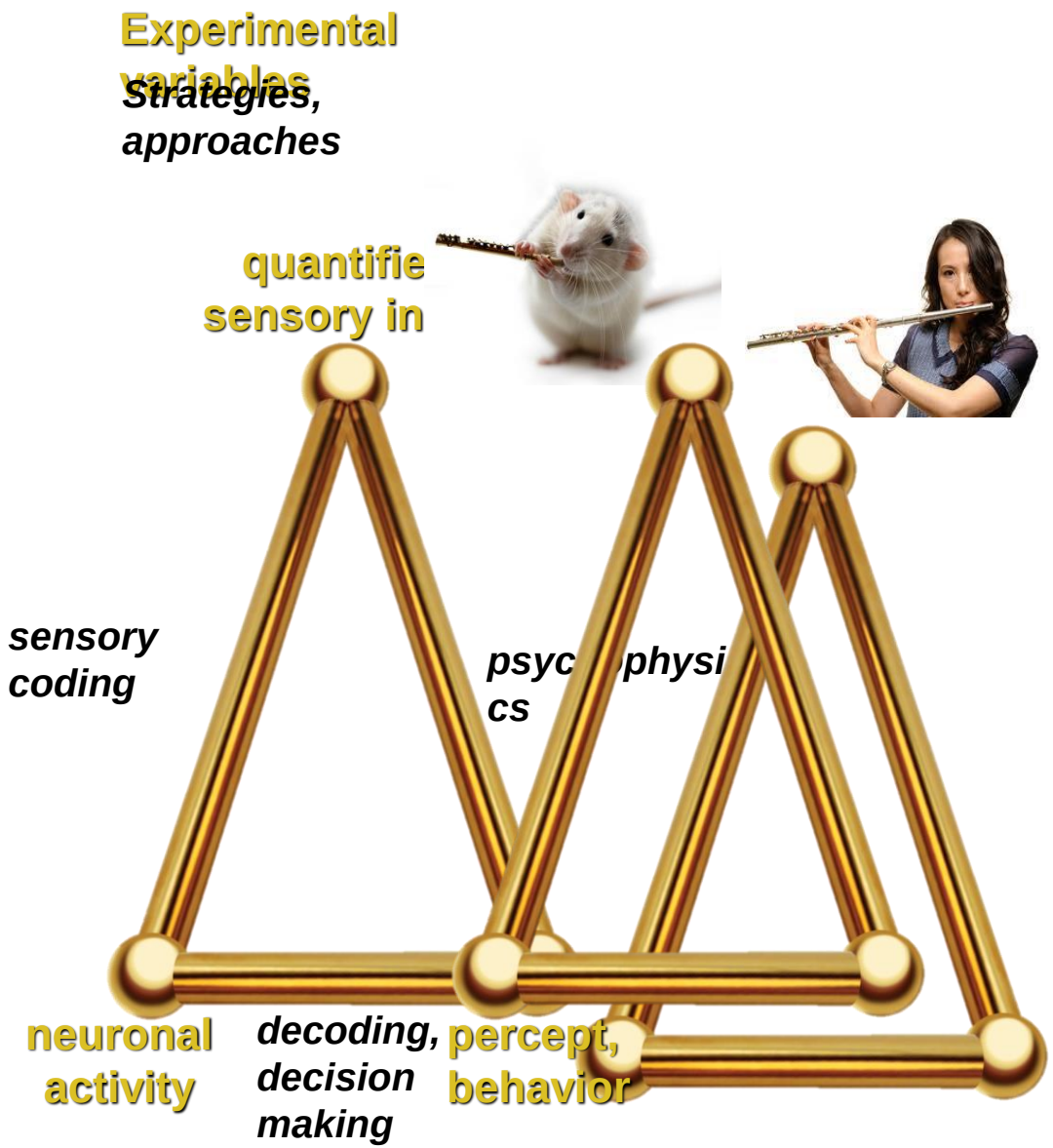
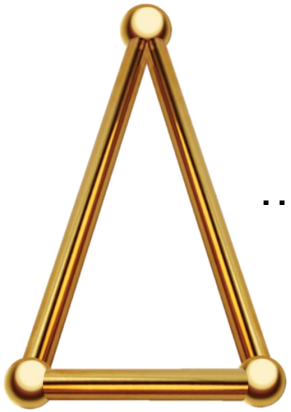
Introduction to Systems and Computational Neuroscience: Tactile Perception

Cognitive Neuroscience is the attempt of our nervous system to understand itself. (think about that for a second!!)

This section of the course will provide an introduction to current knowledge about the neuronal processes involved in sensation and perception.

How can we go about studying the neuronal processes involved in sensation and perception?





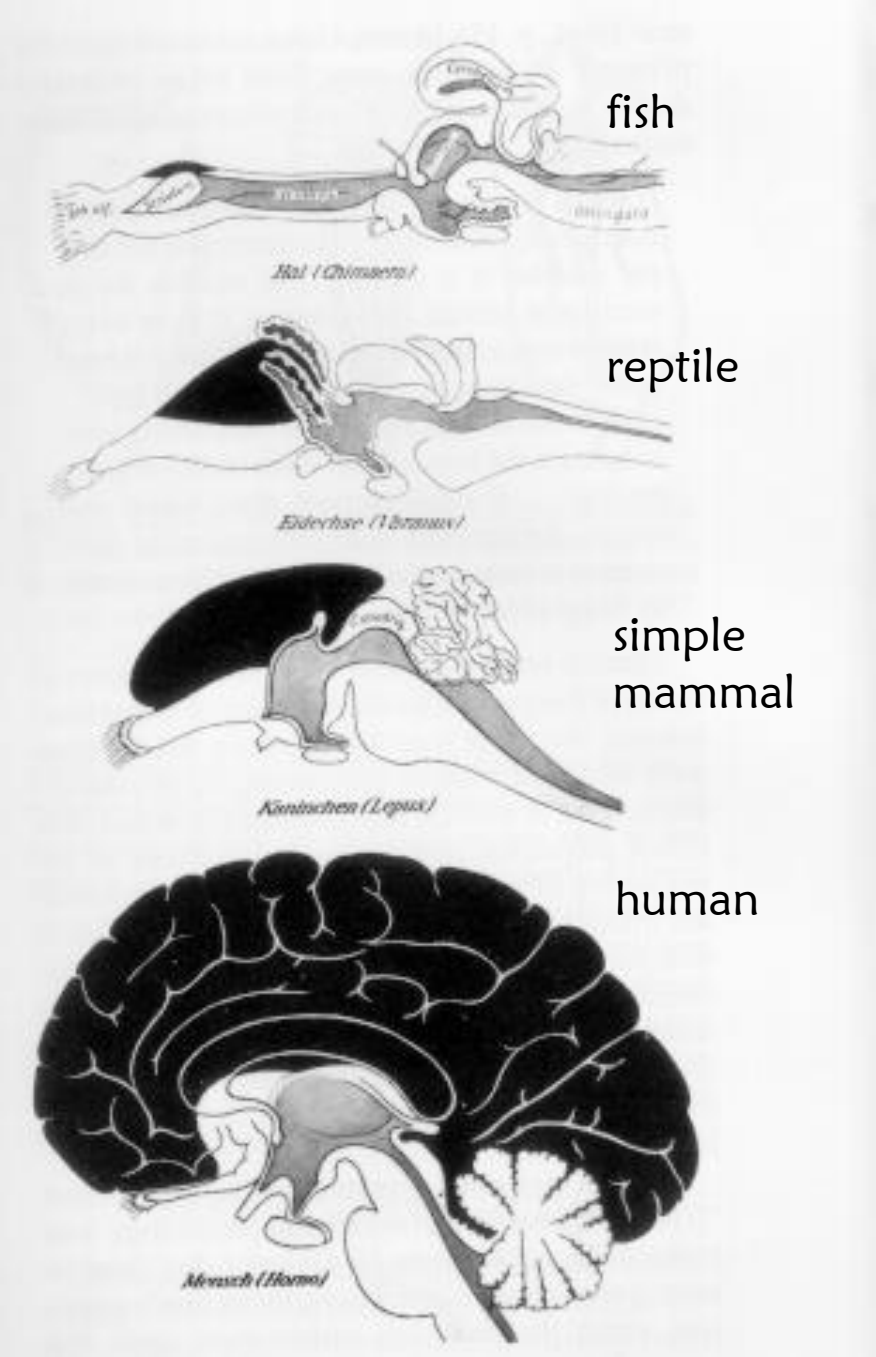
… but the golden triangle will come later.

Today, the minimum knowledge of cortical organization to begin to approach sensory systems.

- Neocortex has evolved… largely to accommodate the processing of sensory channels
- Functions are localized - the oldest chapter in Neuroscience
- Within sensory regions, processing is not *disorganized*, but is arrayed in “maps”

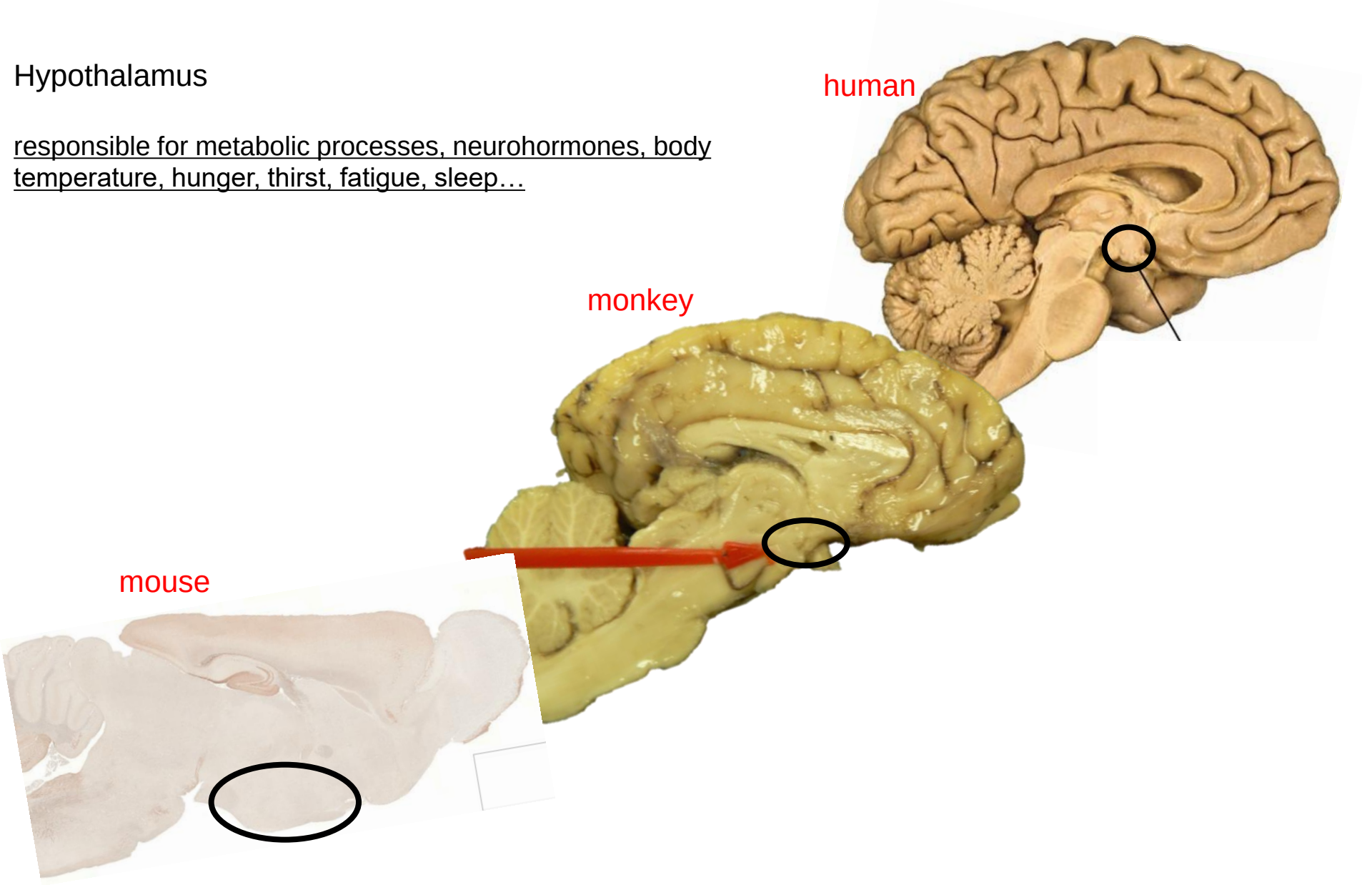
- Maps constrain how we perceive the world
- But maps are the start of the inquiry, not the end

Cerebral cortical evolution:
cerebral cortex / whole brain increases

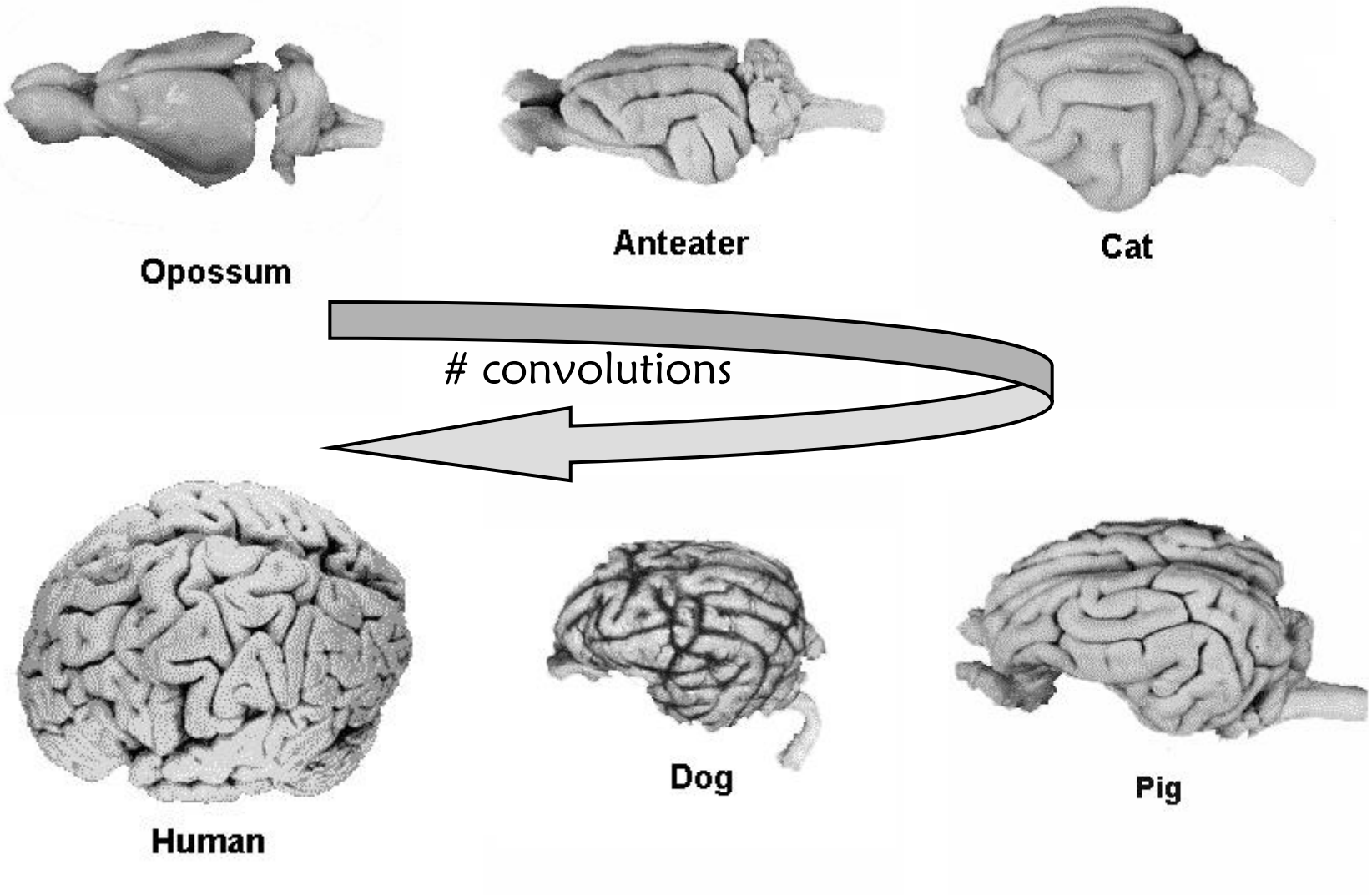


Hypothalamus

<u>responsible for metabolic processes, neurohormones, body temperature, hunger, thirst, fatigue, sleep…</u>



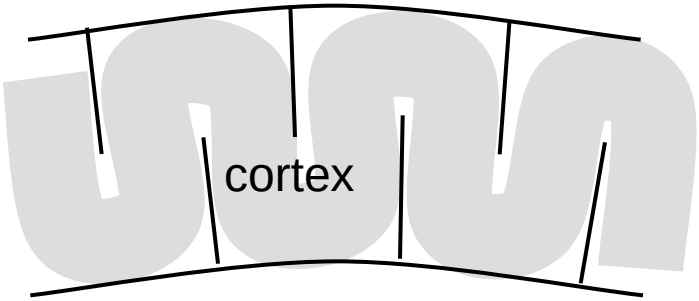
(brain images rescaled to similar size for illustration)


Opossum
Anteater
Cat
convolutions
Human
Dog
Pig

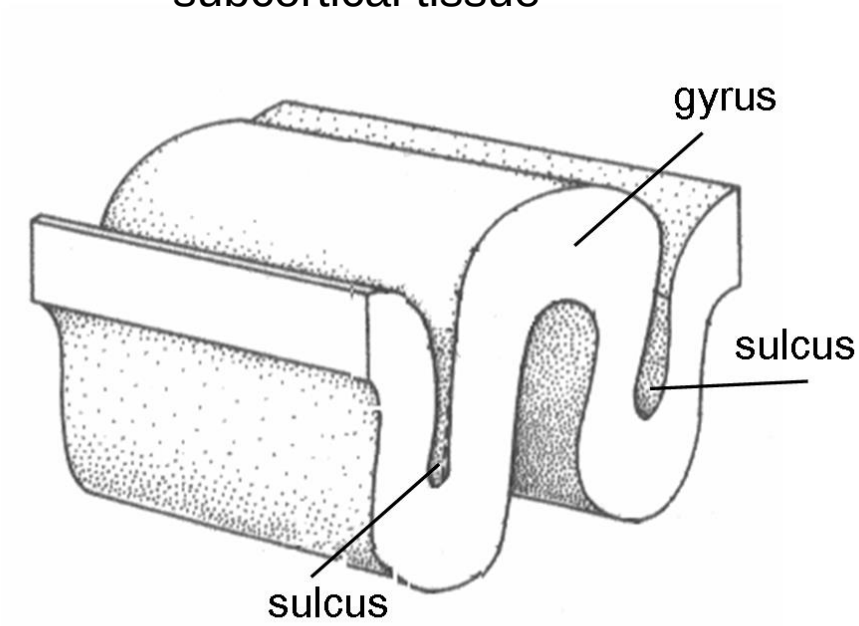
unconvoluted
“lissencephalic”

subcortical tissue

convoluted
“gyrencephalic”



subcortical tissue



To expand volume, why not just increase thickness?

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REPORT

Cortical folding scales universally with surface area and thickness, not number of neurons

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ABSTRACT | EDITOR'S SUMMARY

Larger brains tend to have more folded cortices, but what makes the cortex fold has remained unknown. We show that the degree of cortical folding scales uniformly across lissencephalic and gyrencephalic species, across individuals, and within individual cortices as a function of the product of cortical surface area and the square root of cortical thickness. This relation is derived from the minimization of the effective free energy associated with cortical shape according to a simple physical model, based on known mechanisms of axonal elongation. This model also explains the scaling of the folding index of crumpled paper balls. We discuss the implications of this finding for the evolutionary and developmental origin of folding, including the newfound continuum between lissencephaly and gyrencephaly, and for pathologies such as human lissencephaly.

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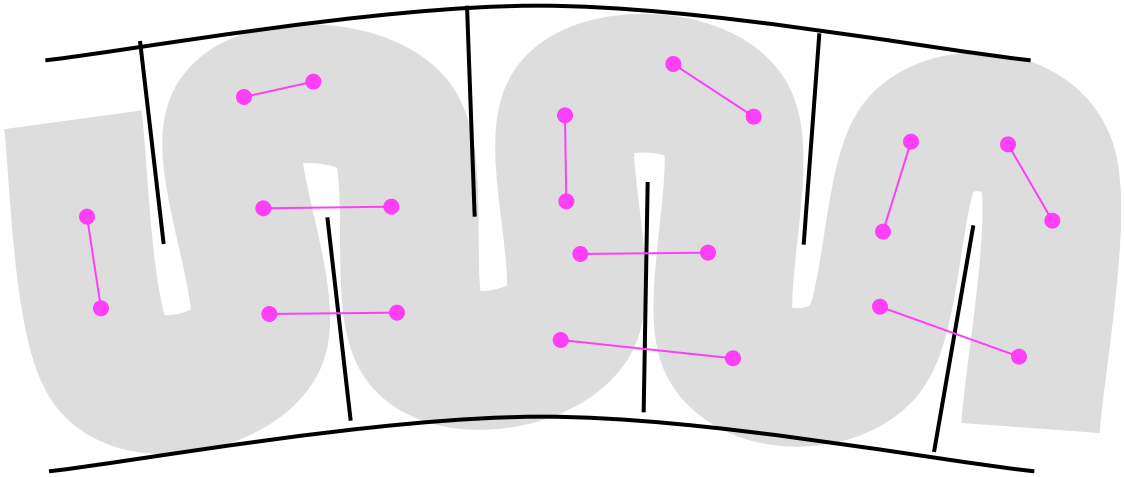
What does this mean??

