1 Brain and Information

Corpo docente

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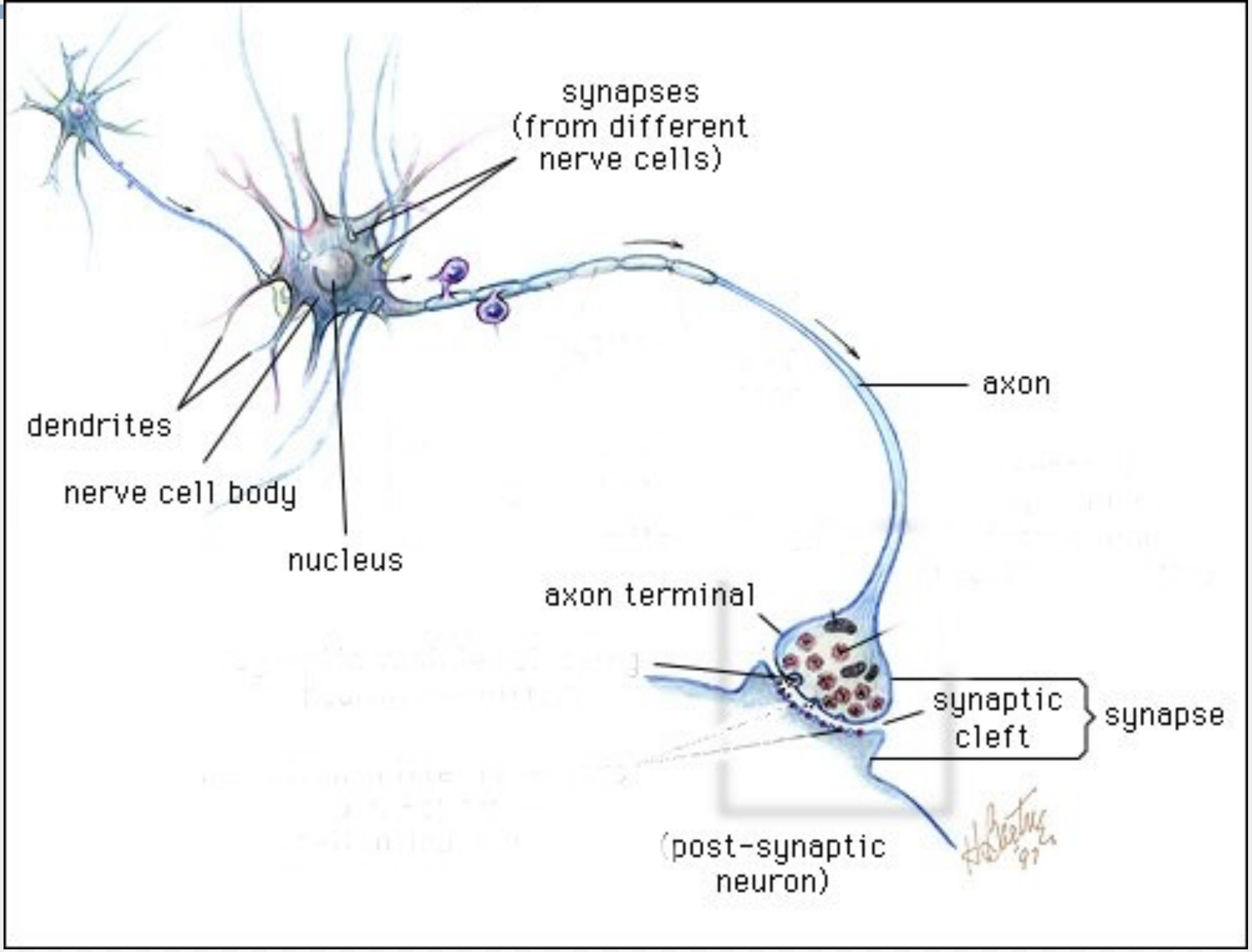
Avaliação

- Presentation (40%)
- +
- Report (60%)

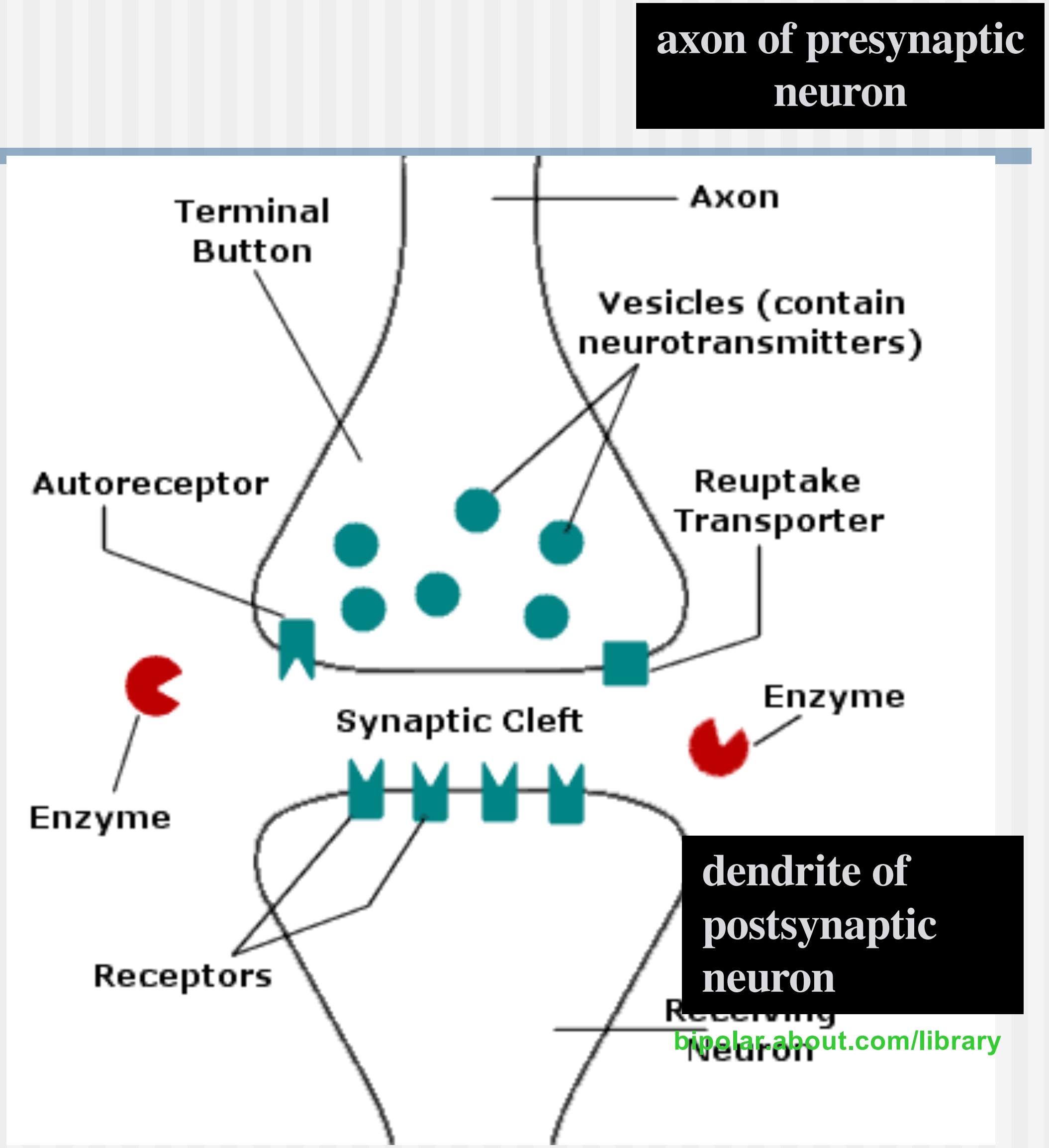
Plan

- Brain
- Convolutional Neural Networks
- Human Acoustic Processing
- Fourier Analysis
- Fourier and Wavelets
- Entropy and Information
- Associative Memory
- Stochastic Methods, Hopfield Model, Boltzmann Machine
- Knowledge in Learning
- Models of Cognition and Learning (SOAR)

Neuron Forming a Chemical Synapse



Synapse


axon of presynaptic neuron
Terminal Button
Axon
Vesicles (contain neurotransmitters)
Autoreceptor
Reuptake Transporter
Enzyme
Synaptic Cleft
Enzyme
Receptors
dendrite of postsynaptic neuron
bipolar.about.com/library

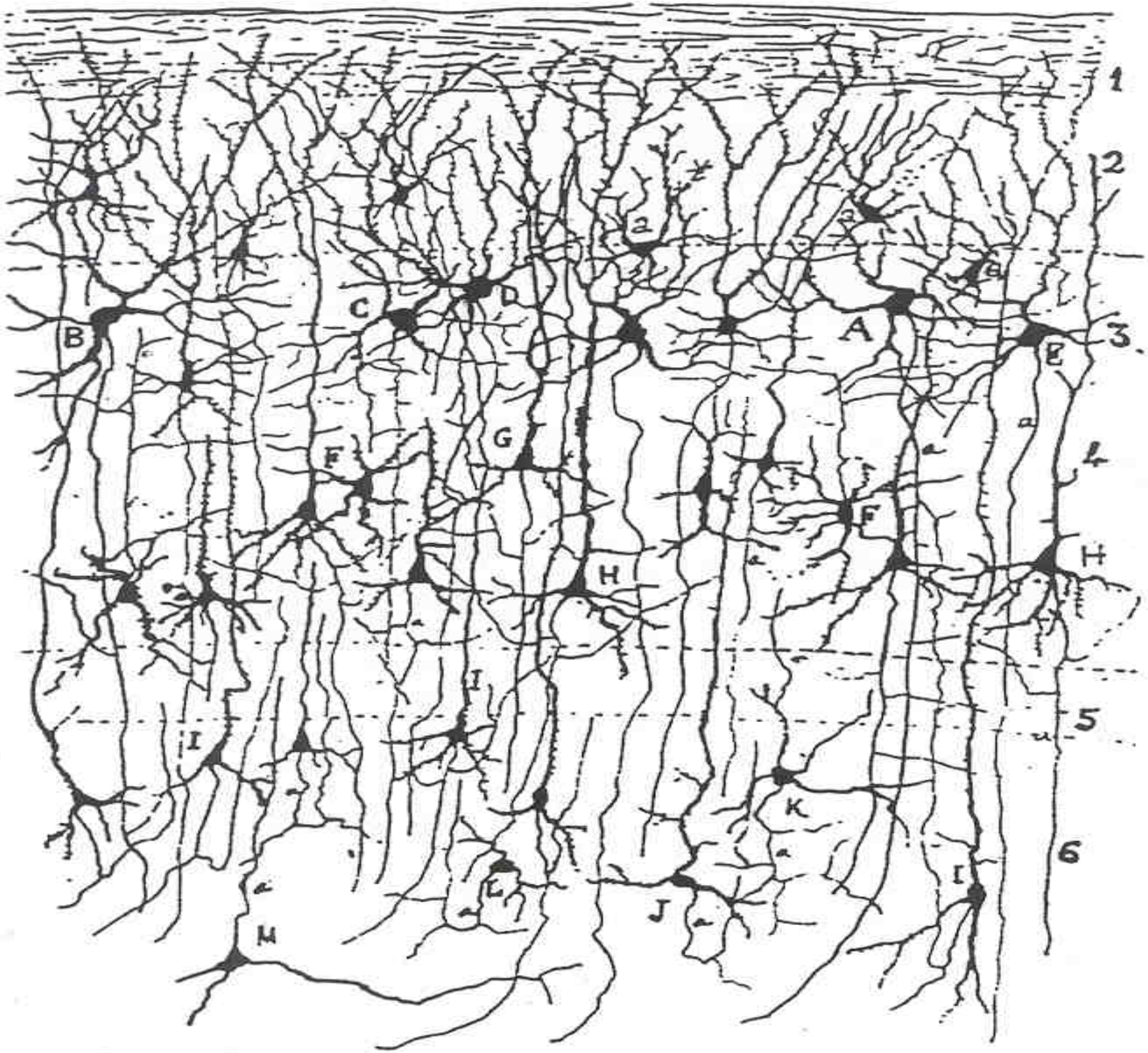
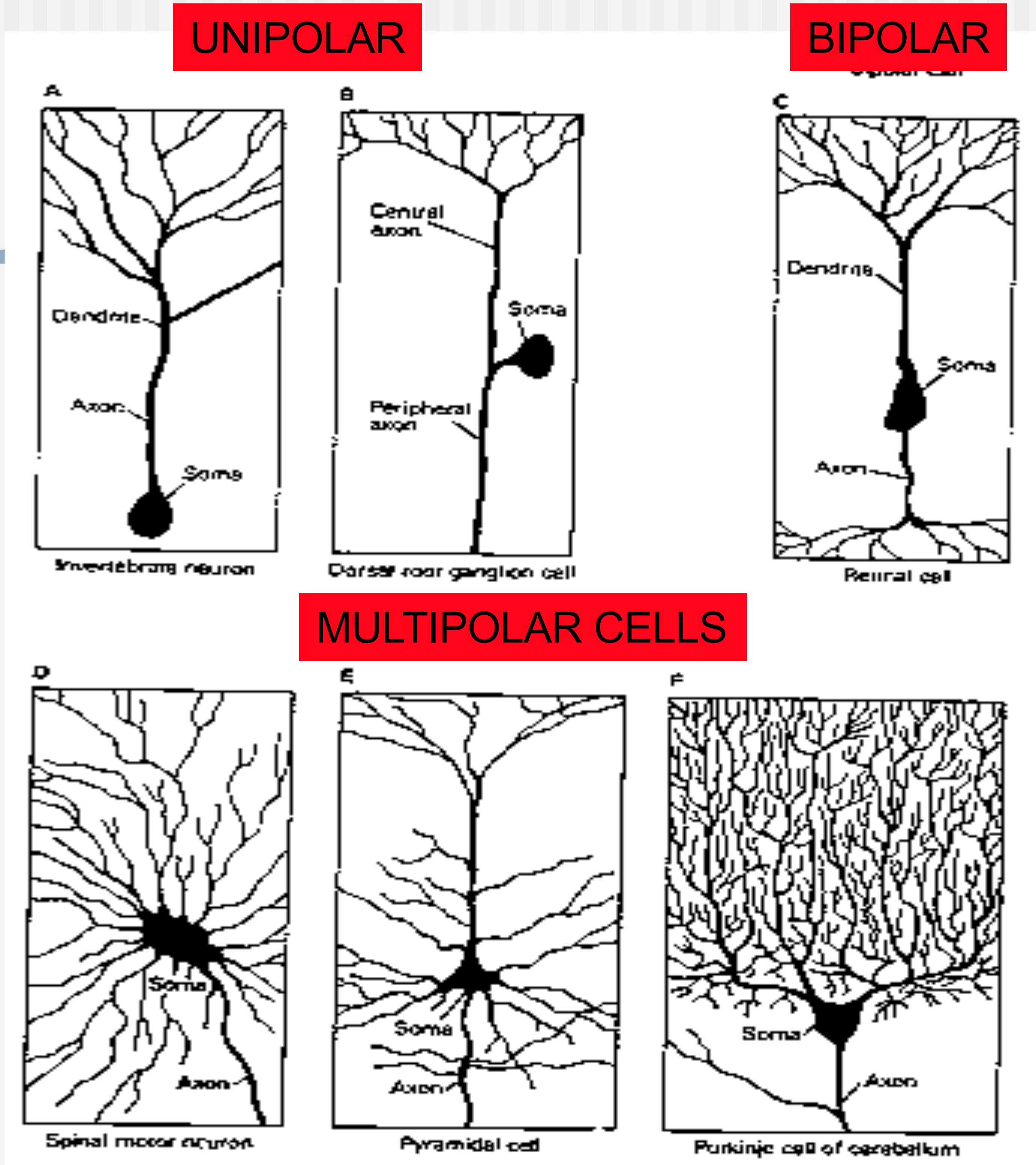
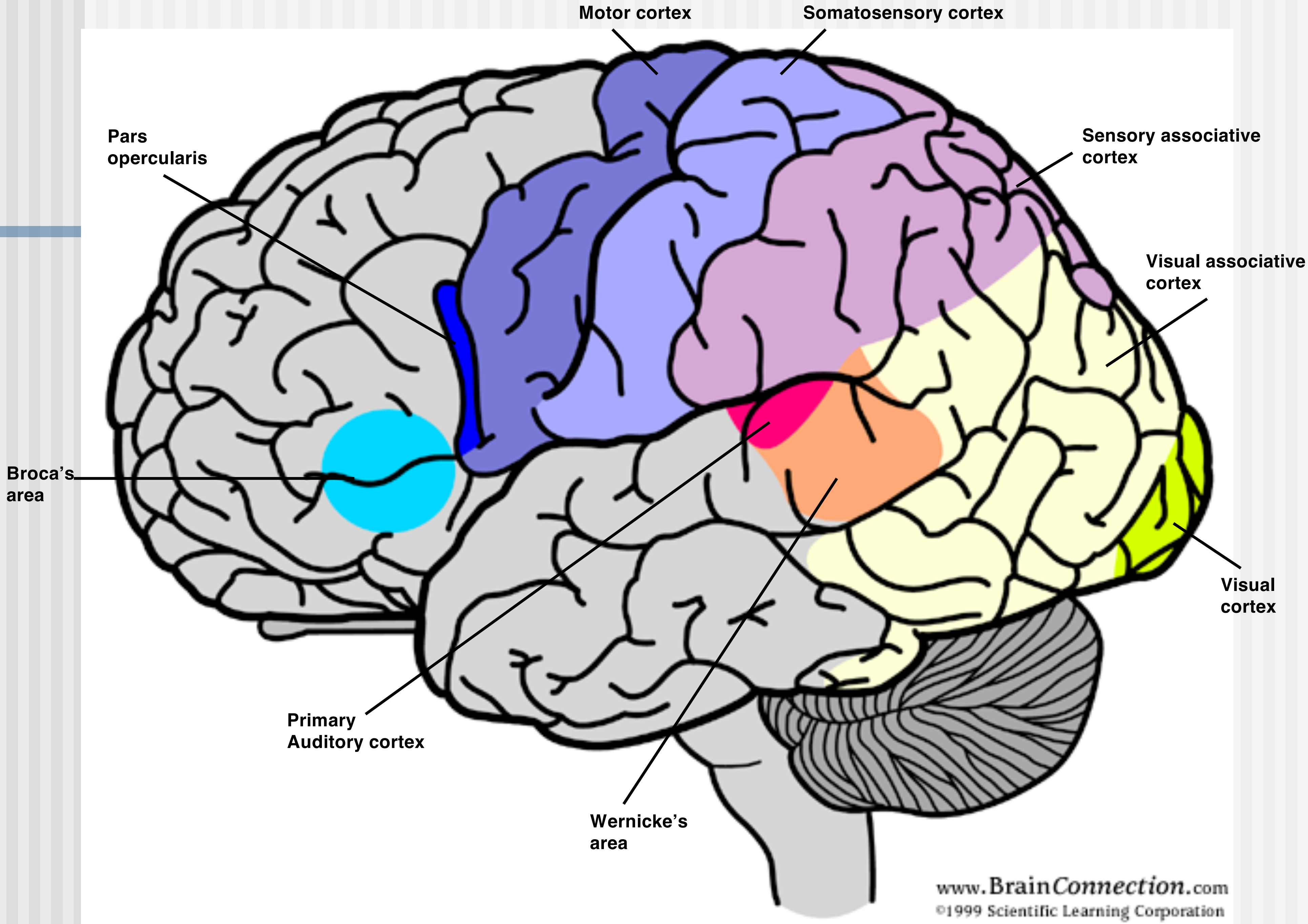
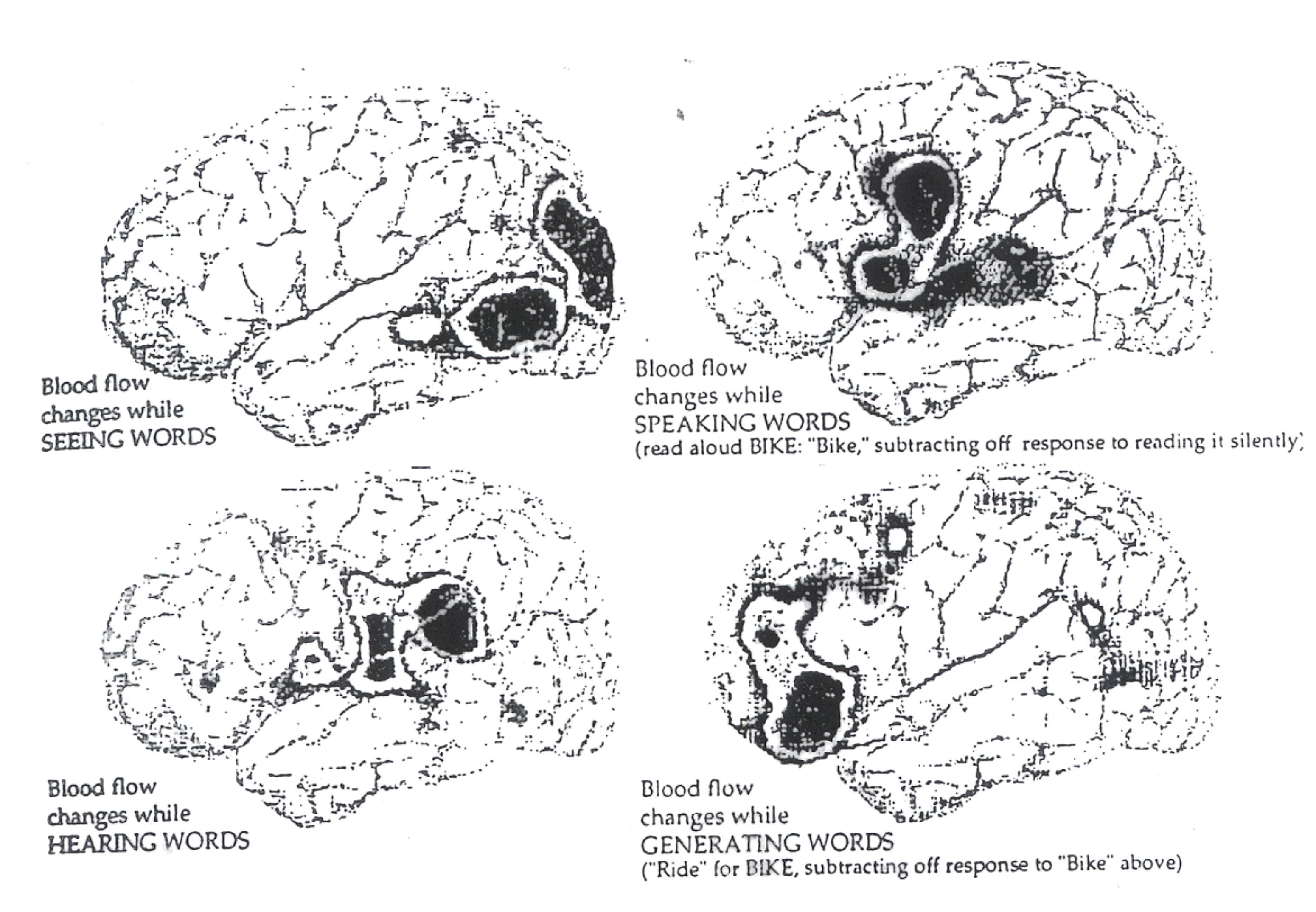


