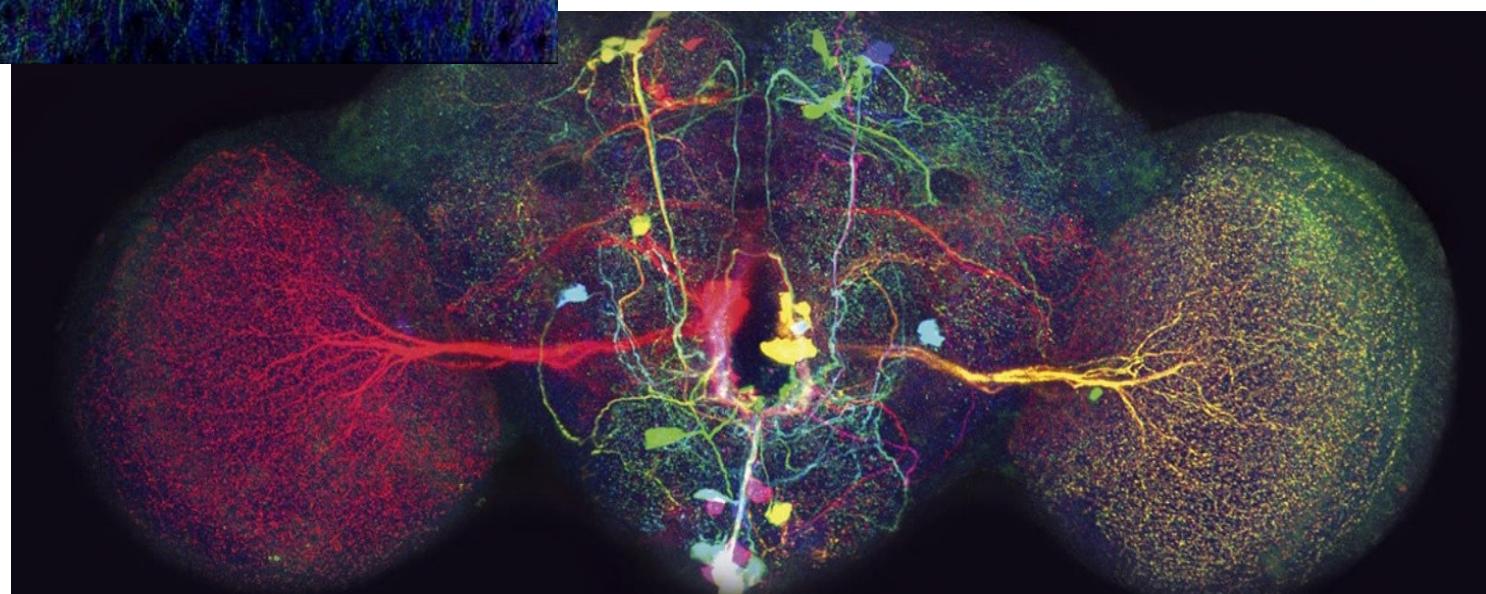


cerebellum

BRAINBOW

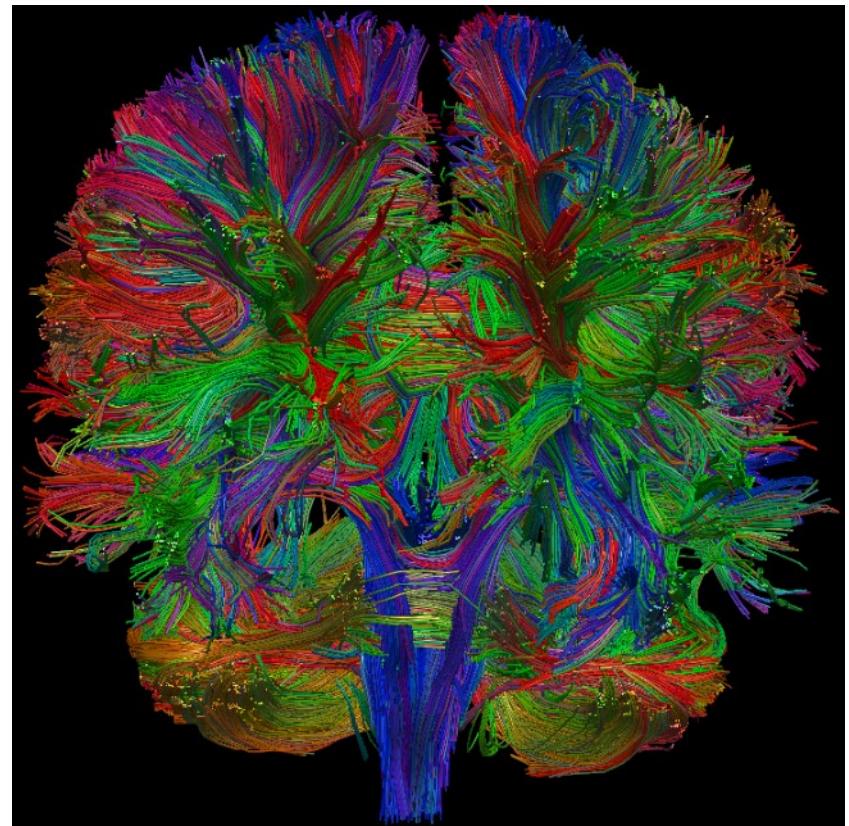
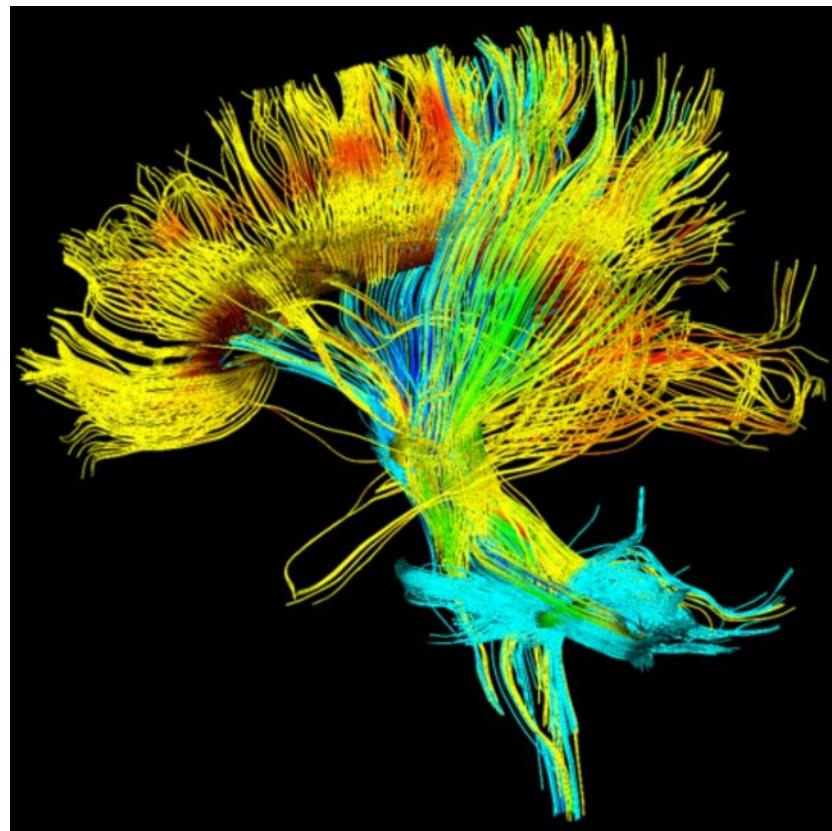