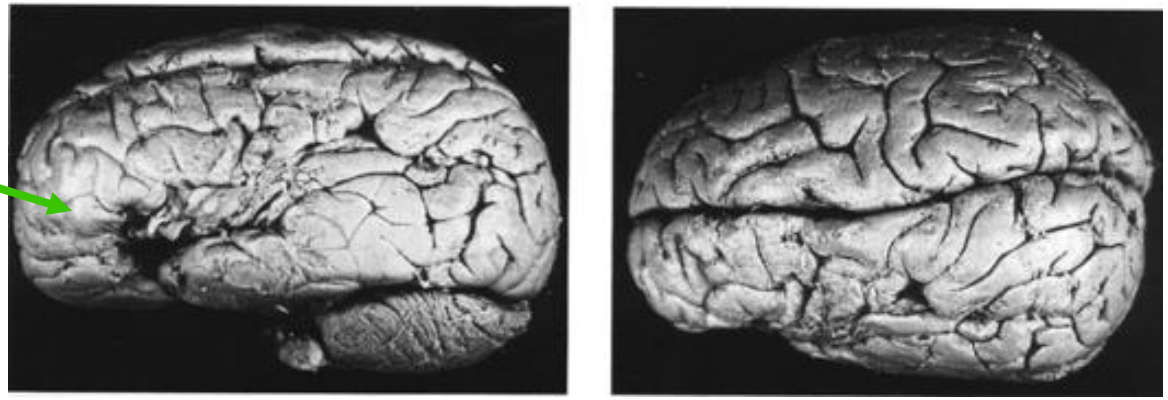


Localization of function

Localization of function by lesion
(neuropsychology)

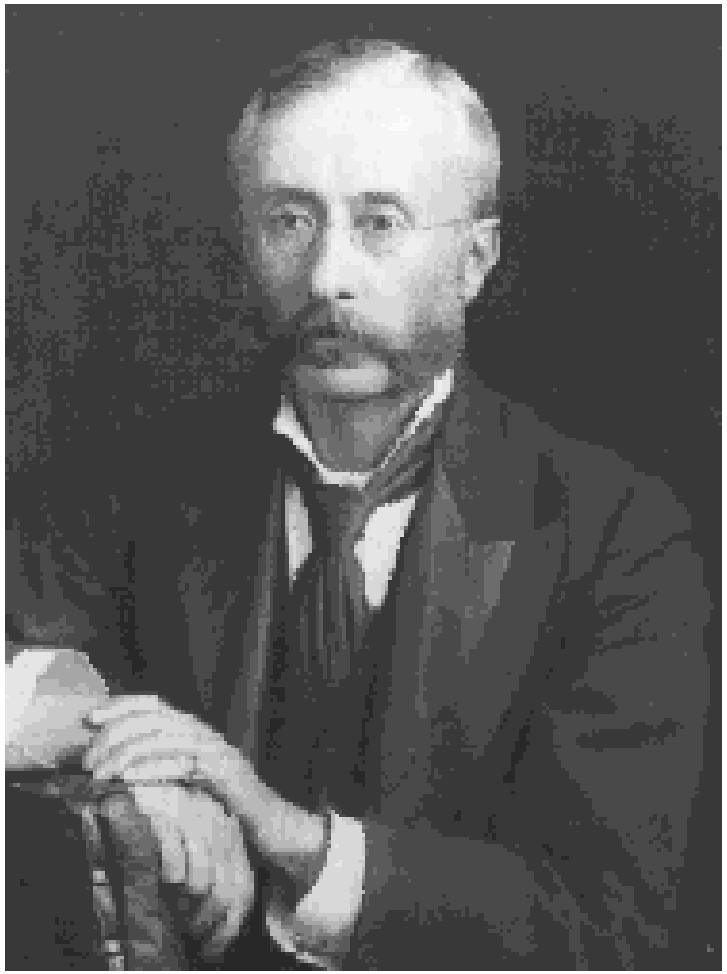
1861
Broca's patient, "Tan"

Broca's area



Localized region for language production

Destruction of area produces behavioral deficit



David Ferrier

In humans, luck (usually bad luck) determines lesion site

Controlled, limited lesions in animals

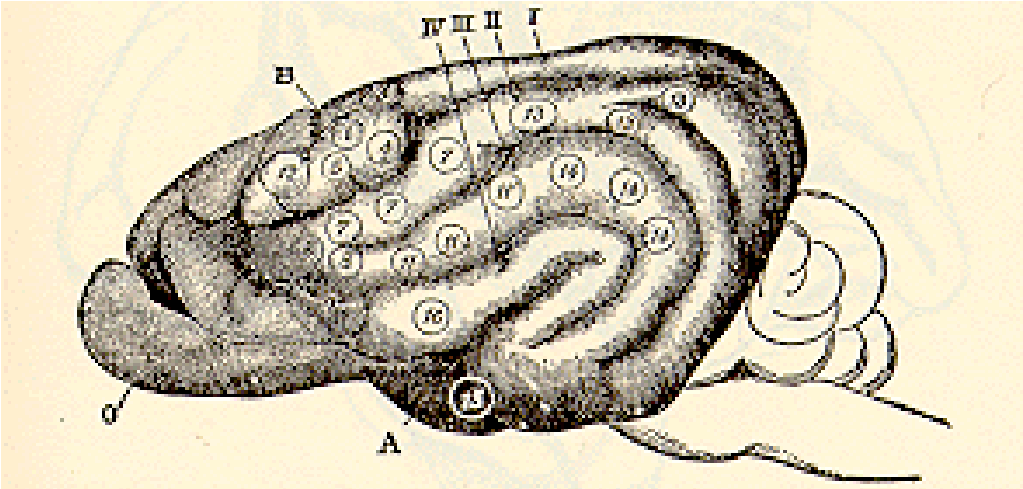
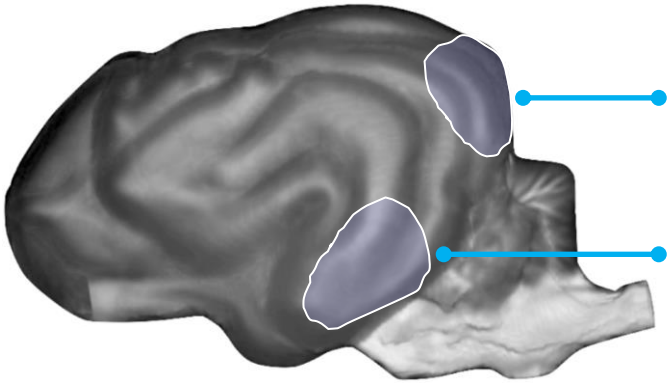


FIG. 5.—Left Hemisphere of Dog's Brain, after Ferrier. *A*, the fissure of Sylvius. *B*, the crucial sulcus. *O*, the olfactory bulb. *I, II, III, IV*, indicate the first, second, third, and fourth external convolutions respectively. (1), (4), and (5) are on the *sigmoid gyrus*.

Ferrier (1870)

Hermann Munk (1878)
"Ueber die Funktionen der Grosshirnrinde"
"On the functions of the cerebral cortex"



blindness; stumbling into objects

vision conserved; loss of "visual memory" (agnosia)

Ian Whitfield (1979)
"The Object of Sensory Cortex"

- based on 100 yrs of neuroscience -- after ablation of sensory and association regions of cerebral cortex, animals can still perform many forms of sensory discrimination.

- cortical ablation → deficit whenever behavioral task requires the elemental sensory signals to assume meaning according to previous experience.

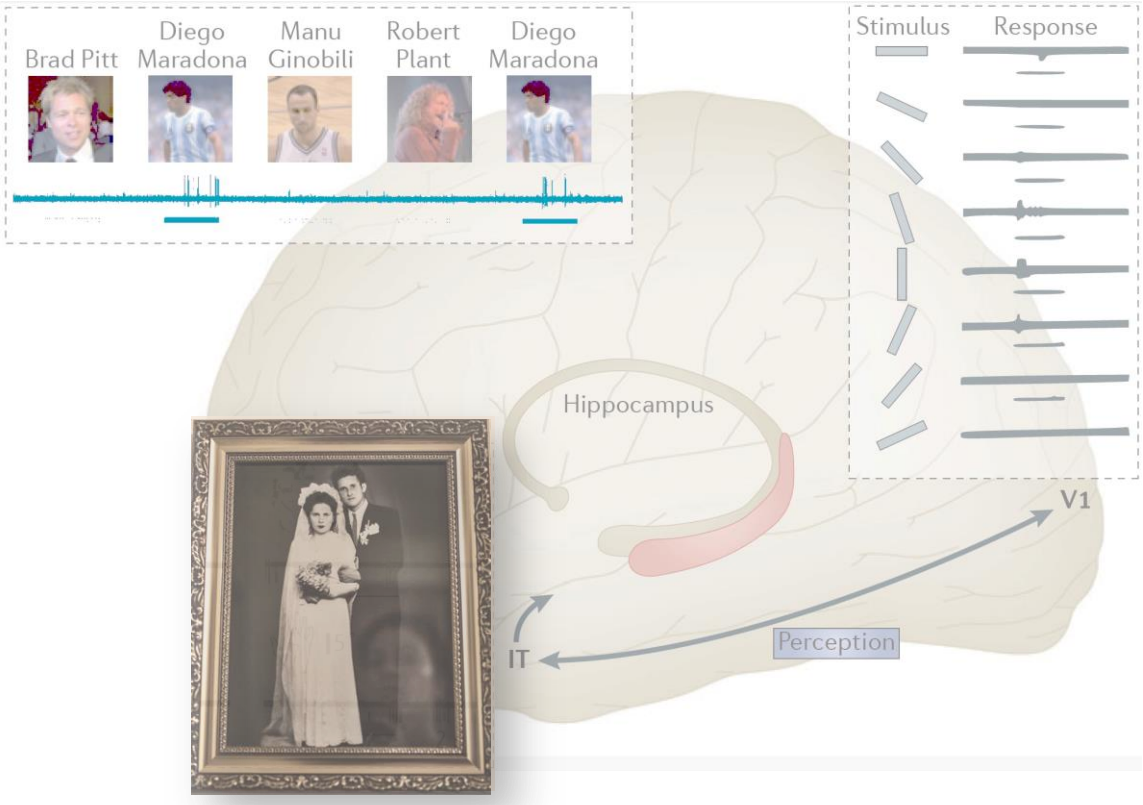
- intracortical processing transforms mere physical data into the perception of things that are "out there" (Whitfield, p. 146) in the world.

more on Whitfield later in course

Munk (1880)

First to distinguish sensation from perception.

Temporal lobe lesion leads to visual agnosia: loss of visual knowledge
= loss of visual perception

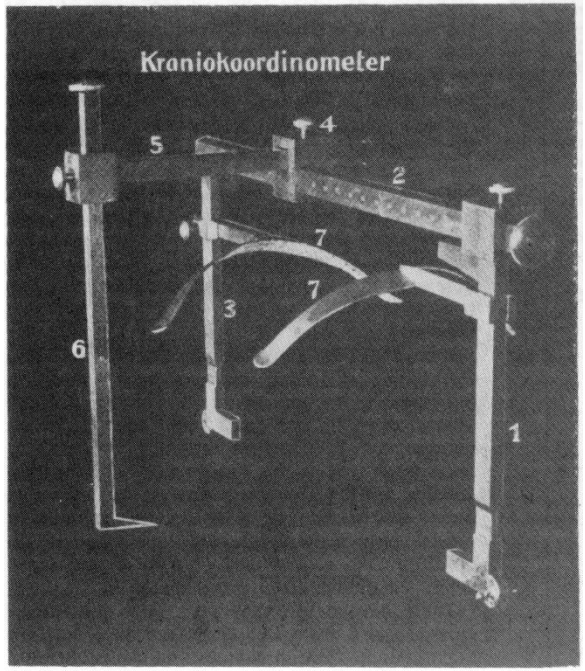


Tatsuji Inouye, 1905

perspectives

Tatsuji Inouye and the mapping of the visual fields on the human cerebral cortex

Mitchell Glickstein and David Whitteridge


Kraniokoordinometer
5
4
2
7
7
3
6
1

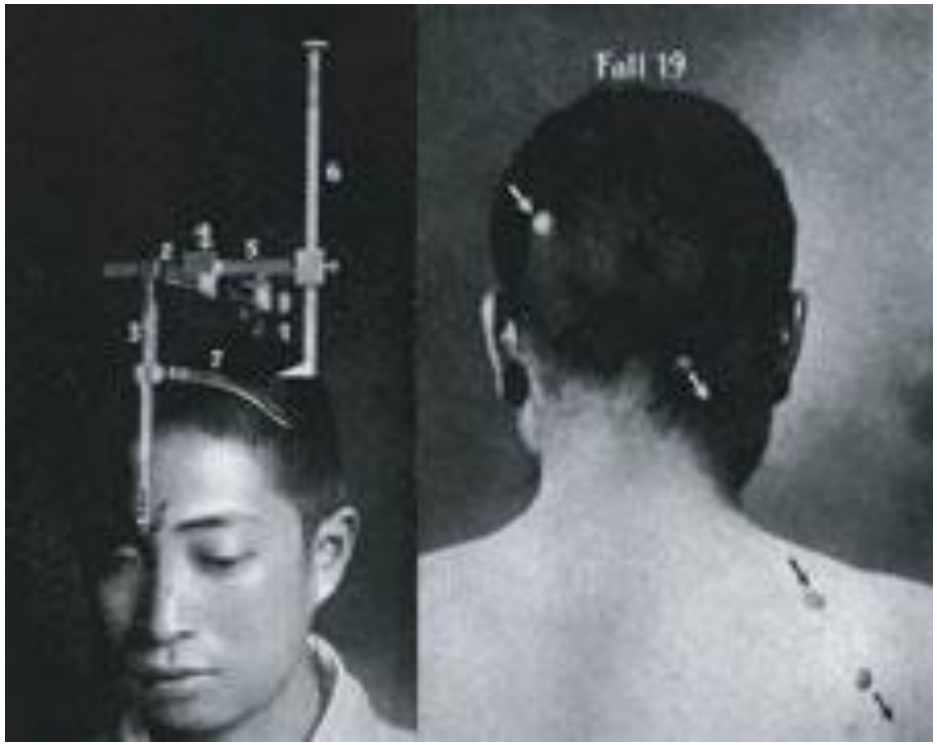

Fall 19

Fig. 2.
Inouye's schema for the projection of the visual fields on the striate cortex.

cortex is devoted to the representation of the centre of the visual field than to the periphery. Some years later, Talbot and Marshal[10] coined the term 'magnification factor' to mean the extent of visual cortex in millimeters that represents one degree of the visual field. Magnification is high in the centre of gaze, and

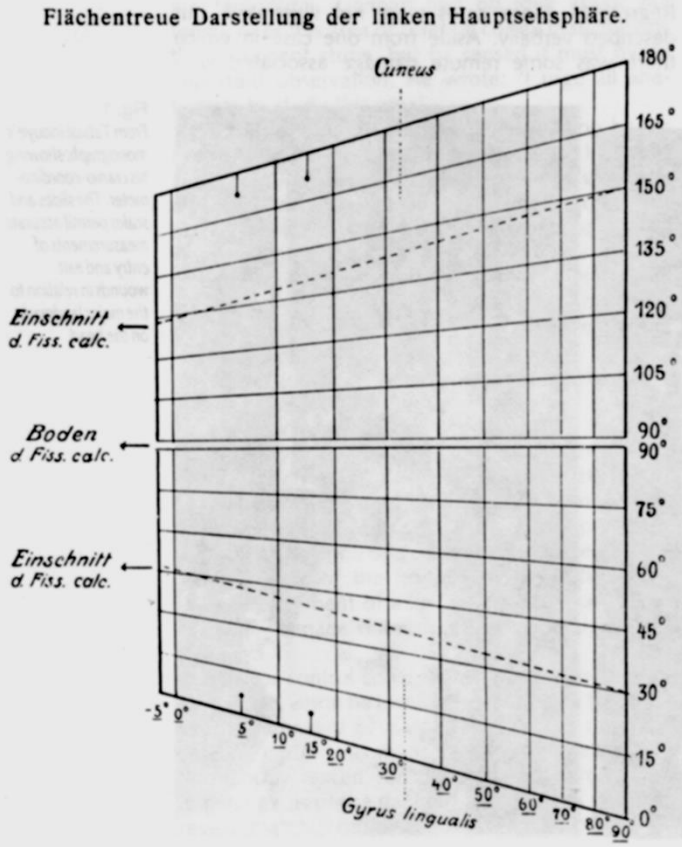
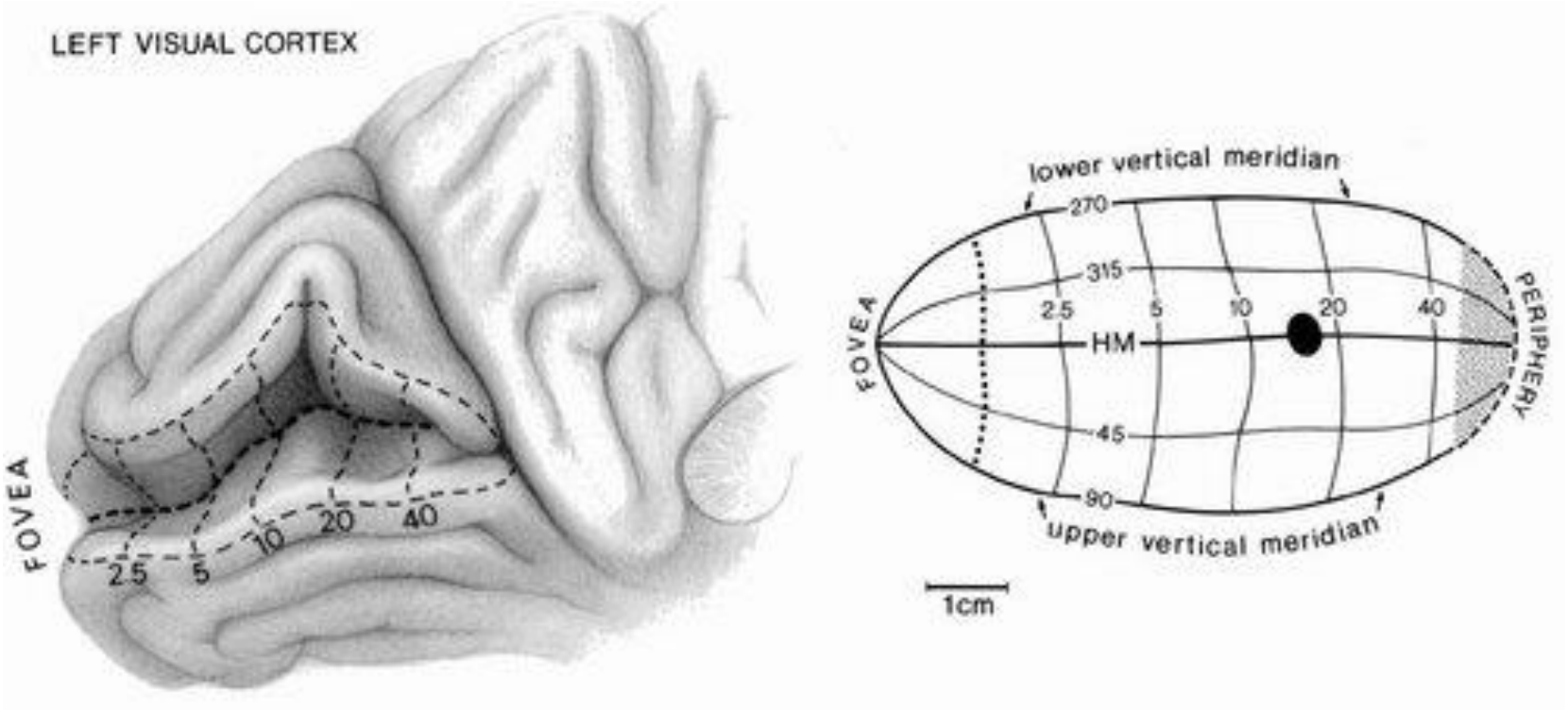


Fig. 2.
Inouye's schema for the projection of the visual fields on the striate cortex.

human visual cortex retinal map by modern methods

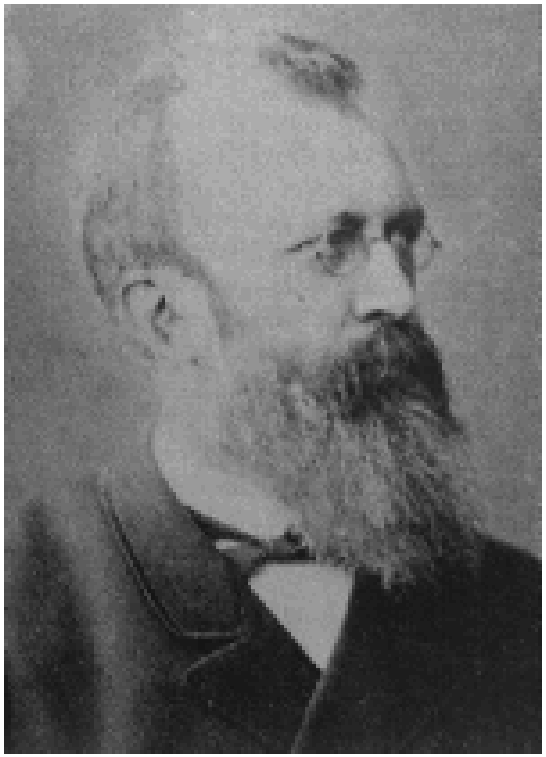


Localization of function

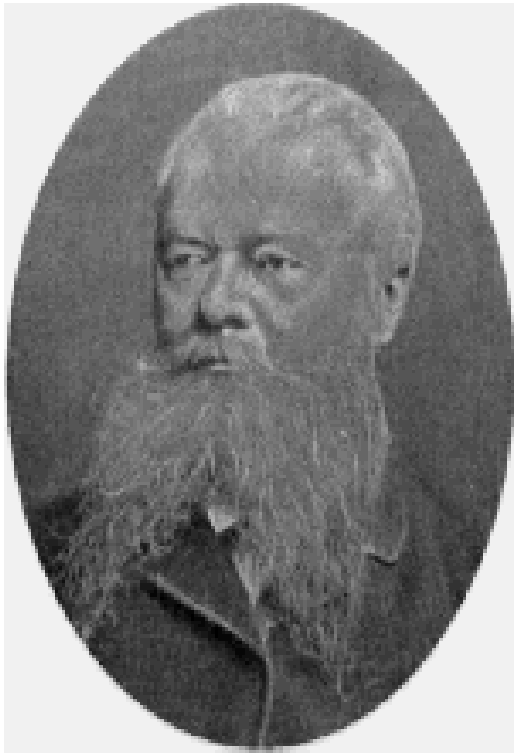
Localization of function by electrical
electrical recording and stimulation

(neurophysiology and neurosurgery)

the method of targeted and
restricted electrical stimulation...