Figure 1: Drawing of the visual cortex of the rat (S. Ramón y Cajal, 1888).

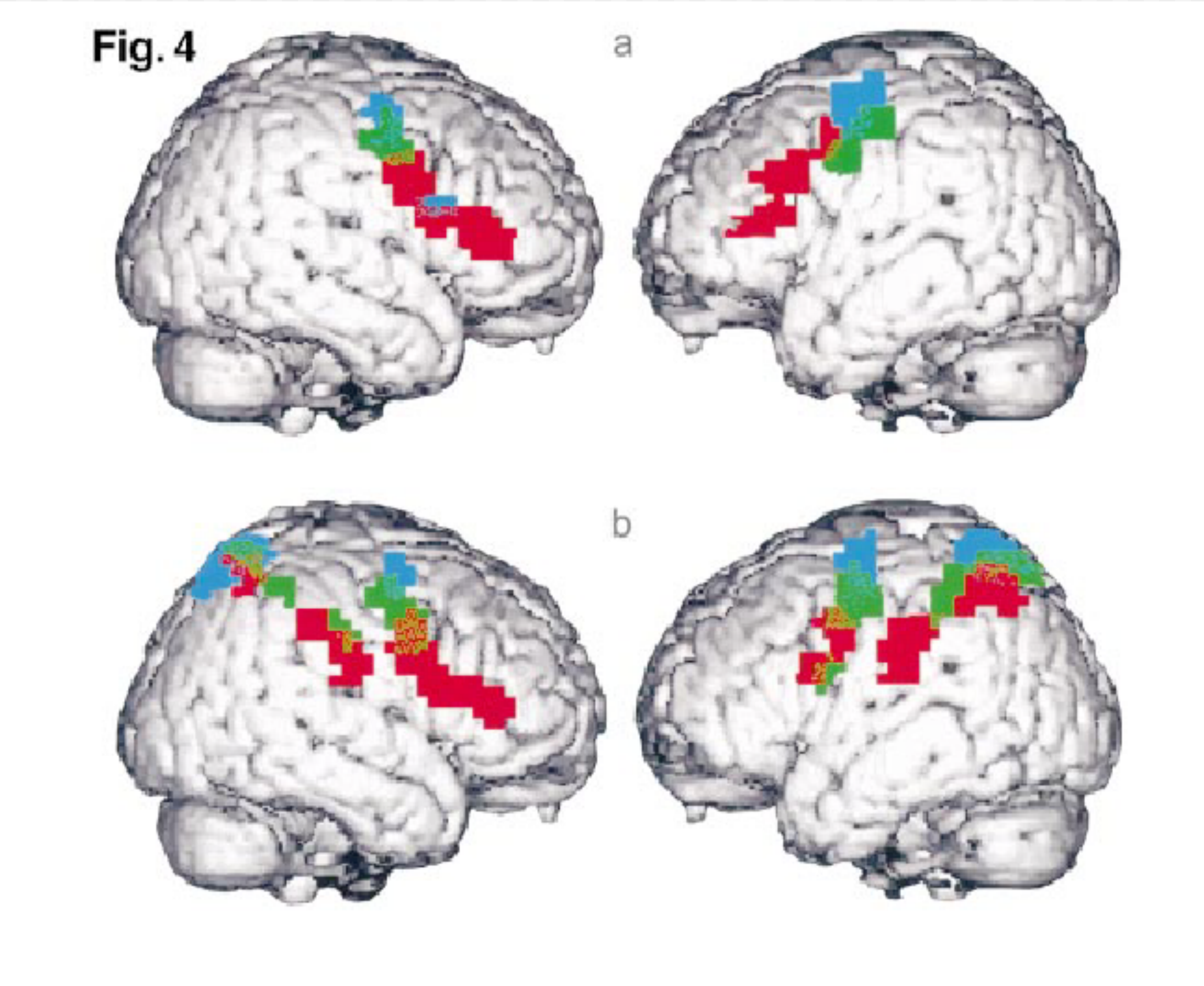

UNIPOLAR
BIPOLAR
A
Dendrite
Axon
Soma
Invertebrate neuron
B
Central axon
Soma
Peripheral axon
Dorsal root ganglion cell
C
Dendrite
Soma
Axon
Retinal cell
MULTIPOLAR CELLS
D
Soma
Axon
Spinal motor neuron
E
Soma
Axon
Pyramidal cell
F
Soma
Axon
Purkinje cell of cerebellum


Motor cortex
Somatosensory cortex
Pars opercularis
Sensory associative cortex
Visual associative cortex
Broca's area
Visual cortex
Primary Auditory cortex
Wernicke's area
www.BrainConnection.com
©1999 Scientific Learning Corporation



PET scan of blood flow for 4 word tasks

Somatotopy of Action Observation

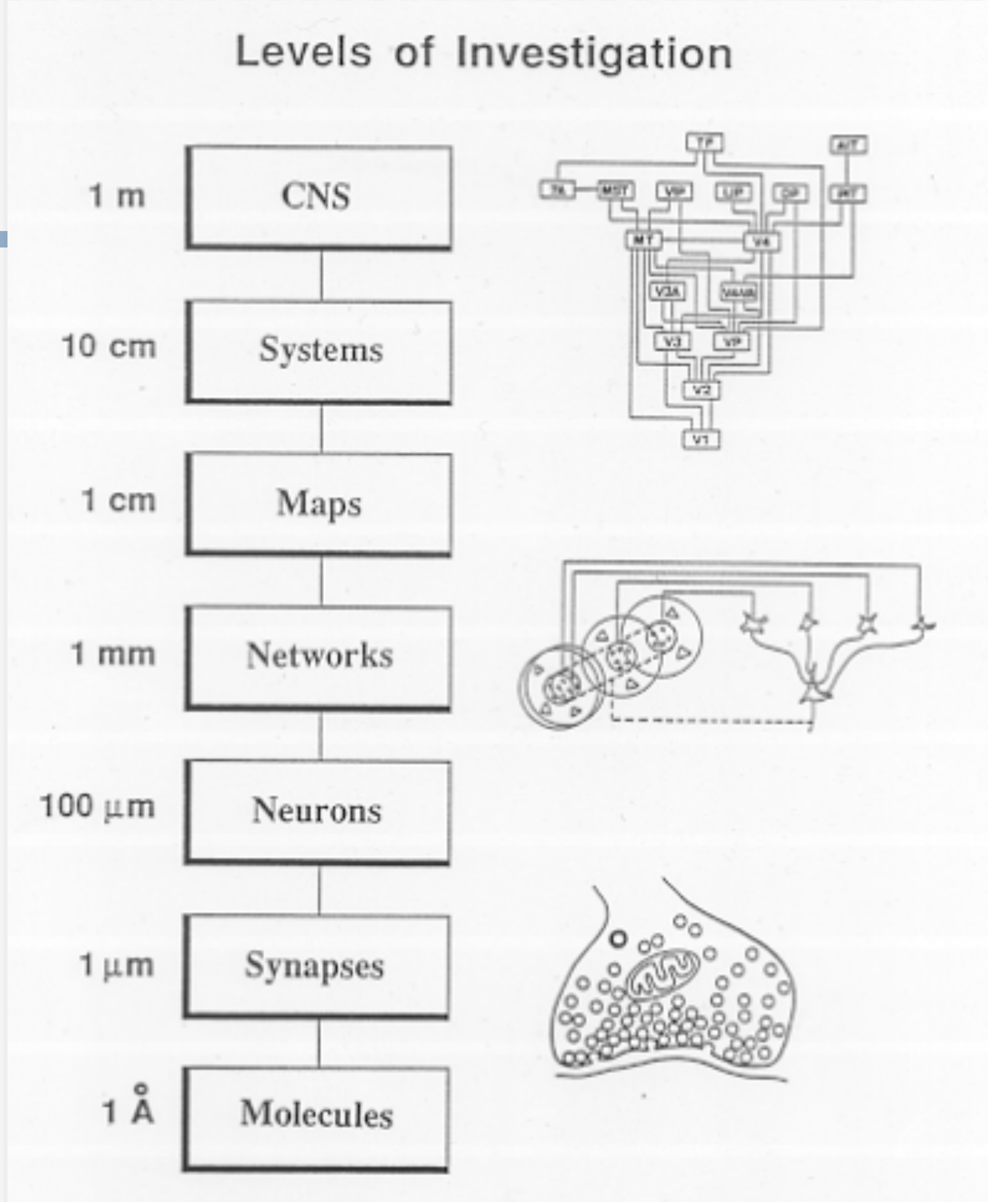


Foot Action

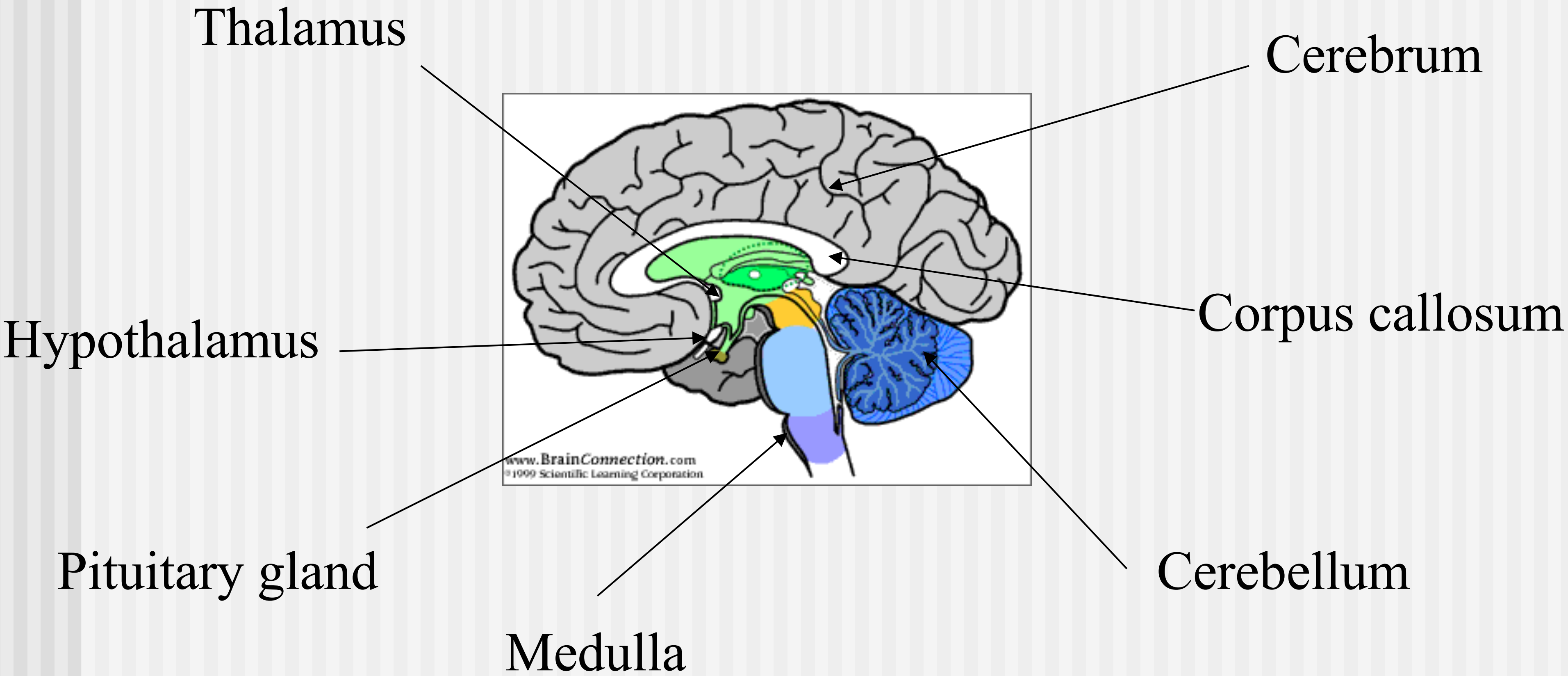
Hand Action

Mouth Action

Buccino et al. Eur J Neurosci 2001


Levels of Investigation
1 m
CNS
10 cm
Systems
1 cm
Maps
1 mm
Networks
100 µm
Neurons
1 µm
Synapses
1 Å
Molecules

The Brain - Functions



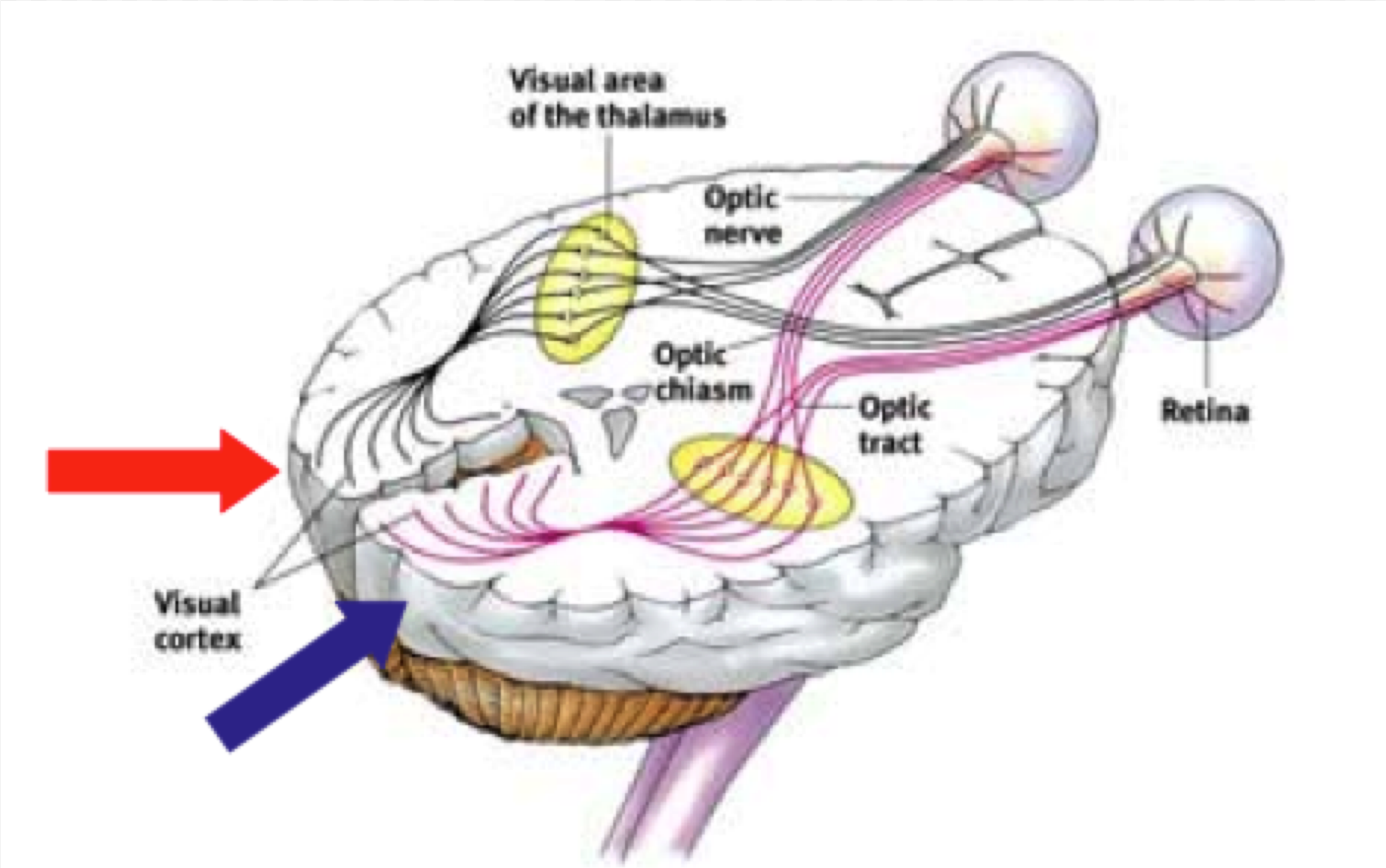
The Different Regions of the Brain

- The medulla controls heart rate, breathing, peristalsis, and reflexes such as sneezing.
- The hypothalamus controls temperature and water homeostasis. Also controlling the release of hormones by the pituitary gland.
- The thalamus is a relay station, integrating sensory input and channelling it to the sensory areas of the cerebrum.
- The cerebellum co-ordinates muscle movement and so controls balance, posture and movement.