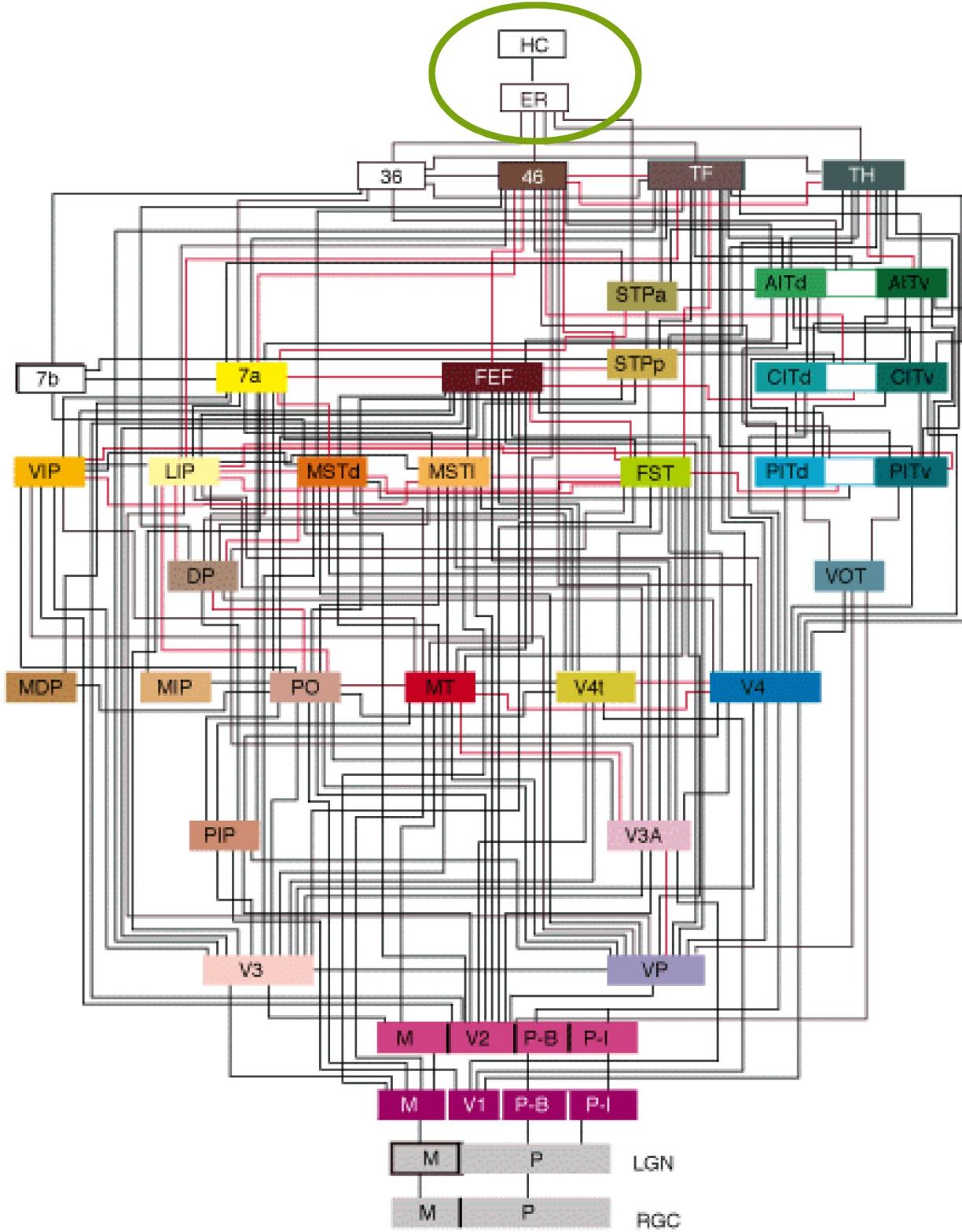
Mouse
Gyrus Dentatus



Fruit fly

DIFFUSION TENSOR IMAGING

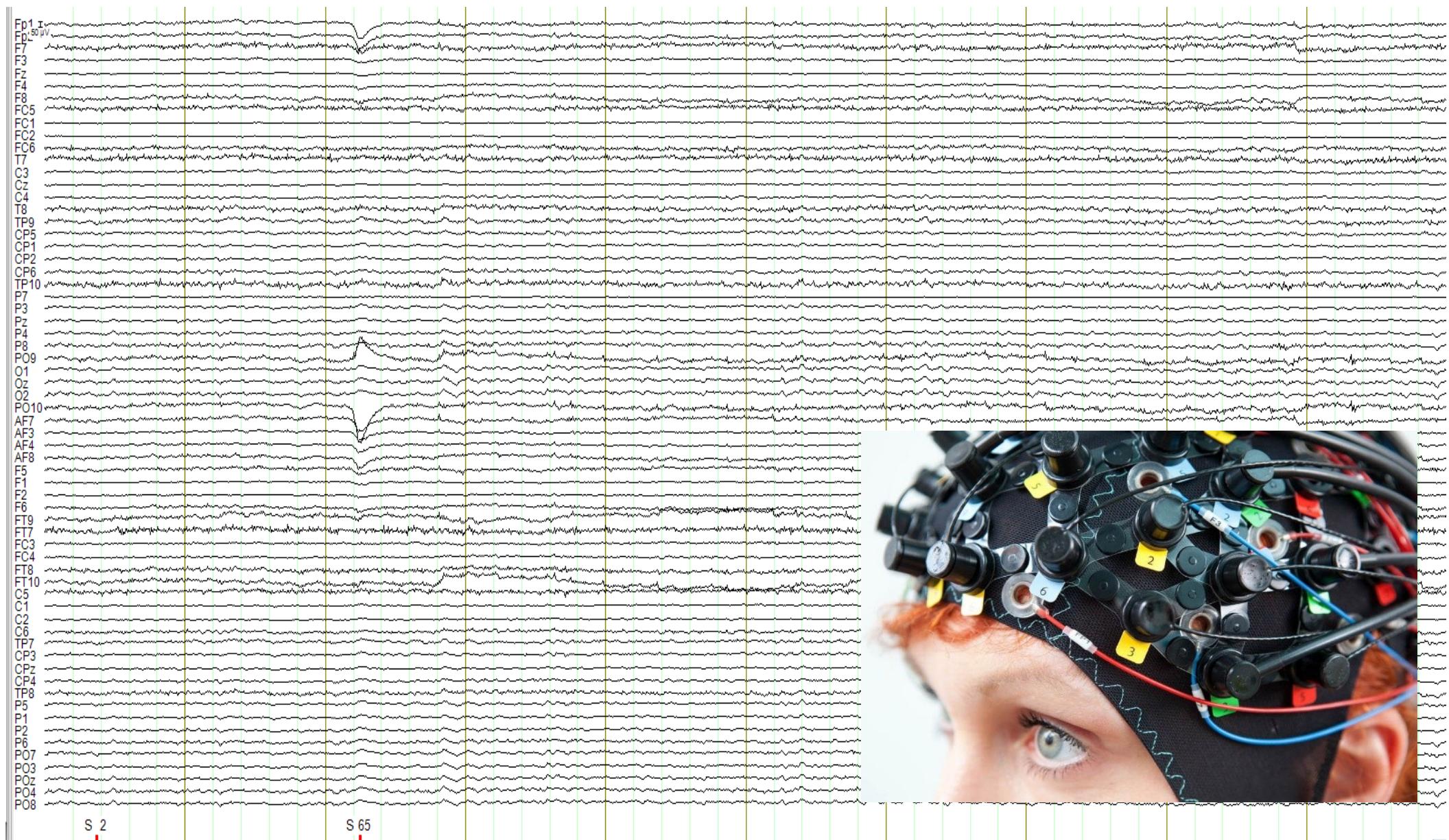