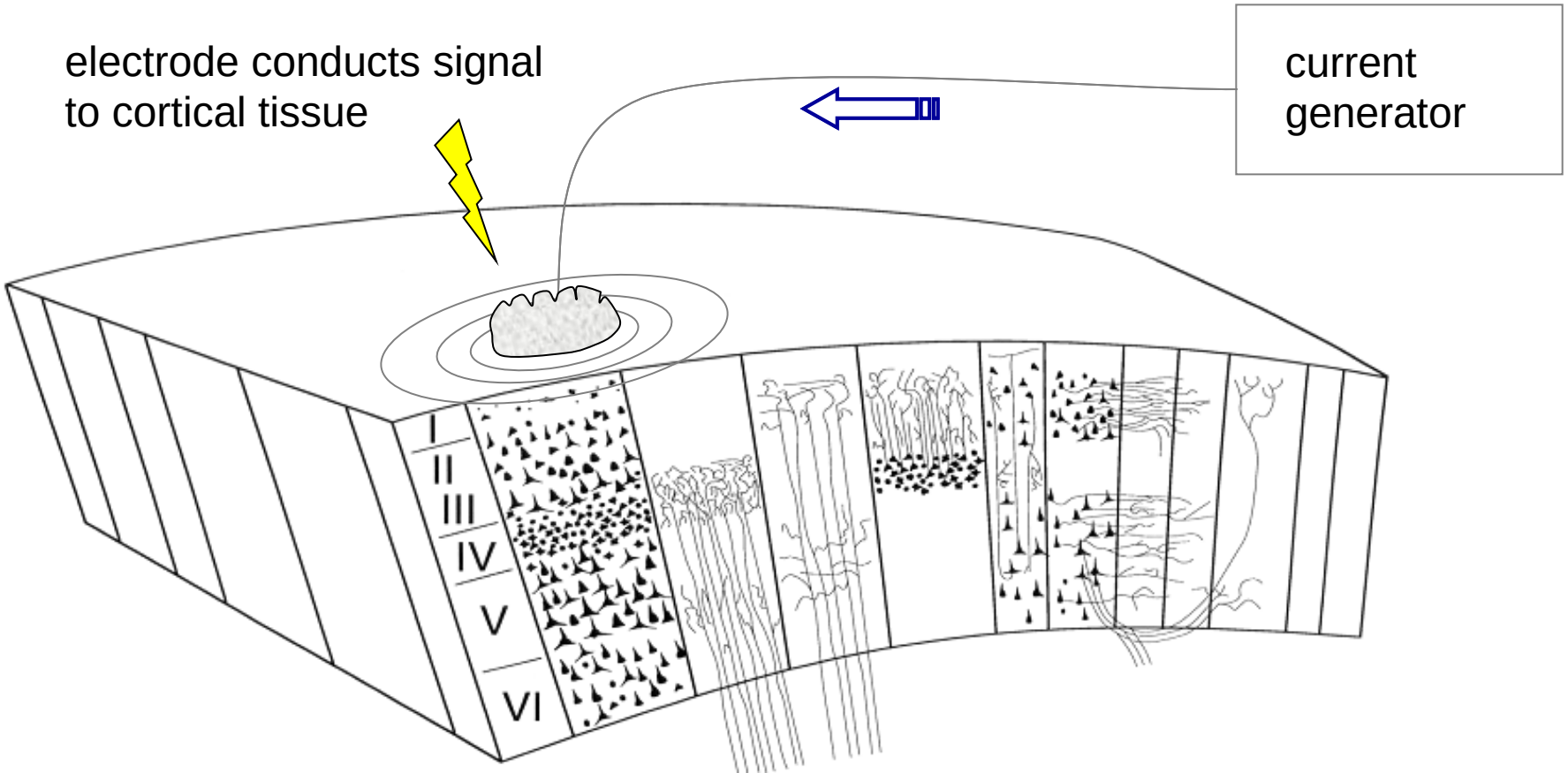


Hitzig

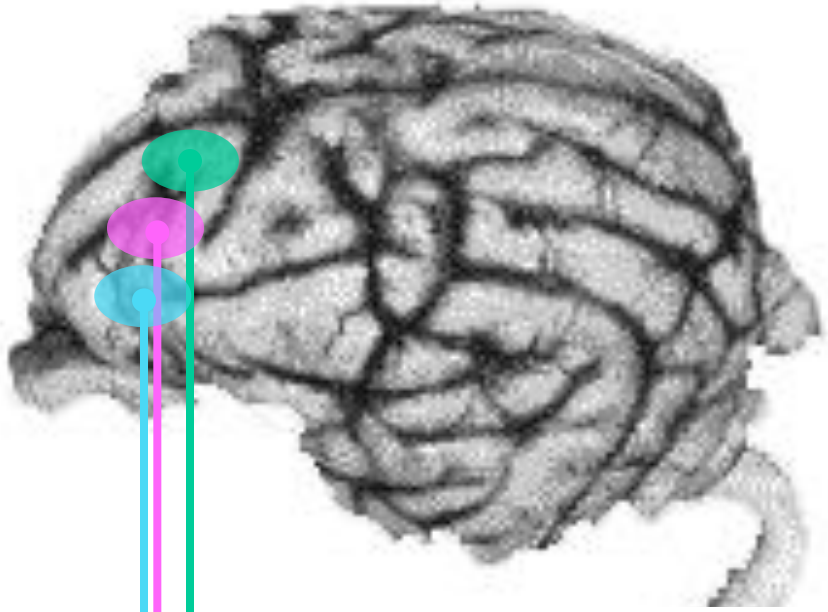


Fritsch

electrical stimulus



…led to the detection of areas with specific motor functions

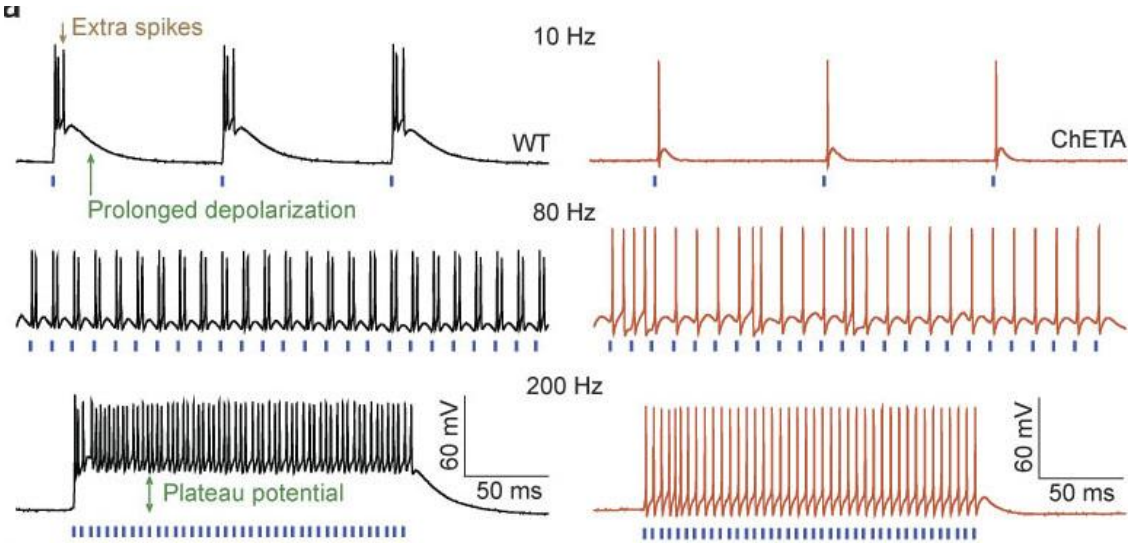


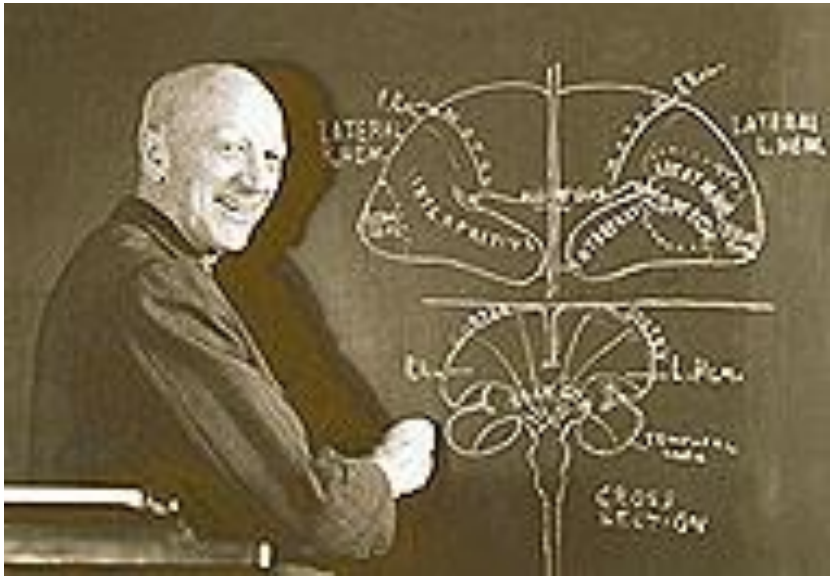
movement of back leg

movement of front leg

movement of snout (face)

Today's methods





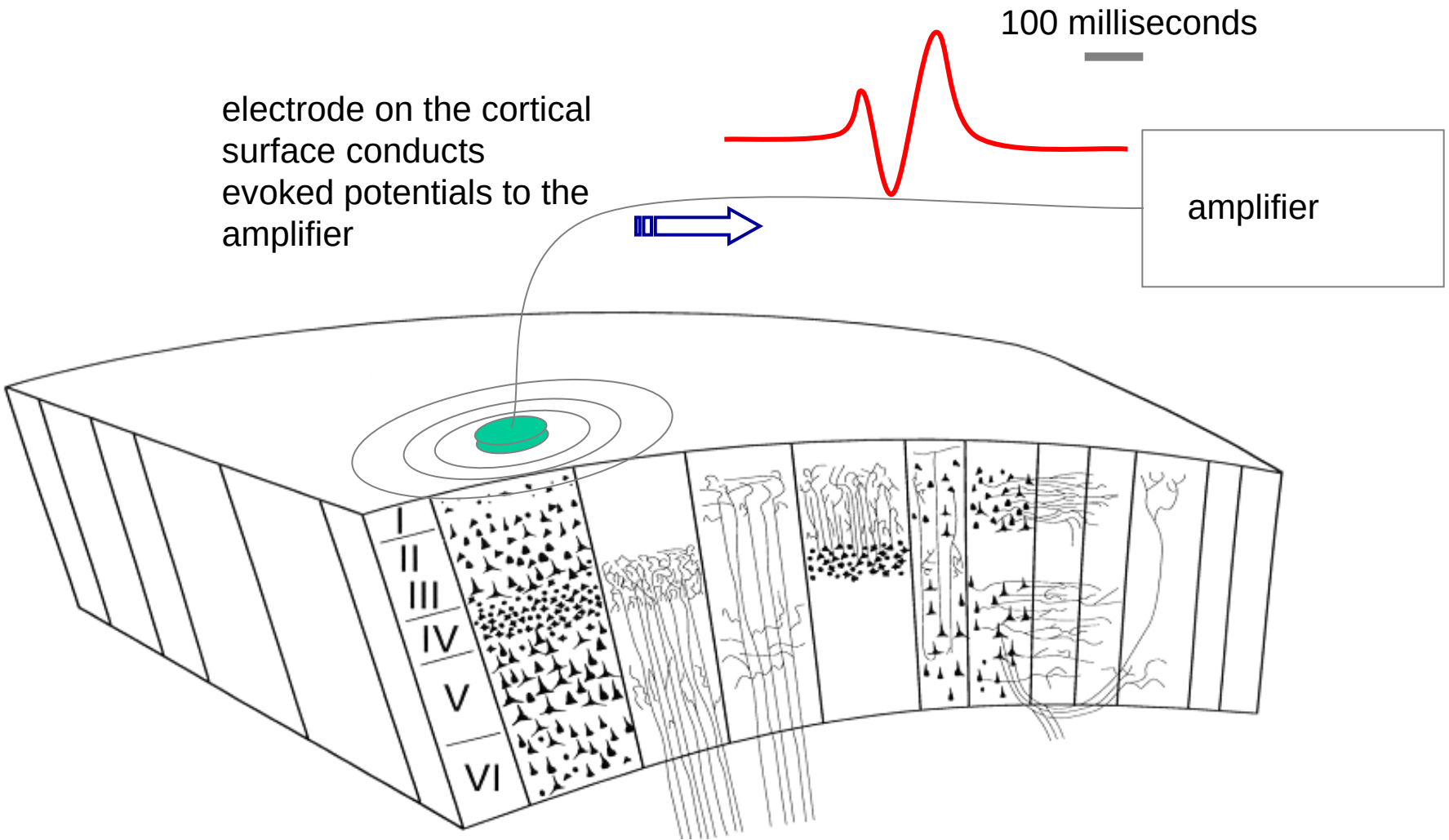
Wilder Penfield

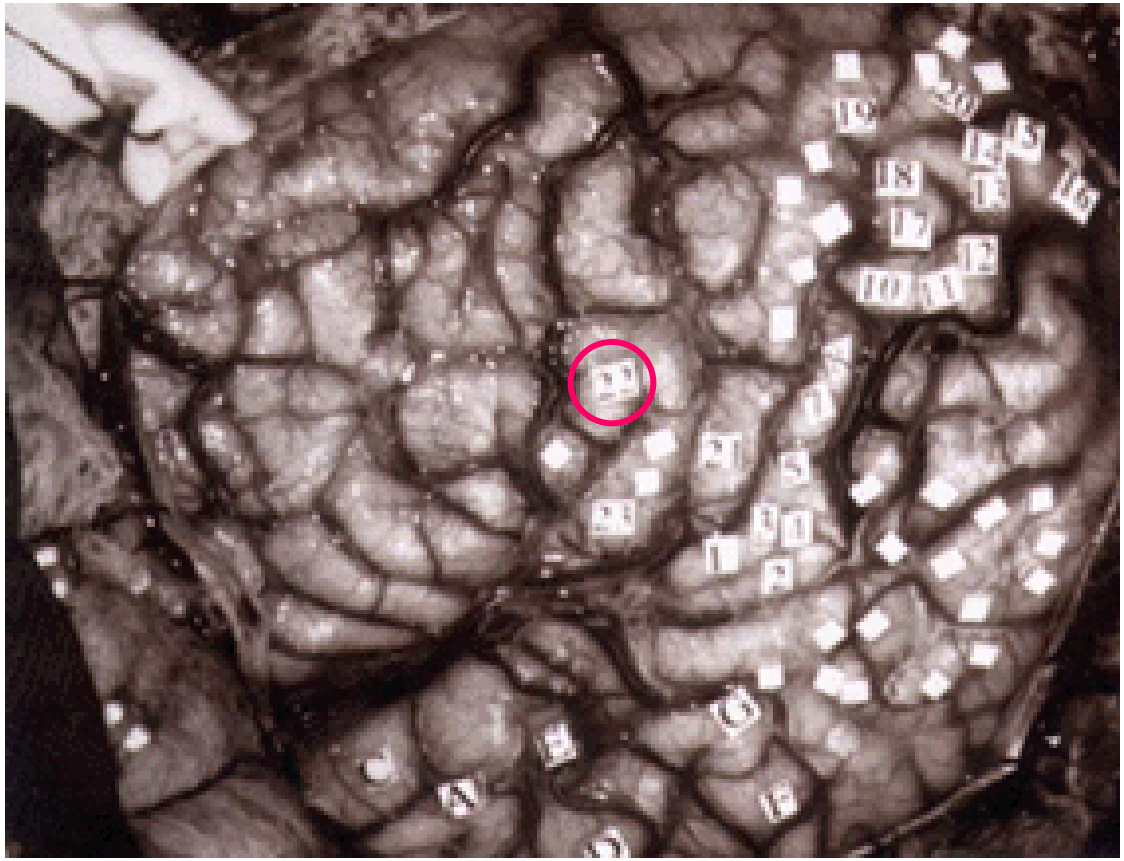
physiological exploration of the human cerebral cortex

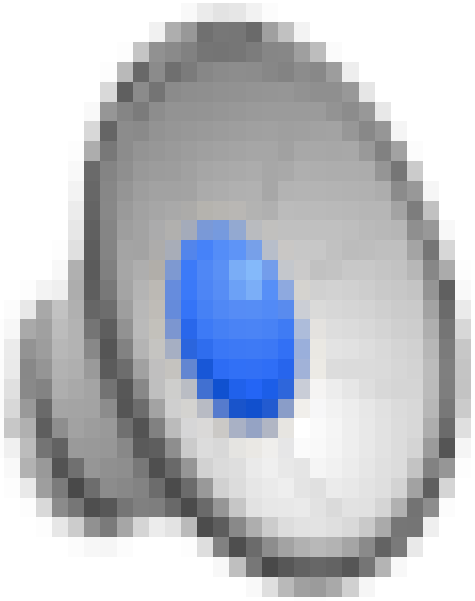
(c. 1930-1970)

Epilepsy and the Functional Anatomy of the Human Brain. 2nd edition.
Jasper, H., and Penfield, W. Little, Brown and Co., 1954.

“evoked potentials“
a probe of the activity of neuronal populations

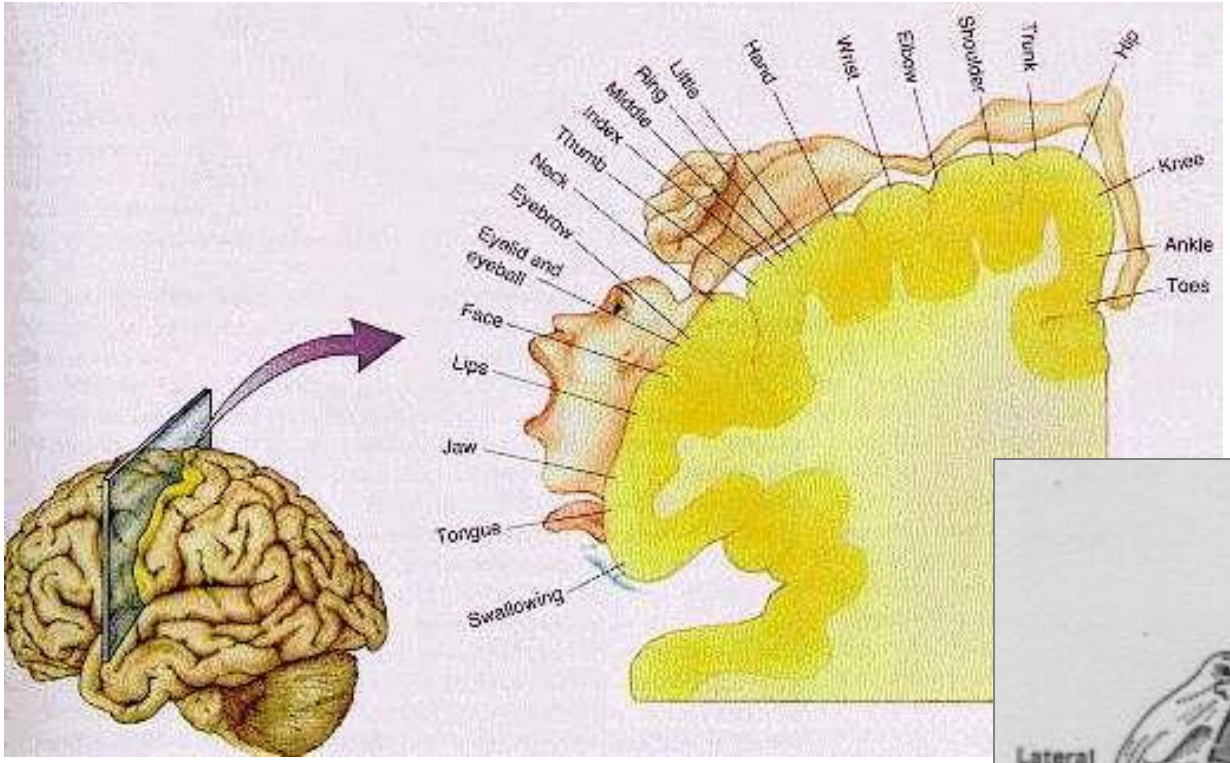


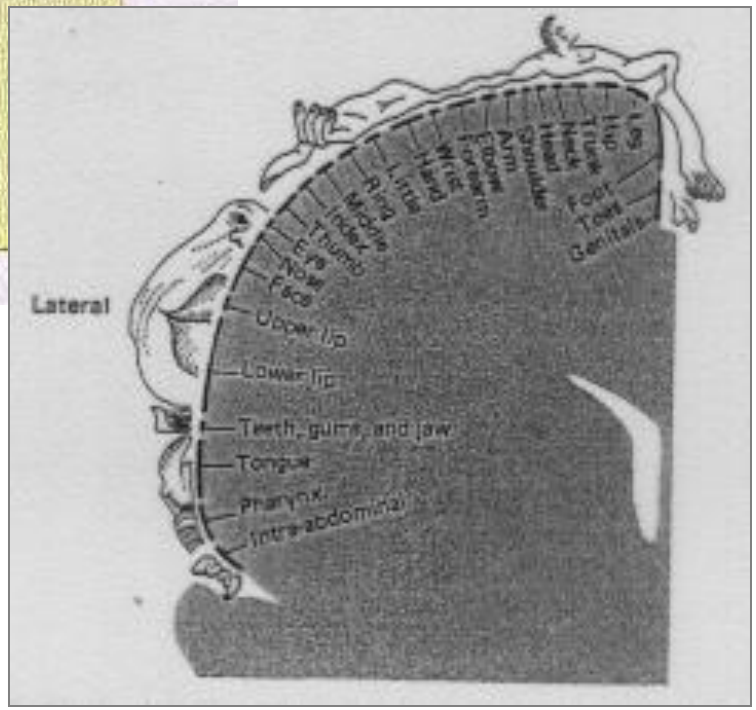




Singing - 2:40

the motor and the sensory maps in the human





Human

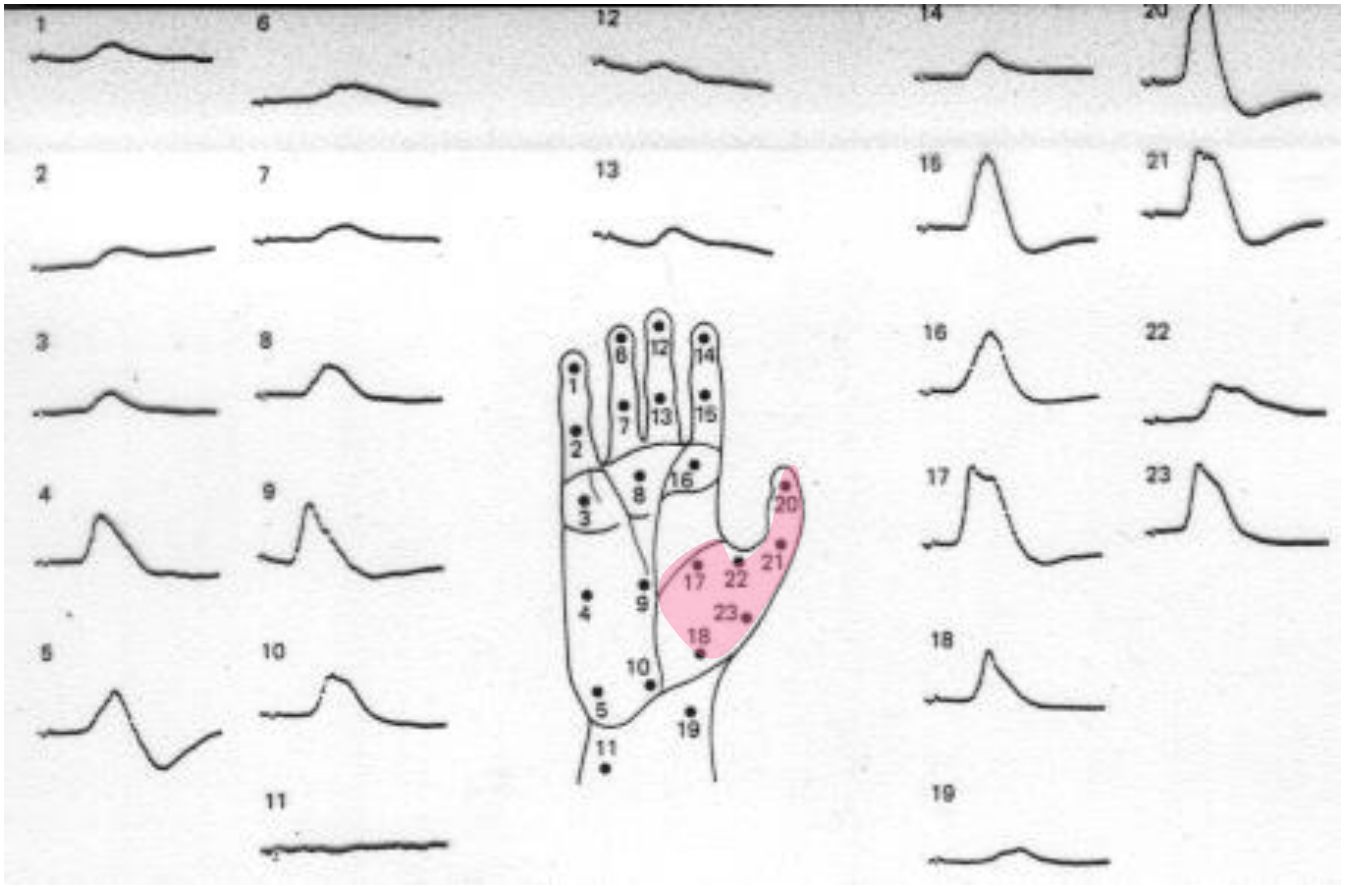
experimental basic research proceeds in parallel