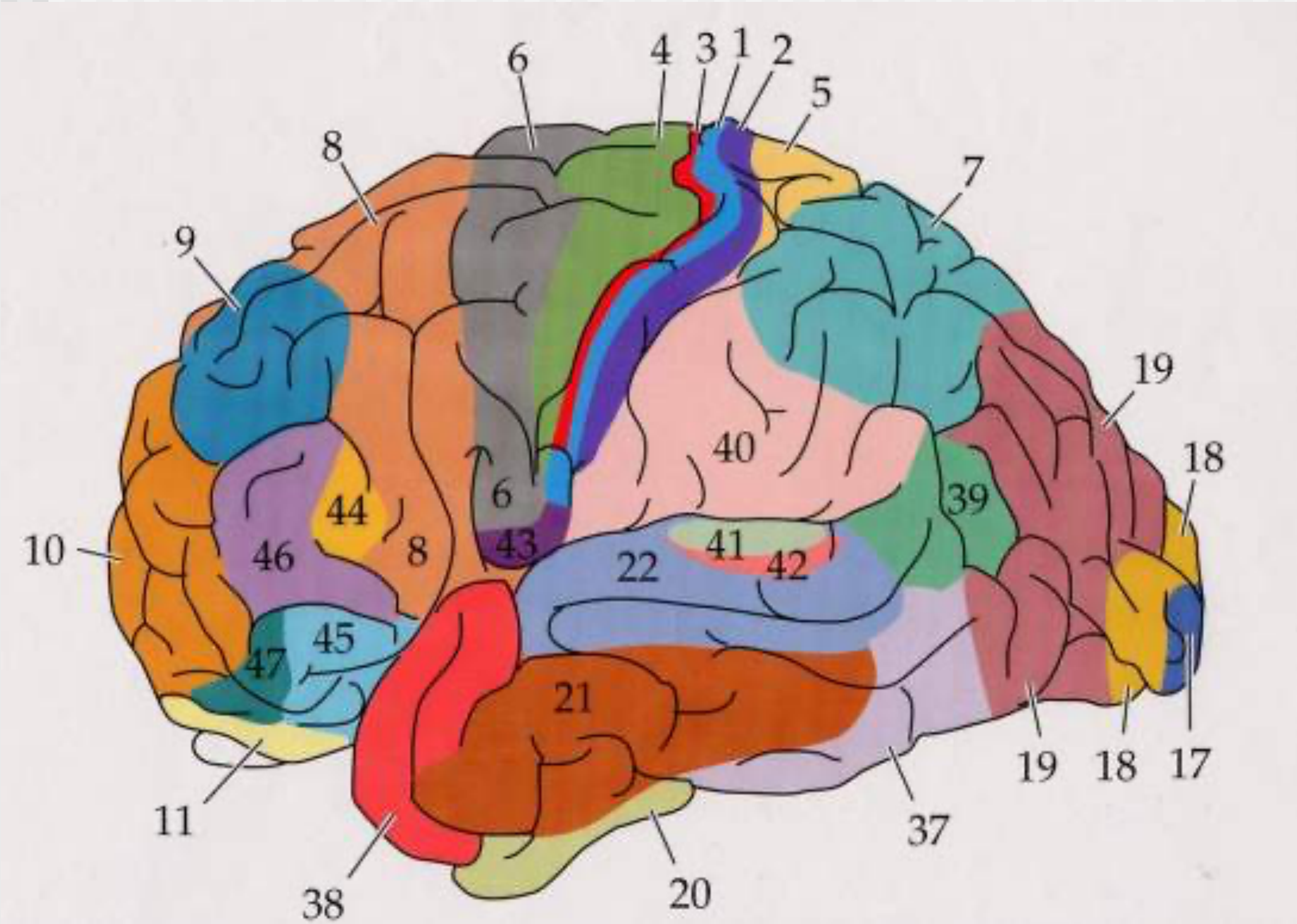
Cortex

- Sensory Areas- these receive impulses via sensory neurones from receptors that detect the stimuli reaching the body. The skin has more receptors in some parts of the body than others
- Motor areas send impulses to skeletal muscles along nerve fibres passing down the brain stem and spinal cord. As with the sensory areas the part of the body is represented by an area of the motor cortex
- Association areas make decisions and send impulses through the motor areas

Visual cortex



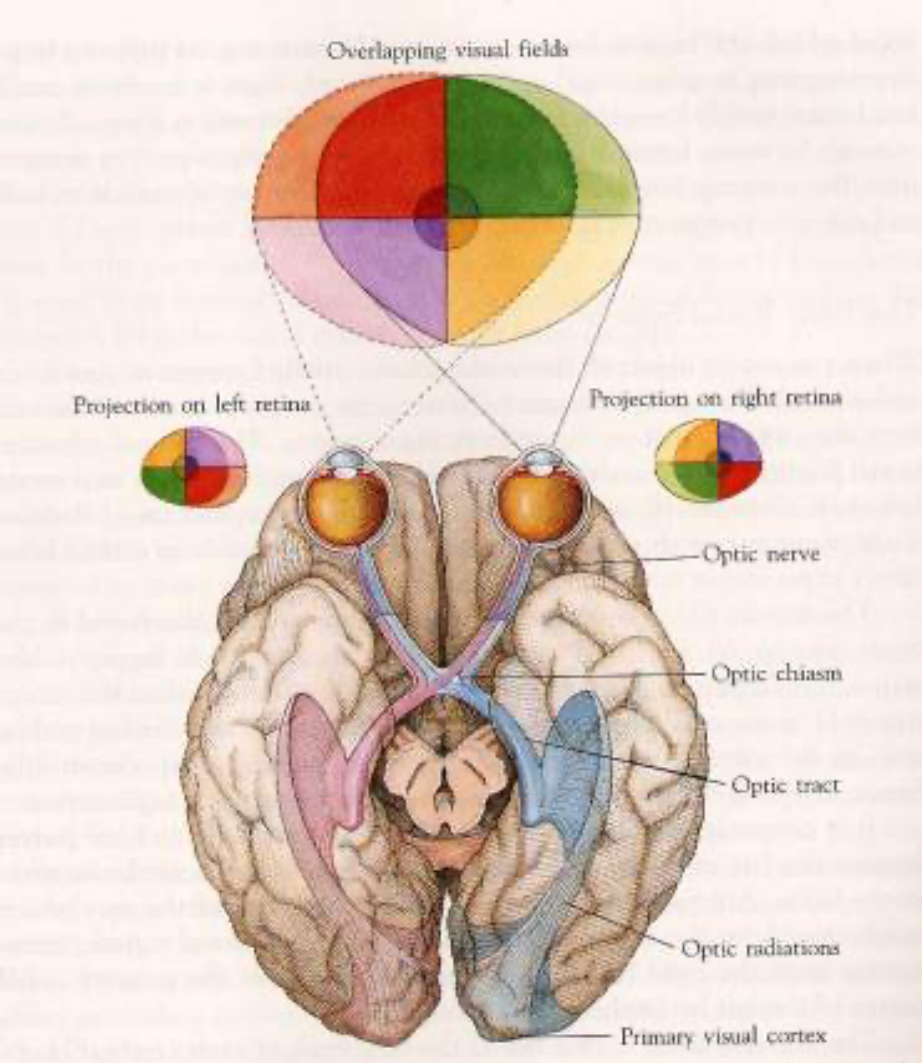
Classic Cytoarchitectonic Map of Brodmann (1909)

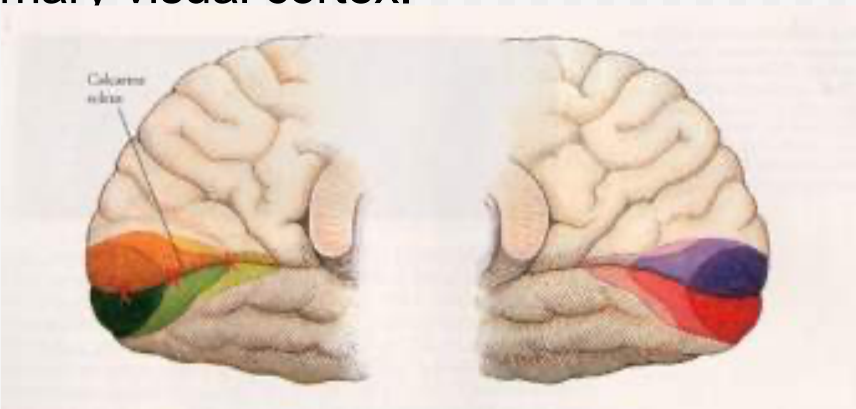


Classic name for visual cortex: Areas 17, 18, 19

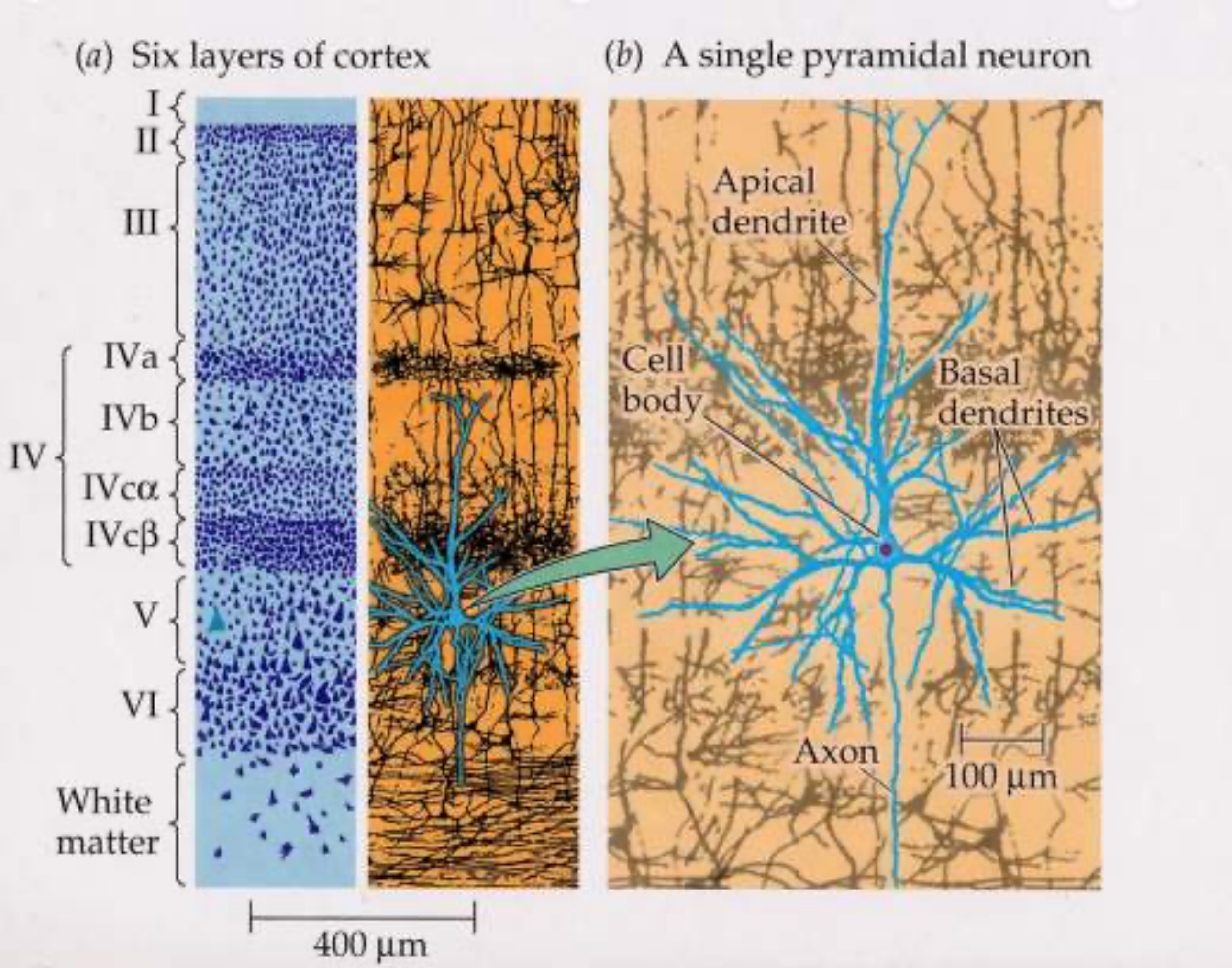
Visual Field and the Human Visual System

The visual field represented in its projection to the retina demonstrates how the lens of the eye inverts the image being viewed. Up is ***inverted down and right is represented on the left***. Signals from the **right retinas** (left visual field) of both eyes travel through the optic nerve, optic tract, and optic radiations to the primary visual cortex in the **right hemisphere**. Signals from the *left retinas* (right visual field) travel to the *left hemisphere*. Primary visual cortex lies in the colored area along the calcarine sulcus. Colors show how the different sectors of the visual fields map on to primary visual cortex.