Circuit diagram of the regions involved in vision.

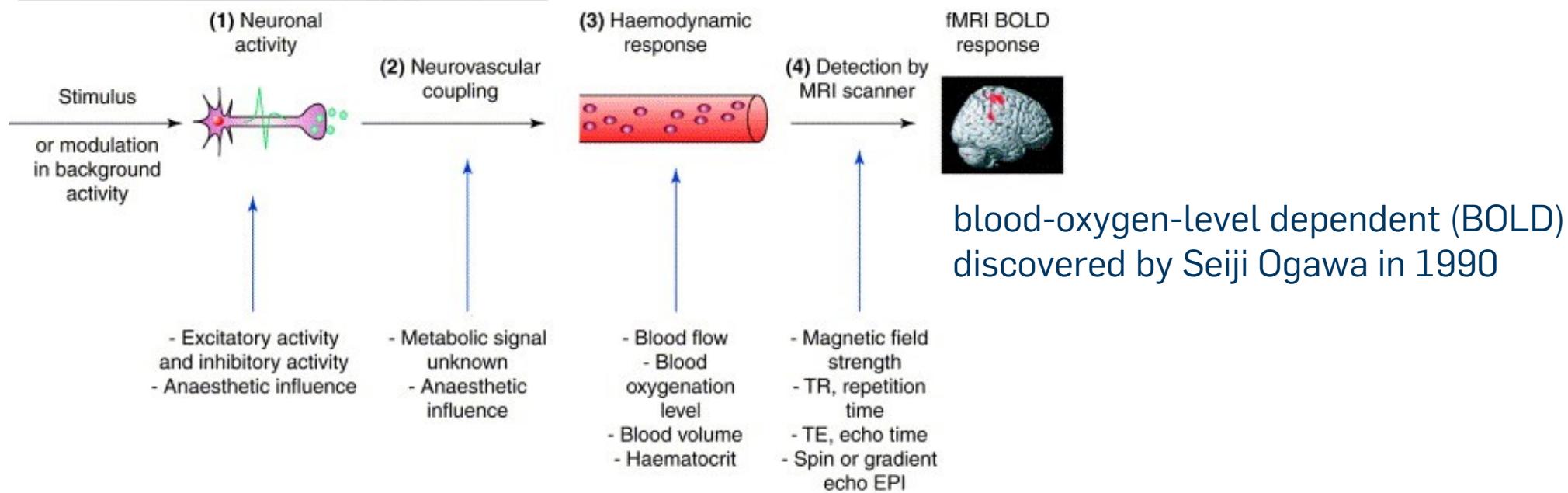
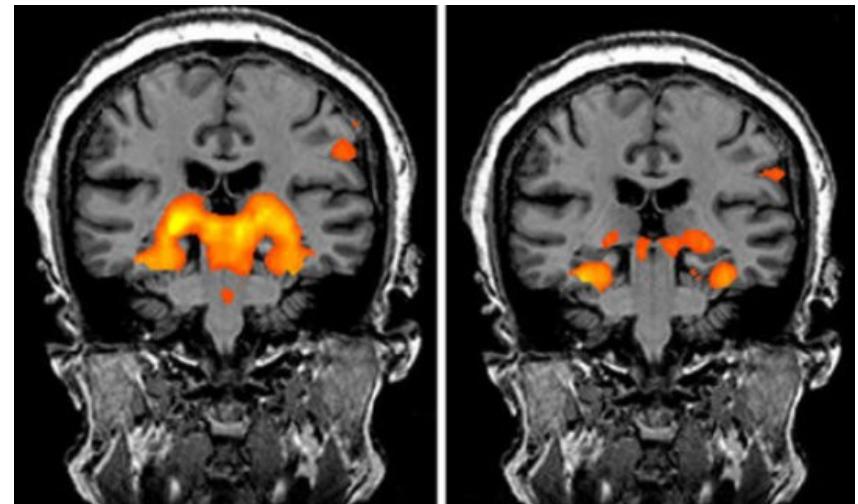
Felleman & van Essen (1991)