neurophysiology laboratory, 1930s

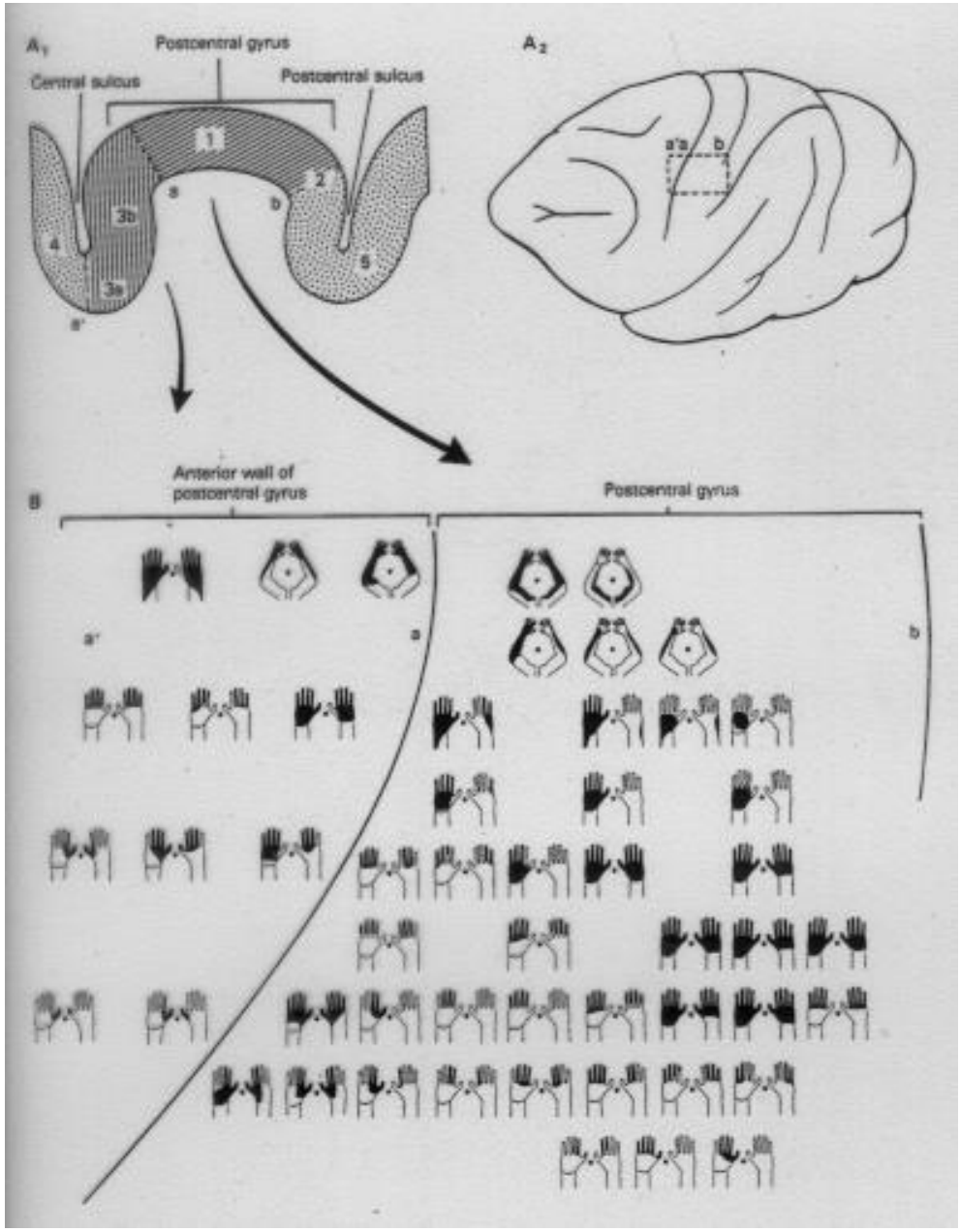
Clinton Woolsey

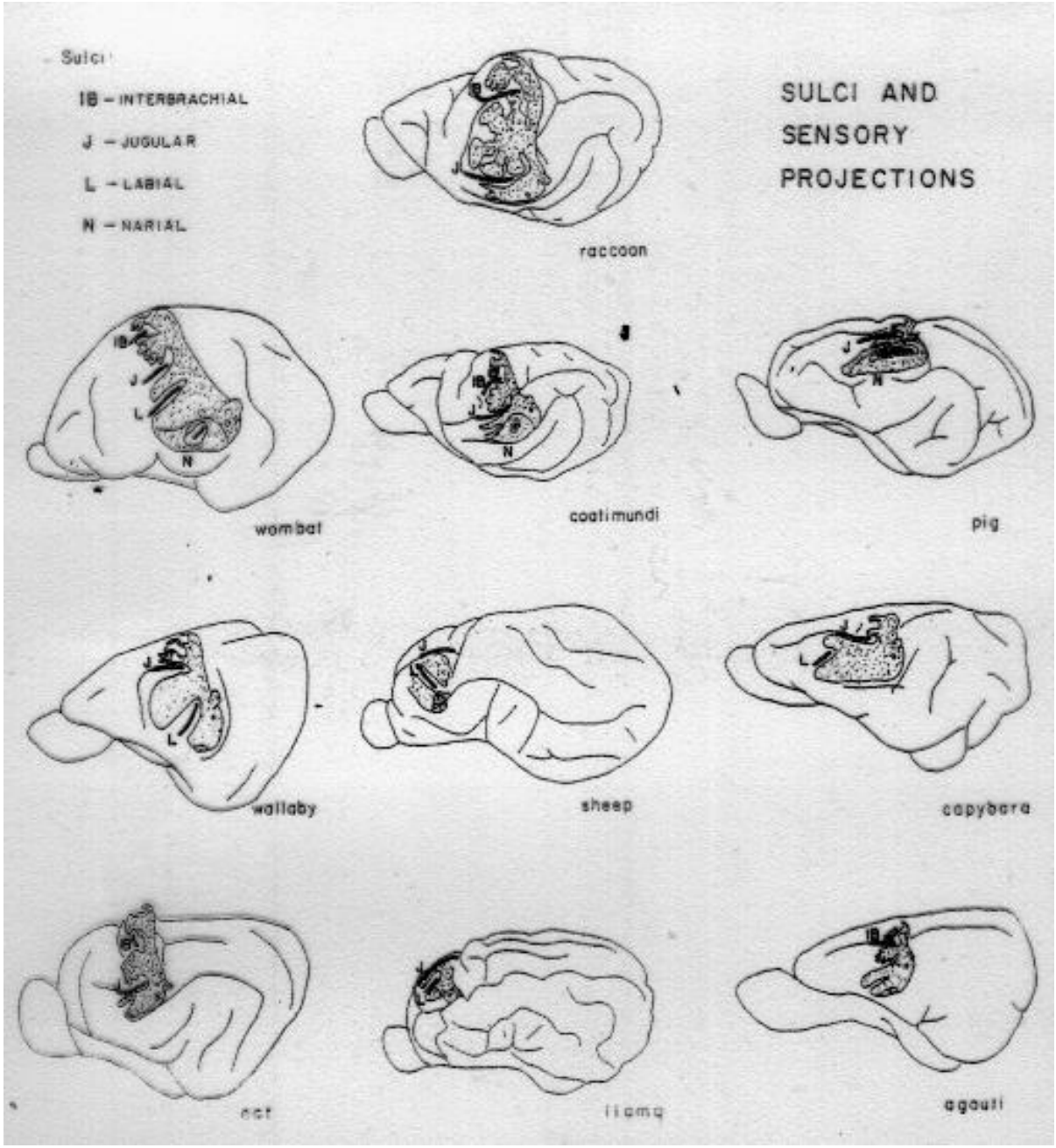
University of Wisconsin

*What is the **receptive field** for this cortical site?*

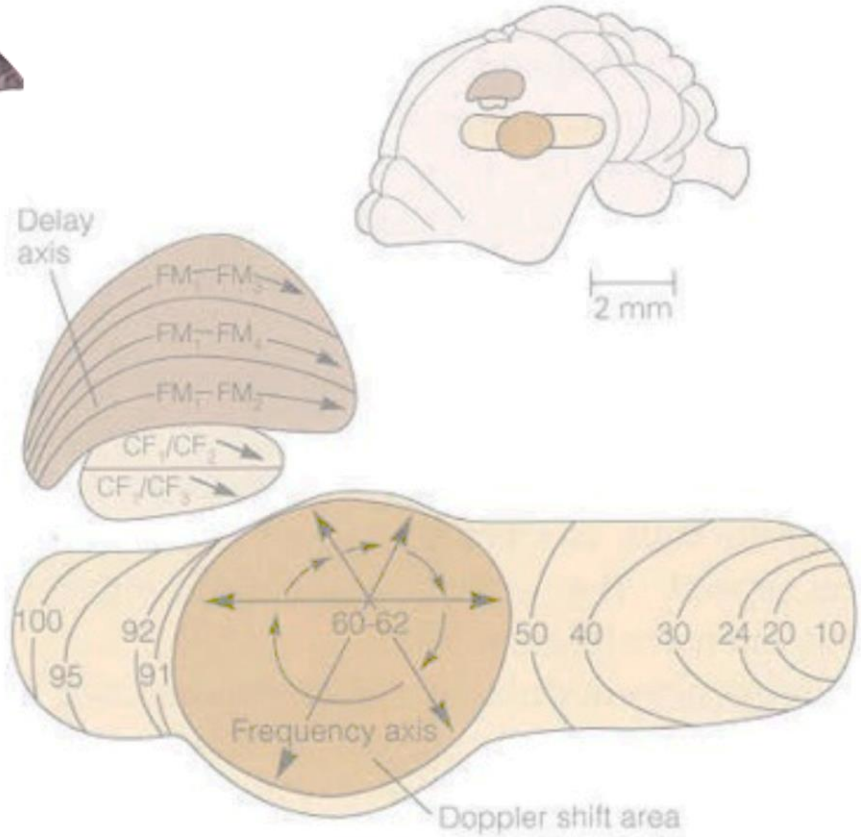


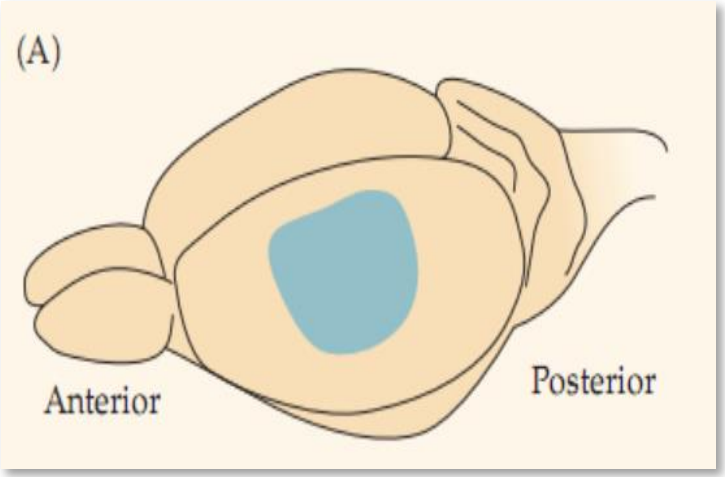
Woolsey's evoked potential mapping:
the skin area projecting to a single cortical site

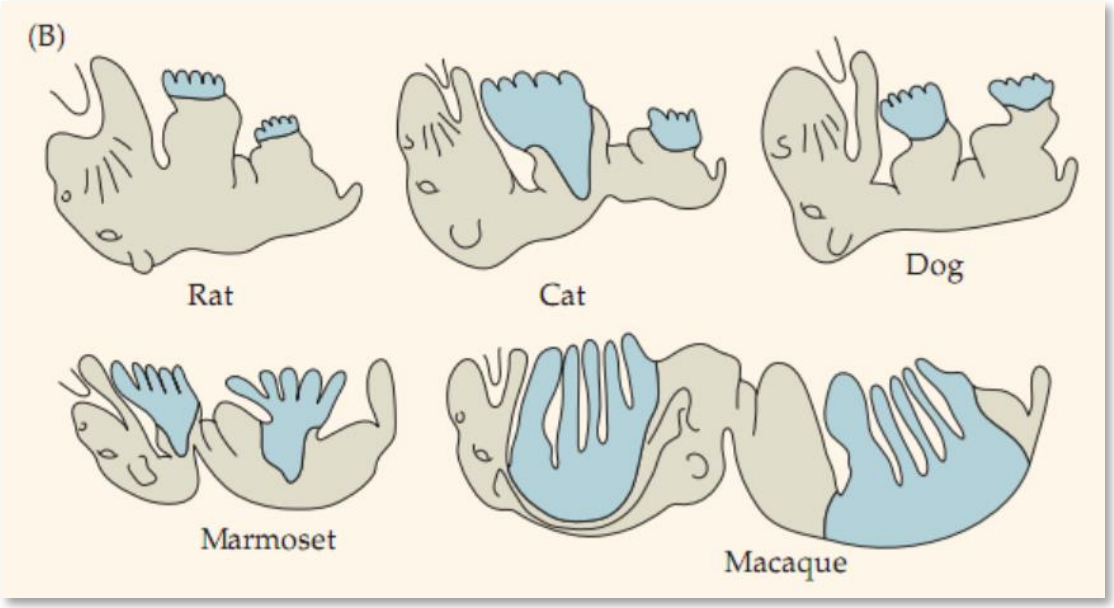

A1
Postcentral gyrus
Central sulcus
Postcentral sulcus
1
2
3b
3a
4
5
a
b
a'
A2
a'a
b
B
Anterior wall of postcentral gyrus
Postcentral gyrus
a'
a
b


Sulci
IB – INTERBRACHIAL
J – JUGULAR
L – LABIAL
N – NARIAL
SULCI AND SENSORY PROJECTIONS
raccoon
wombat
coatimundi
pig
wallaby
sheep
capybara
cat
llama
agouti

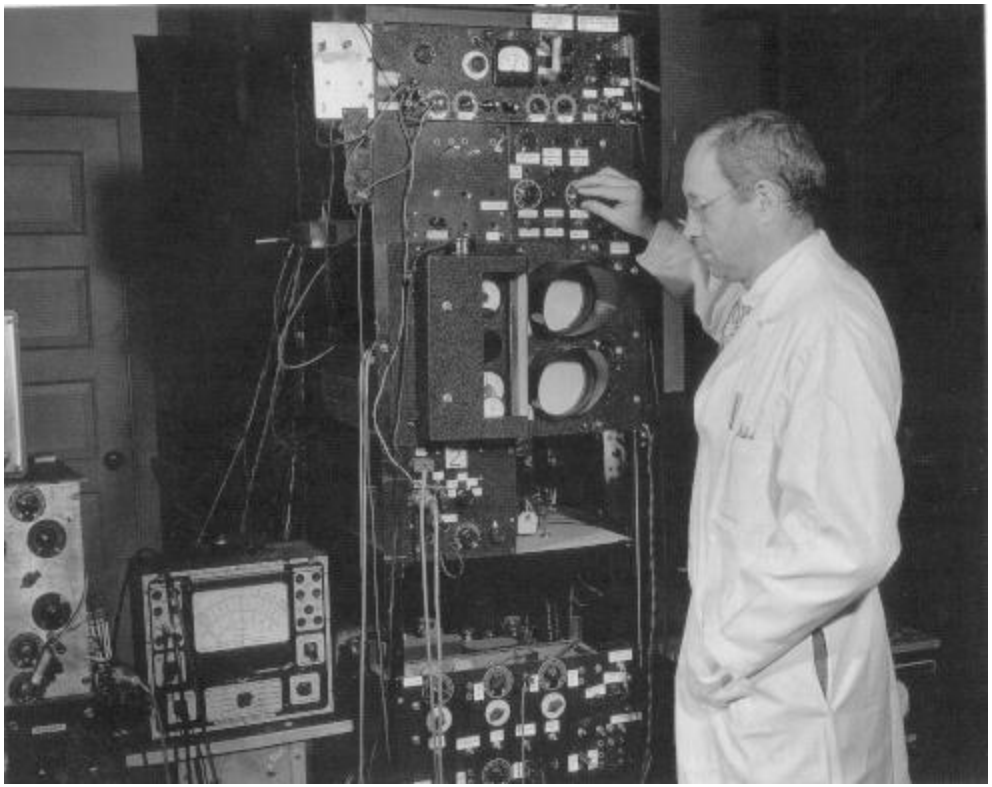
bat auditory cortex





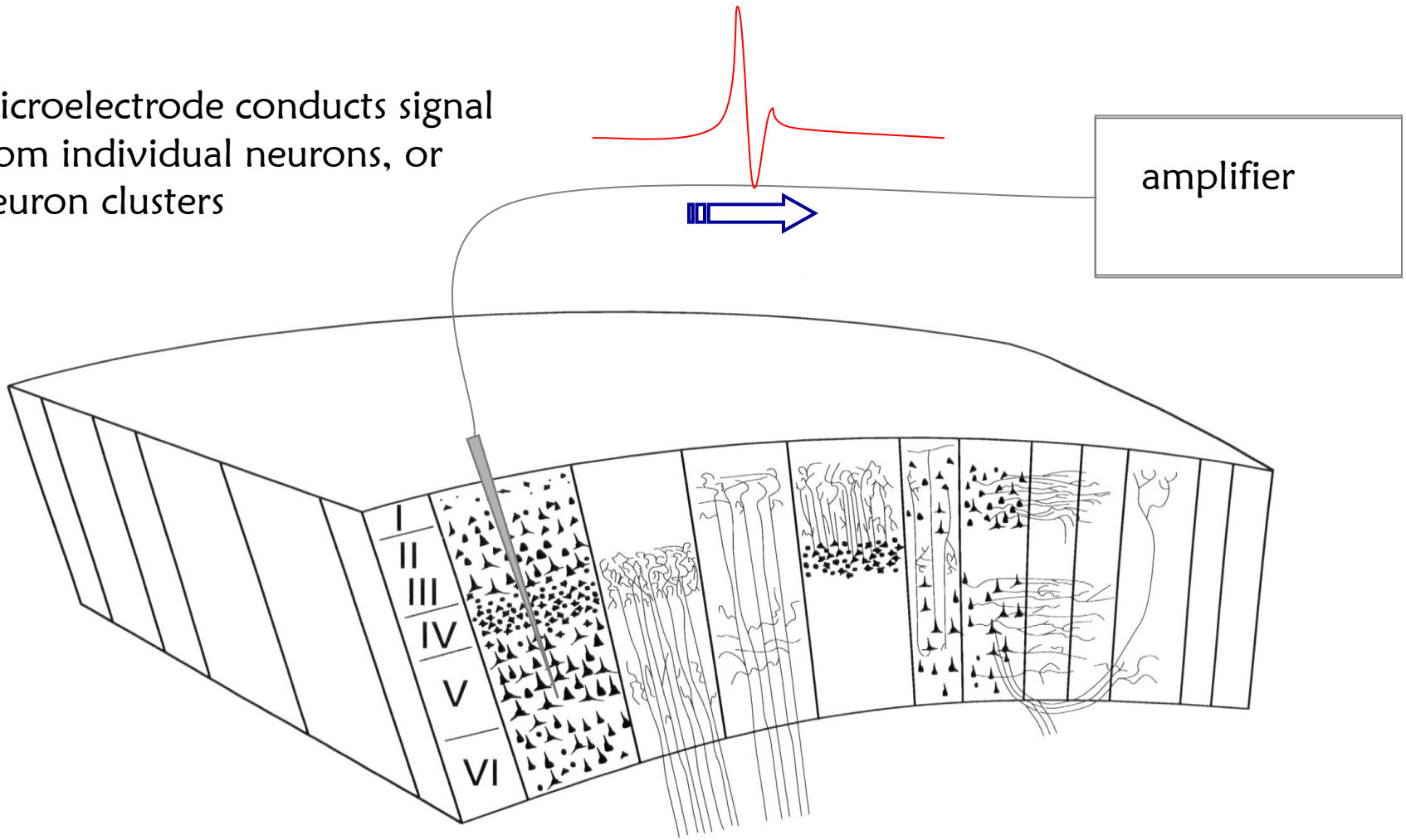


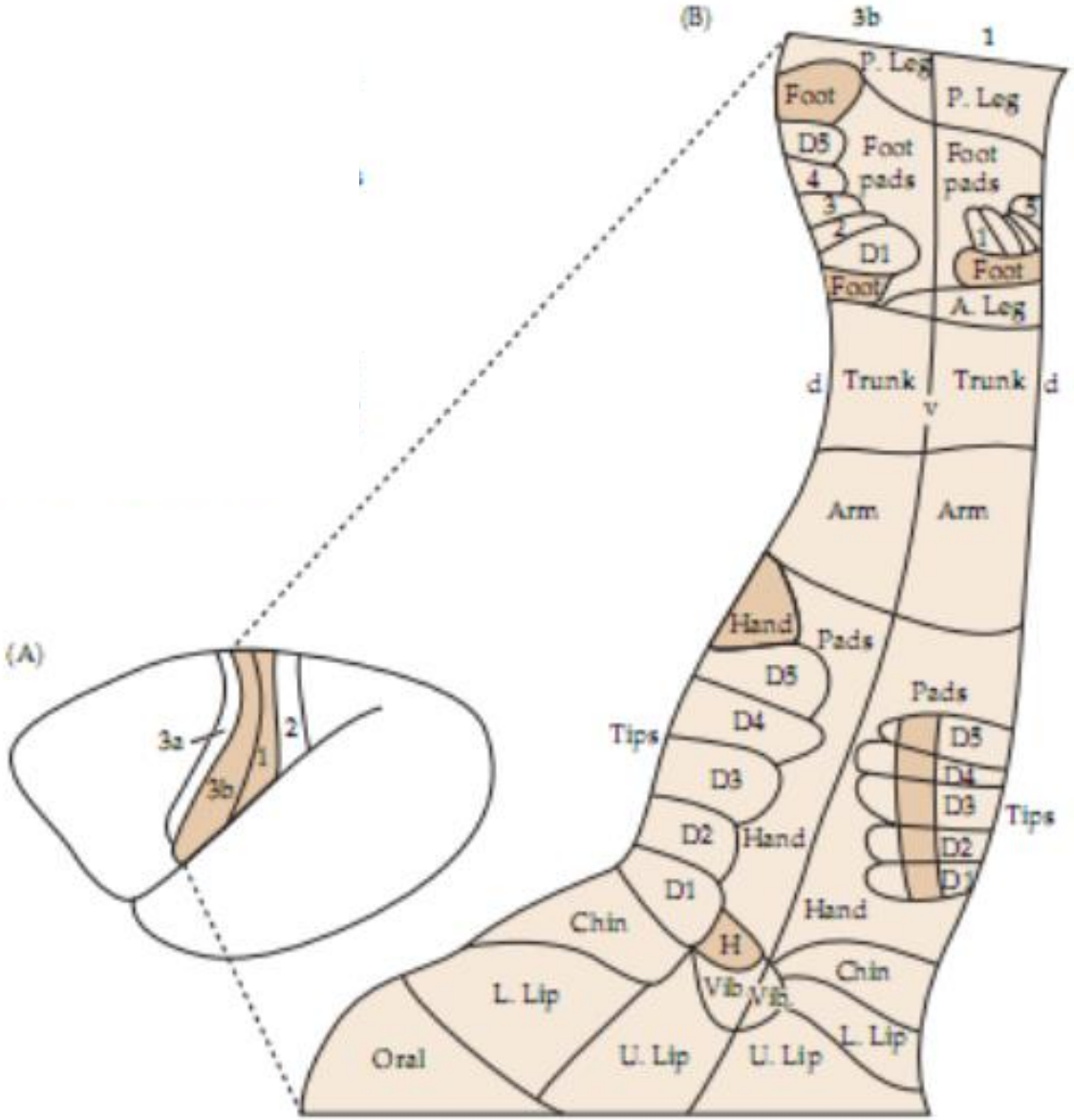
- expansion of the most valuable sensory modality
- expansion of the most valuable receptors within a given representation



Baltimore (USA), 1955

microelectrode conducts signal from individual neurons, or neuron clusters




(A)
3a
3b
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2
(B)
3b
1
P. Leg
P. Leg
Foot
D5
Foot pads
Foot pads
4
3
2
D1
Foot
Foot
A. Leg
d
Trunk
Trunk
d
v
Arm
Arm
Hand
Pads
D5
Pads
Tips
D4
D5
D4
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Tips
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L. Lip
VIb
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L. Lip
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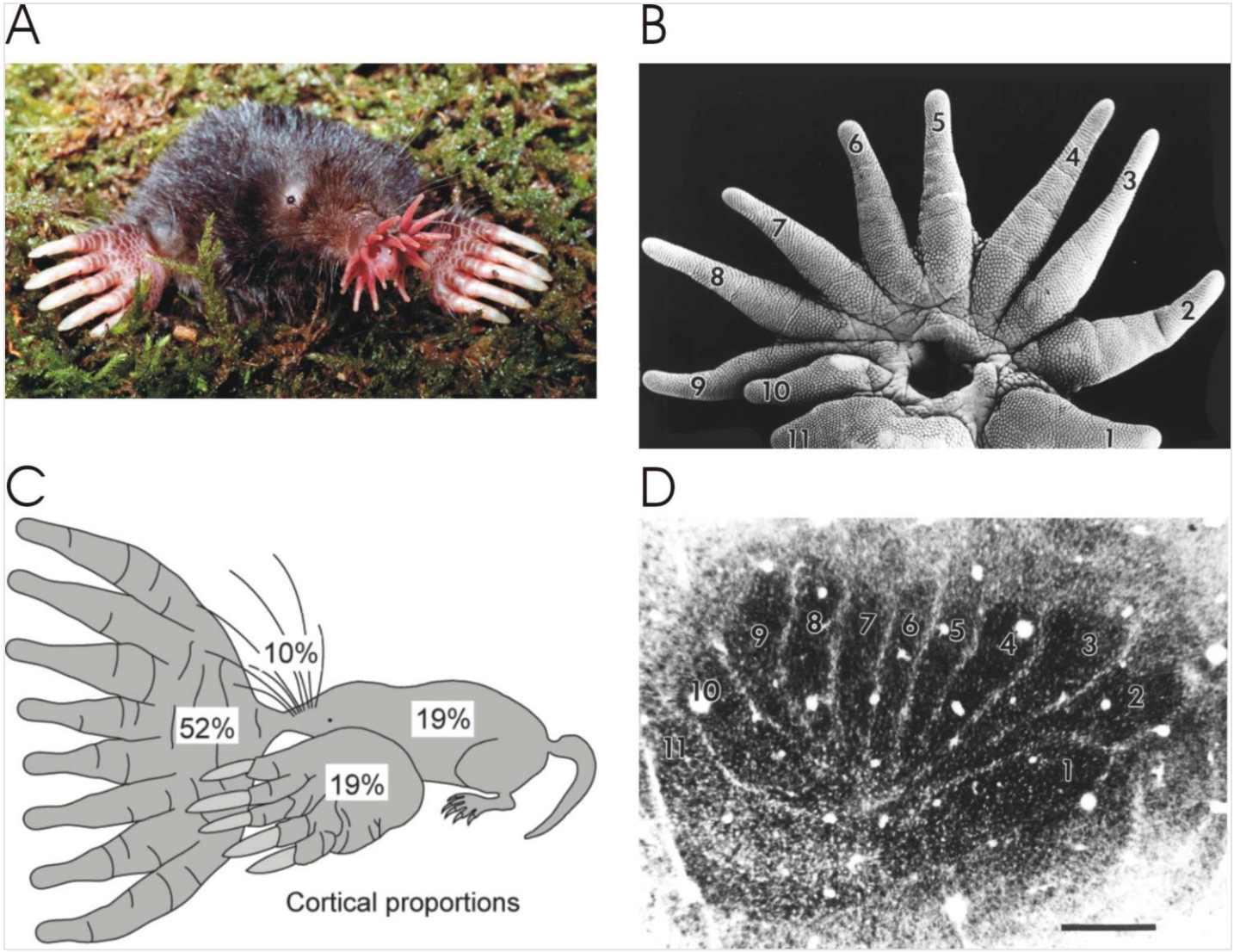
U. Lip
U. Lip


