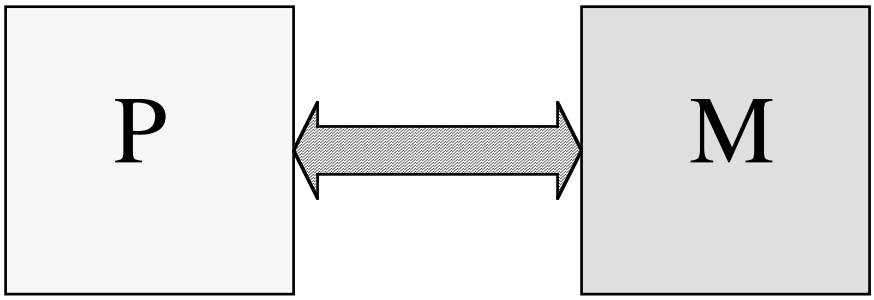
# Natural Nervous Systems and the Brain

Neural Networks

# von Neumann Bottleneck




**Bottleneck (Bandwidth/Memory Hierarchy)**

***Separation of Processing and Memory***

**State-to-State (Sequential)**

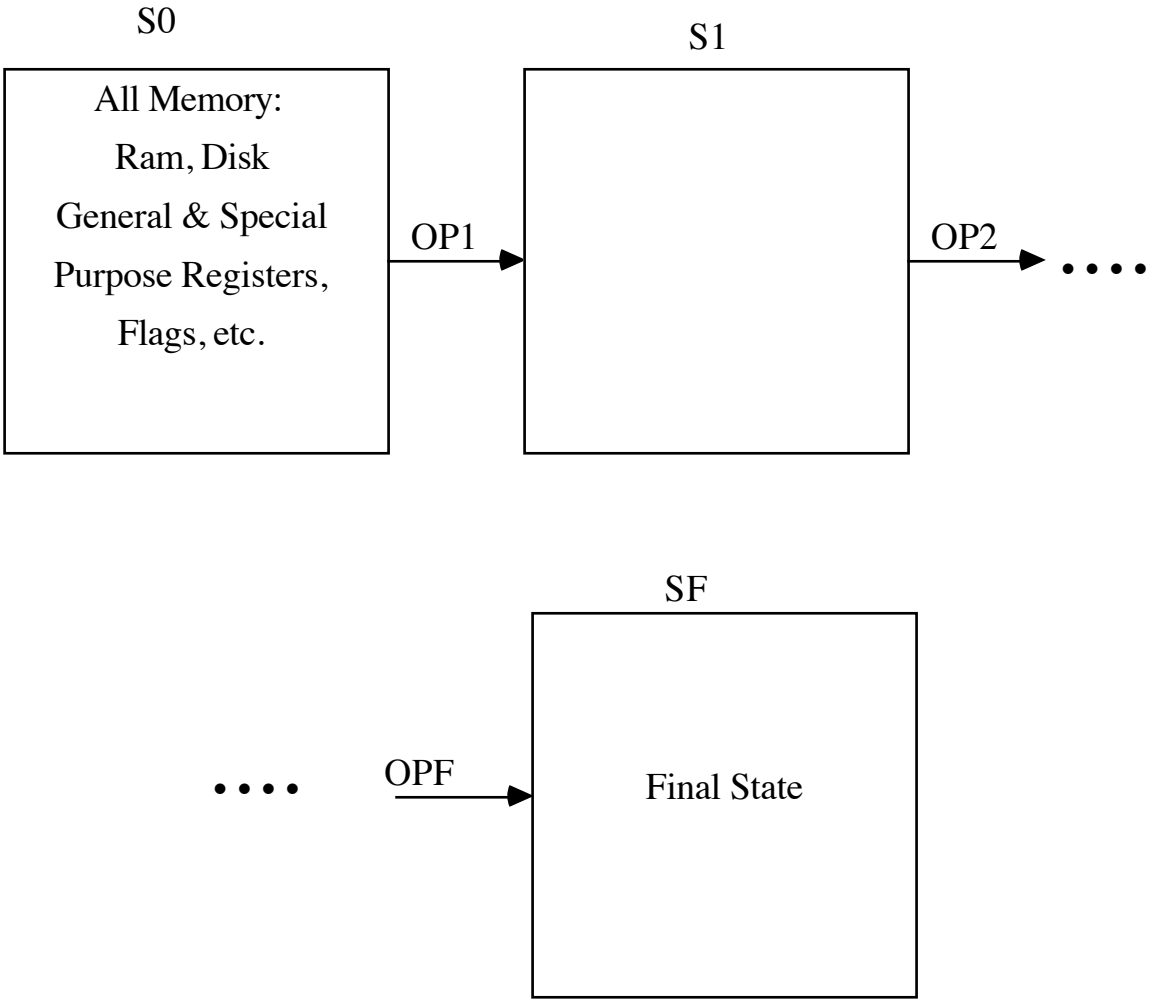
**Prescriptive Control**

**Psychological Bottleneck**

**Technology - Density - Fault Tolerance**

**I/O Bottleneck**

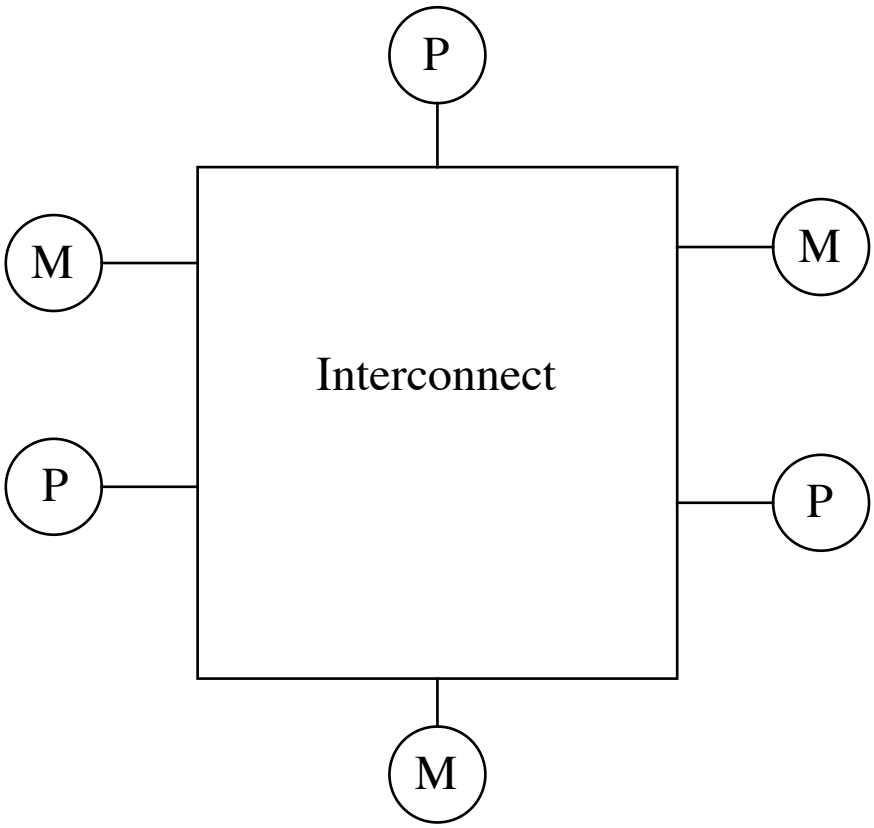
# Current State Model (Traditional von Neurmann)