EEG



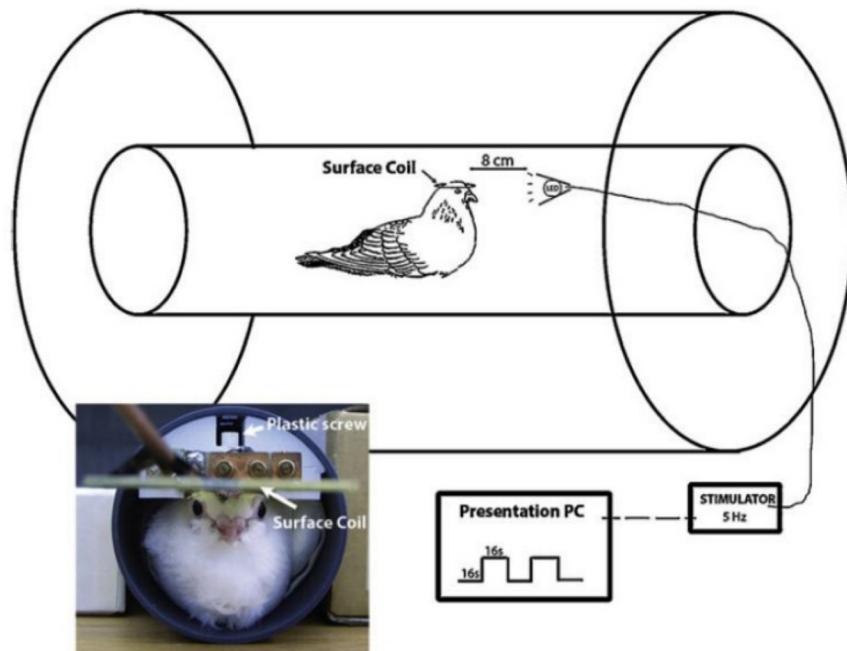
NEURAL ACTIVITY

FUNCTIONAL MAGNETIC RESONANCE IMAGING (FMRI)



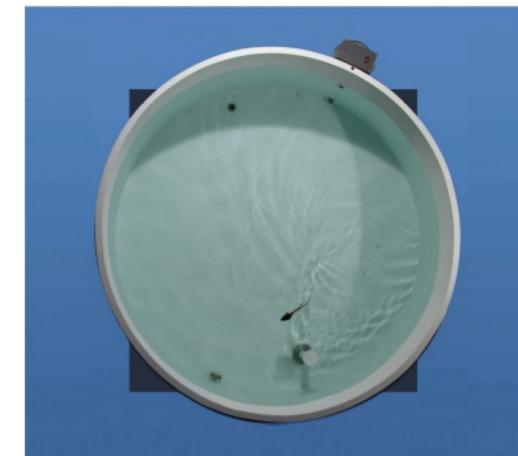
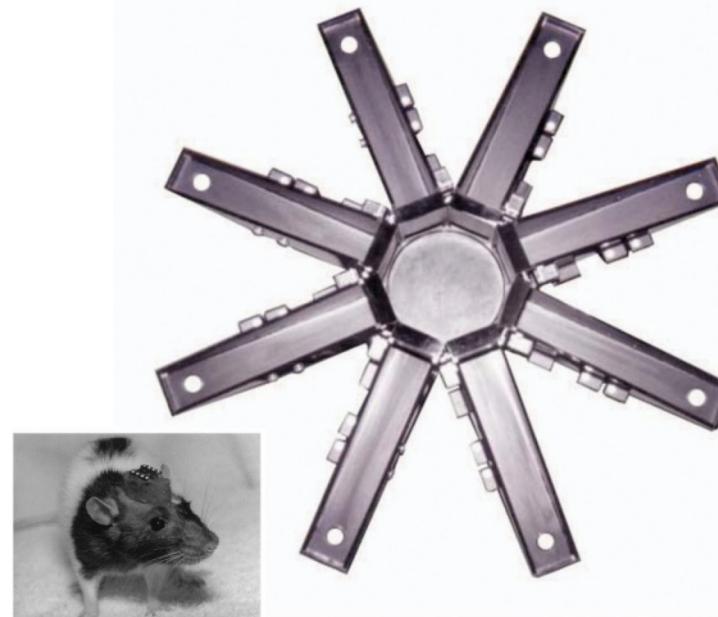
TRENDS in Neurosciences