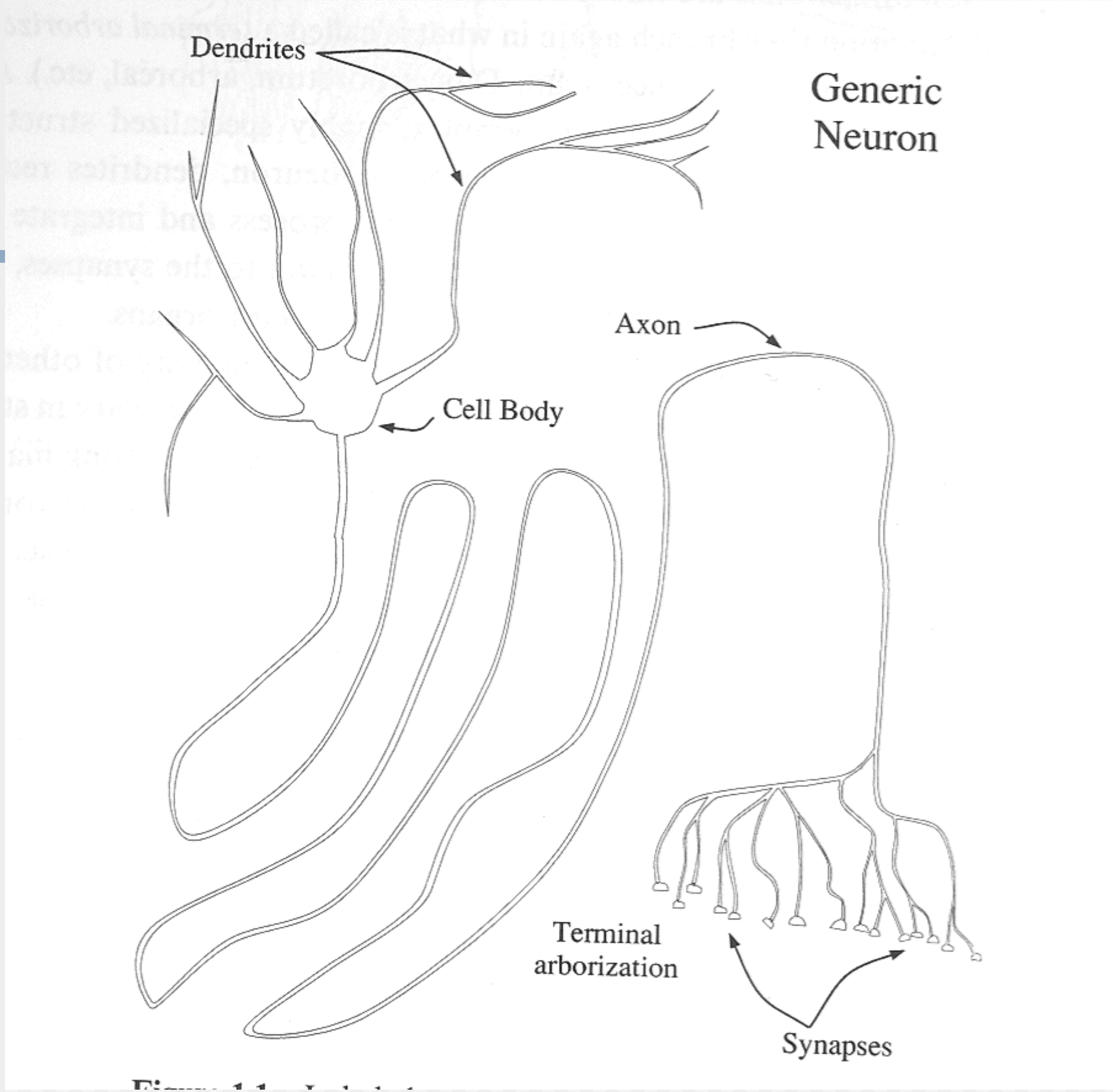




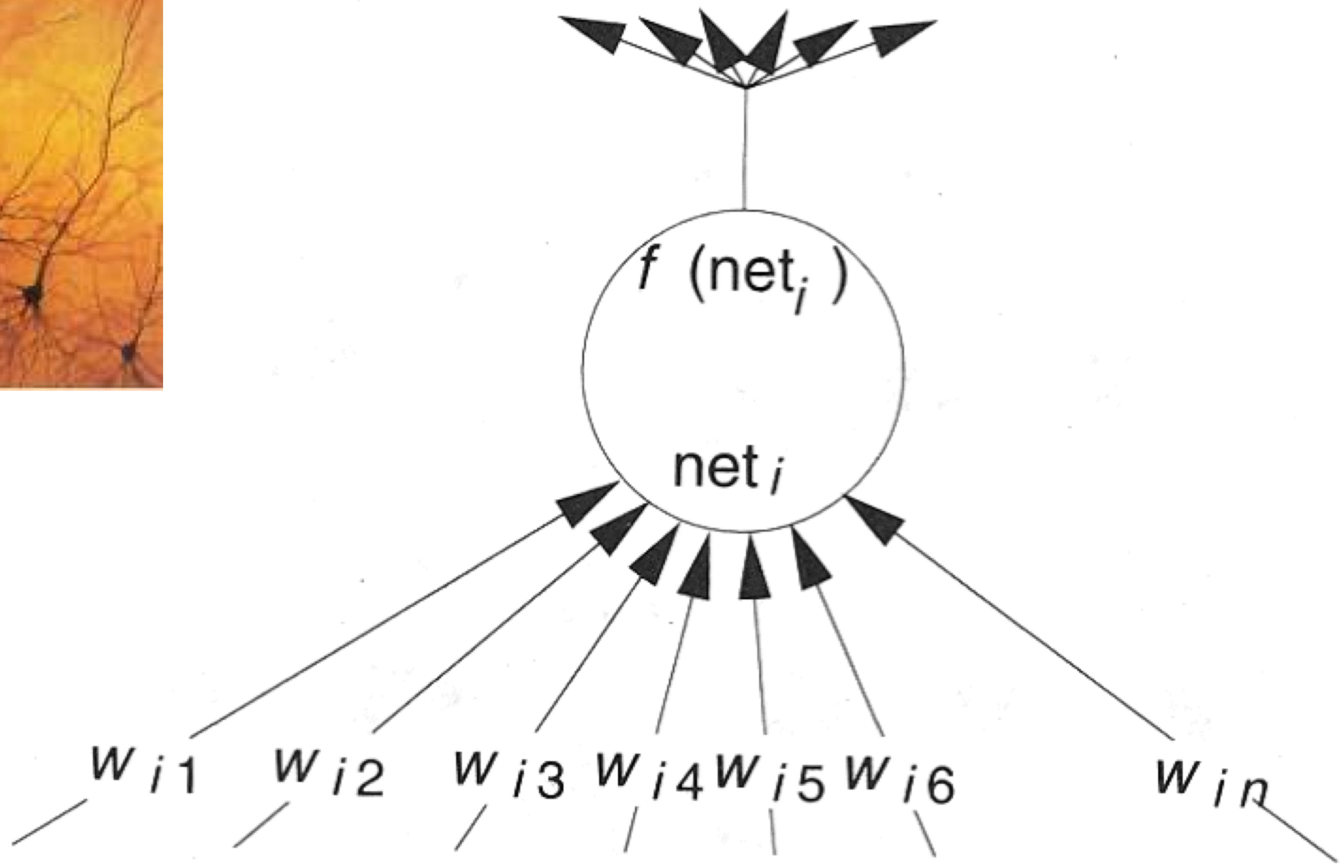
Cortex



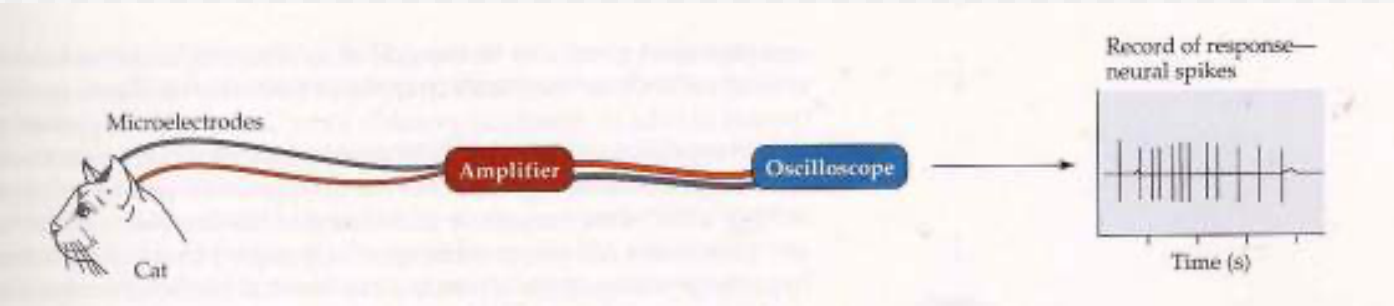
(a) Six layers of cortex
(b) A single pyramidal neuron
I
II
III
IVa
IVb
IV
IVcα
IVcβ
V
VI
White matter
400 µm
Apical dendrite
Cell body
Basal dendrites
Axon
100 µm

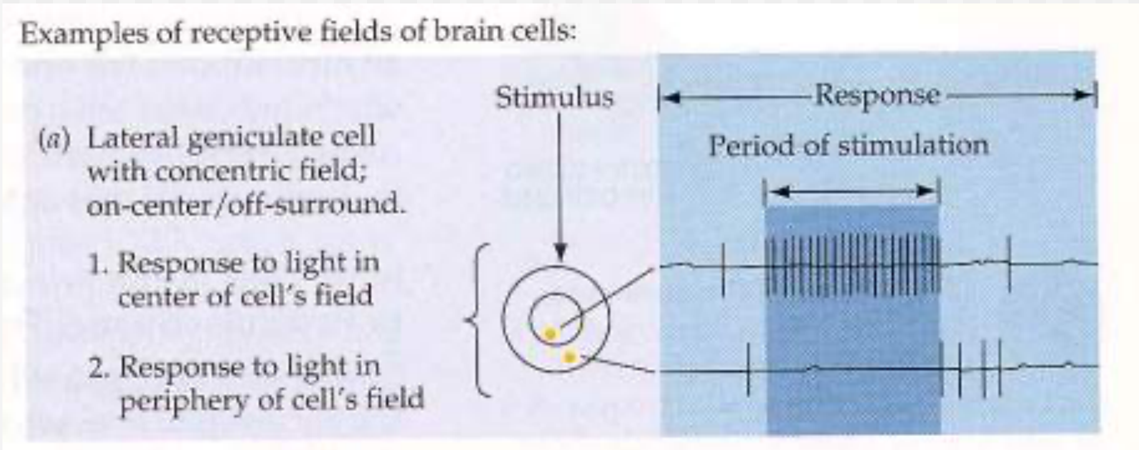

Generic
Neuron
Dendrites
Axon
Cell Body
Terminal
arborization
Synapses

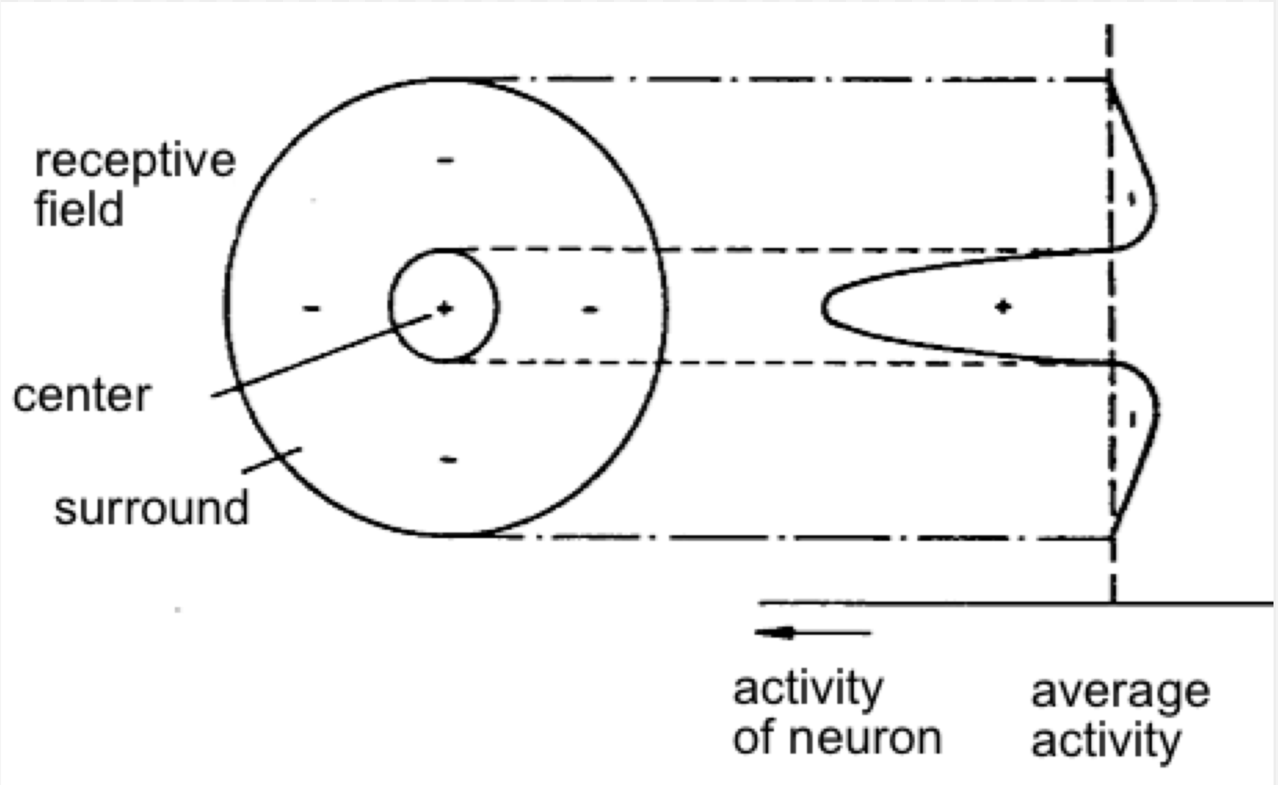
Graphical representation



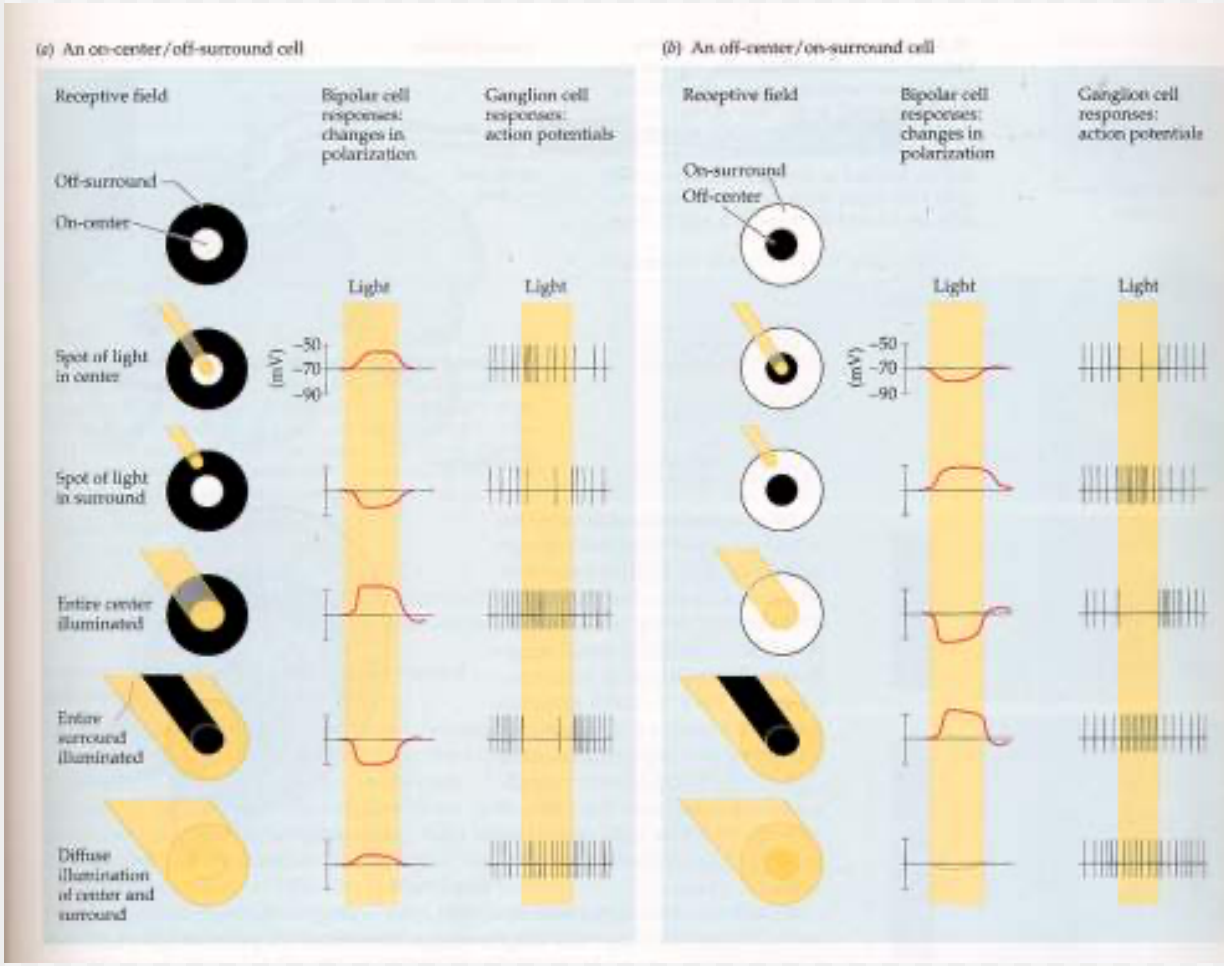
Receptive Fields of Lateral Geniculate Nucleus






receptive field
center
surround
activity of neuron
average activity

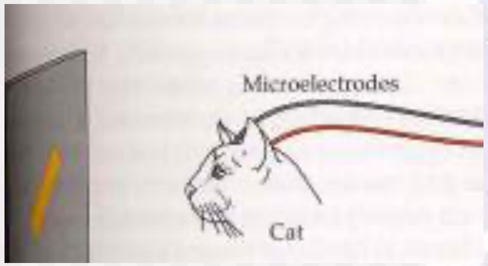
Receptive Fields in Retinal Bipolar and Ganglion Cells