## Operation Order Critical

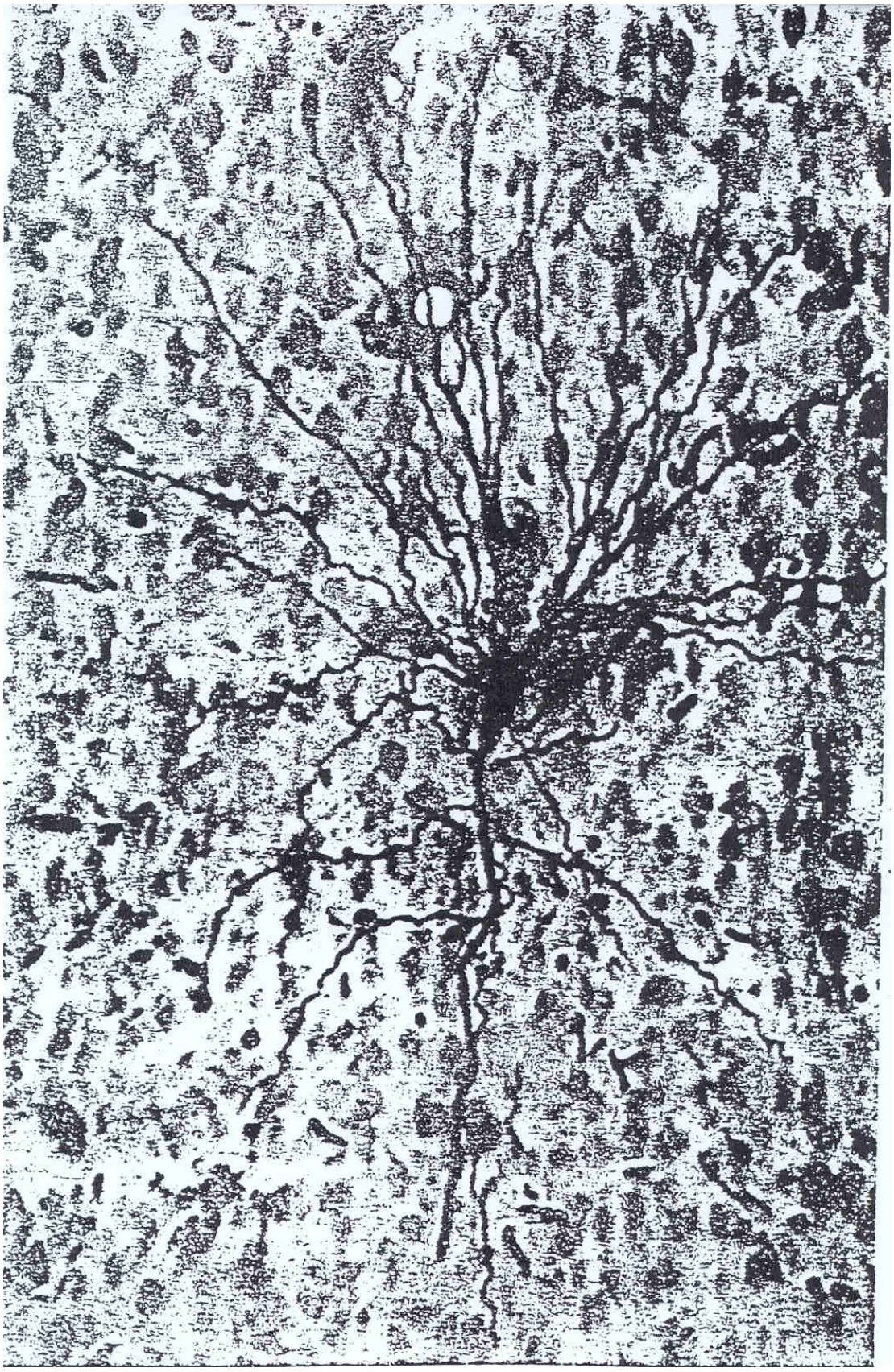
## One at a Time

**Parallel Environment**




**The bottleneck is many times worse.**

**Contention**
**Synchronization**
**Bandwidth**
**Latency**
**Complexity**



*Neural Networks - Brain and Nervous System*

# Human Brain and Natural Nervous Systems

Fascinating, Awe-Inspiring, Frustrating

The right approach?