IN-VIVO BEHAVIORAL EXPERIMENTS



learning to categorize

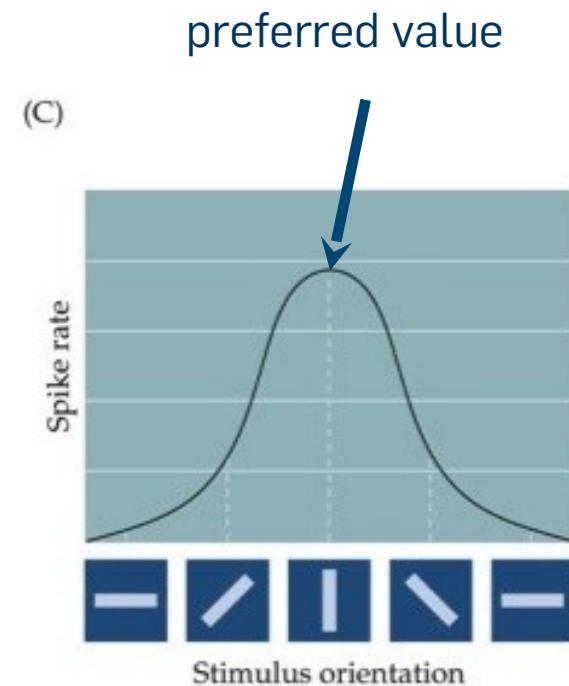
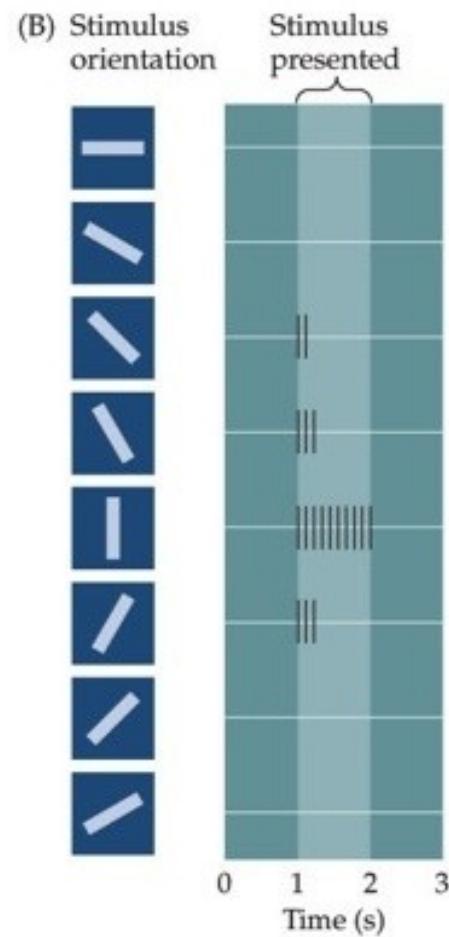
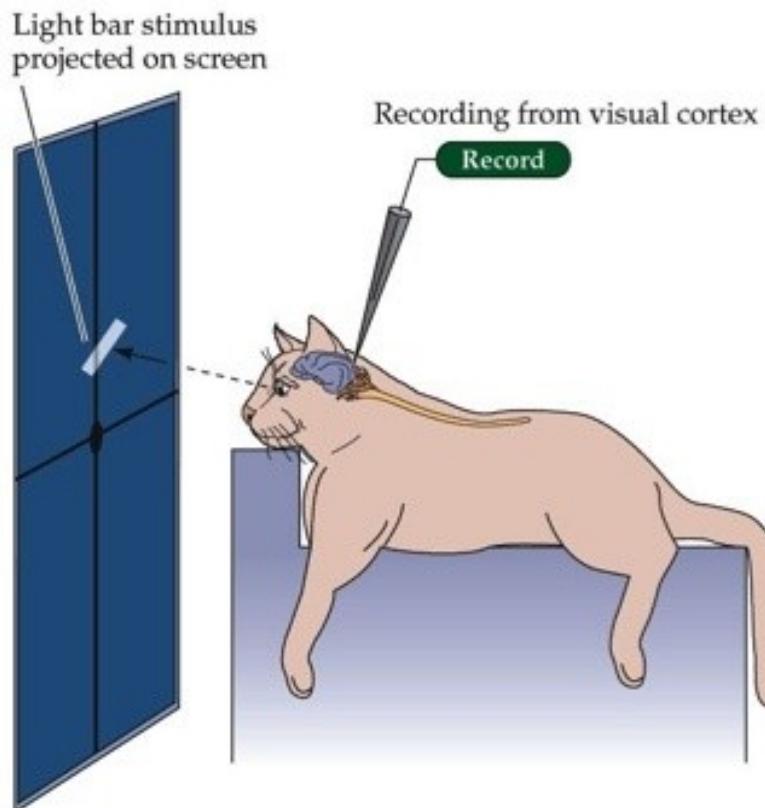
spatial
navigation



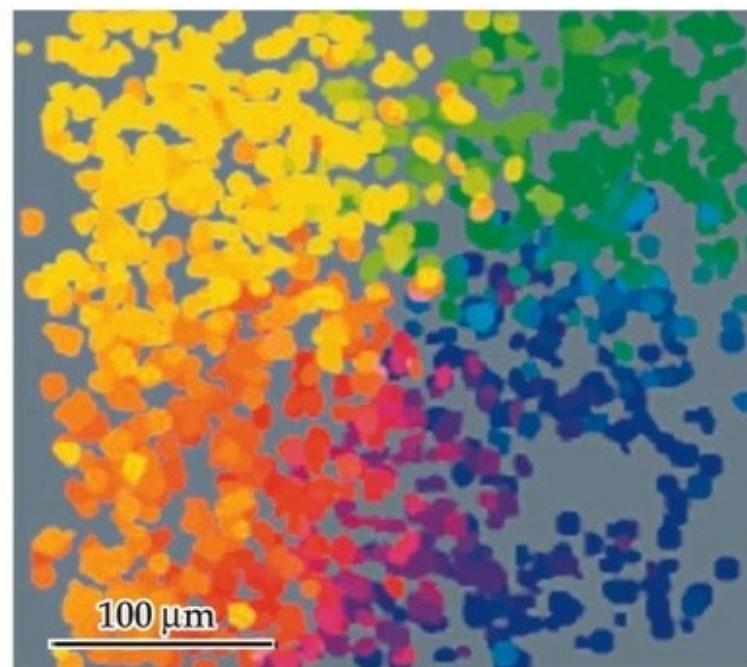
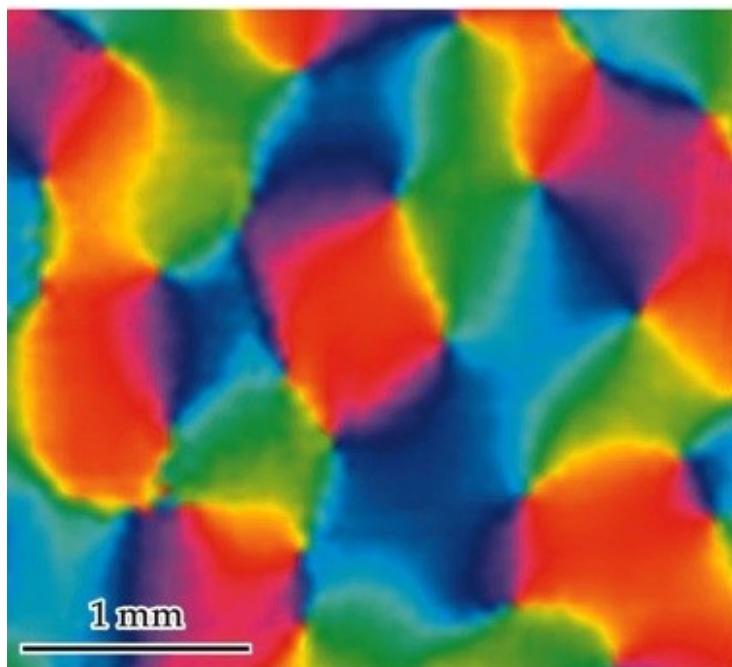
RECEPTIVE FIELD AND TUNING CURVES