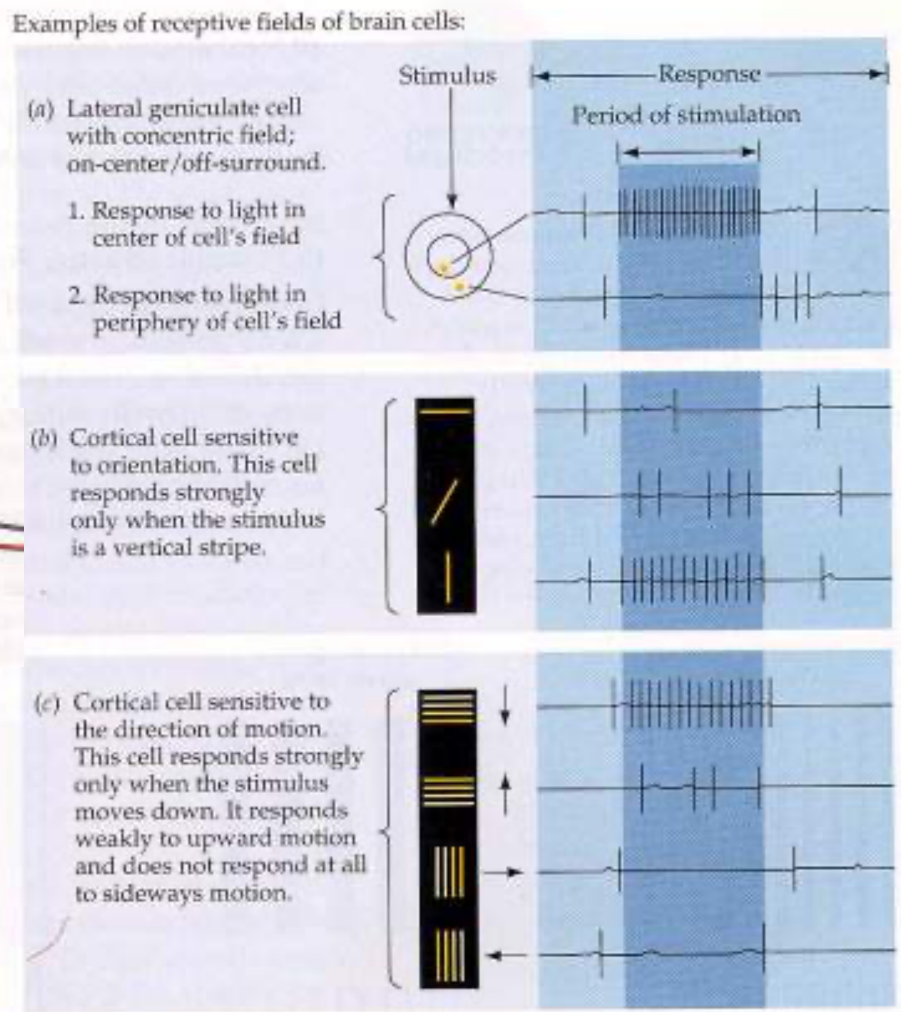


Receptive Fields of Lateral Geniculate and Primary Visual Cortex

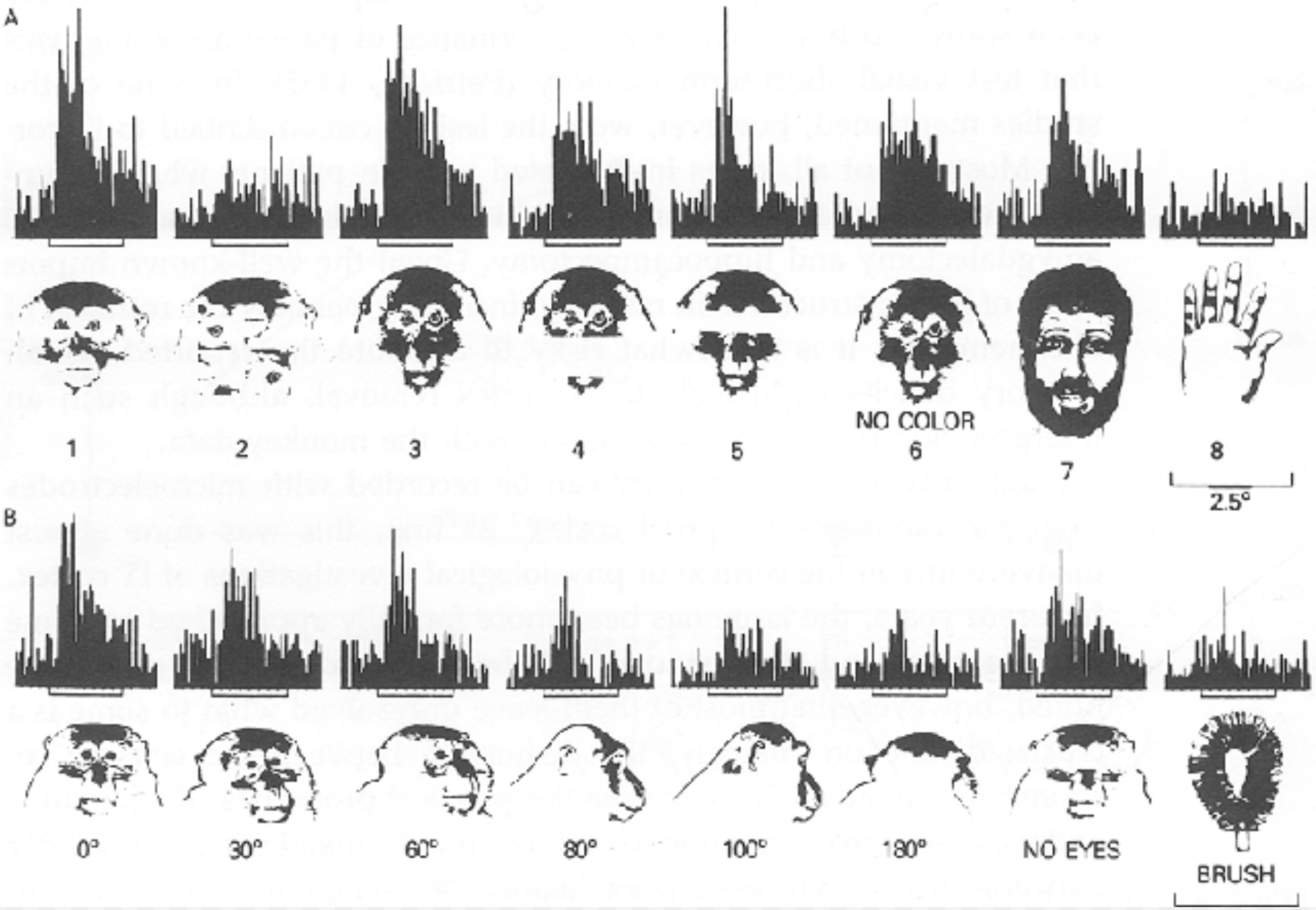
David Hubel

Torsten Wiesel

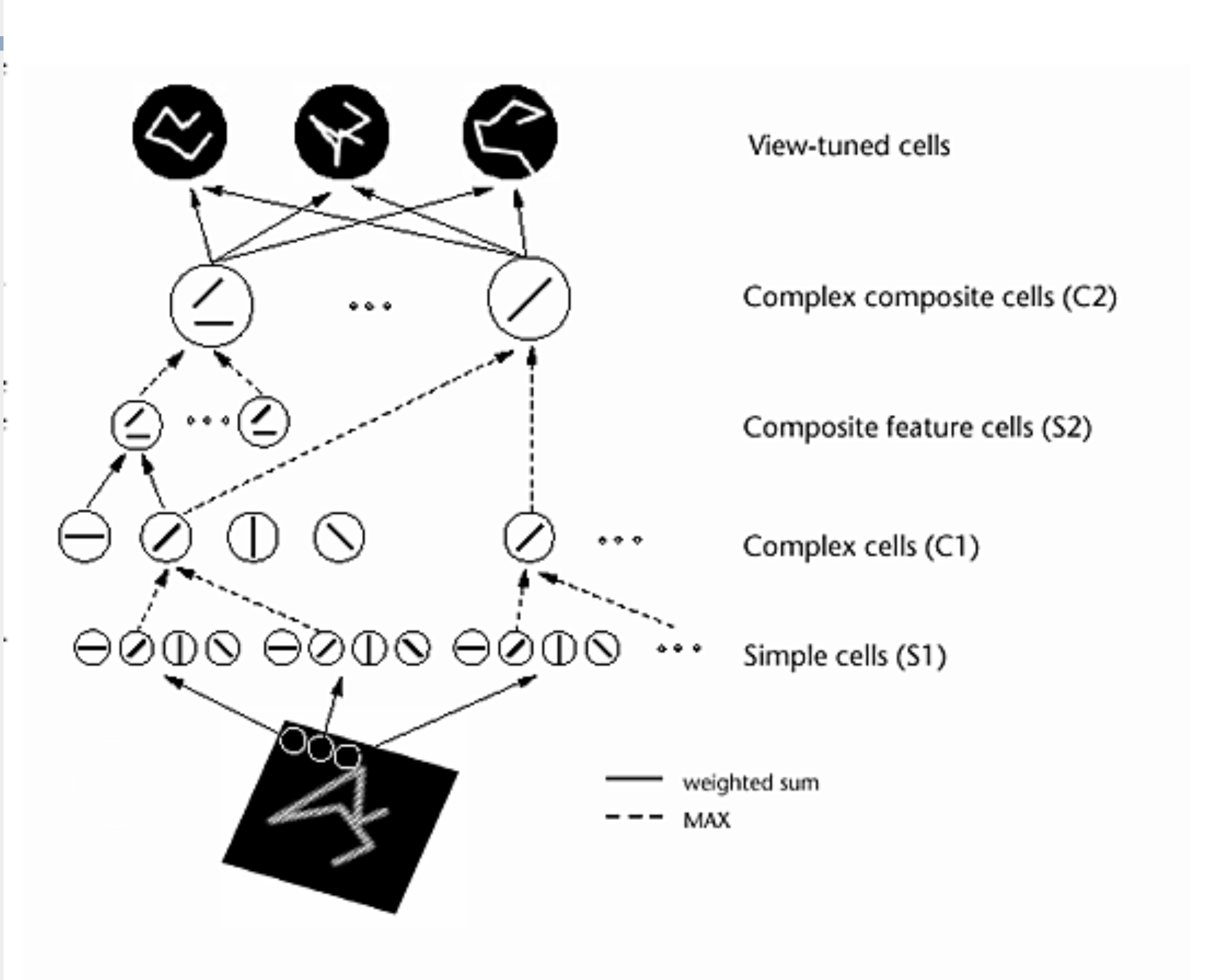




Face Cells in Monkey

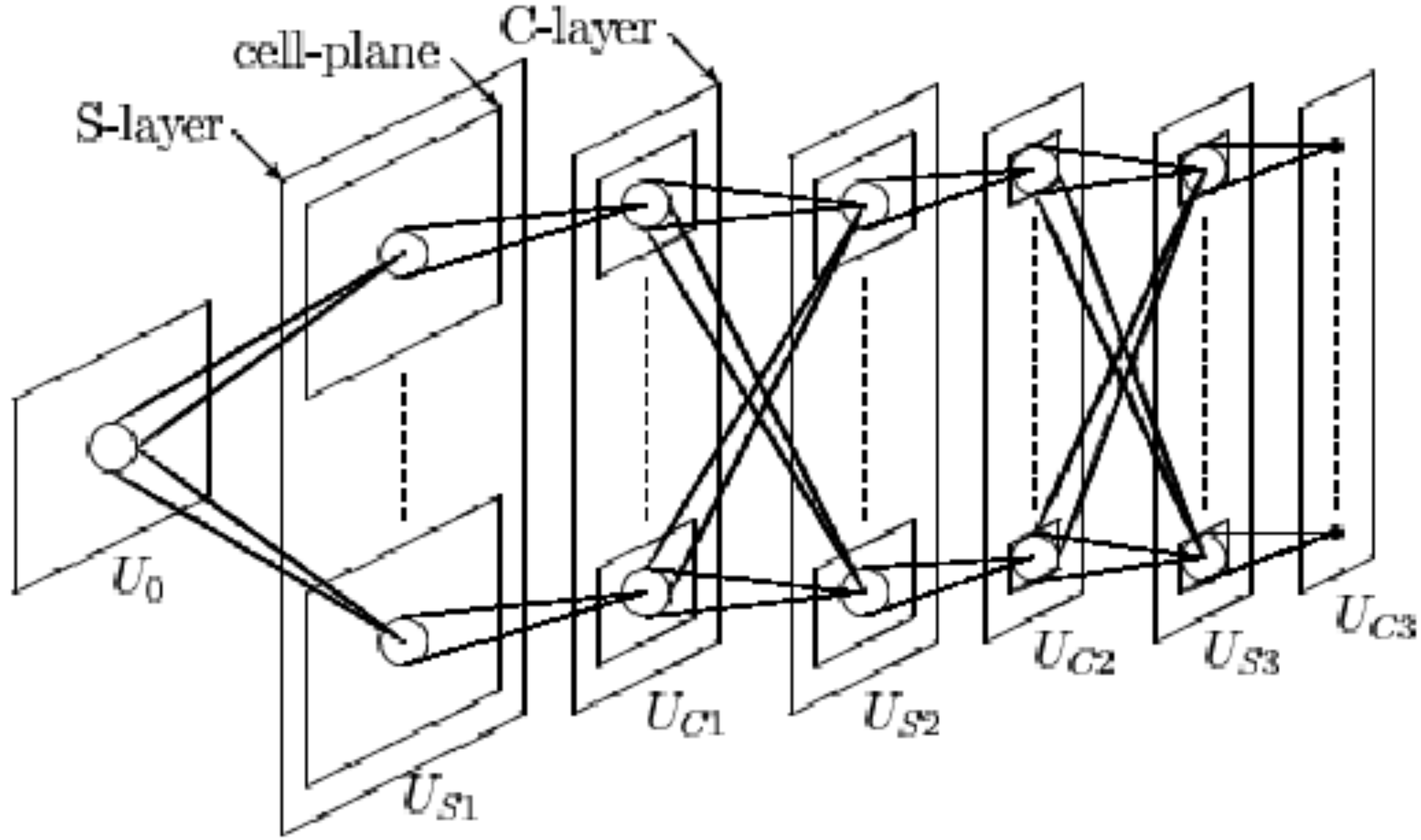


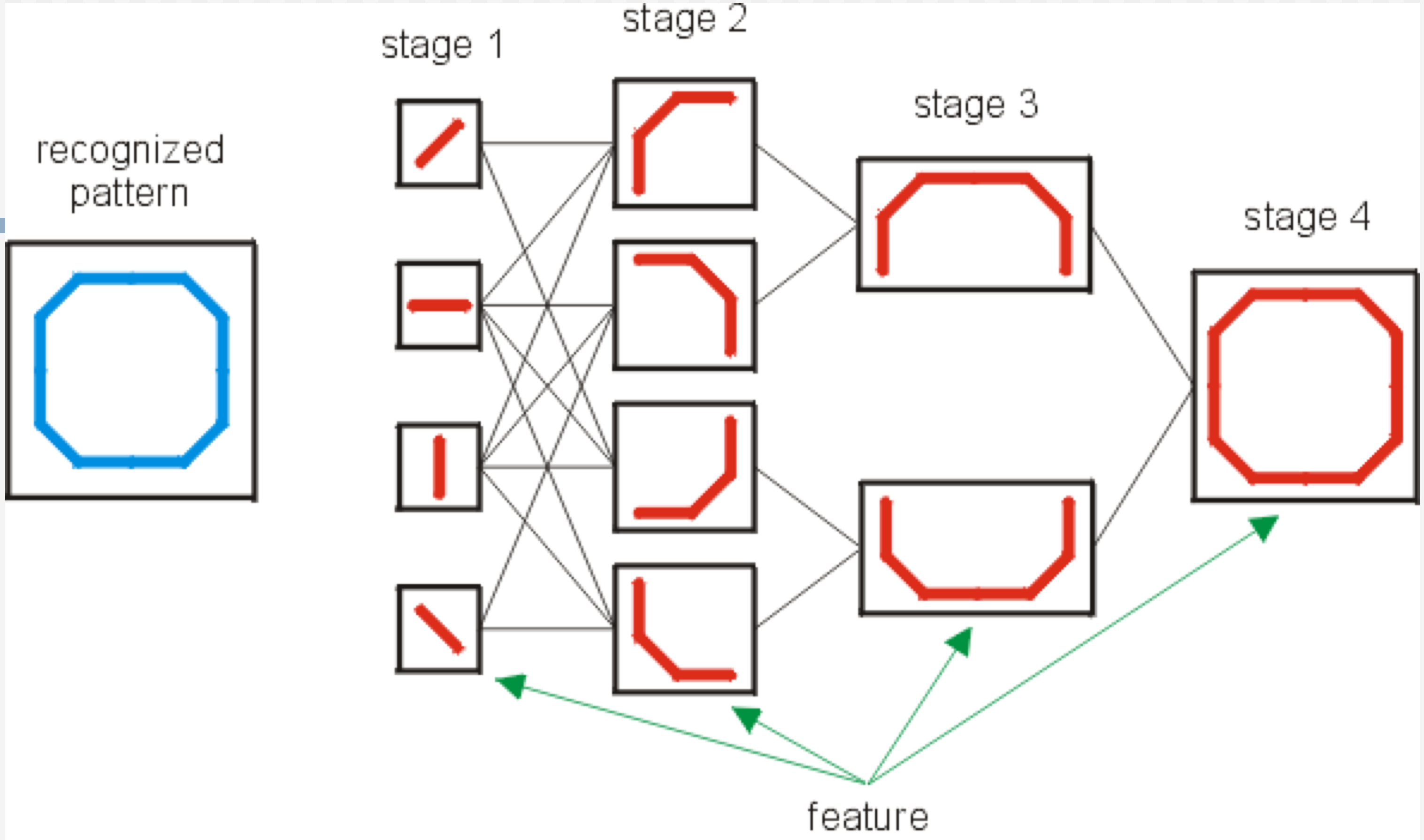
Computational Model of Object Recognition
(Riesenhuber and Poggio, 1999)



Hierarchical Template Matching:

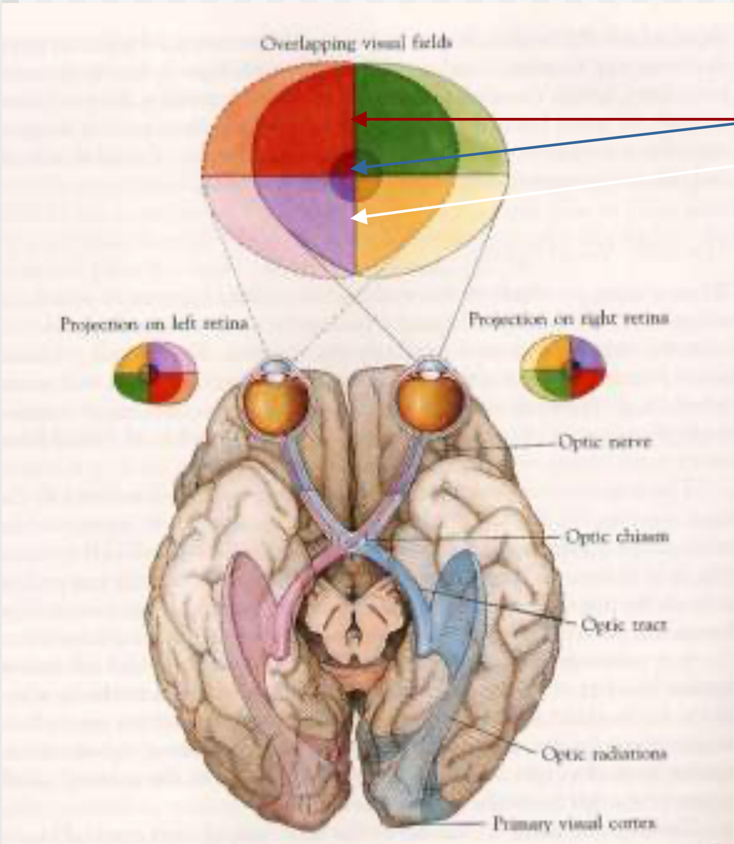
Fukushima & Miyake (1982)'s Neocognitron

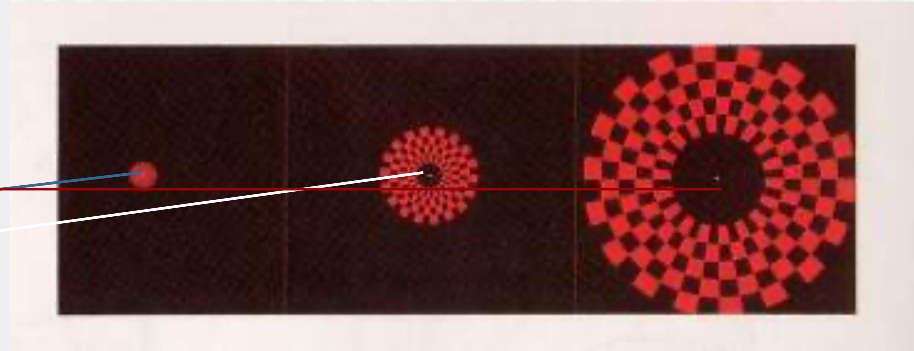




- Image passed through layers of units with progressively more complex features at progressively less specific locations.
- Hierarchical in that features at one stage are built from features at earlier stages

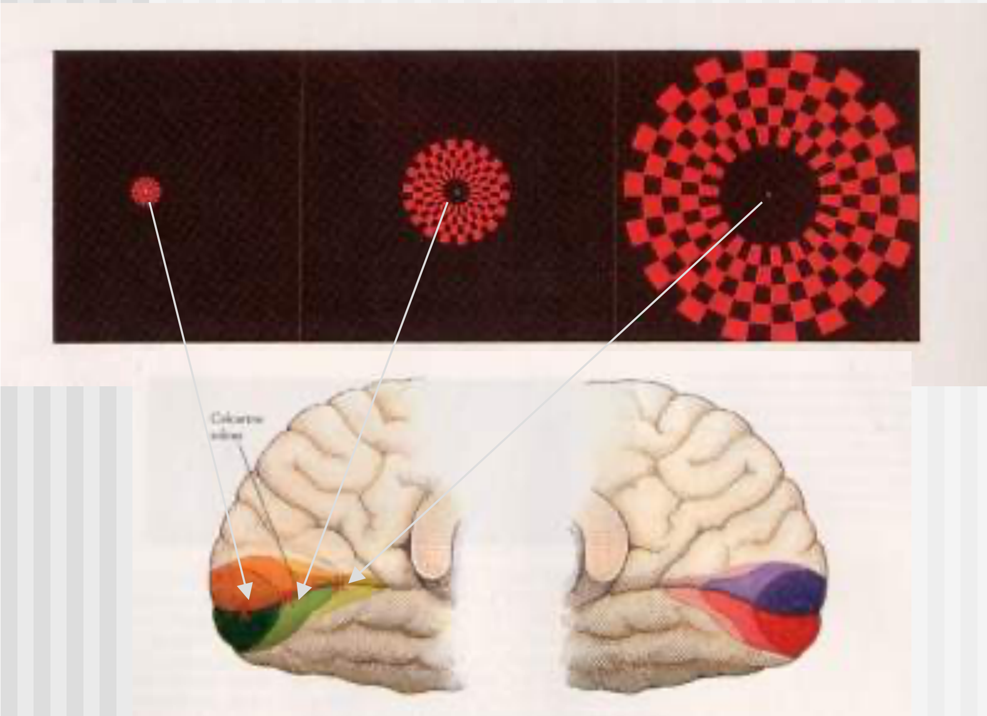
Mapping Human Striate Cortex (V1) with Positron Emission Tomography (PET)



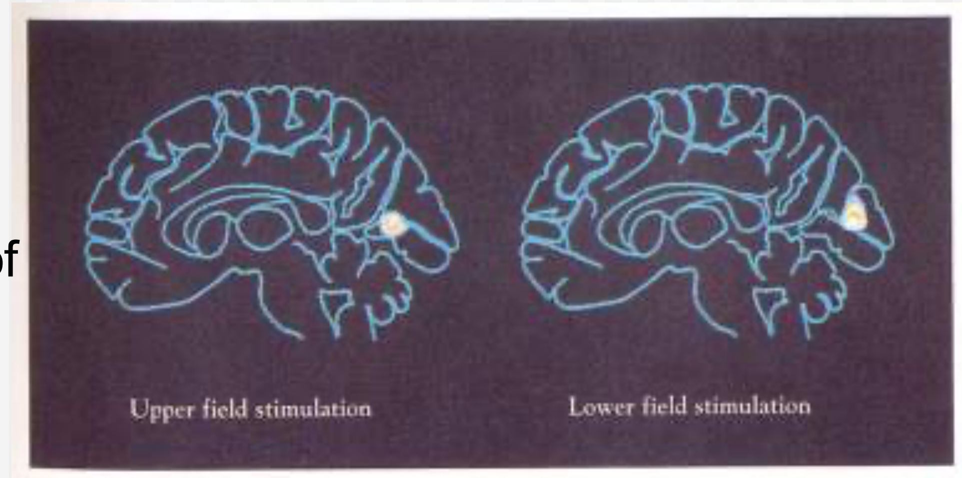


- Checkerboards were used to present stimuli to different parts of the visual fields. The leftmost checkerboard is a **foveal** stimulus, the middle one presents a stimulus close to the fovea (**parafoveal**), and the rightmost one is a peripheral stimulus that **surrounds the parafovea from 5.5 to 15°.**
- Stimuli could also be presented to the upper quadrant (e.g., **rightmost** stimulus) or the lower quadrant (e.g., **middle** stimulus). (Courtesy of Posner and Raichle).