Our current ignorance

Diversity and Regularity

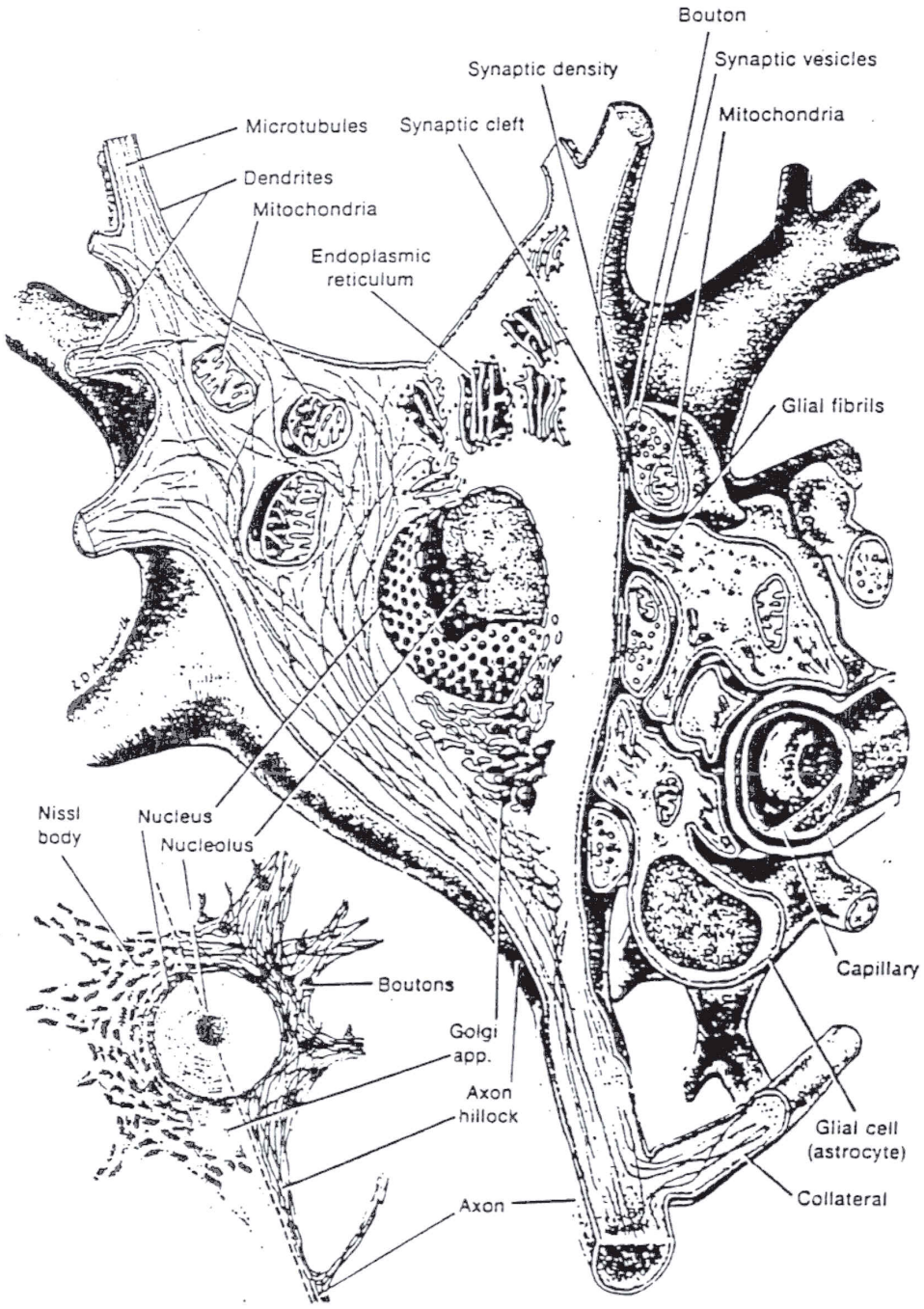
10**11 Neurons in Brain

Order of magnitude more Glial Cells (support, energy, trophic responsibilities)

1000-10000 inputs for each (dendrites)