A
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C
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52%
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Cortical proportions
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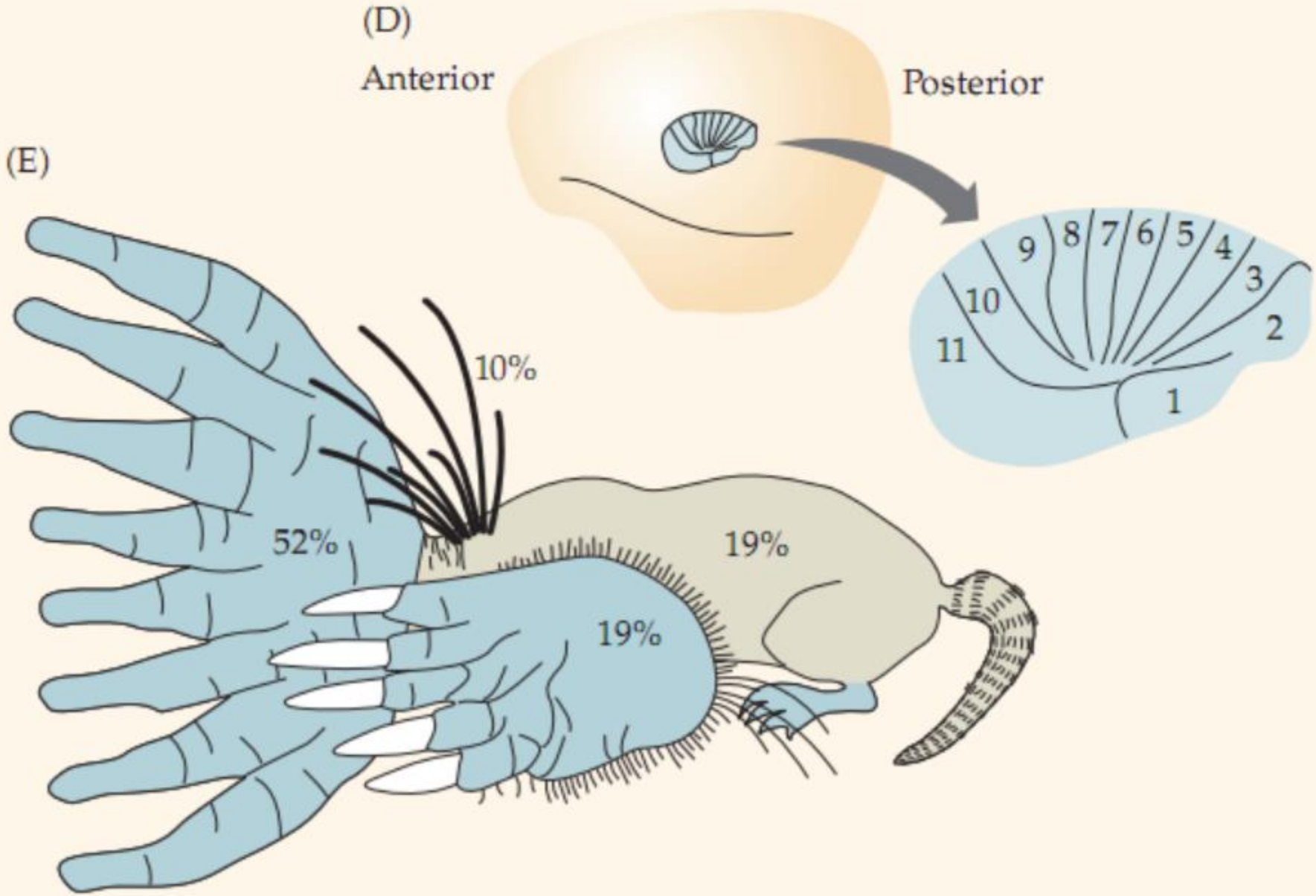
(D)
Anterior
Posterior
(E)
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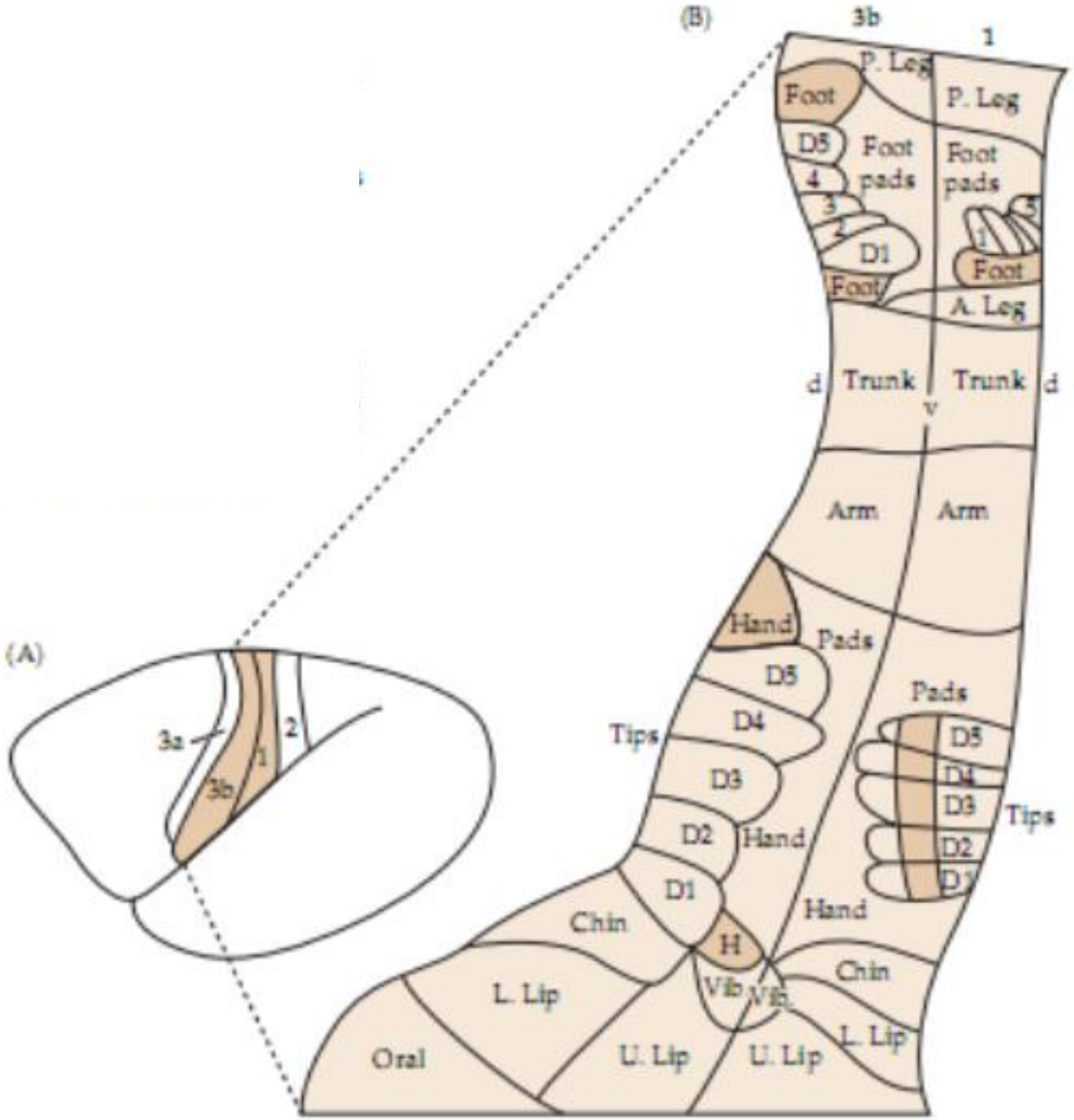
10%
52%
19%
19%

90 min. into lesson


(A)
3a
3b
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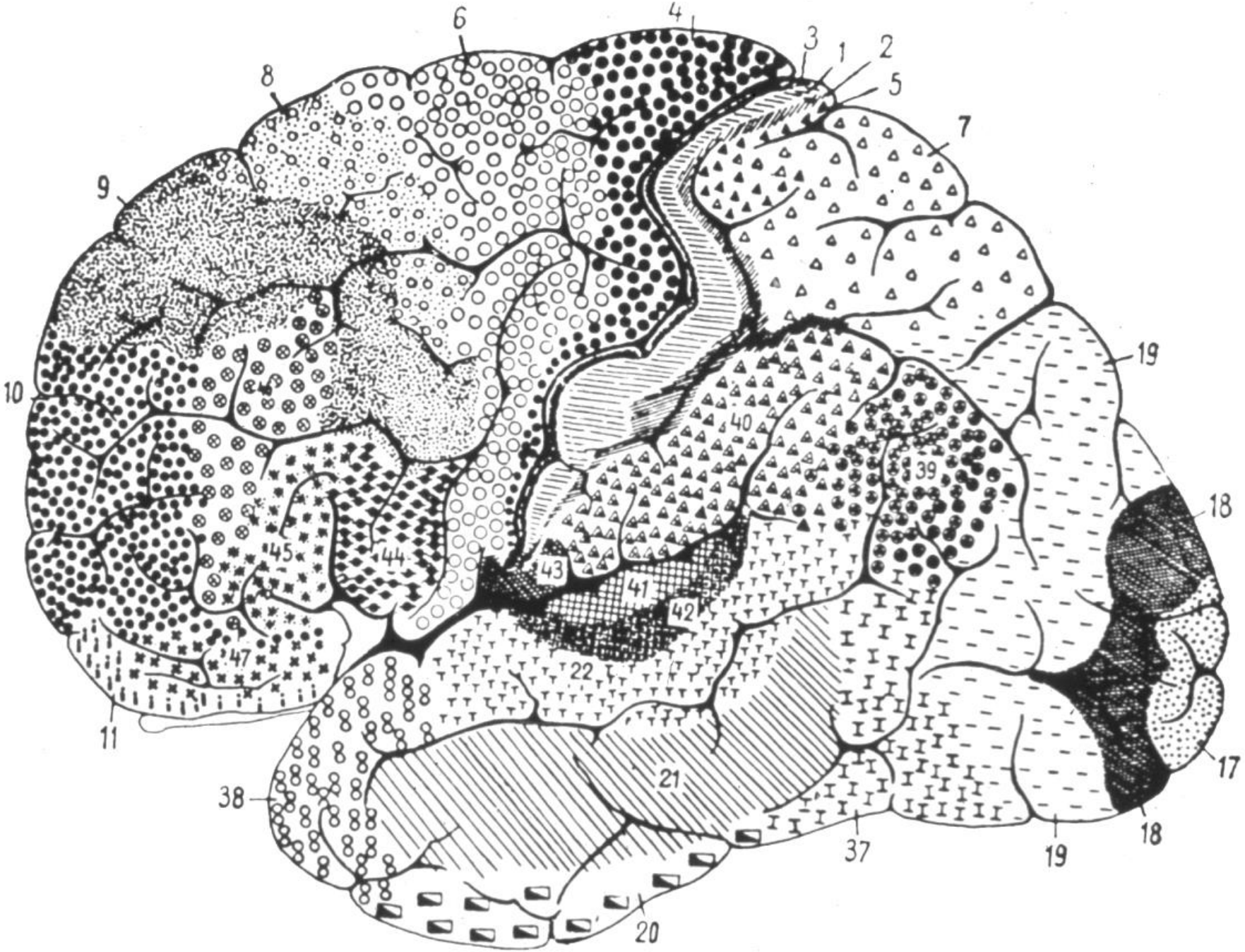
(B)
3b
1
P. Leg
P. Leg
Foot
D5
Foot pads
Foot pads
4
3
2
D1
Foot
Foot
A. Leg
d
Trunk
Trunk
d
v
Arm
Arm
Hand
Pads
D5
Pads
Tips
D4
D5
D4
D3
D3
Tips
D2
Hand
D2
D1
D1
Hand
Chin
H
Chin
L. Lip
VIb
VIb
L. Lip
Oral
U. Lip
U. Lip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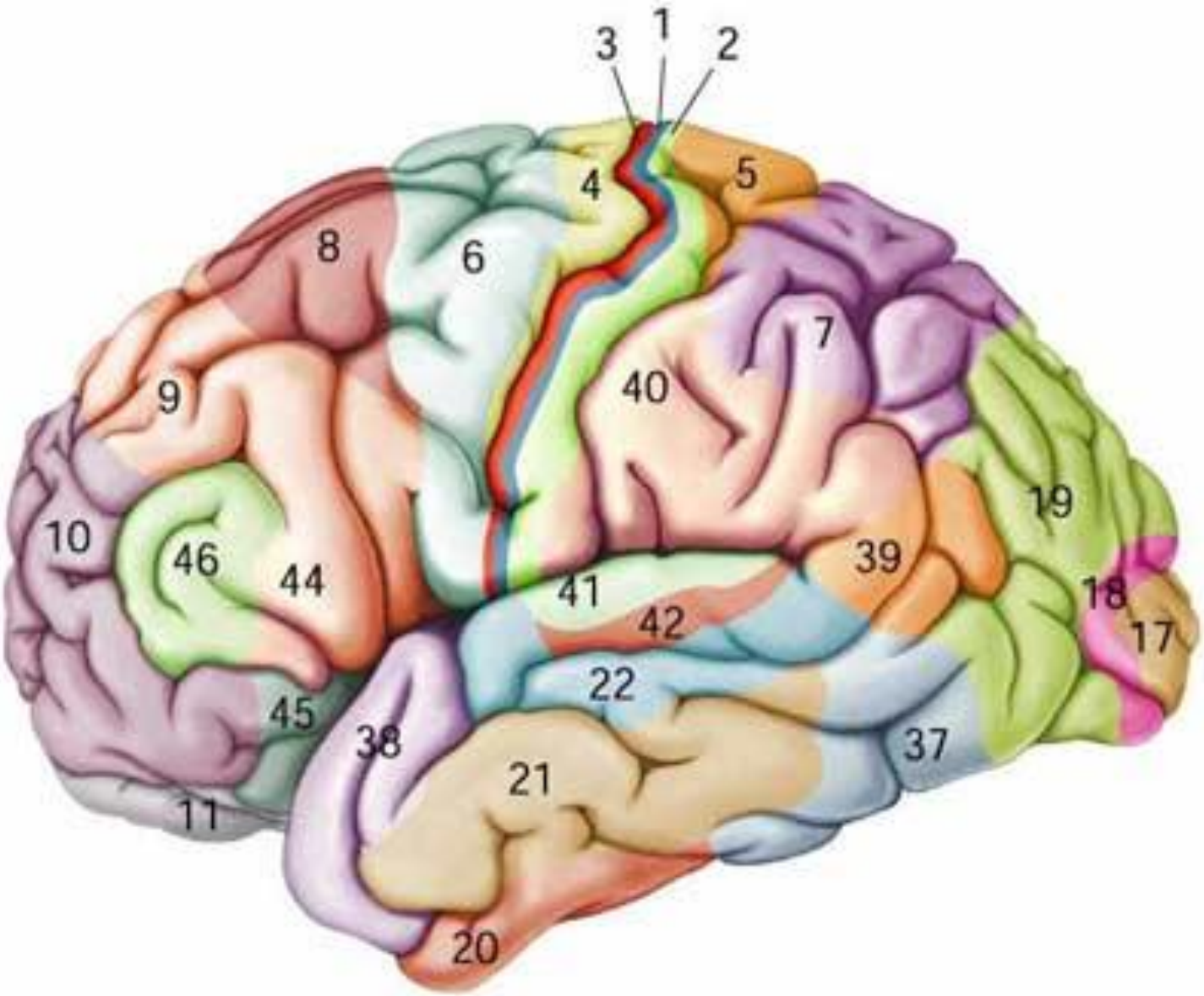
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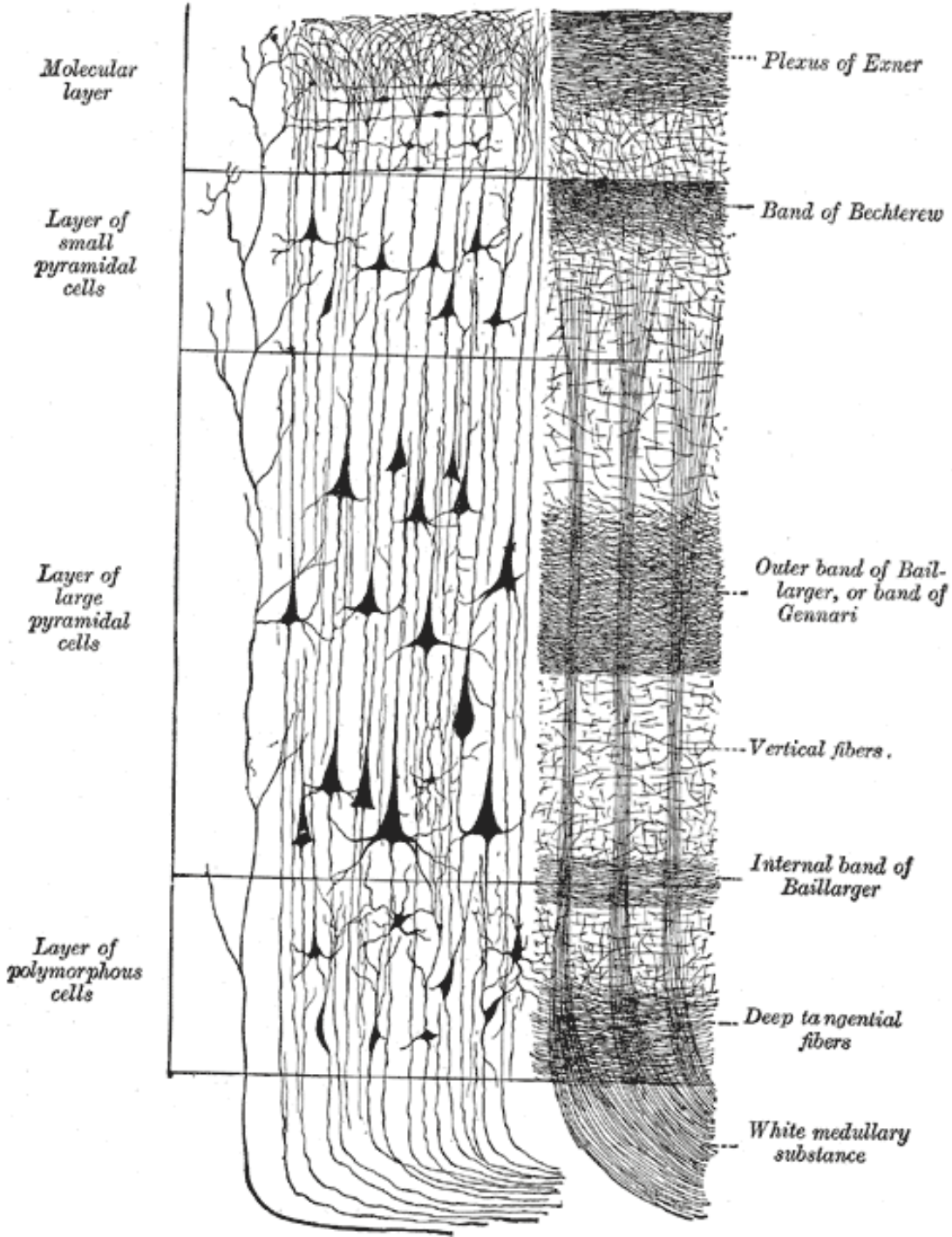

Molecular layer
Layer of small pyramidal cells
Layer of large pyramidal cells
Layer of polymorphous cells
Plexus of Exner
Band of Bechterew
Outer band of Baillarger, or band of Gennari
Vertical fibers.
Internal band of Baillarger
Deep tangential fibers
White medullary substance