Checkerboard Stimuli and Calcarine Sulcus Activation



The foveal stimulus presented in the center of the visual field activated calcarine cortex most posteriorly and at the midline, the middle parafoveal stimulus stimulated calcarine cortex more anteriorly at the midline, and the rightmost more peripheral stimulus produced the most anterior activations at the midline.

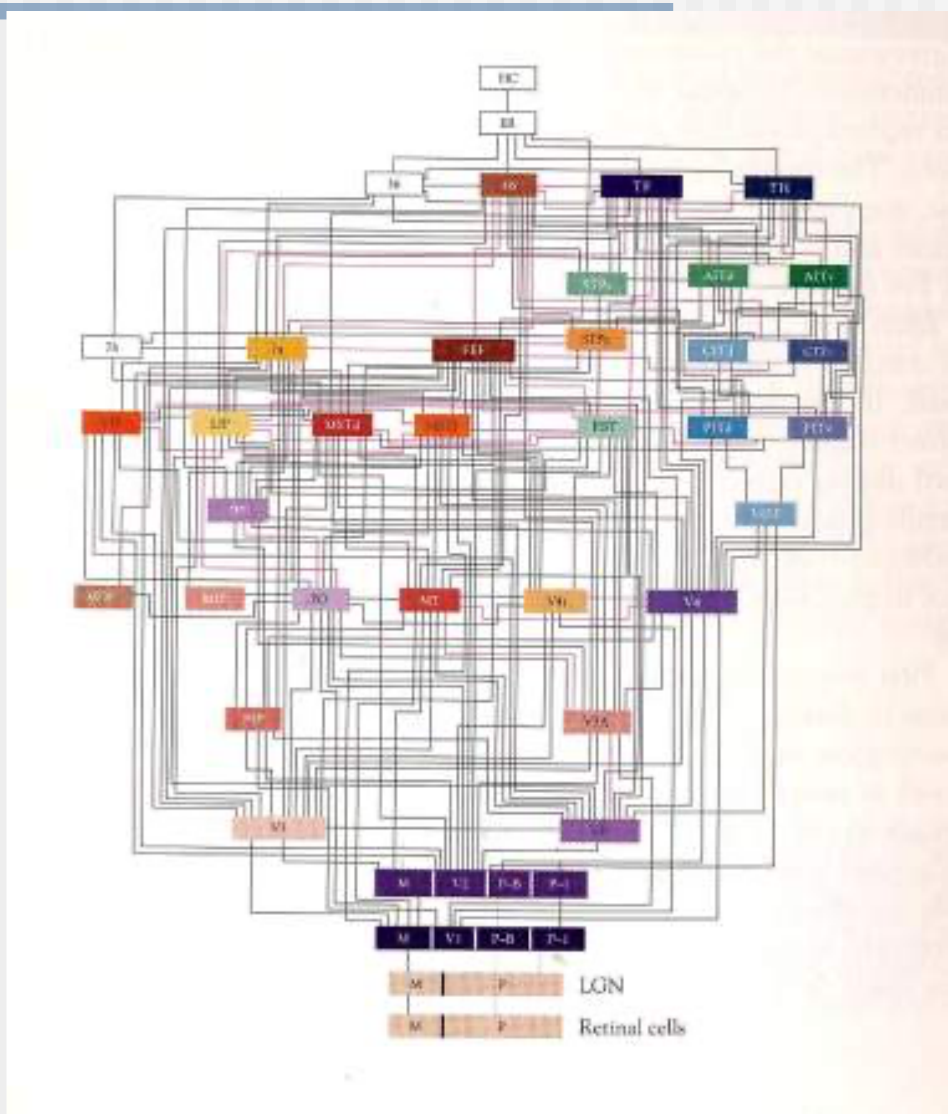


Stimulation of the upper and lower halves of the visual field reliably produces areas of activation below (left) and above (right) the calcarine sulcus.

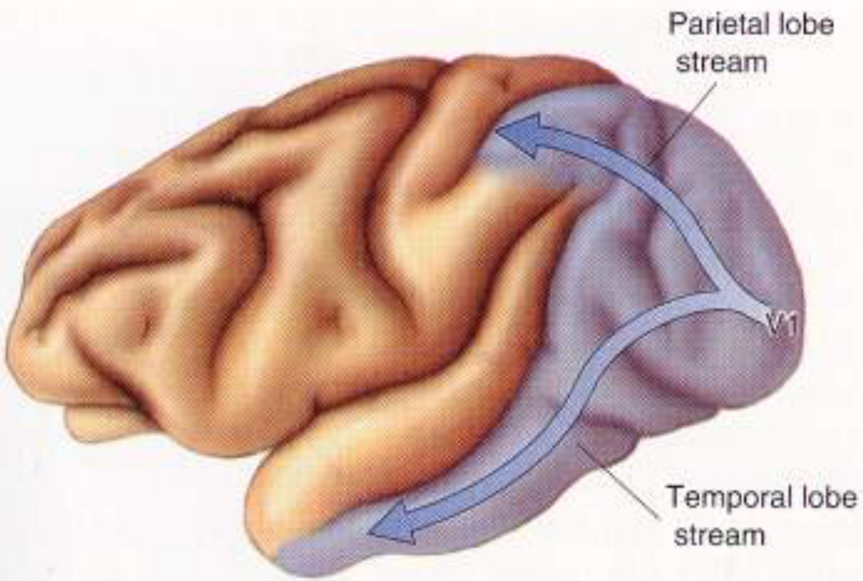
Extensive Interconnections Between Systems Identified in Primate Brain

Separation and Integration of Function

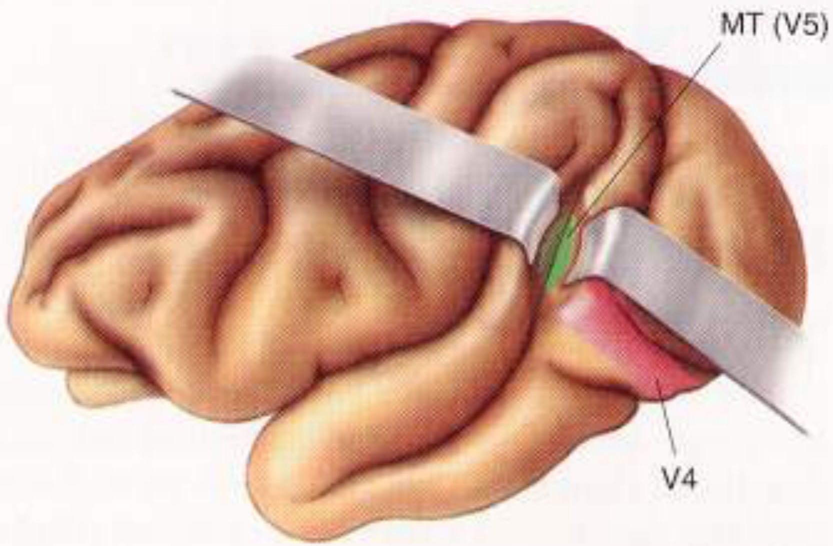
Areas of the monkey visual system (shown previously on unfolded cortex) are heavily interconnected.



Dorsal ("Where") and Ventral ("What") Visual Streams in Monkey



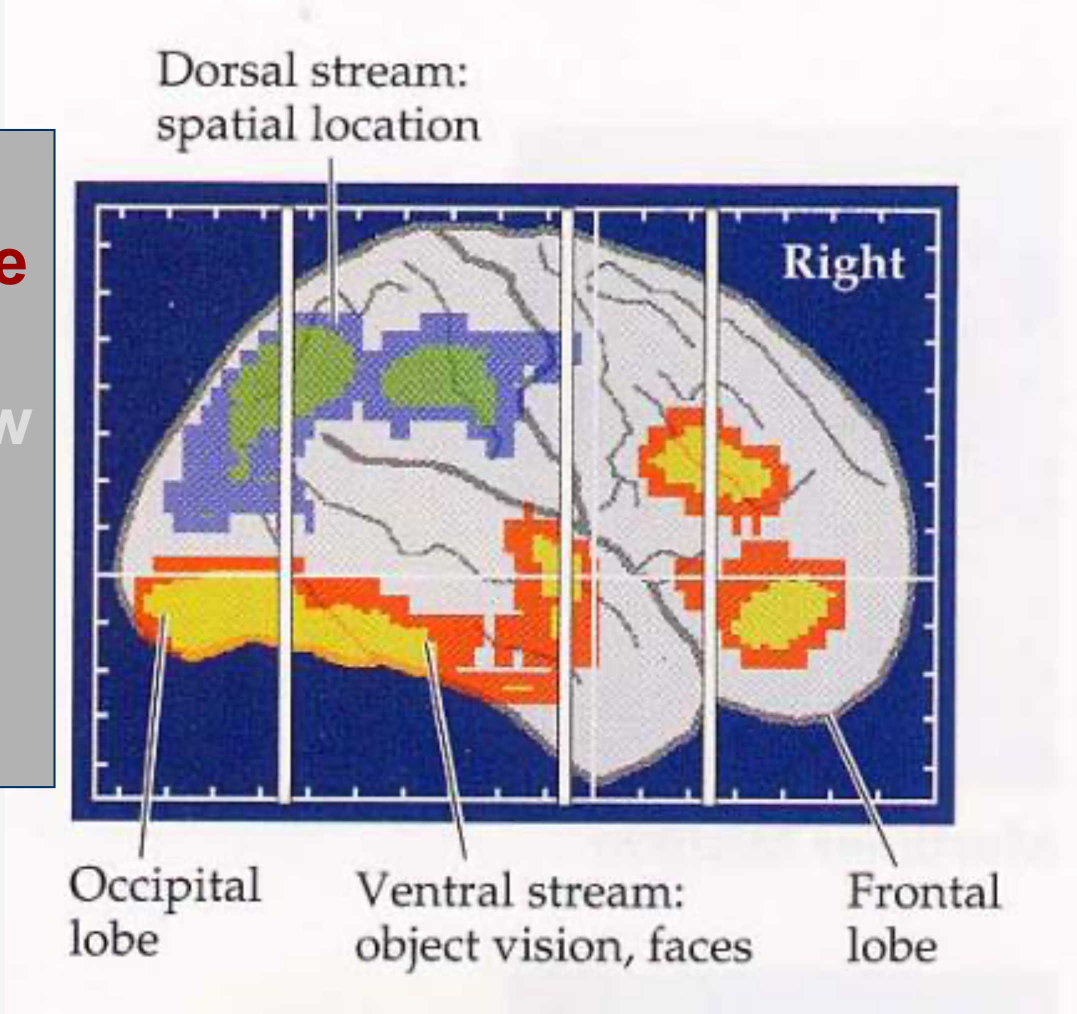
Parietal (Dorsal) and Temporal (Ventral) Processing Streams



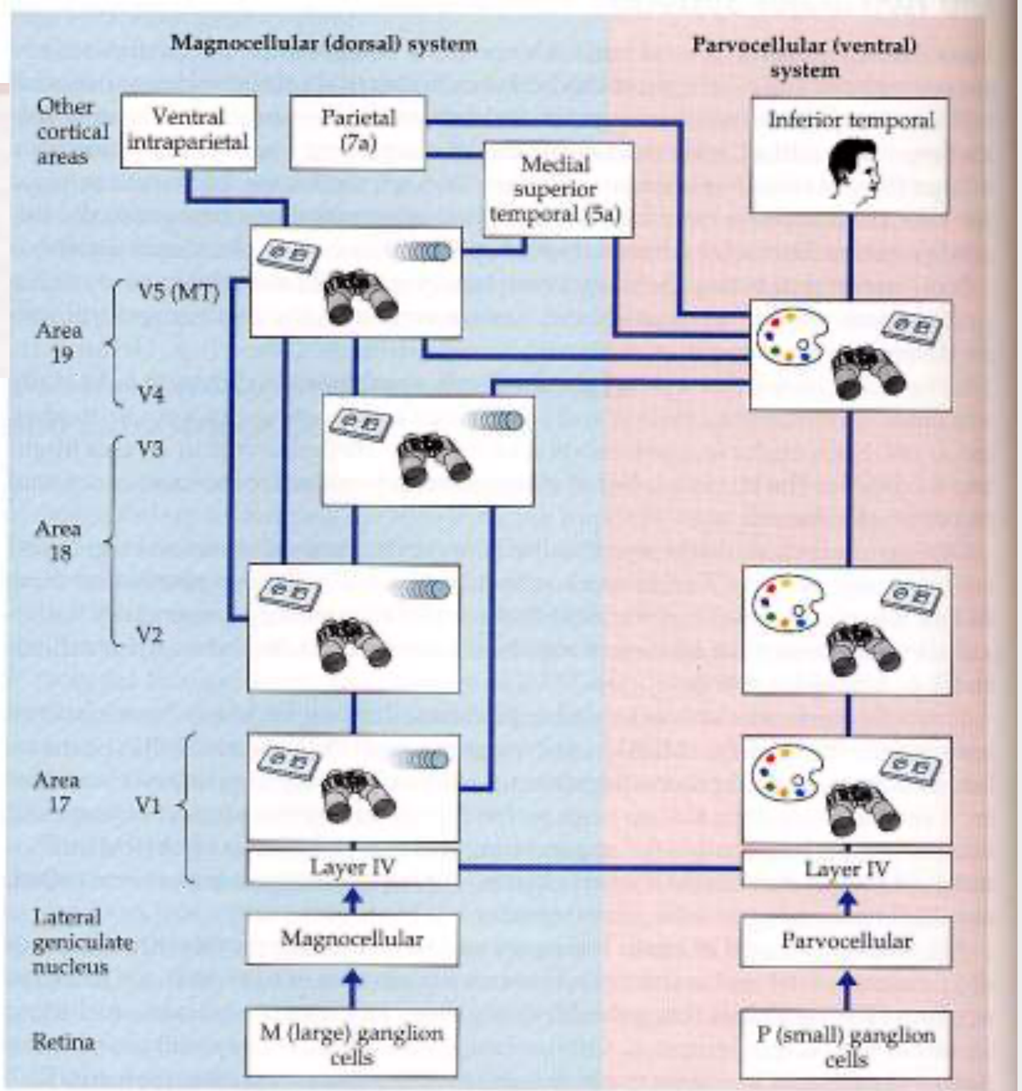
Areas MT and V4 in the Macaque Brain

Dorsal ("Where") and Ventral ("What") Visual Streams in Human (PET)

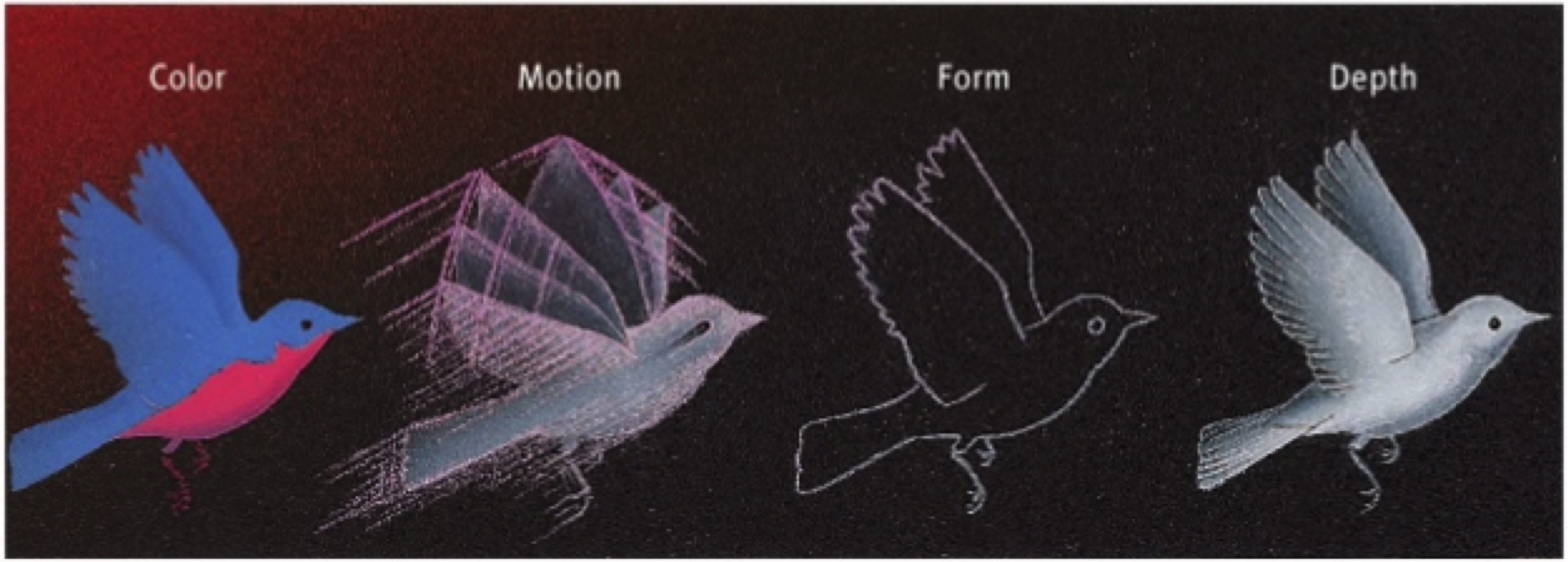
Dorsal (***where***) pathway shown in green and blue and Ventral (***what***) pathway shown in yellow and red serve different functions. (Courtesy of Leslie Ungerleider).



Retinal and Thalamic Precursors of the Dorsal and Ventral Visual Pathways



Magnocellular (dorsal) and parvocellular (ventral) pathways from the retina to the higher levels of the visual cortex are separate at the lower levels of the visual system. At higher levels they show increasing overlap.