1 output (axon) which typically arborates to 1000-10000 other neurons

# Neuron Soma

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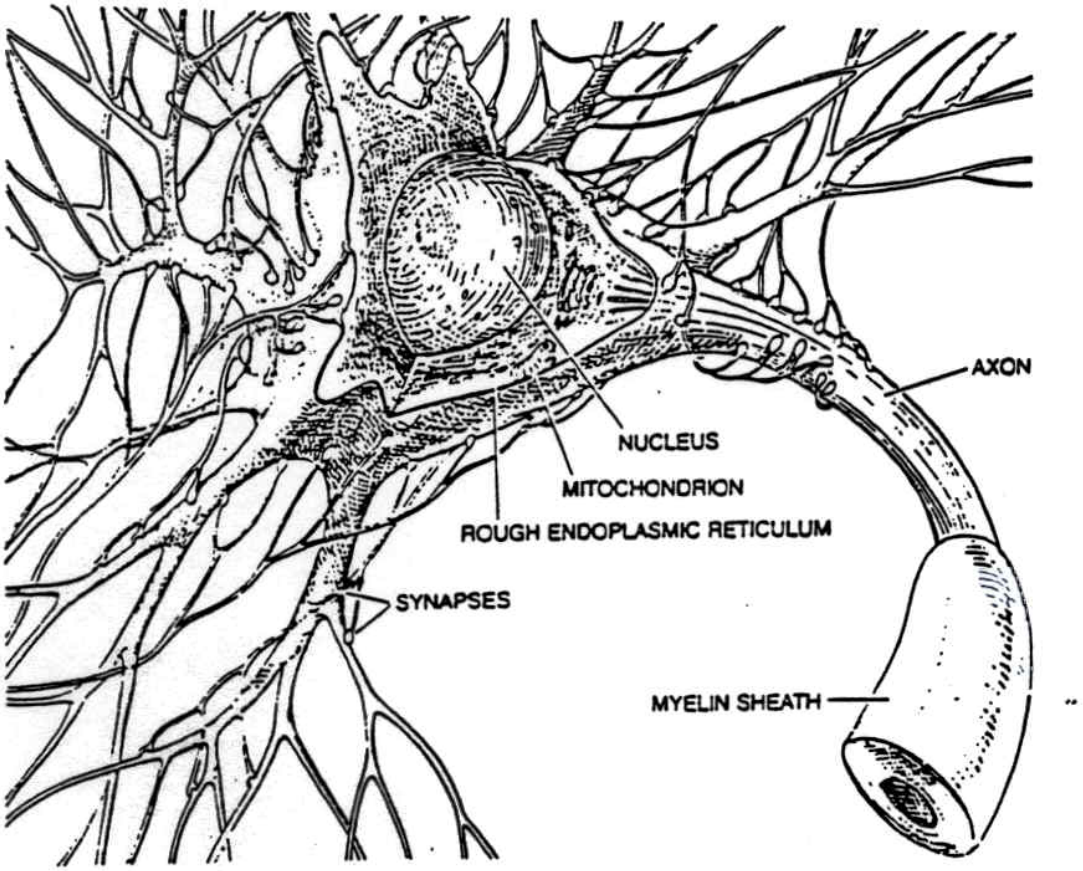
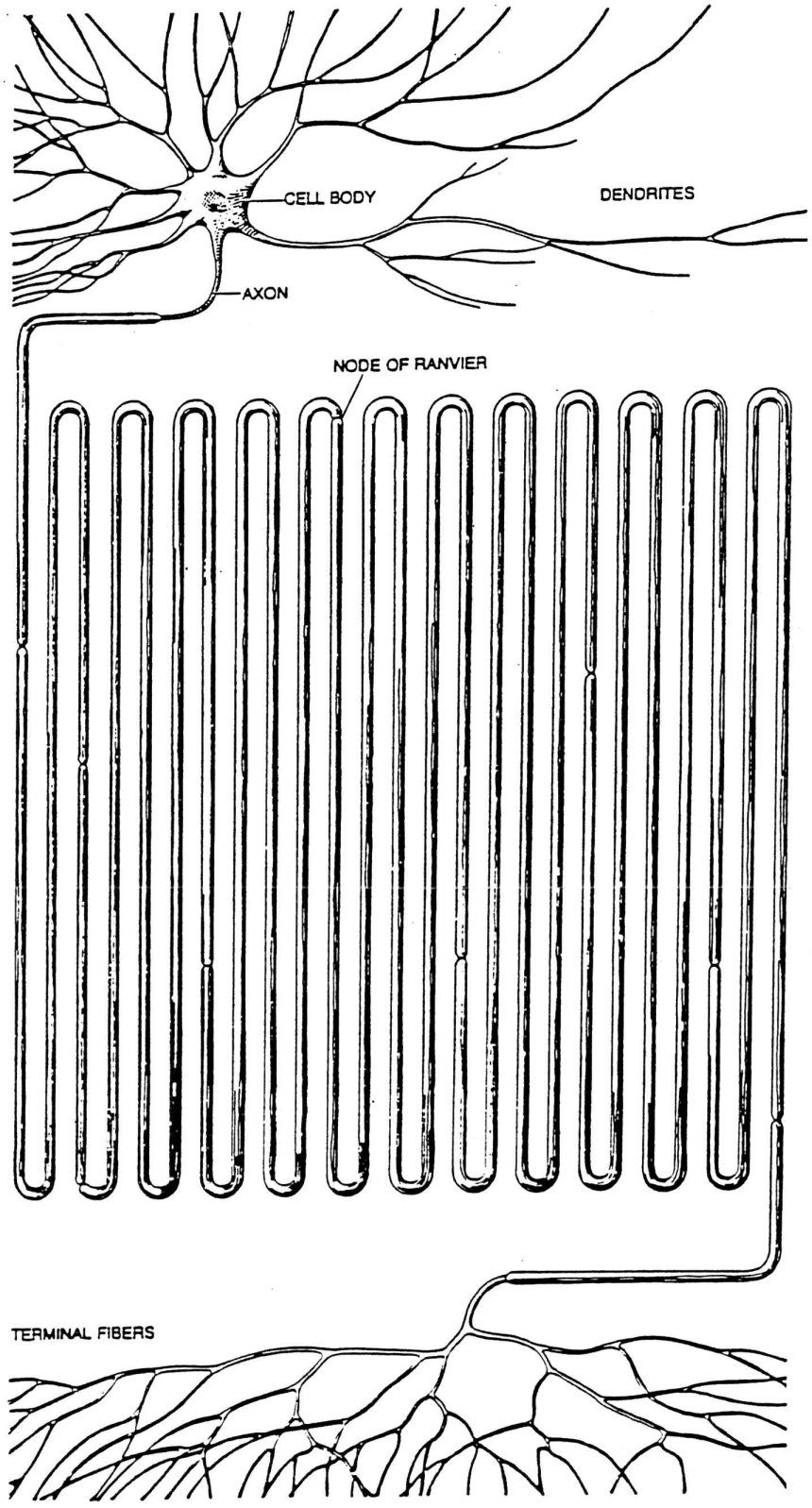
# Expanded View