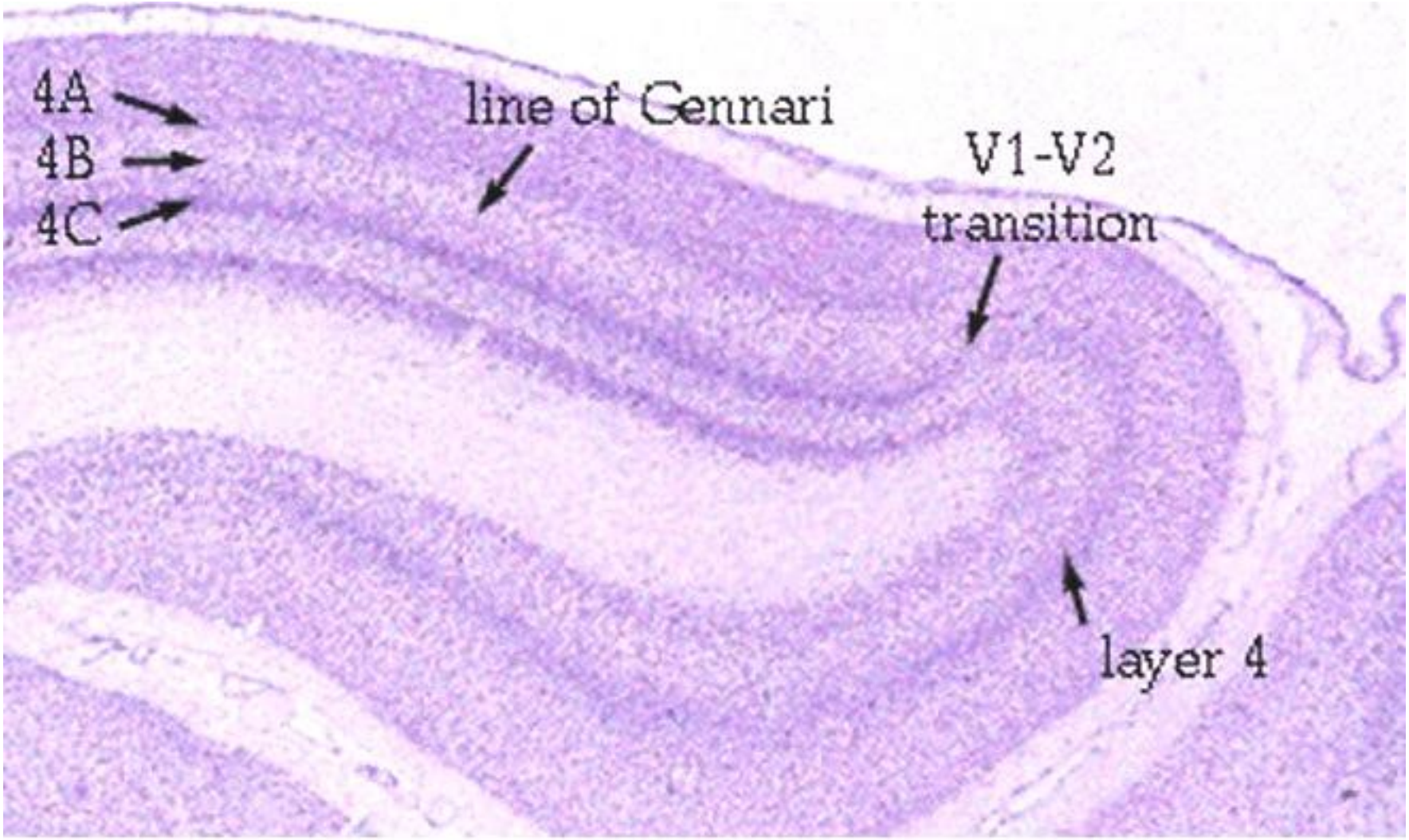
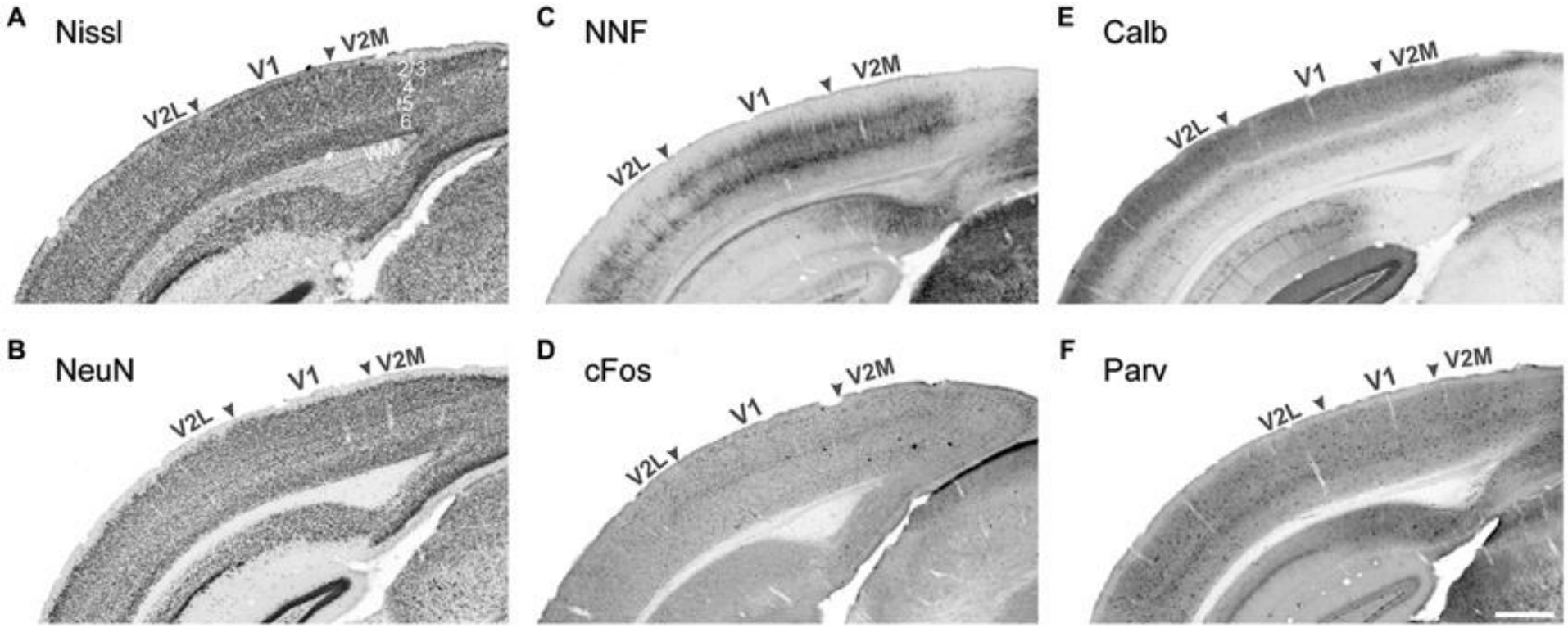
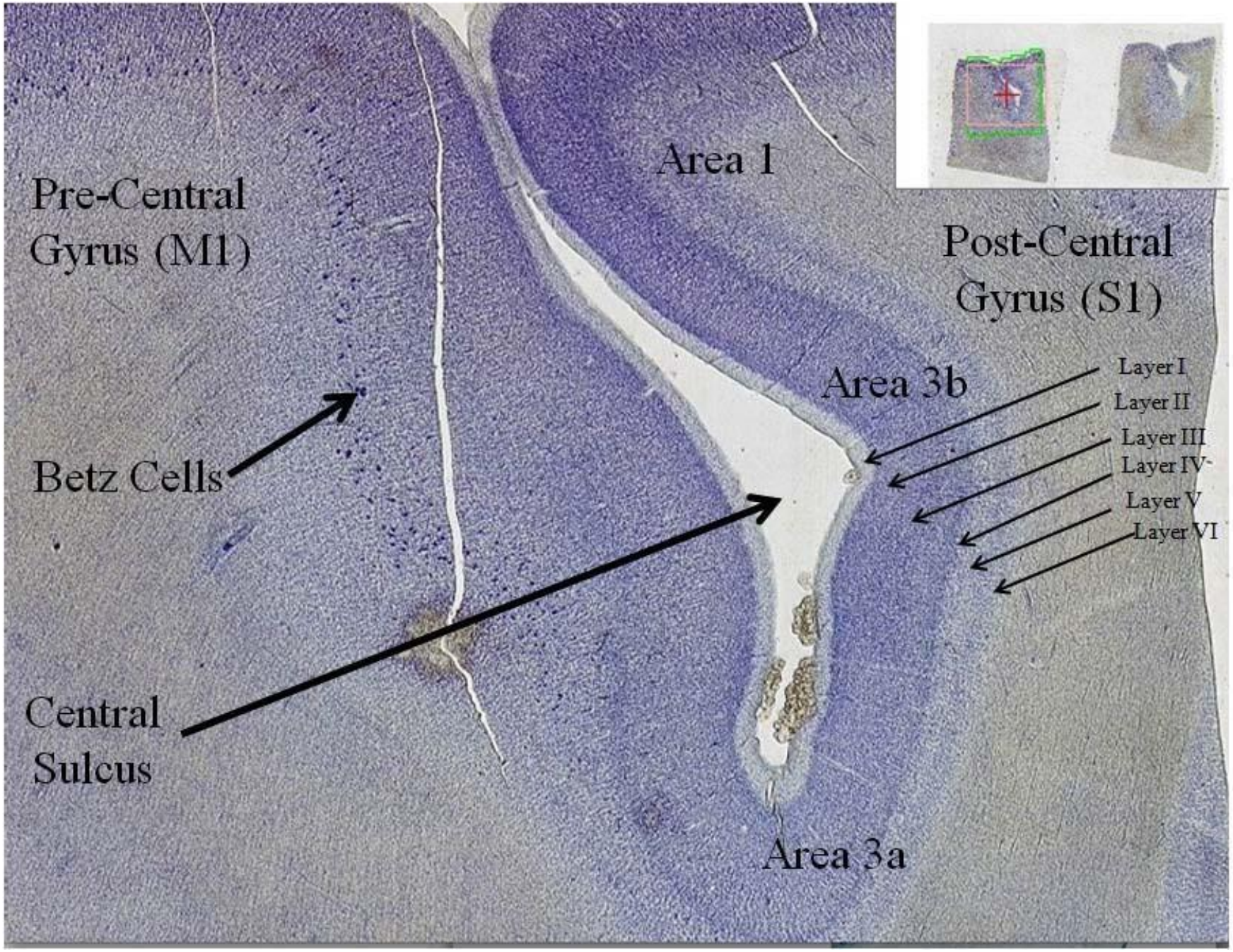
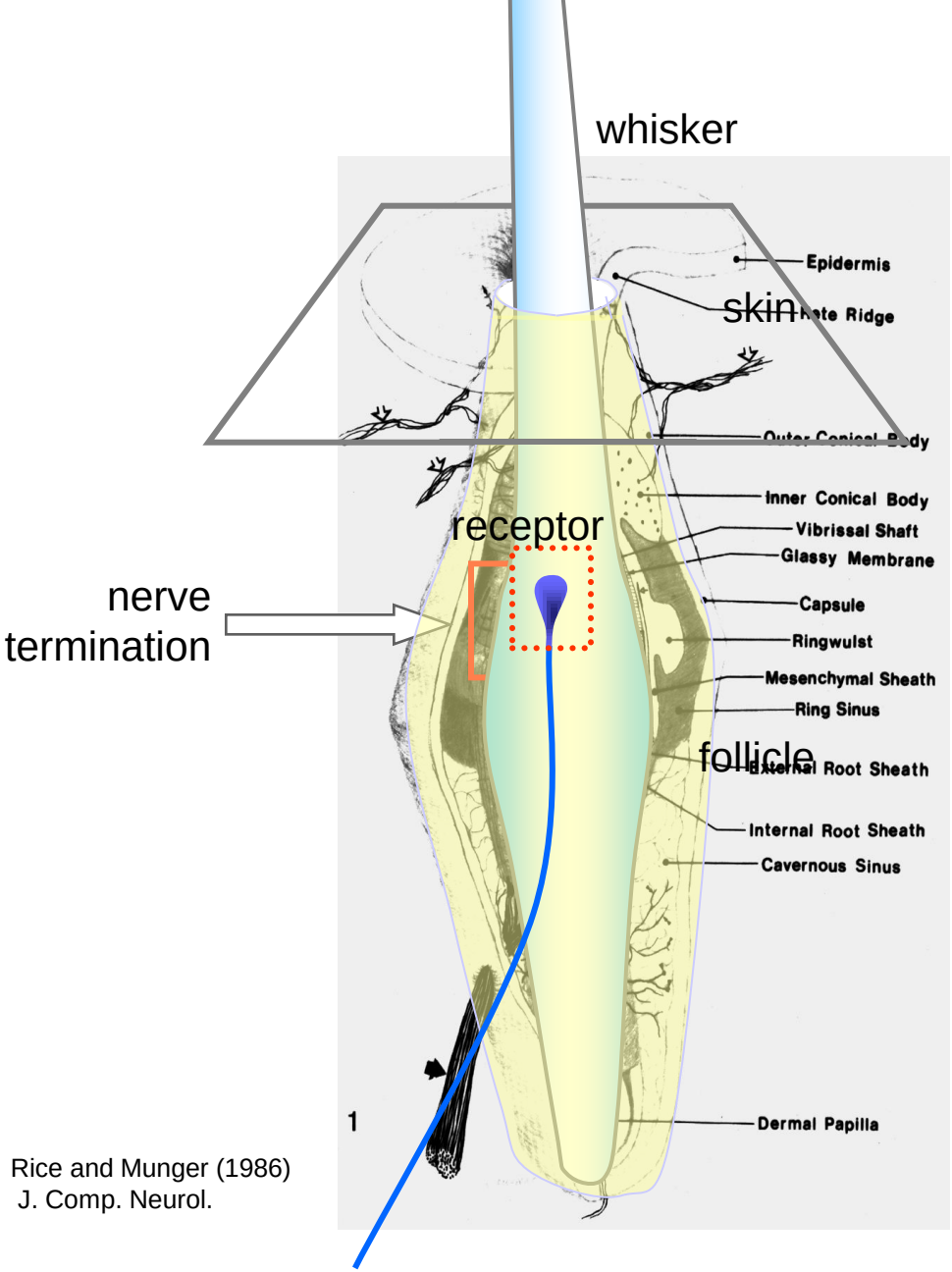


Figure 9. Nissl stained section of the visual cortex to show the border between area 17 (V1) and area 18 (V2).

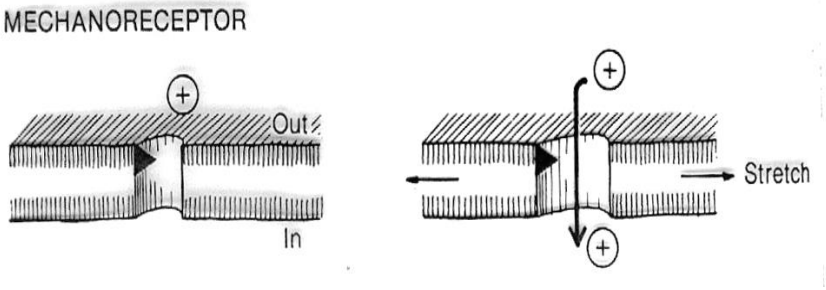

A
Nissl
V2L
V1
V2M
2/3
4
5
6
WM
B
NeuN
V2L
V1
V2M
C
NNF
V2L
V1
V2M
D
cFos
V2L
V1
V2M
E
Calb
V2L
V1
V2M
F
Parv
V2L
V1
V2M

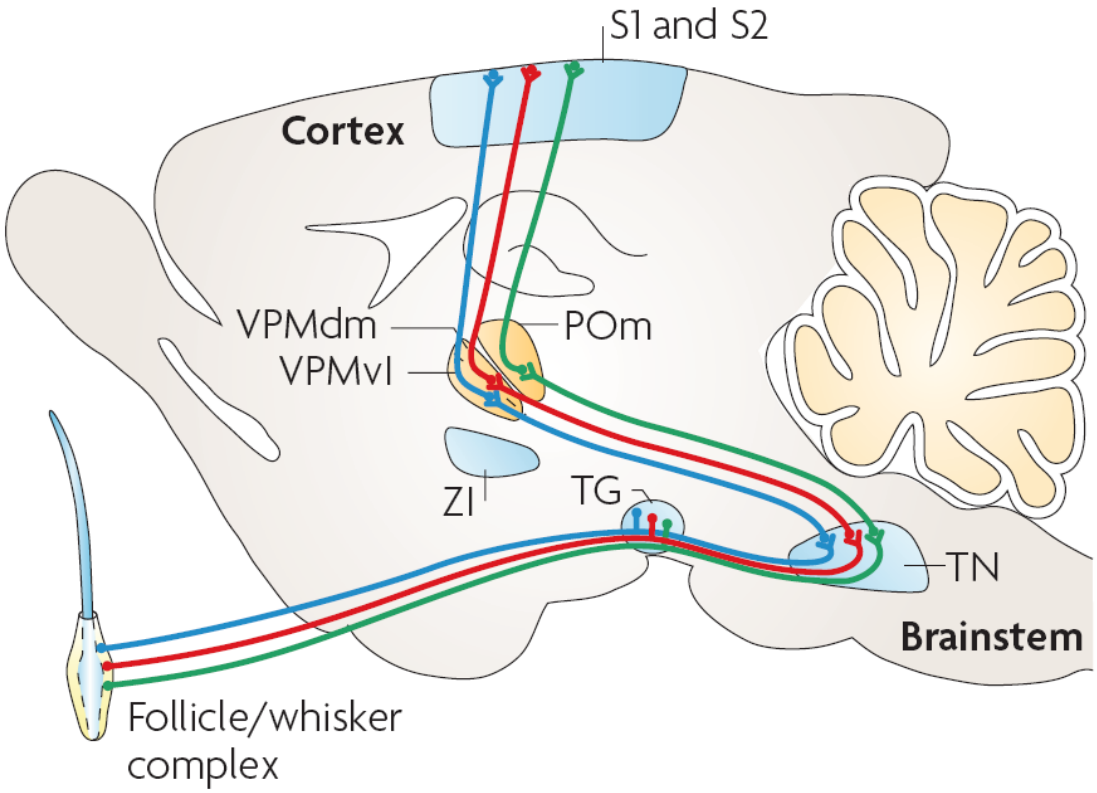

Pre-Central
Gyrus (M1)
Area 1
Post-Central
Gyrus (S1)
Area 3b
Layer I
Layer II
Layer III
Layer IV
Layer V
Layer VI
Betz Cells
Central
Sulcus
Area 3a

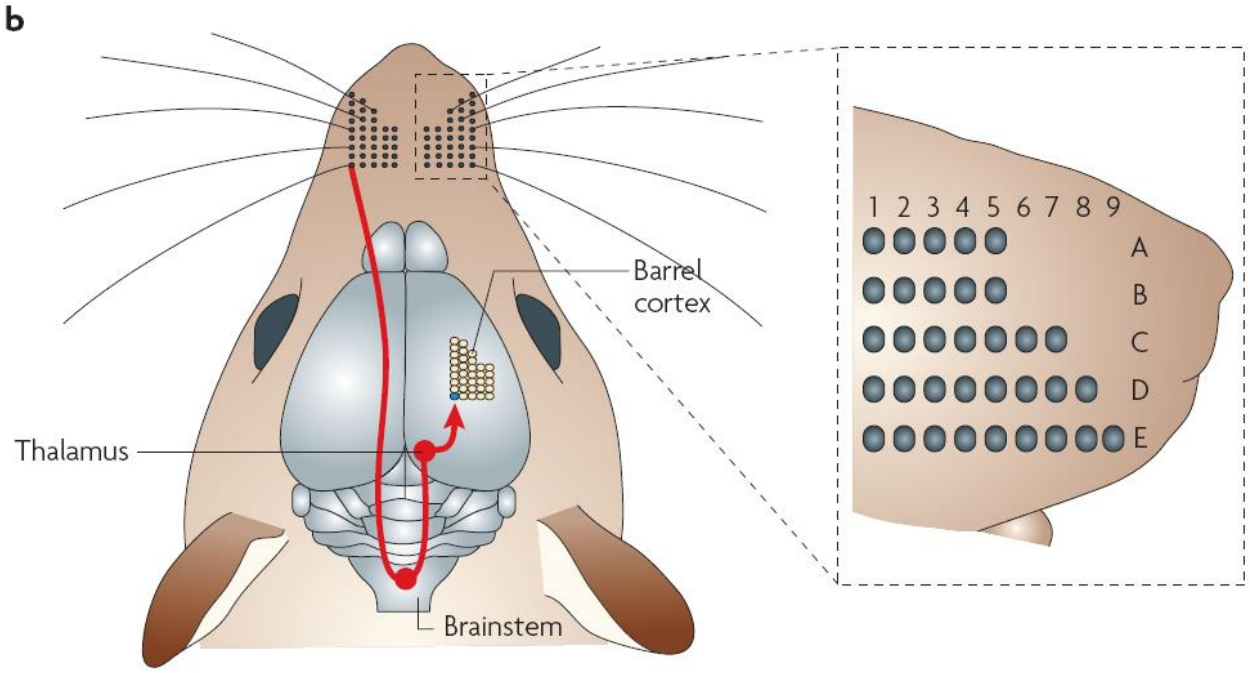
An artistic interpretation of what the newly identified cynodont Bonacynodon schultzi looked like during its lifetime about 235 million years ago during the Triassic. (Jorge Blanco)

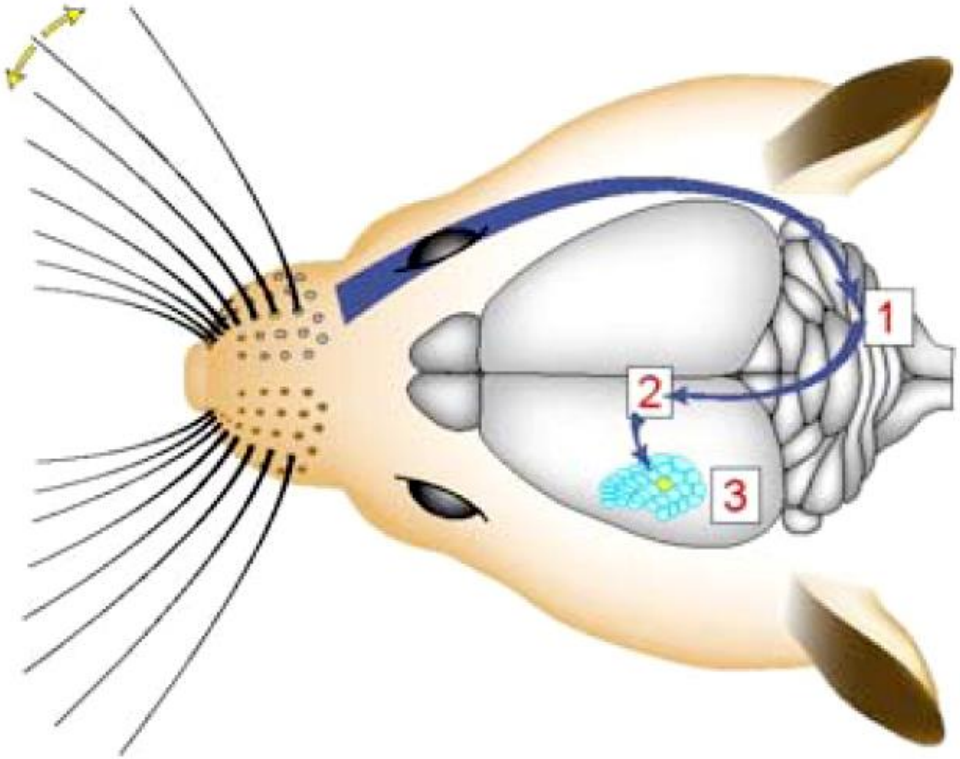


Rice and Munger (1986)
J. Comp. Neurol.