Hubel, Wiesel (1959)

(A) Experimental setup



ORIENTATION MAP IN V1

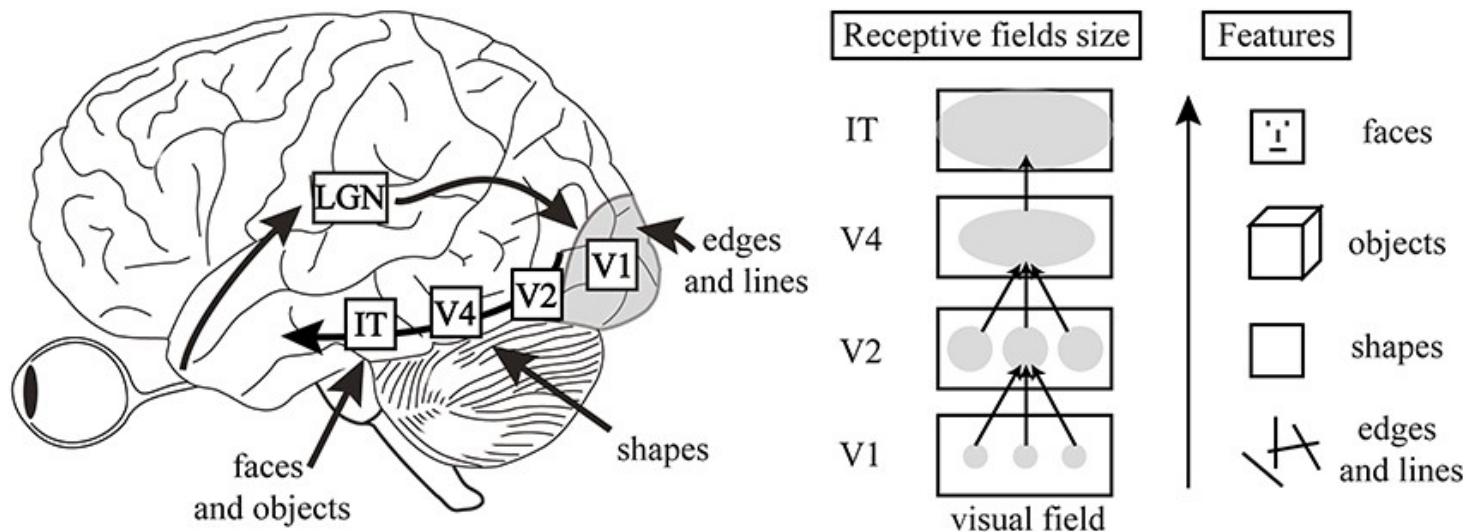


maps



preferred orientations

HIERARCHICAL VISUAL SYSTEM



SYNAPTIC PLASTICITY

HEBBIAN POSTULATE



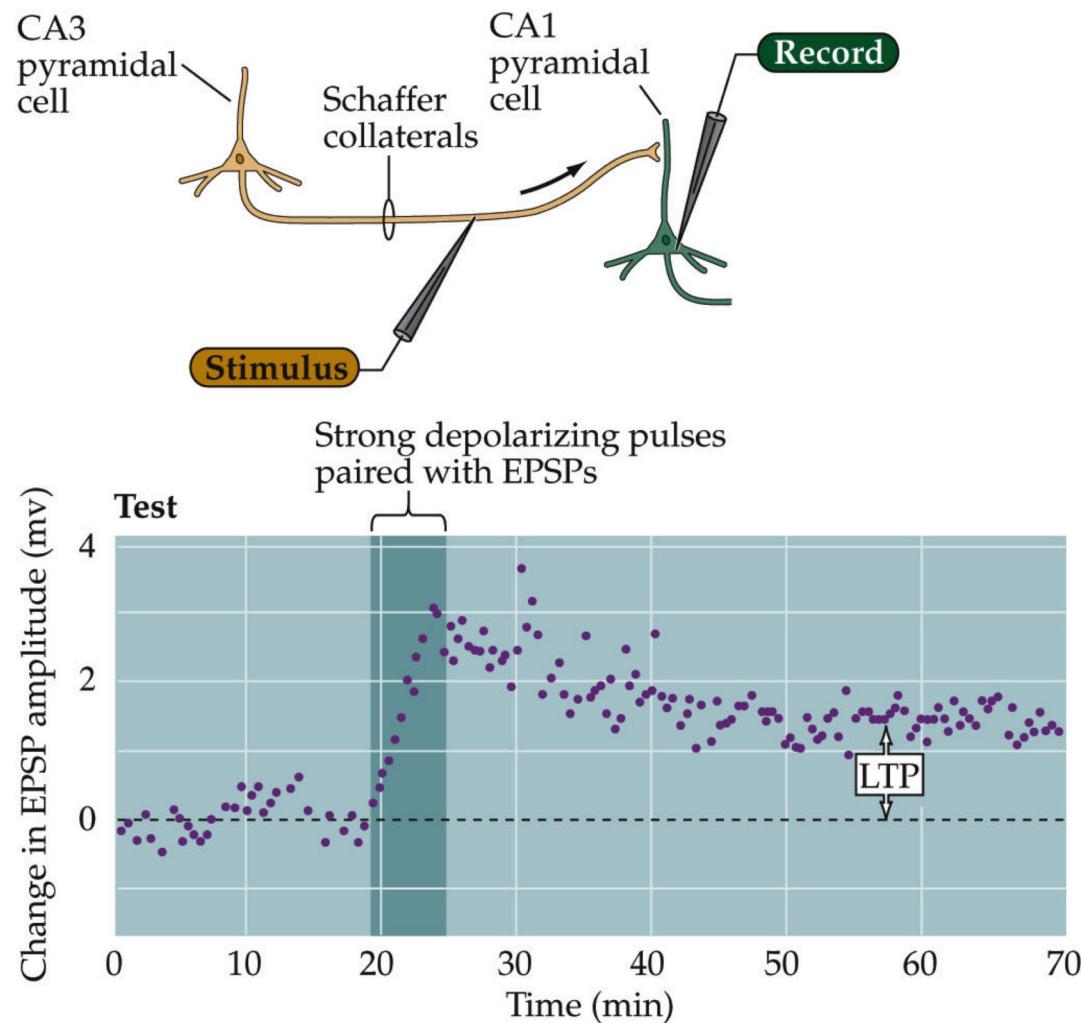
Donald O. Hebb
(1904-1985)