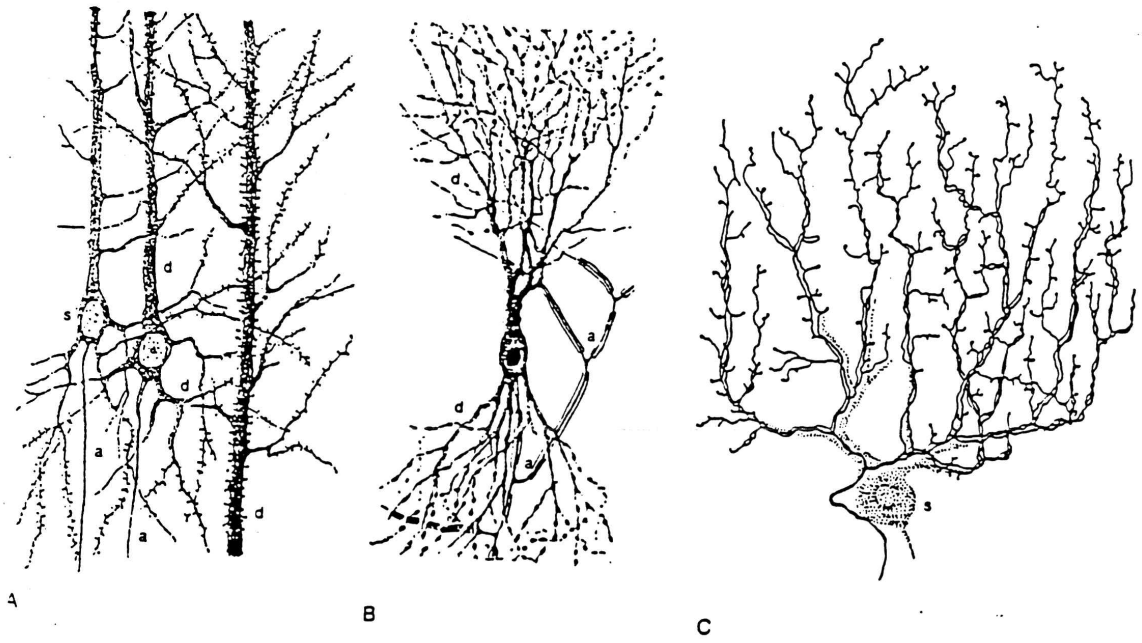


# Generic Neuron and Neurites



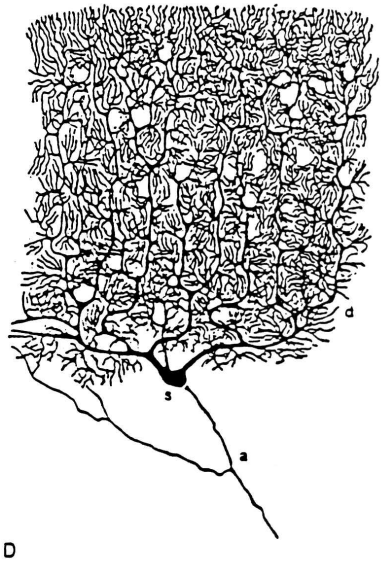
## Cell Varieties

## Pyramidal of Cerebral Cortex
## Pyramidal of Hippocampus
## Purkinje



## Cell Varieties

## Purkinje
## Basket Cell
## Cerebral Cortex
## Intrinsic Neuron (local affect)

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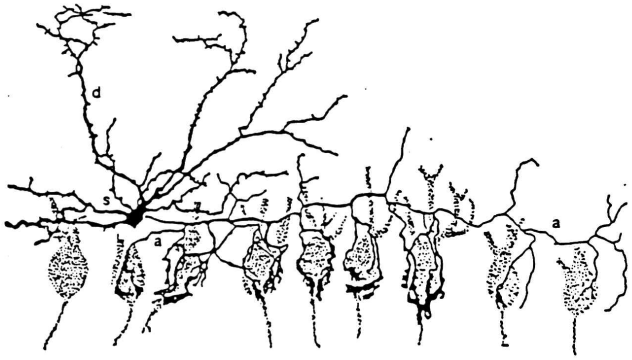
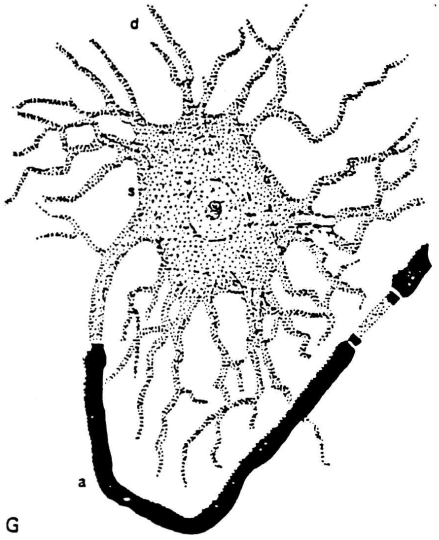



E


F

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## Excitation and Conduction

Resting Potential Across Membrane of axon

Simple version - 9/1 Na+, 11/1 Cl- on the outside
20/1 K+ on inside

Membrane is selectively permeable
Inside is -70mv resting potential relative to outside

K+ is always permeable, but electric gradient balances with chemical (concentration) gradient

Firing threshold at ~ -60mv. Begins at neuron Soma or synaptic junction. This changes membrane permeability and allows Na+ to rush in until ~ +40mv.