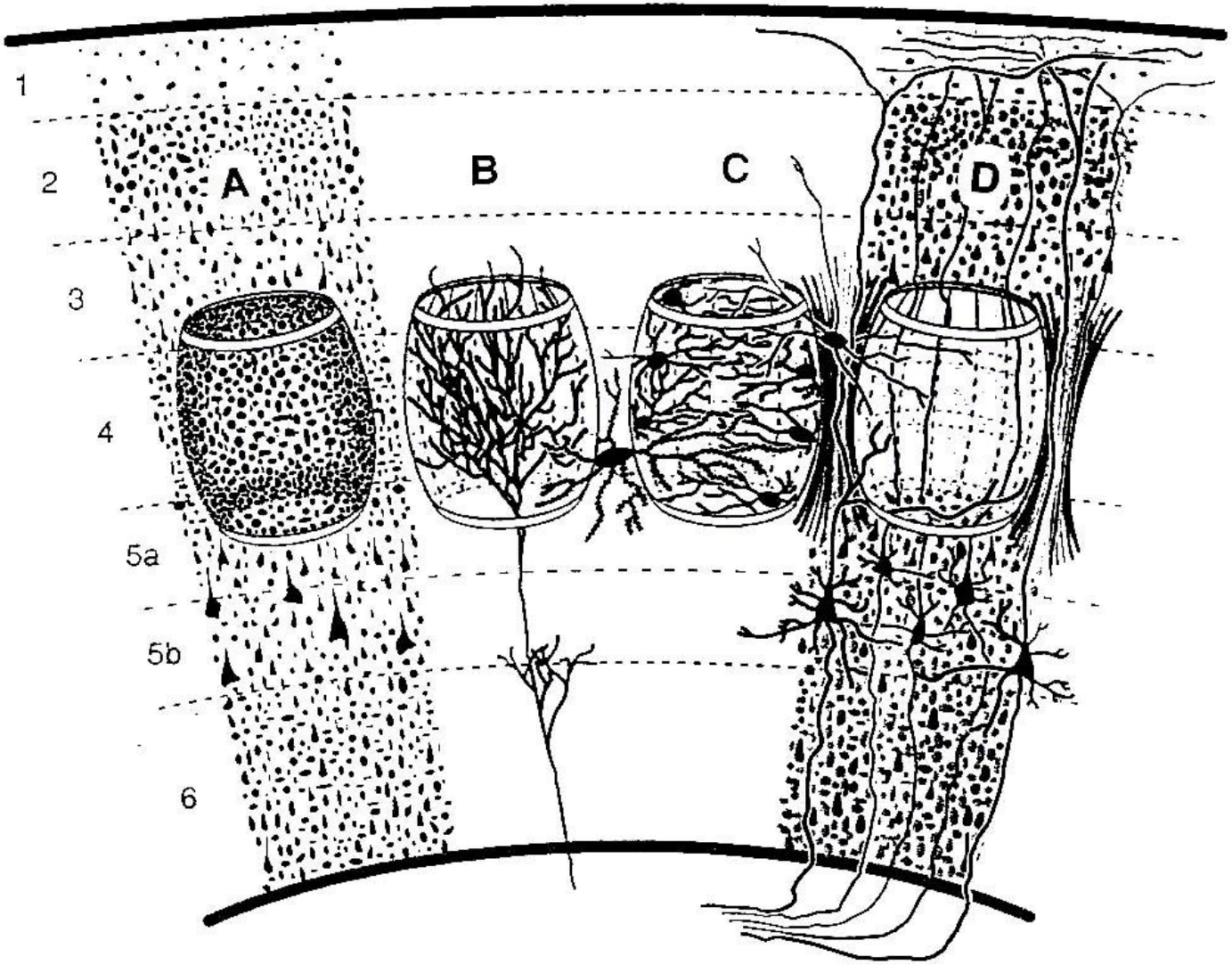



S1 and S2
Cortex
VPMdm
VPMvl
POm
ZI
TG
TN
Brainstem
Follicle/whisker
complex

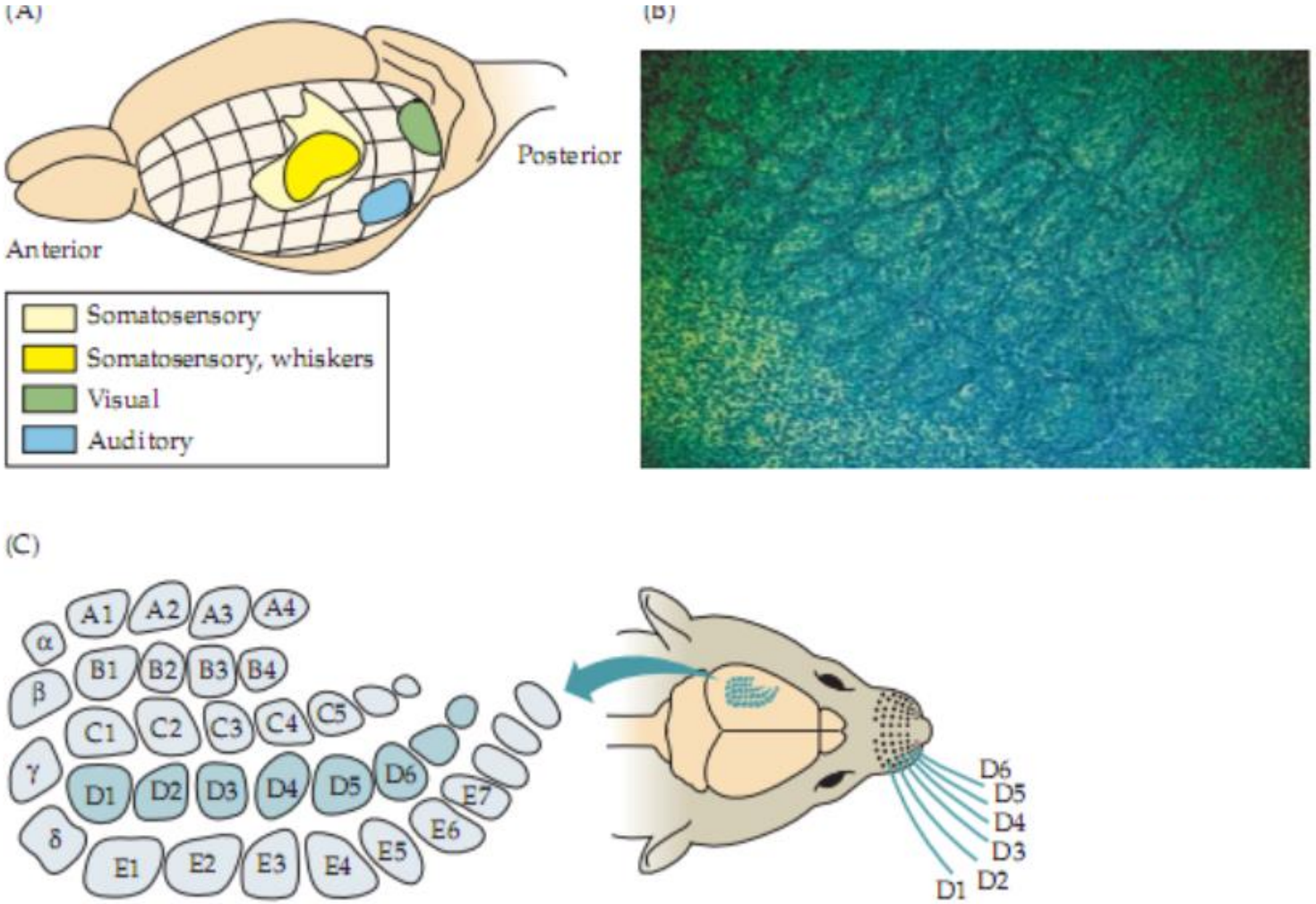

b
Barrel
cortex
Thalamus
Brainstem
1 2 3 4 5 6 7 8 9
A
B
C
D
E


1
2
3

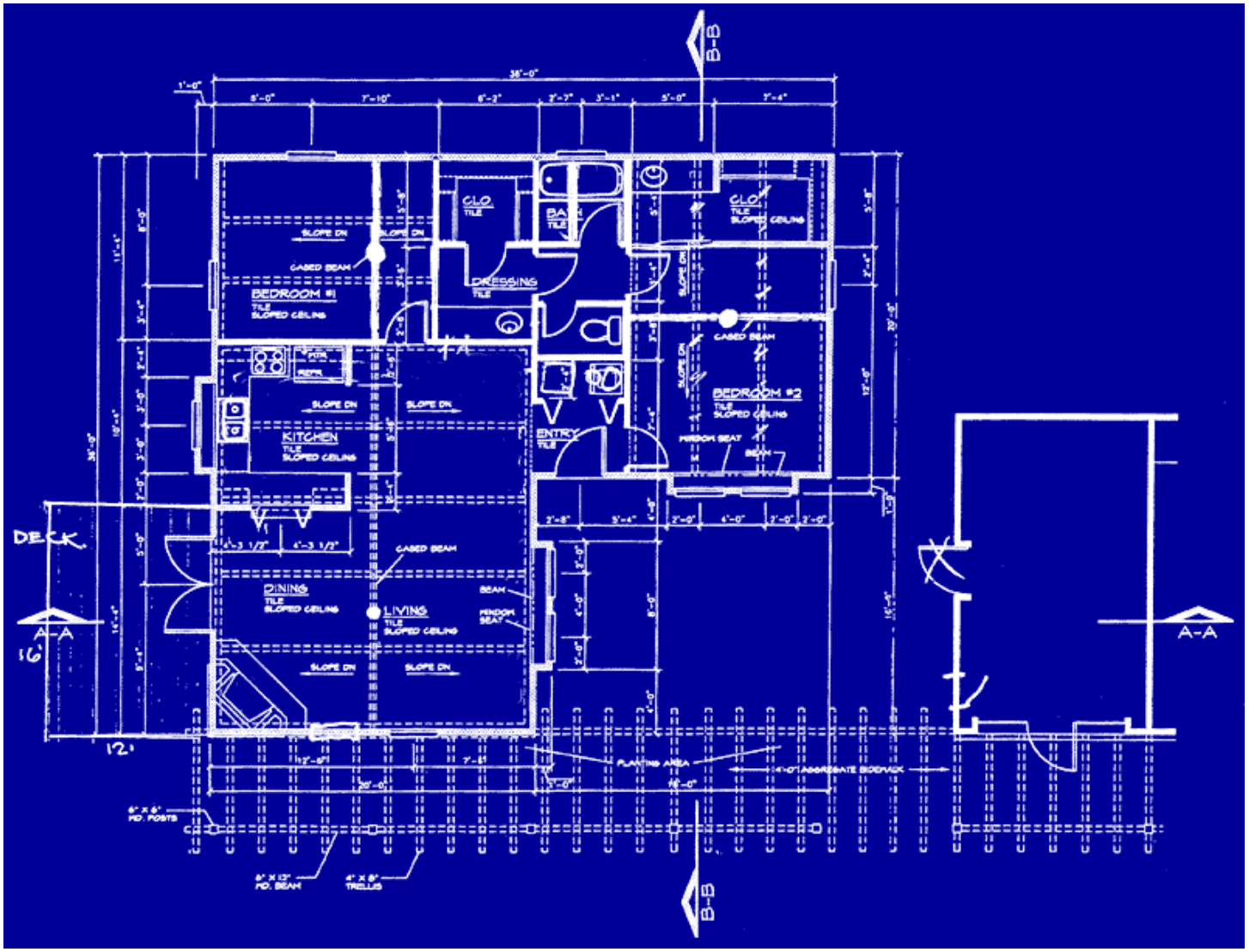
barrel cortex is one of the most robust examples of mammalian columnar organization



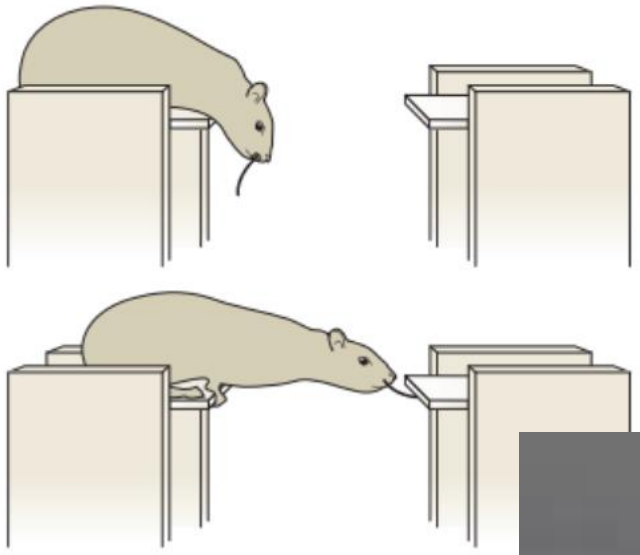
Waite & Tracey (1995)

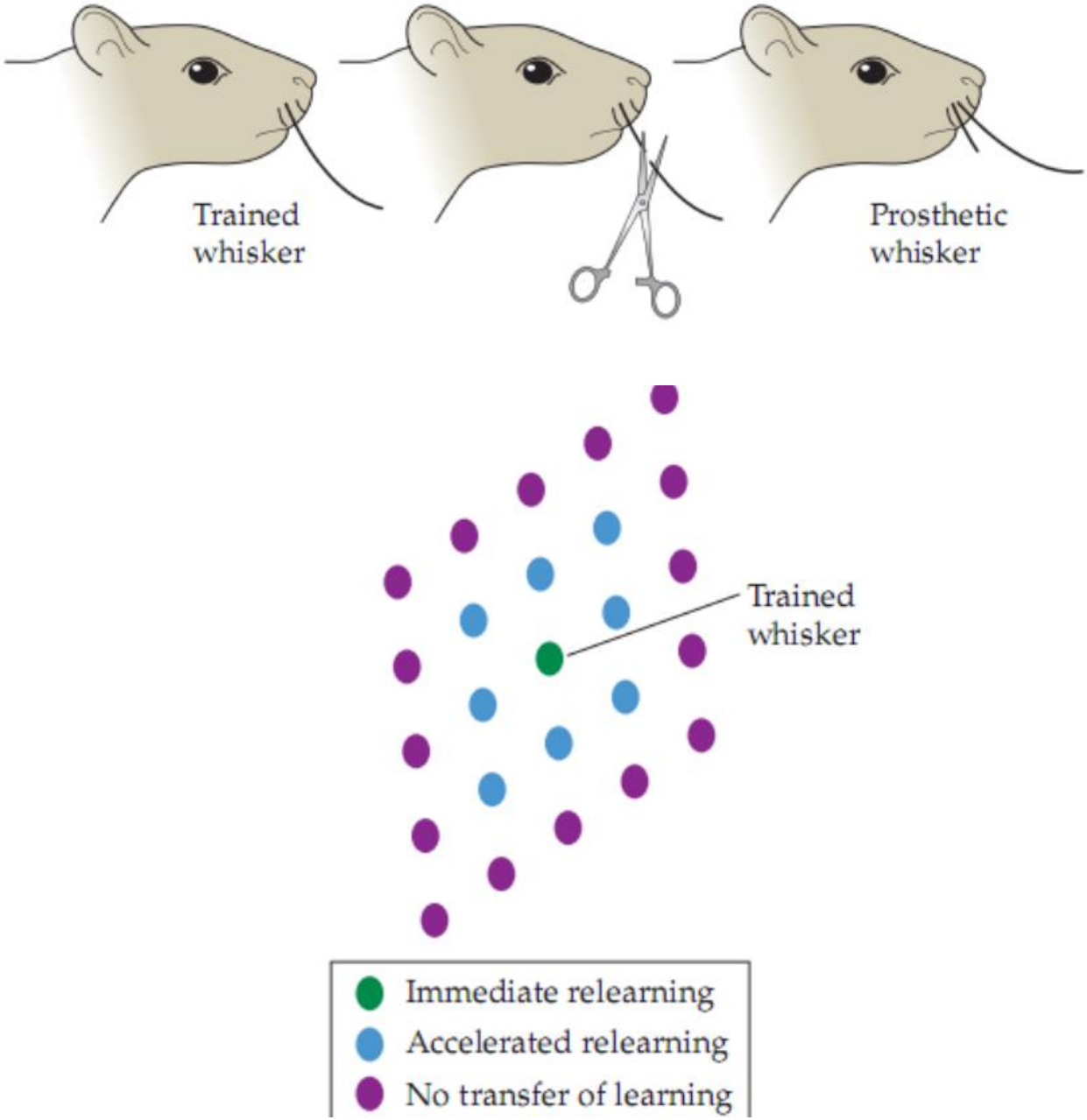

(A)
Posterior
Anterior
Somatosensory
Somatosensory, whiskers
Visual
Auditory
(B)
(C)
A1
A2
A3
A4
α
B1
B2
B3
B4
β
C1
C2
C3
C4
C5
γ
D1
D2
D3
D4
D5
D6
E7
E6
δ
E1
E2
E3
E4
E5
D6
D5
D4
D3
D1
D2

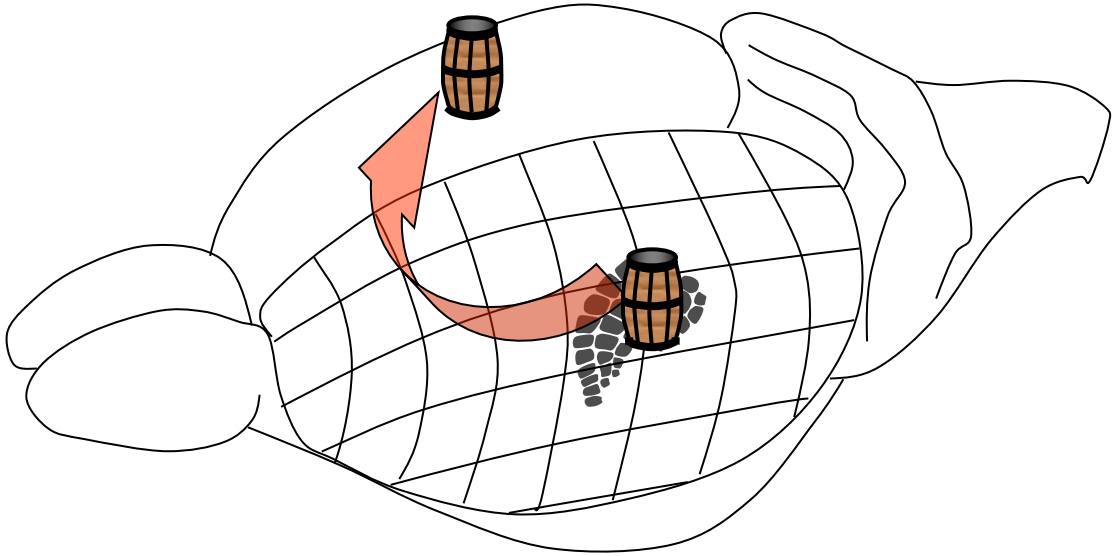
Does the map really mean anything?



(A)

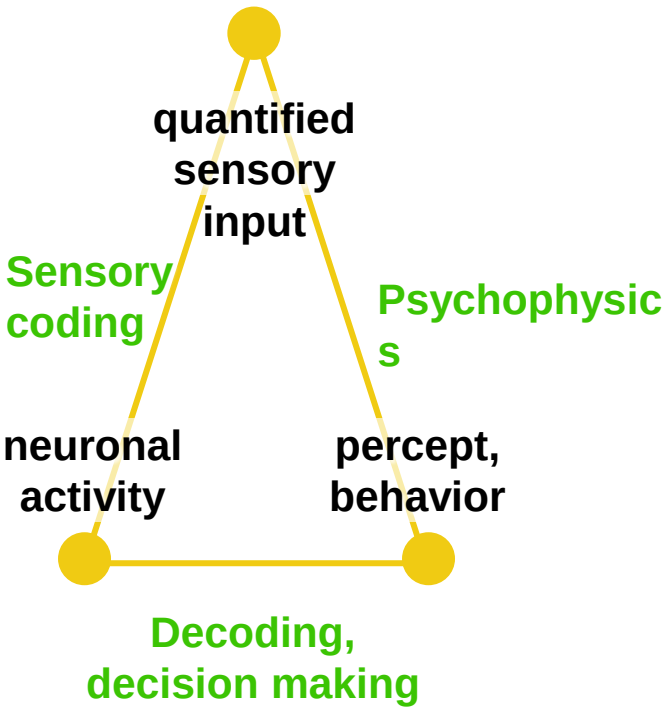



Trained whisker
Prosthetic whisker
Trained whisker
Immediate relearning
Accelerated relearning
No transfer of learning

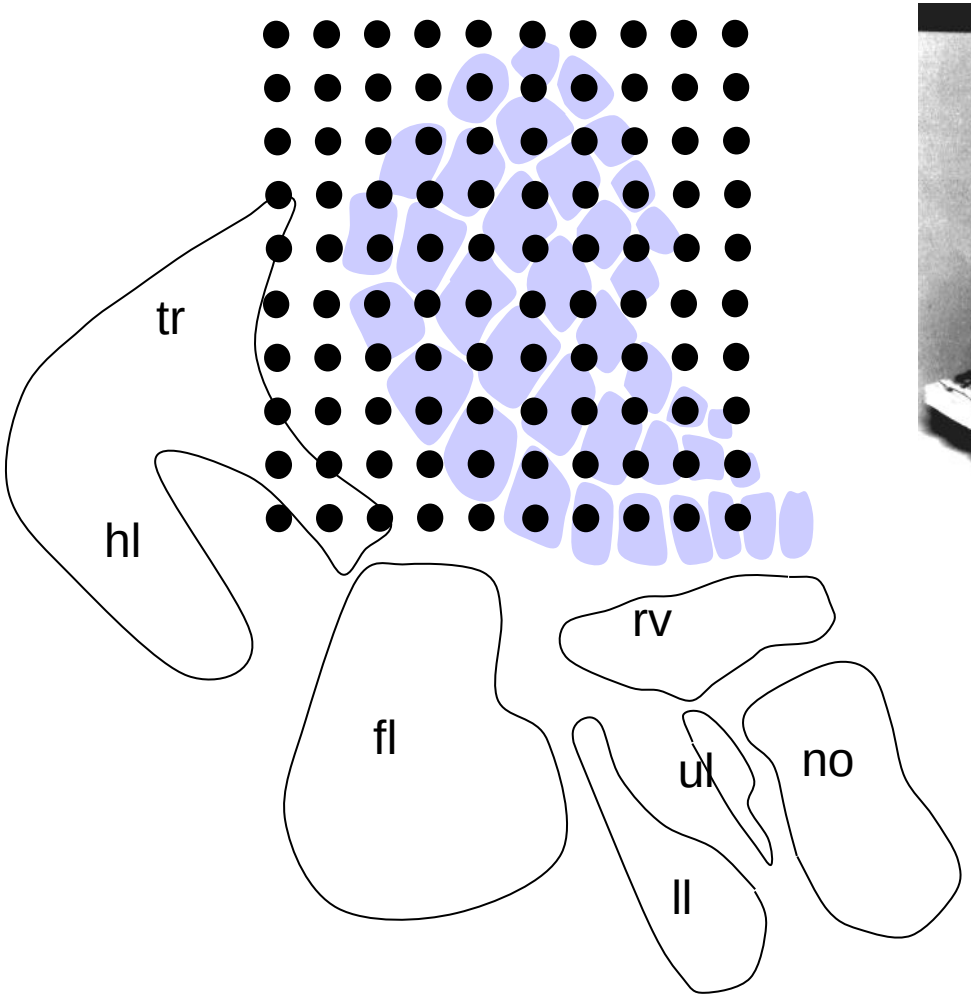


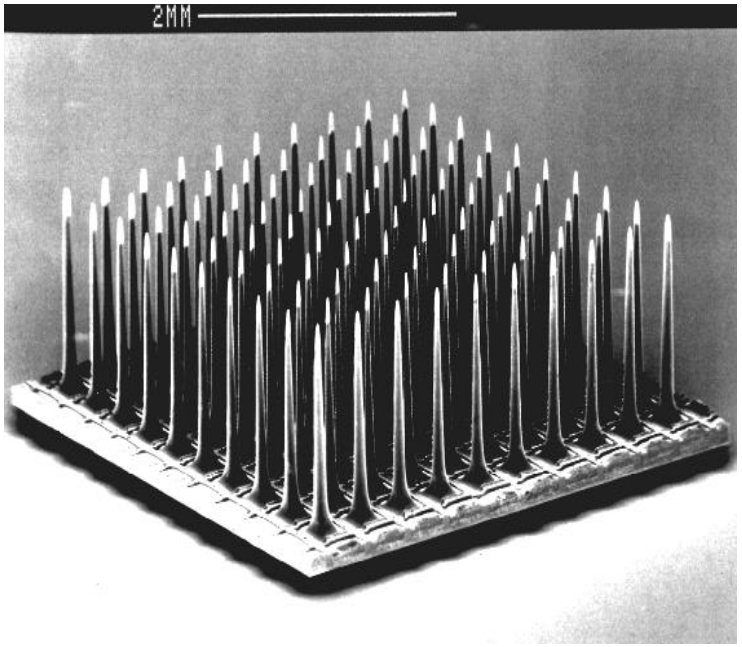
Experimental variables

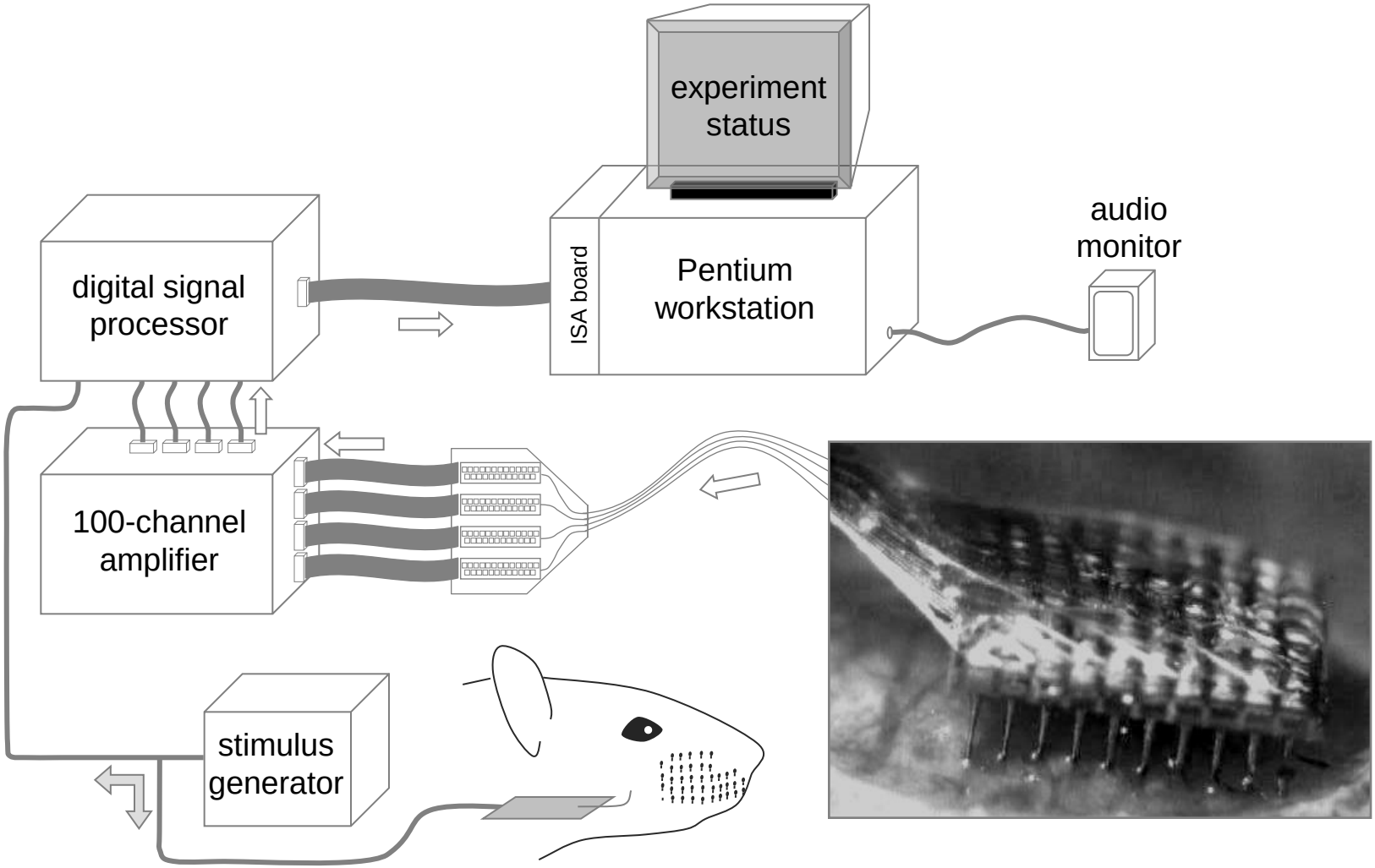
Strategies, approaches



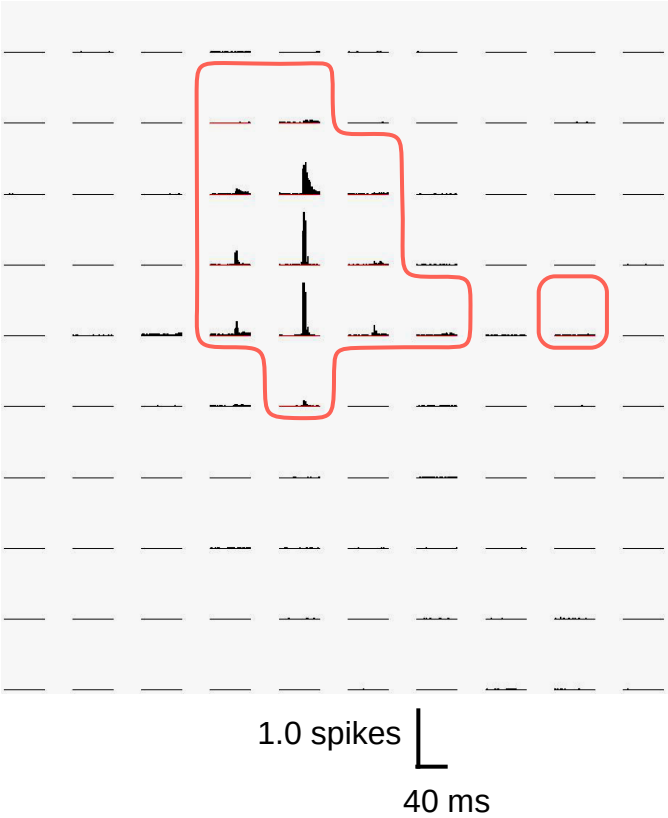
10x10 electrode matrix



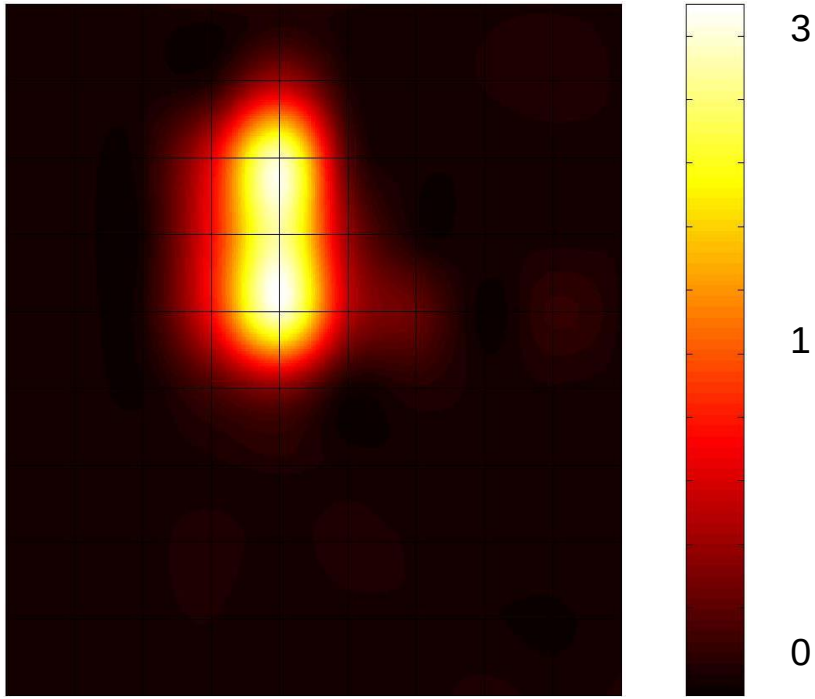



experiment status
digital signal processor
ISA board
Pentium workstation
audio monitor
100-channel amplifier
stimulus generator