“When an axon of cell A is near enough to excite cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficiency, as one of the cells firing B, is increased”

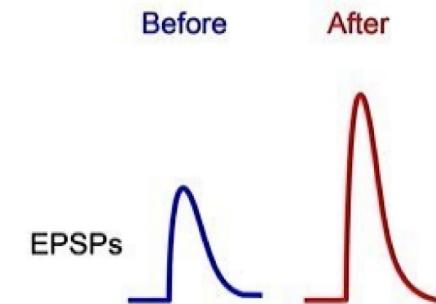
The Organization of Behavior, 1949

LONG-TERM POTENTIATION (LTP)

Bliss & Lomo (1973)



NEUROSCIENCE, Fourth Edition, Figure 8.8

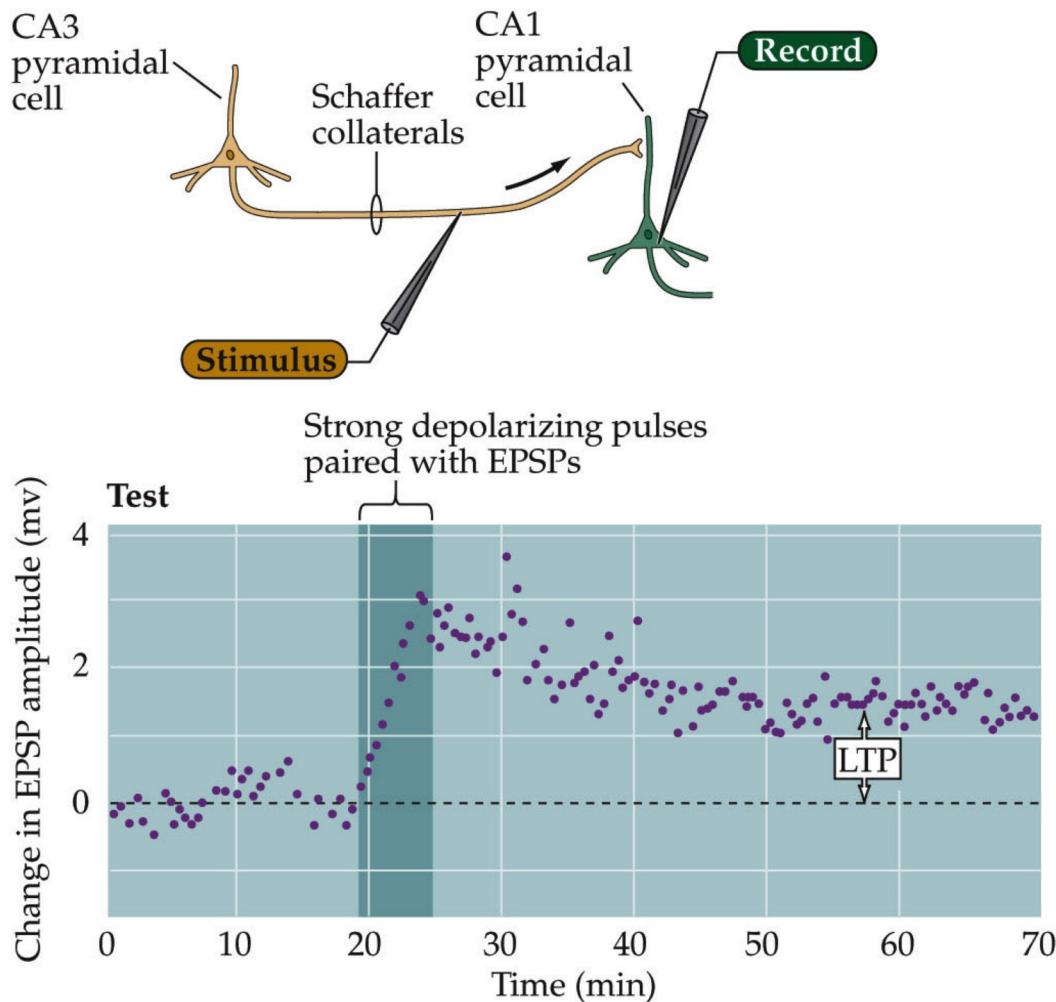


increase in evoked potential

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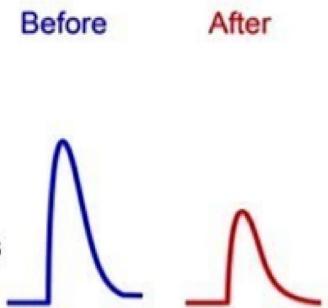
LONG-TERM DEPRESSION (LTD)

Dudek & Bear (1992)