Color
Motion
Form
Depth

Object Recognition

- What is Object Recognition?
  - Segmentation/Figure-Ground Separation:
  - Labeling an object [The focus of most studies]
  - Extracting a parametric description as well
- Object Recognition versus Scene Analysis
  - An object may be part of a scene or
  - Itself be recognized as a “scene”

Shape perception and scene analysis

- Shape-selective neurons in cortex
  - Coding: one neuron per object
  - or population codes?
- Biologically-inspired algorithms for shape perception

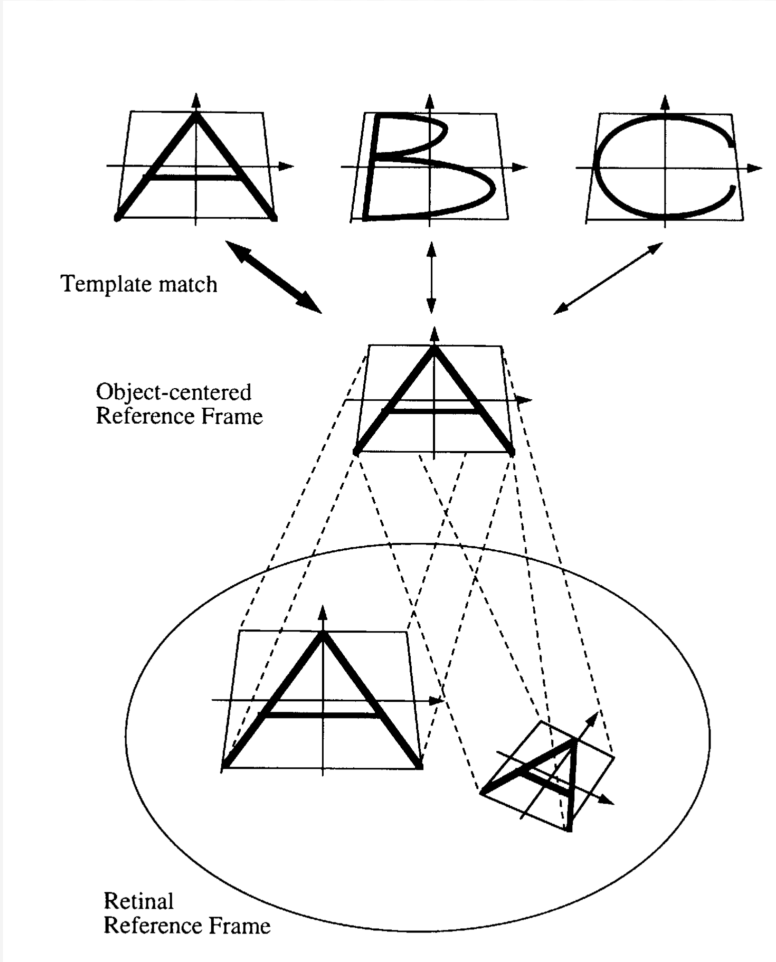
- Visual memory: how much do we remember of what we have seen?
- The world as an outside memory and our eyes as a lookup tool

Four stages of representation (Marr, 1982)

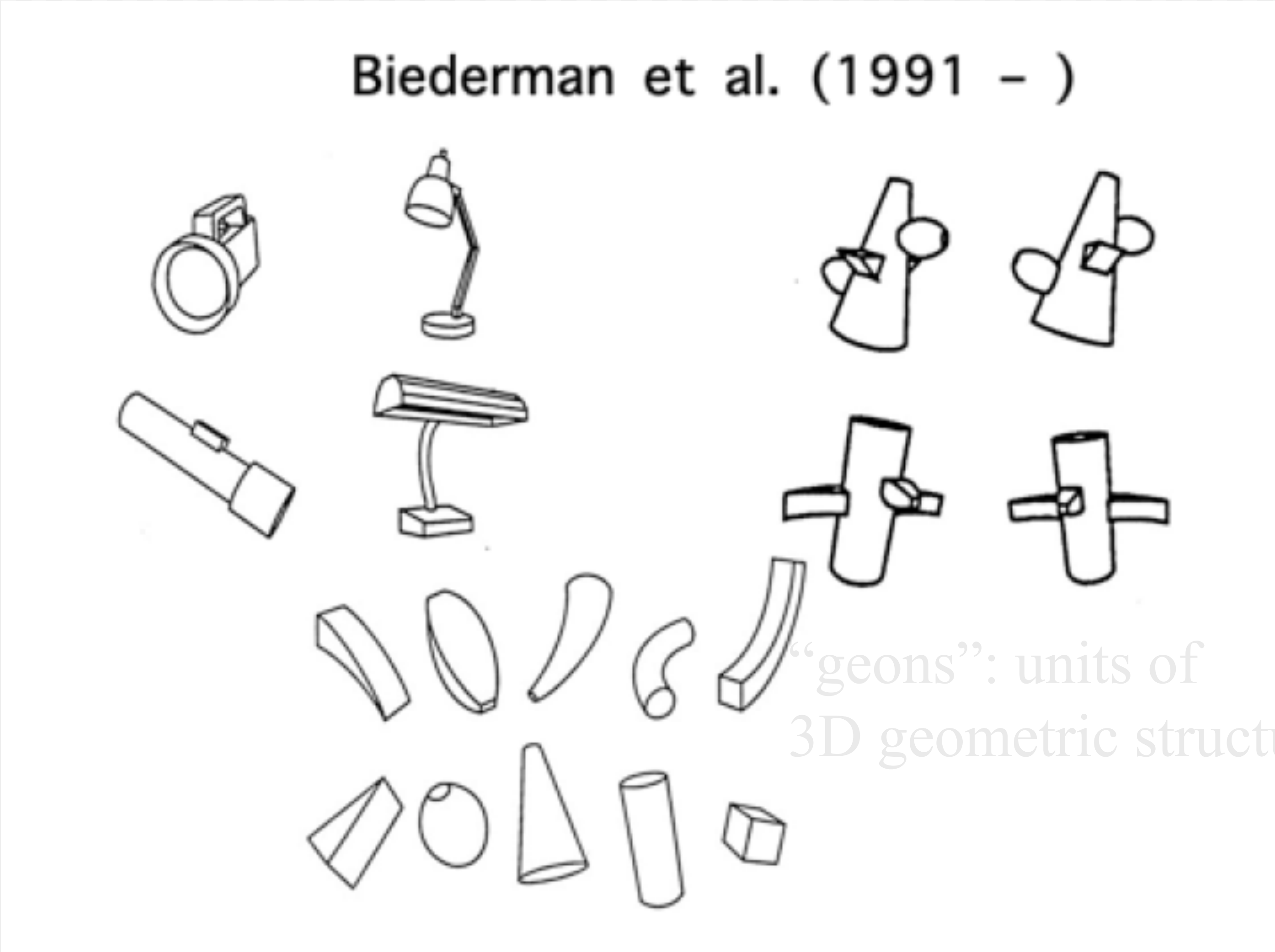
- 1) pixel-based (light intensity)
- 2) primal sketch (discontinuities in intensity)
- 3) 2 ½ D sketch (oriented surfaces, relative depth between surfaces)
- 4) 3D model (shapes, spatial relationships, volumes)

Models of Object Recognition

- Transform & Match:
- First take care of rotation, translation, scale, etc. invariances
- Then recognize based on standardized pixel representation of objects.



Biederman: Recognition by Components



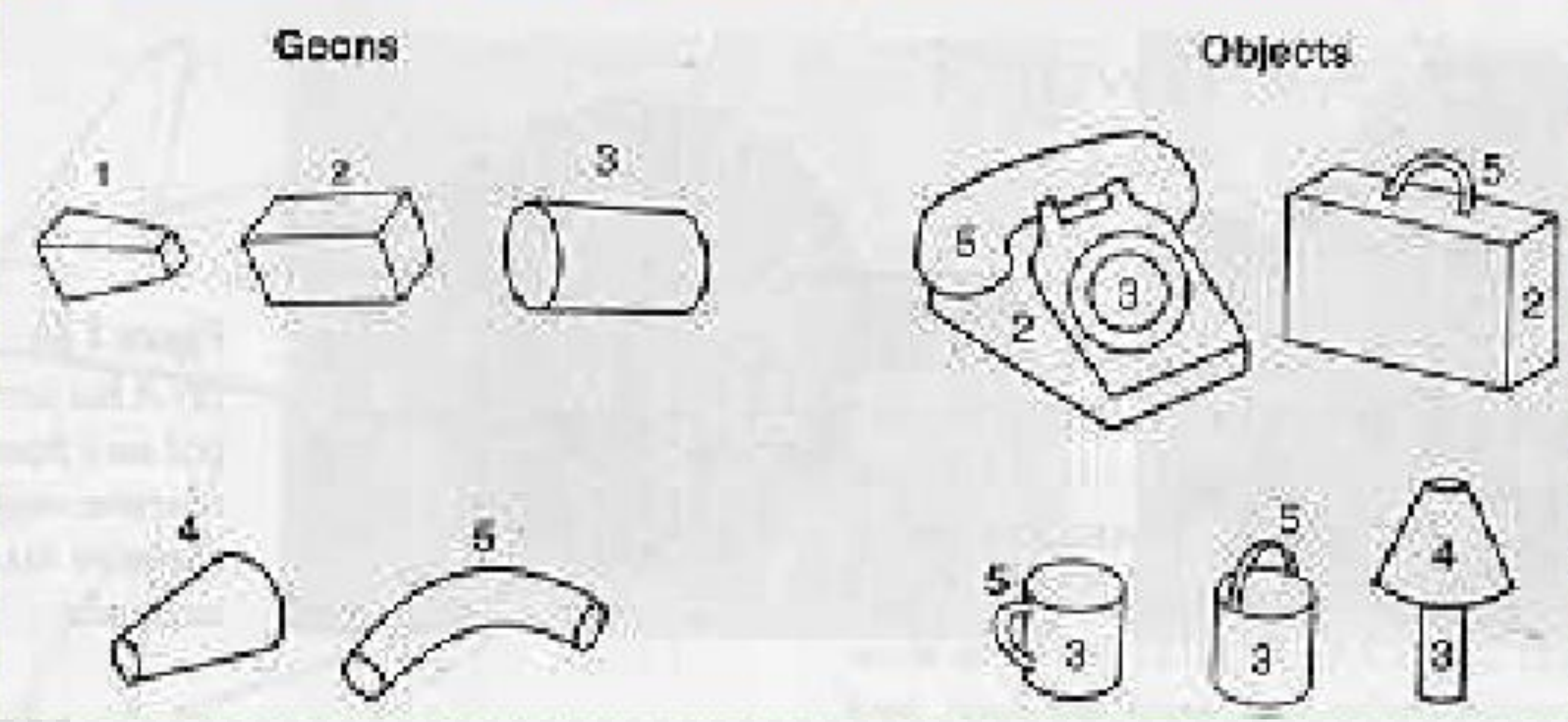
"geons": units of
3D geometric structure

Recognition by components
(Biederman, 1987)

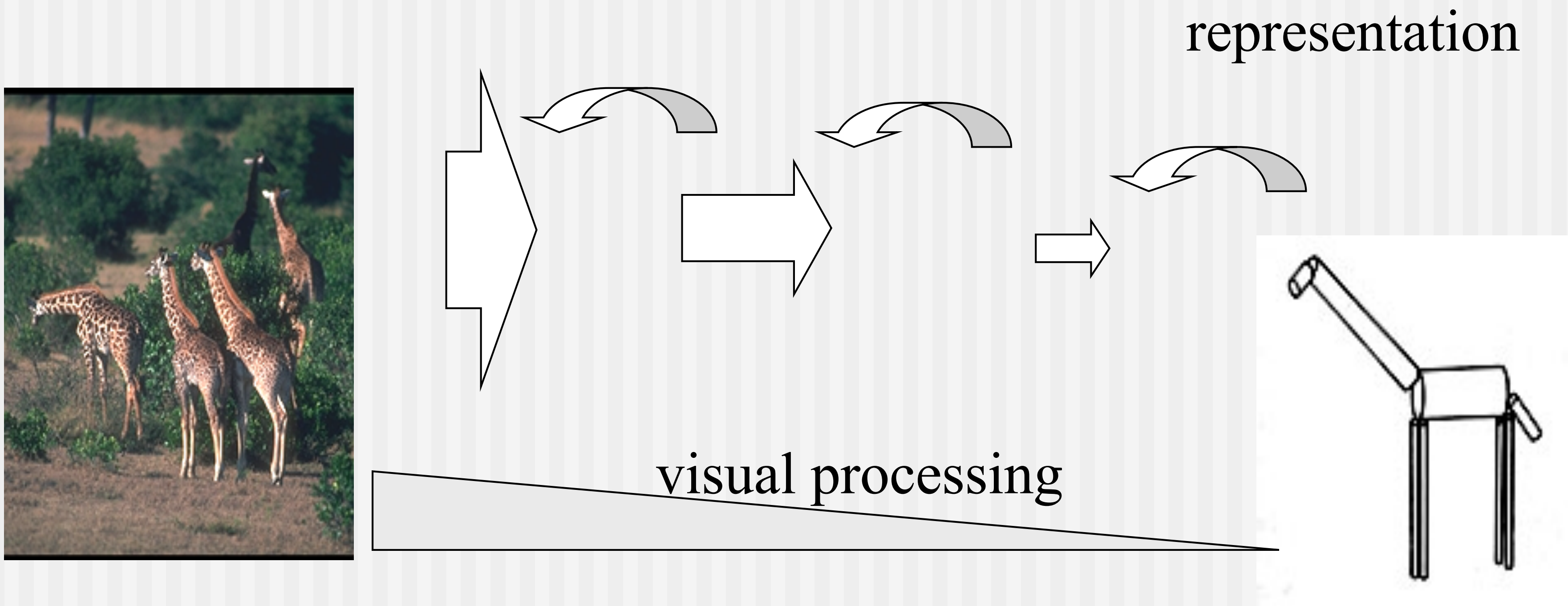
- ***GEONS:*** geometric elements of which all objects are composed (cylinders, cones, etc). On the order of 30 different shapes

- Skips 2 ½ D sketch: Geons are directly recognized from edges, based on their nonaccidental properties (i.e., 3D features that are usually preserved by the projective imaging process)

Geons



Standard View on Visual Processing



- Image specific
- Supports fine discrimination
- Noise tolerant

- Image invariant
- Supports generalization
- Noise sensitive

Potential difficulties

A. Structural description not enough, also need **metric info**

B. Difficult to extract geons from real images

C. Ambiguity in the structural description: most often we have several candidates

D. For some objects, deriving a structural representation can be difficult

• Edelman 1997

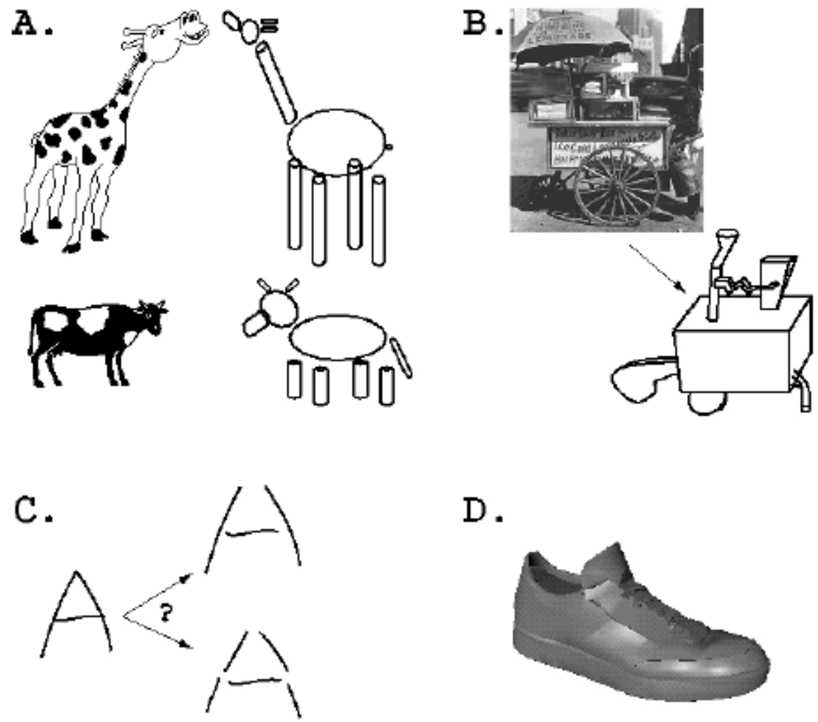
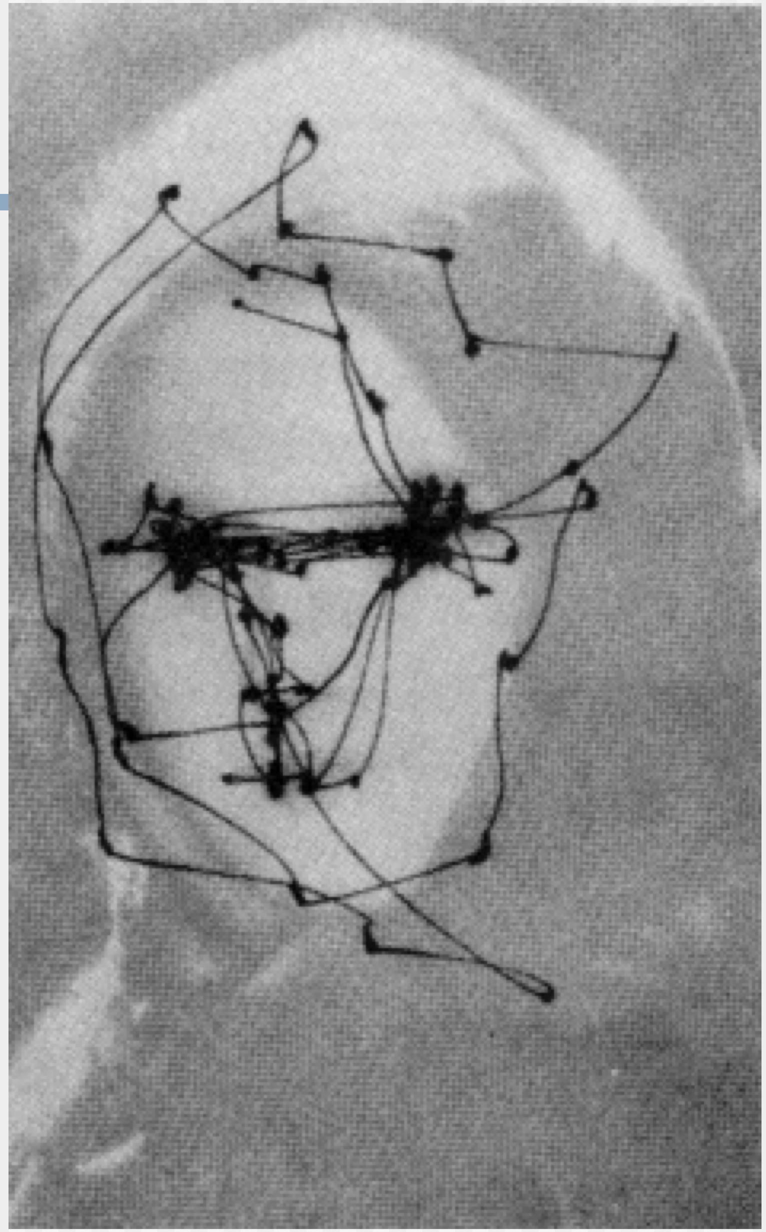
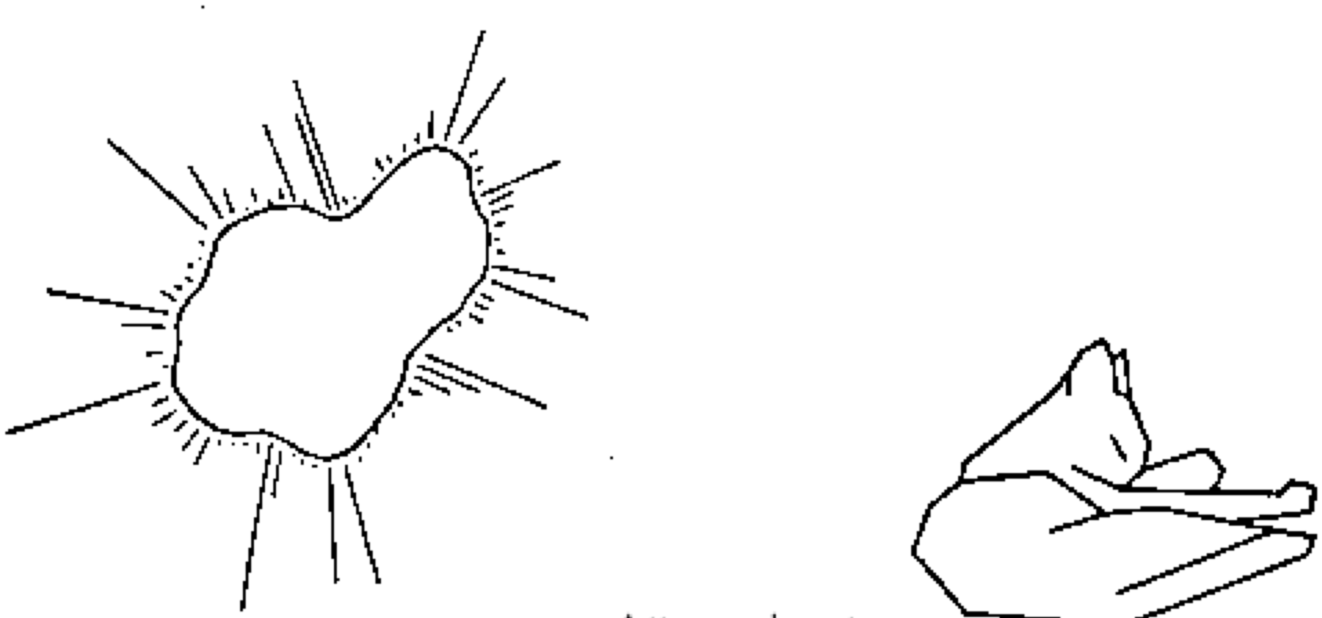


Figure 1: Computational problems with structural representations. A. Structural descriptions must be accompanied by metric information, to represent differences among commonly encountered categories. The inclusion of metric details reduces the ability of structural methods to deal with novel objects. B. A picture of a New York City street-corner hot dog cart, and a stylized object, which, as Biederman [8] suggests, may be described as such following a structural decomposition in the visual system. At present, there is no reliable method for mapping a gray-level image into a collection of (labeled) primitives (lines, corners, etc.) from which RBC's geons are constructed. Thus, although a carefully engineered system such as that described in [22] can form a structural description of the line drawing of a cart-like object, the goal of deriving such a description directly from an image remains elusive. C. Even in simpler tasks (e.g., in character recognition, where the figure is readily separable from the ground), the derivation of a structural description is problematic. The difficulty here stems from the possibility to assign multiple structural descriptions to the same image. D. In some tasks, coming up even with one structural description is problematic; how does one represent a shoe in terms of RBC's geons [7]?