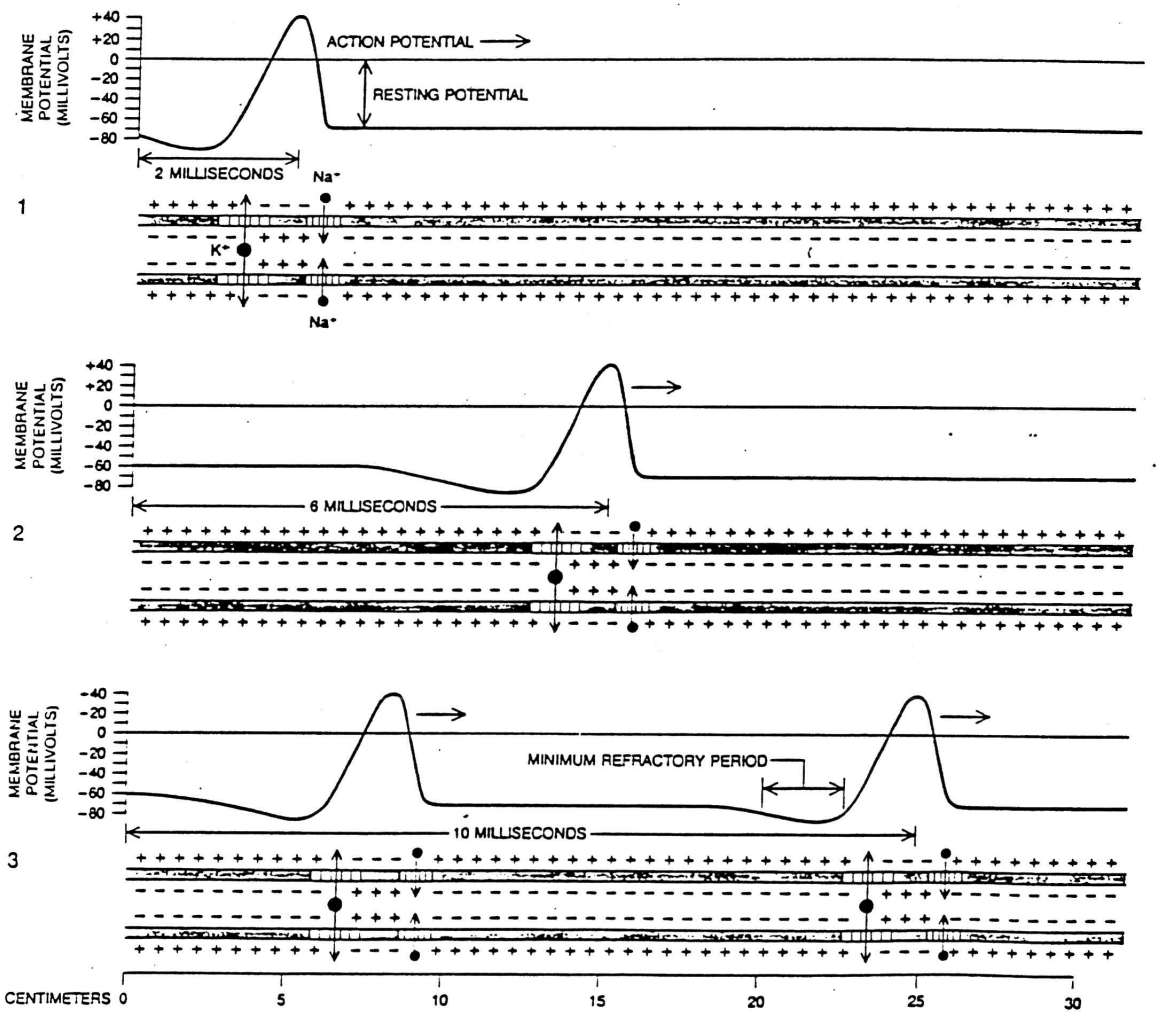
Chemical and Electric gradient then cause outflow of K+ which stabilizes axon.

Speed of action potential .5m/s - 100 m/s - dependent on size and cabling quality (myelin sheath) of axon.