NEUROSCIENCE, Fourth Edition, Figure 8.8

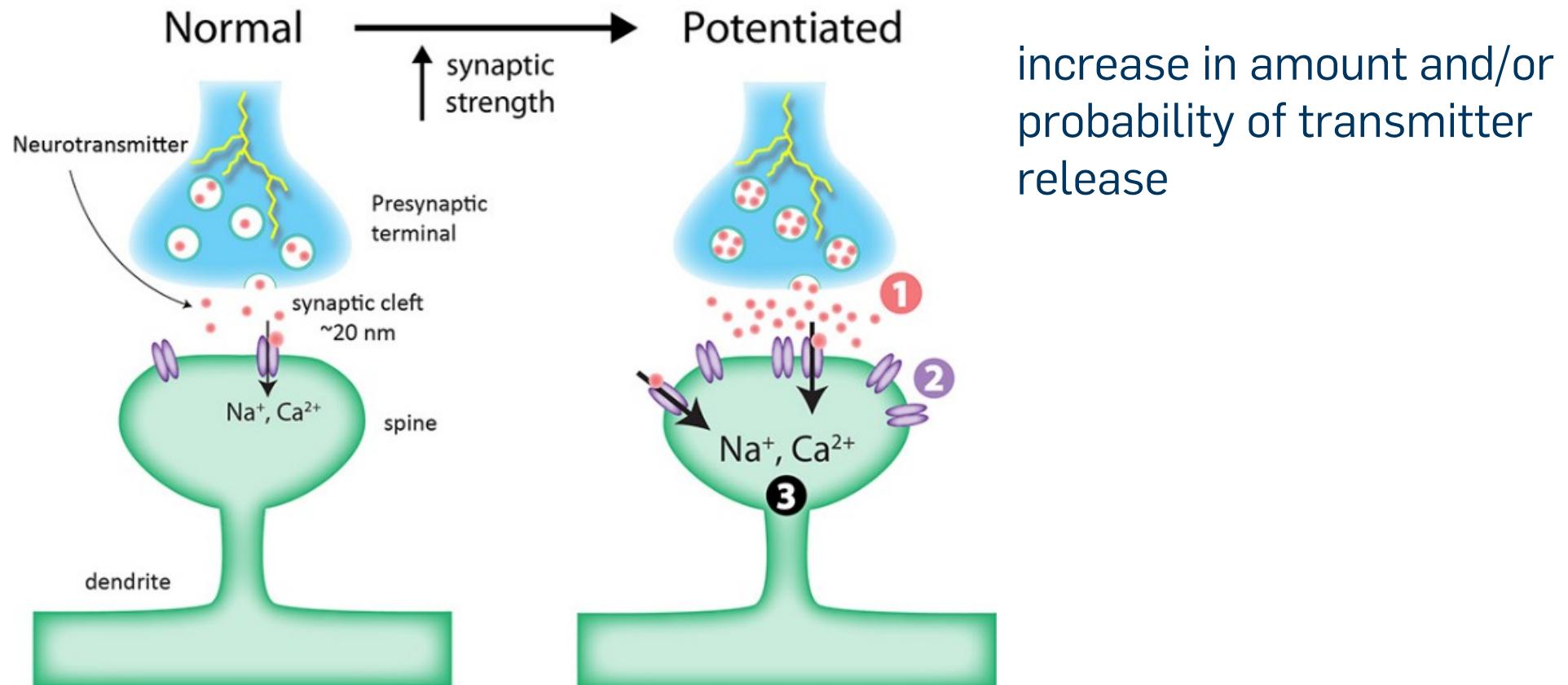
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decrease in evoked potential

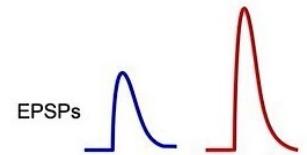
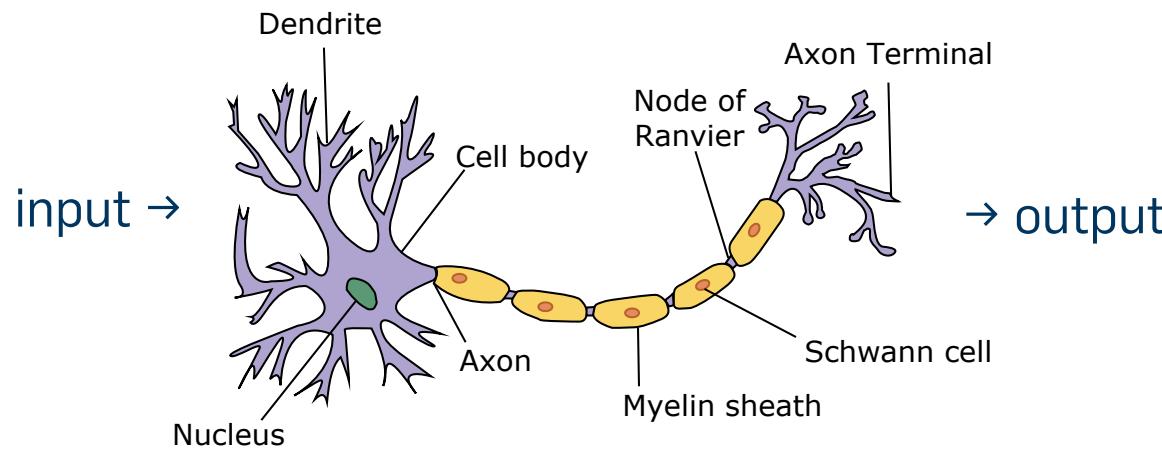
predicted by BCM theory (1982)

CELLULAR MECHANISMS OF PLASTICITY

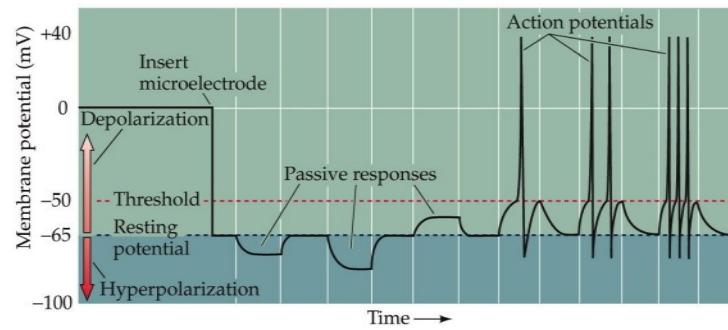


RECAP

synaptic weights and plasticity



threshold



hierarchical network