Eye Movements

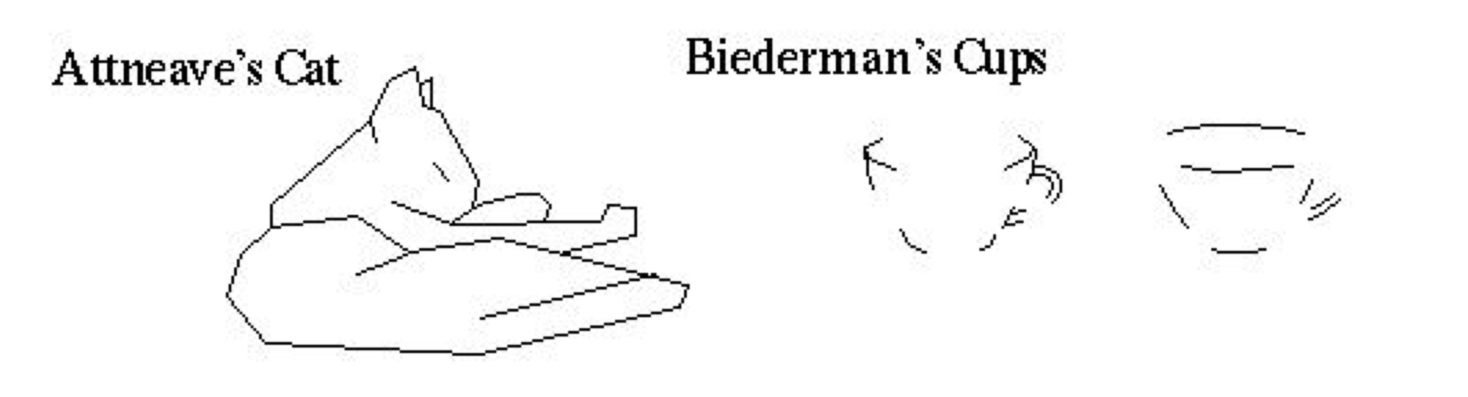
- Saccadic Movement
  - fixation point to fixation point
  - dwell period: 200-600 msec
  - saccade: 20-100 msec
- Smooth Pursuit Movement
  - tracking moving objects in visual field
- Convergent Movement
  - tracking objects moving away or toward us



Attneave's cat

- For example Attneave showed that a picture of a cat can be simplified by replacing all lines of low curvature with straight lines, as shown below, without adversely affecting the recognizability of the cat
- In other words, the lines of low curvature represent redundant information, which therefore need not be explicitly stored in memory



- Biederman gives further evidence for this notion by showing that a cup remains recognizable after removal of its lines of low curvature, whereas it becomes unrecognizable after removal of its points of high curvature and line intersections.

Information Content of Contours

- Information associated with a contour is not uniformed distributed
- Experiment
  - Ask subject to place a number of fixed points on a blank sheet of paper so that they provide best approximation of a curve
  - People tend to place the points in the same relation
  - Histogram, number of subjects that placed points into these segments

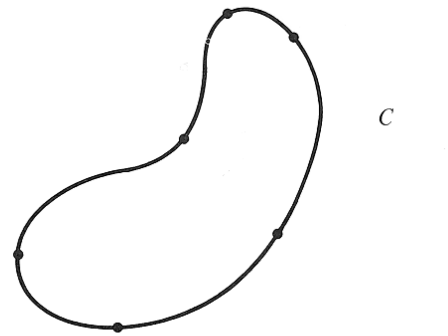


Figure 5.6.1 A simple closed curve.

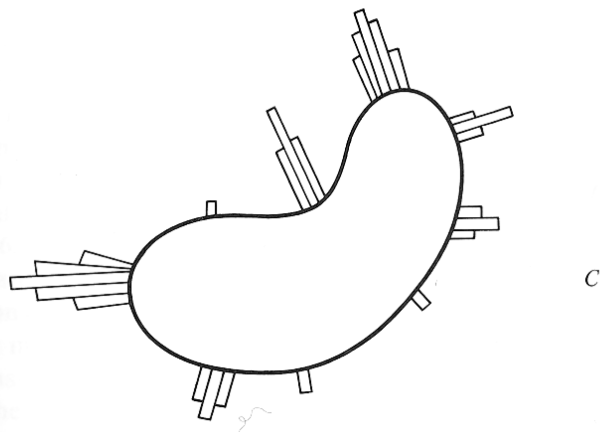
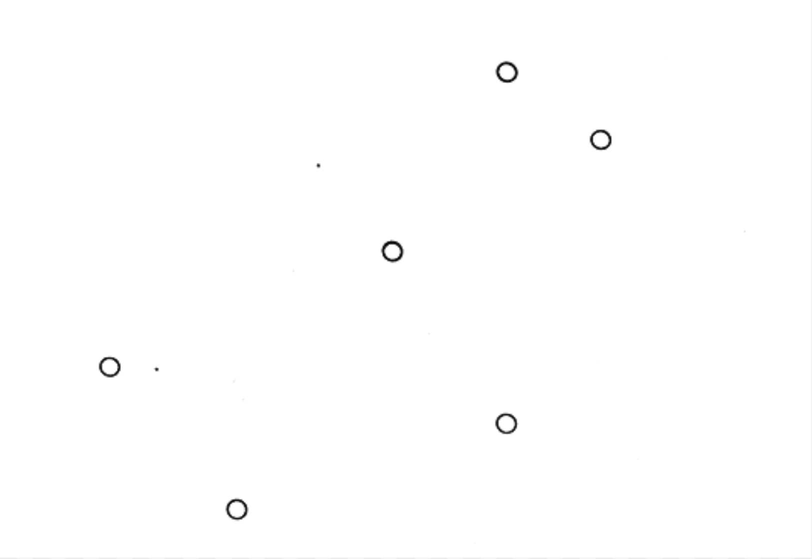
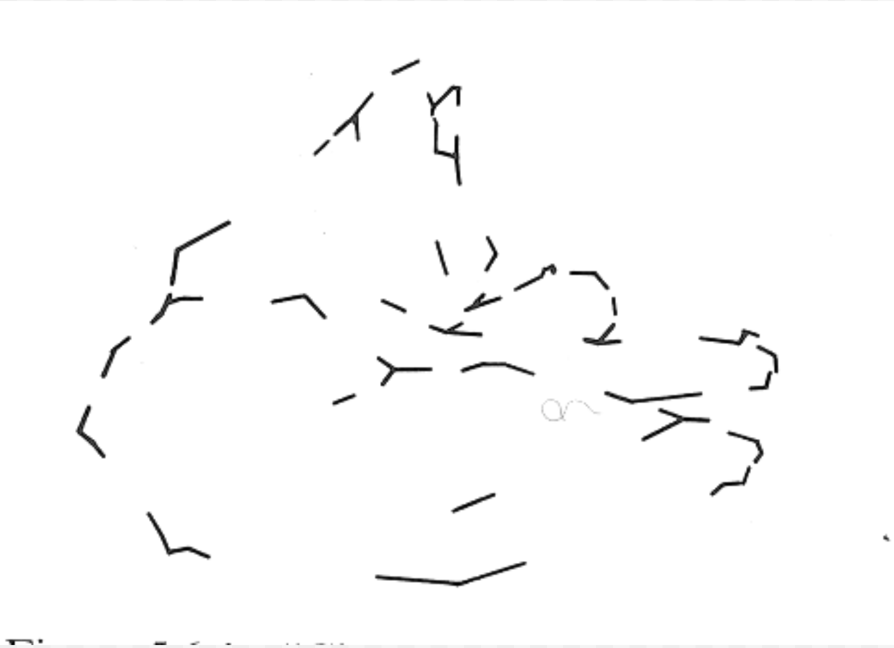


Figure 5.6.2 Histogram for approximations to C.

- If only six points were available, a person would most likely place them as shown (approximate the curve best)

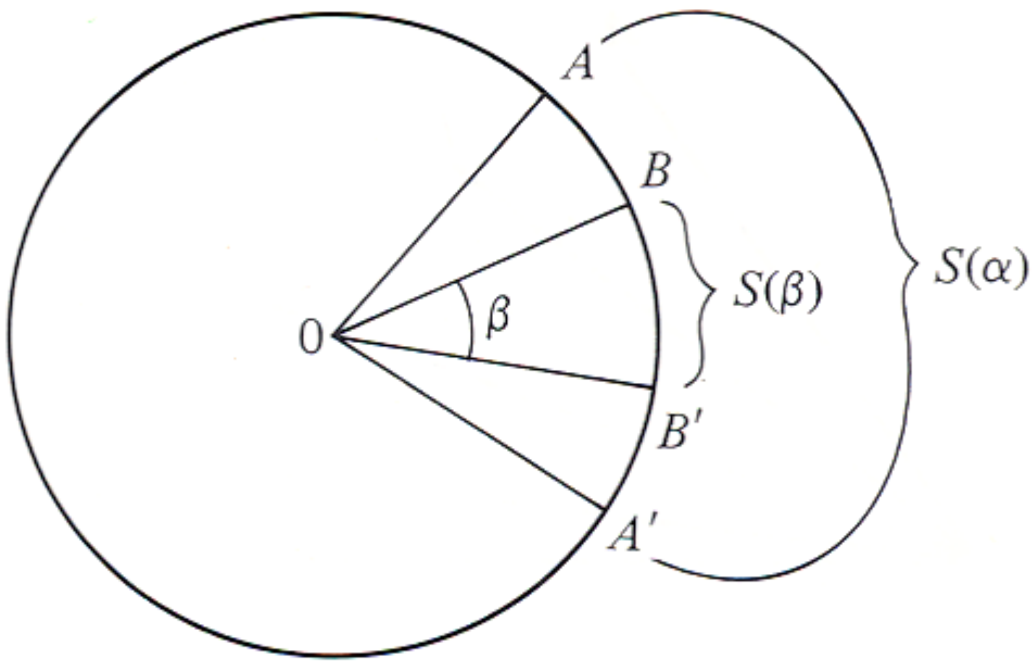




- Illusion of the cat remains if large portions of the line segments are erased
- The information is concentrated in the neighborhood of the points of extreme

Measurement on a circle

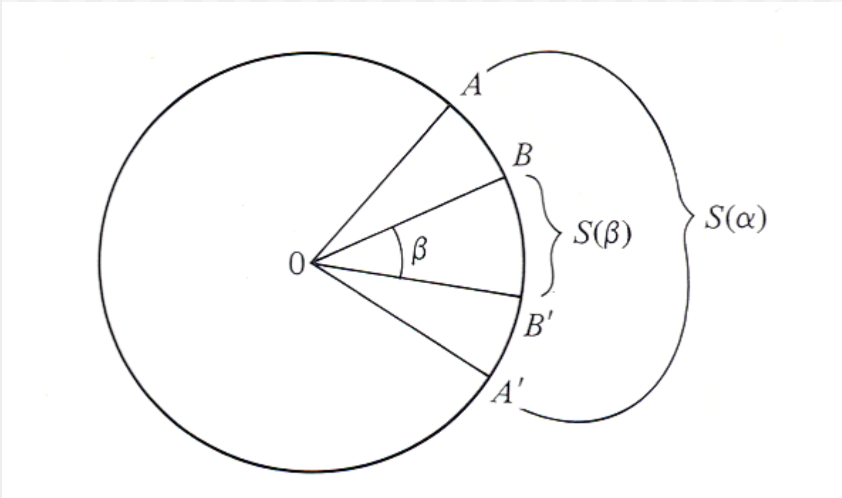
- First measurement the length is $S(\alpha)$, the more exact measurement is $S(\beta)$



Information Gain

- Length of arc of a circle of radius r subtended by an angle Θ is $S(\Theta)=r*\Theta$ if Θ is measured in radians

    - $S(\alpha)= \alpha*r$
    - $S(\beta)= \beta*r$



- $I=\log_2(S(\alpha)/ S(\beta))=\log_2(\alpha/ \beta)$ bits

- Information is always a relative quantity
- Information gained from the measurement of an interval must always be considered relative to some prior measurement

- *But* for direction and the angles that correspond to them, the situation is different
- We know a *priori* that the angle measure of a direction must lie between *0* and $2*\pi$

- Let be α =2*π the a *priori* knowledge (one "measurement")
- Let be β a measurement

- $I(\beta) = log_2(\alpha / \beta) = log_2(2*\pi / \beta)$ *bits*

- We need only one measurement!

Example

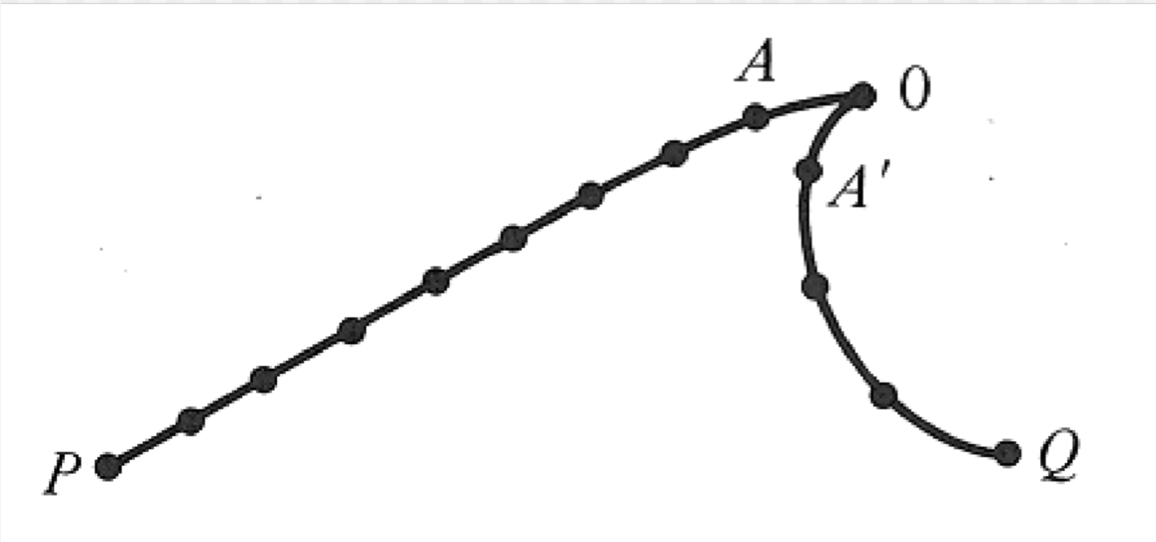
- If $\beta = \pi$ the angle is a straight line and and the information content is
  - $I(\pi) = log_2(2 * \pi / \pi) = log_2(2) = 1$ *bits*
- The measurement has specified that the observed direction lies in one half-of the planes

- If $I(\pi/2)=2$ bits
- If $I(\pi/4)=3$ bits

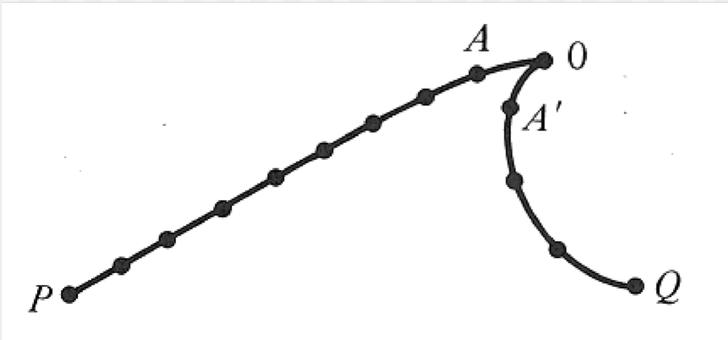
- Smaller angles correspond to greater information

Information and contour

- A contour is subdivided into short segments of equal length for some initial point *P* to some final point *Q*



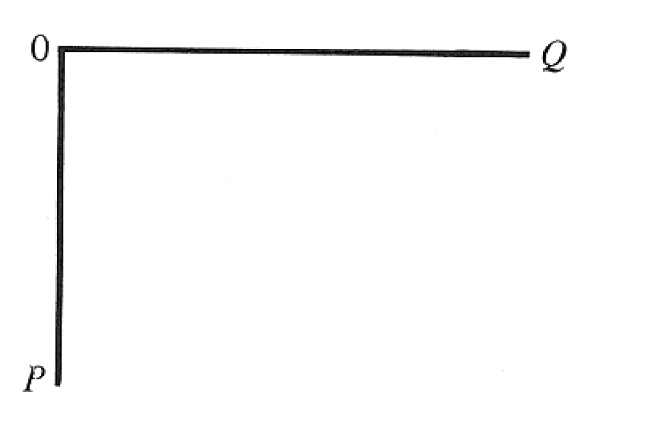
- Each segmenting point (excluding P and Q) can be thought as the vertex of an angle formed with two neighboring points
- *A0A'* is such an angle β



- Associated with that angle is its measure of information given by $I(\beta)$

- For each successive pair pf angles along the path from *P* to *Q* prescribes the gain or loss of information passing from one angle to the next

Example



- As we move in small steps from *P* to *0* along *P0* we see that each angle whose corresponding information is *1* bit
- The information gain is passing from one straight line to the next, it is $I(\pi)-I(\pi)=log_2(\pi/\pi)=0$, since the angle remains unchanged
- When the right angle at vertex *0* is reached, there is a positive gain of information $log_2(\pi/(\pi/2))=1$ bit
- At the next step, passing from right angle to the straight angle there is an information loss $log_2((\pi/2)/\pi)=-1$ bit

- The right angle is the only place where the contour is curved, changes its direction
- At the point of extreme curvature, the information is concentrated
- Corners yield the greatest information
- More strongly curved points yield more information

- Information content of a contour is concentrated in the neighborhood of points where the absolute value of the curvature is a local maximum