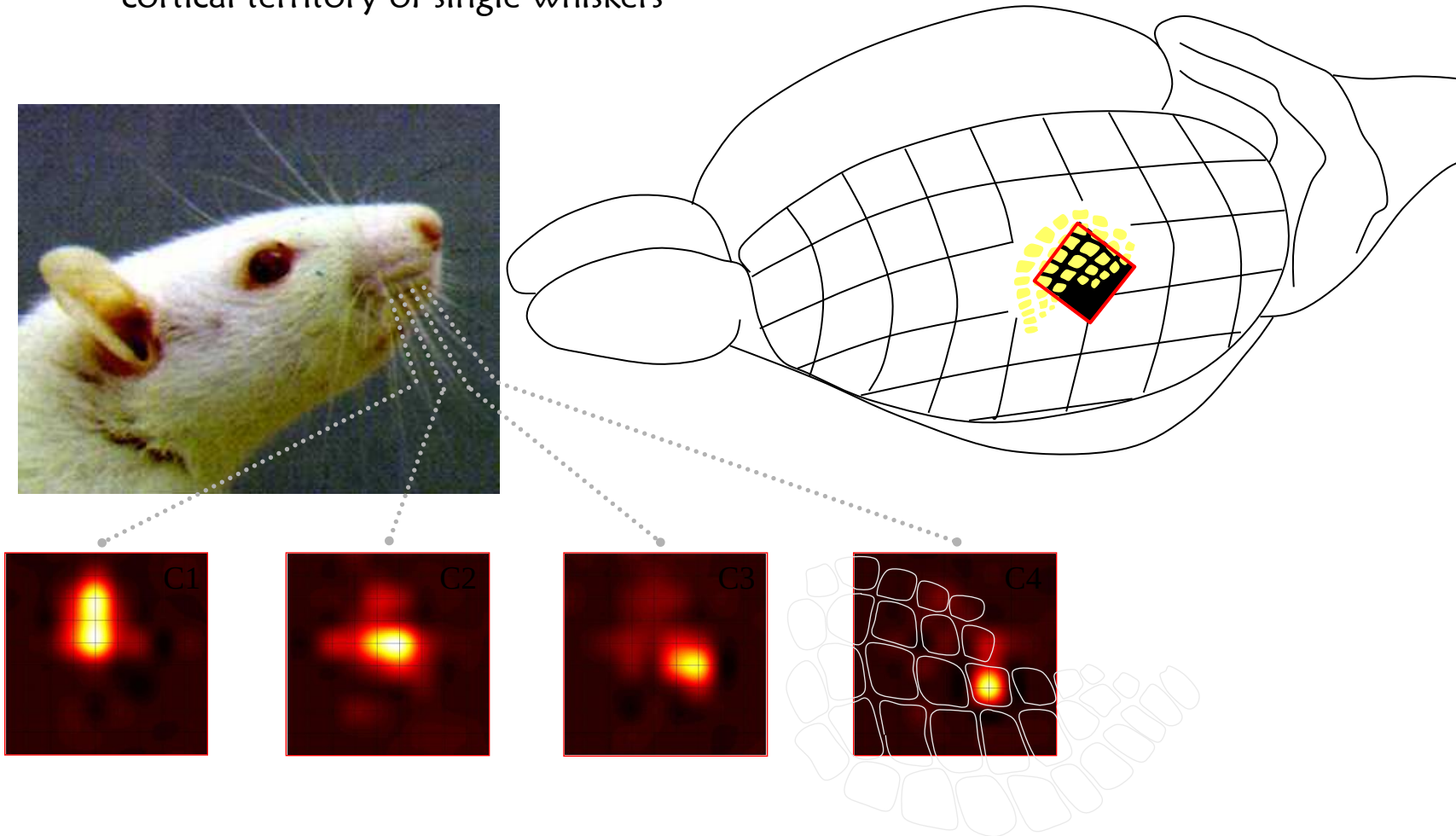
stimulus site C1
multi-unit PSTHs
0-40ms, 5ms bins

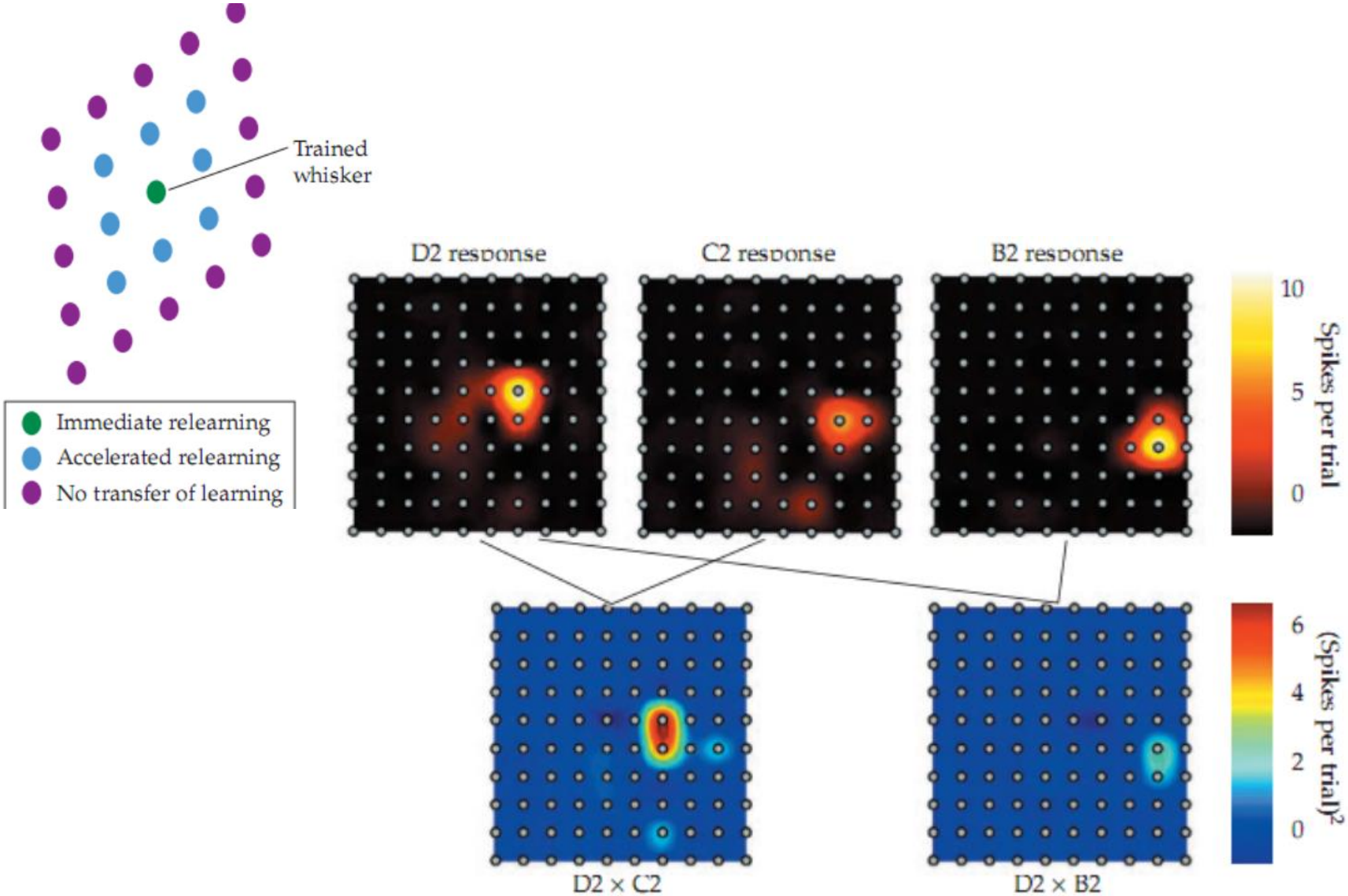


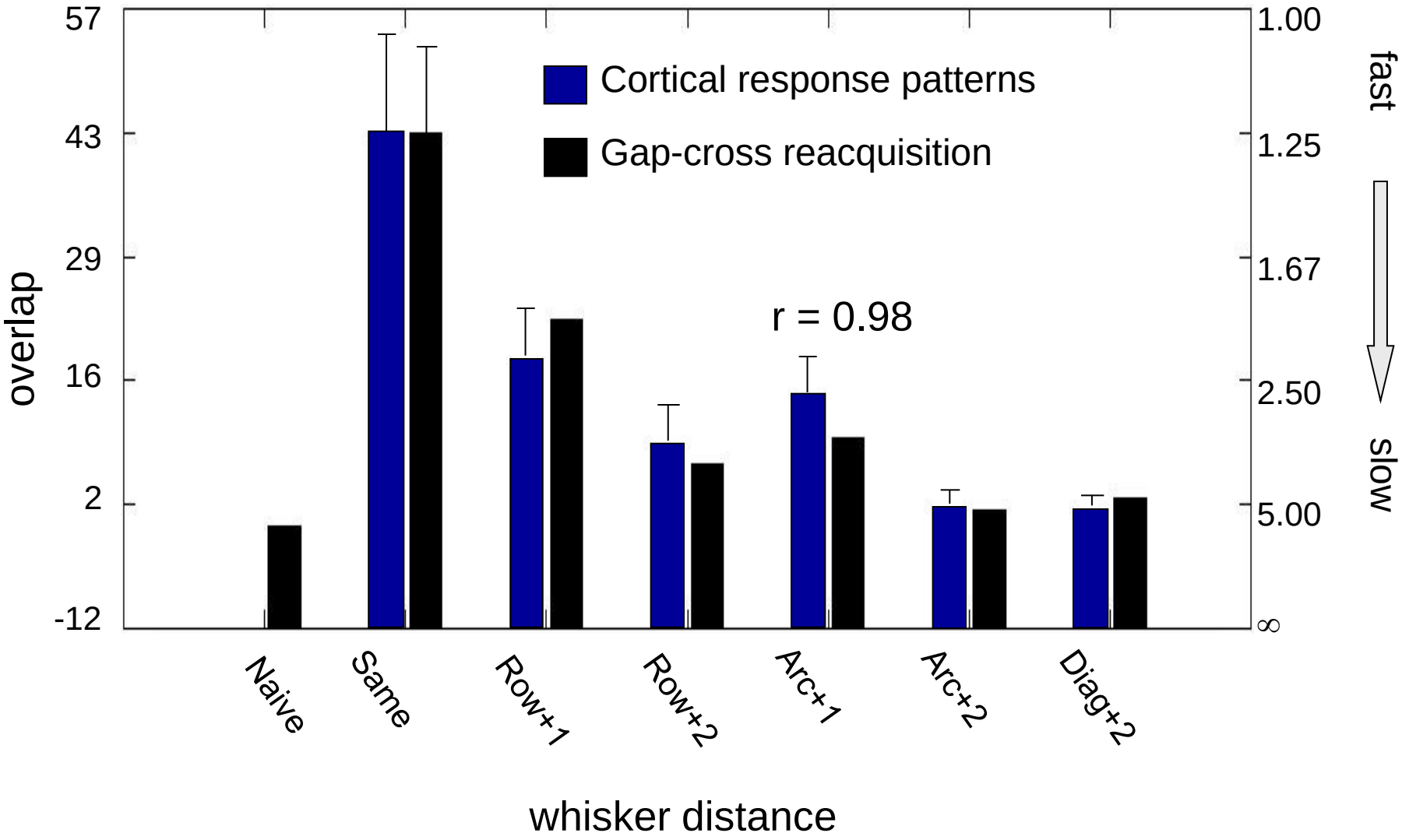
firing rate on each channel
(spikes per trial)
with interpolation



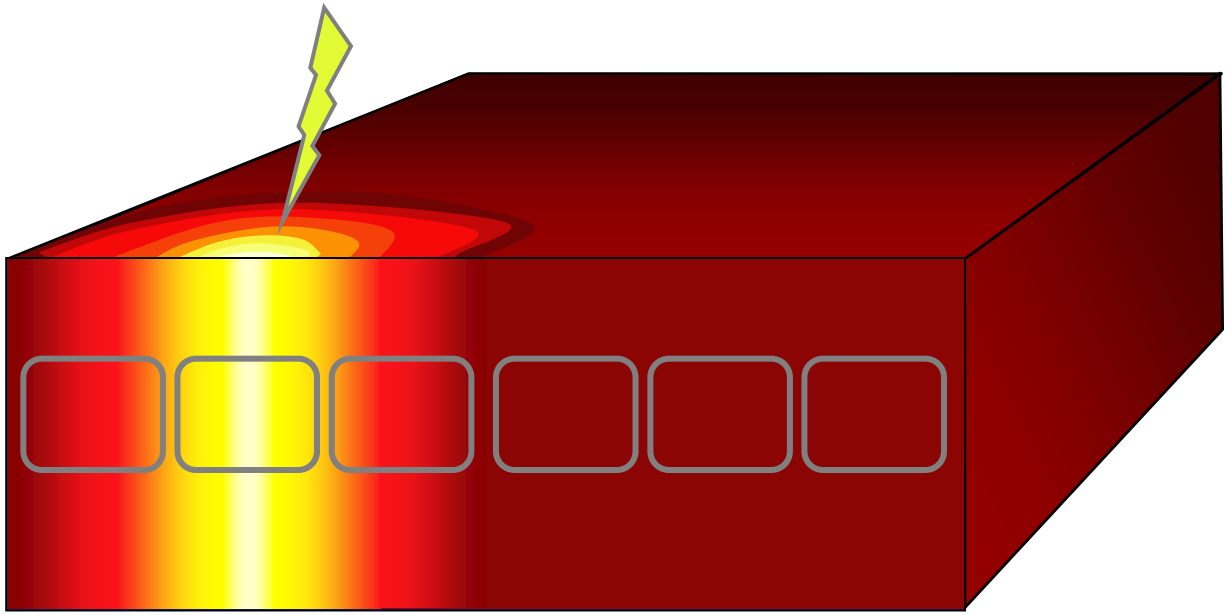
cortical territory of single whiskers

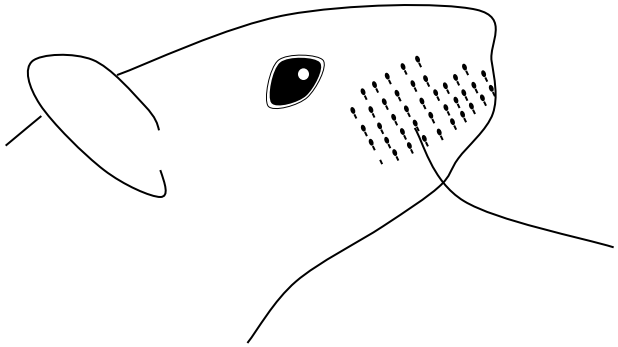



Trained whisker
Immediate relearning
Accelerated relearning
No transfer of learning
D2 response
C2 response
B2 response
10
5
0
Spikes per trial
6
4
2
0
(Spikes per trial)^2
D2 × C2
D2 × B2

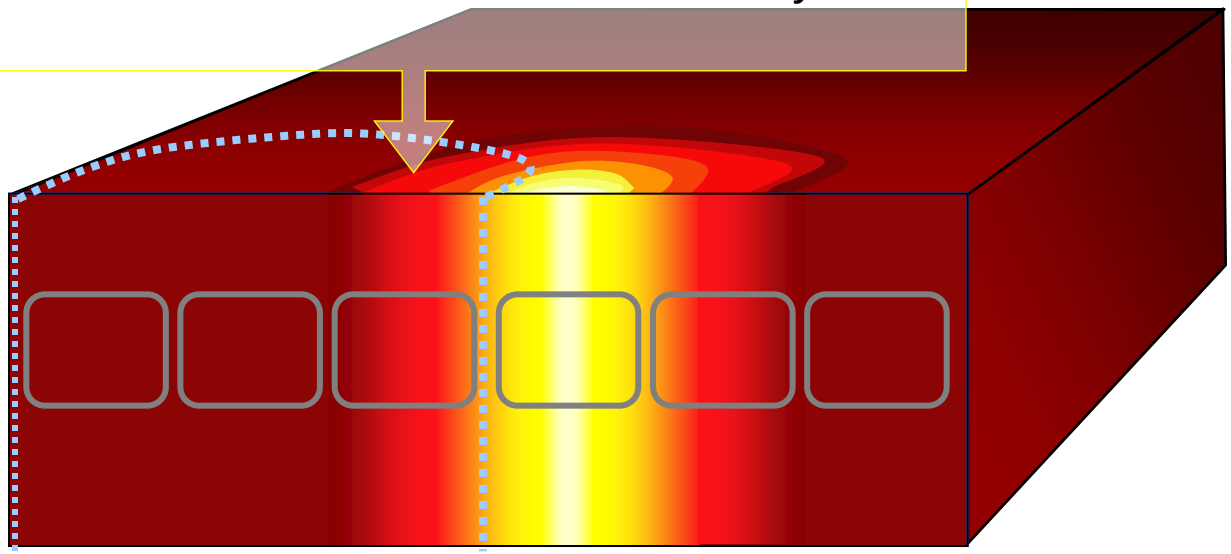

57
43
29
16
2
-12
overlap
1.00
1.25
1.67
2.50
5.00
∞
fast
slow
Cortical response patterns
Gap-cross reacquisition
r = 0.98
Naive
Same
Row+1
Row+2
Arc+1
Arc+2
Diag+2
whisker distance

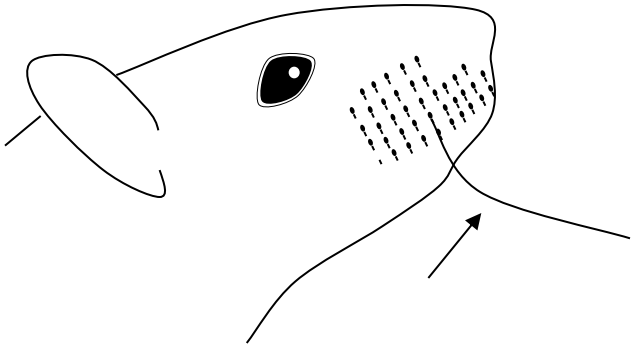
territory in which learned sensory information is stored . . .





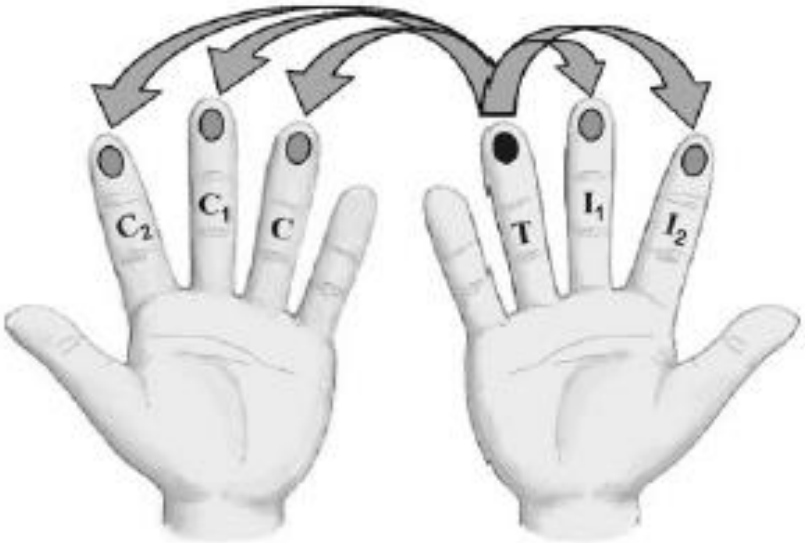
new whisker: common cortical territory



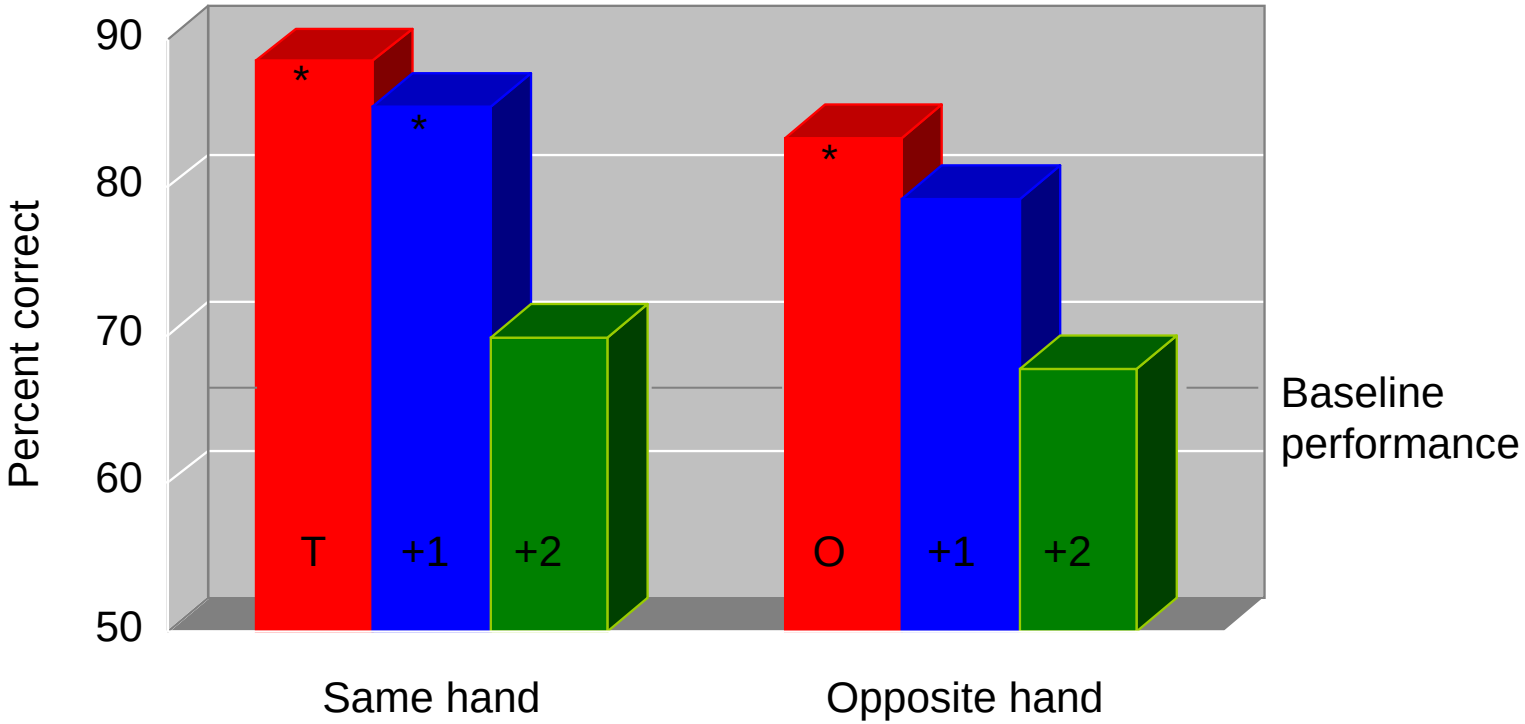


Subjects learned to use one fingertip to discriminate between two grades of sandpaper

400mm


C2
C1
C
T
I1
I2

Transfer from “trained” finger to others



So the representation of a signal – either from a whisker or from a fingertip – passes through a bottleneck in the SI map, and some critical form of learning takes place in this restricted territory.

the law of functional localization

cerebral cortex is composed of many anatomically identifiable regions, each of which carries out some special, unique function.

cognitive processes arise from the coordination between functionally specialized processing areas

Geography is the beginning, not the end

Men in Black

Geography is the beginning, not the end

“Area x is involved with task y” does not fully tell us brain function.

What is the message carried by the neurons of area x during task y?

How does that signal, and the transformation carried out by those neurons, contribute to behavior?

Great challenges in Sensory Neuroscience

- *How do sensory receptors <u>really</u> work?*
- *Coding of real, <u>natural</u> stimuli in spike trains*
- *Transformation from coding of physical signals to representation of meaningful objects.*
- *Sensory-motor integration and decision making*
- *Learning, memory, recall*