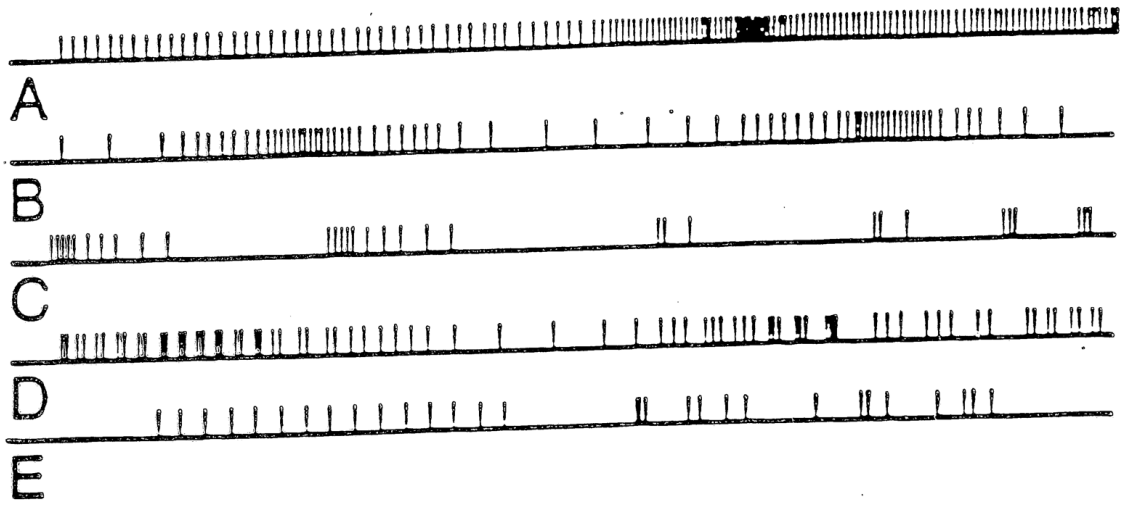
Can fire again after a refractory period. ~1 ms

Inner Na+ ions? - The ever busy sodium pumps

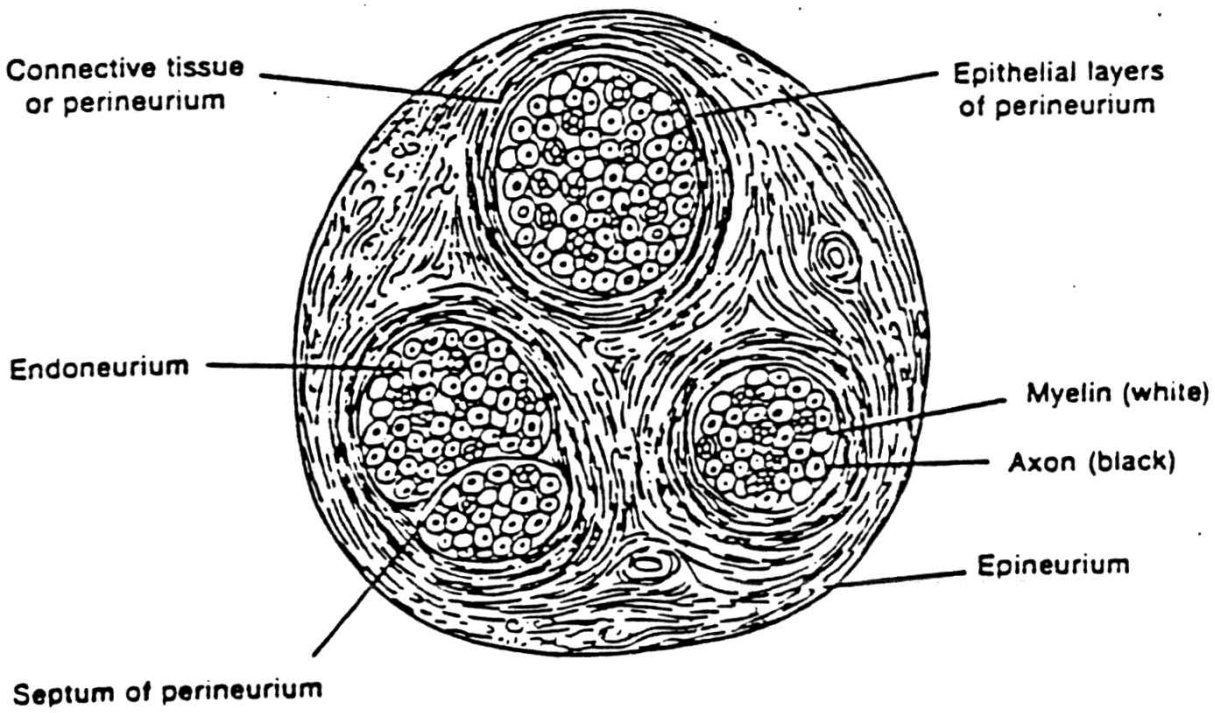
# Propagation of Nerve Impulse



# Temporal Firing Patterns



# Nerve Bundles



# Synaptic Transmission

Axodentritic - most common
also - axoaxonic, dendodendritc, axosomatic, somasomatic, etc.

Electrical and Chemical mechanisms - mostly chemical

The simple version -

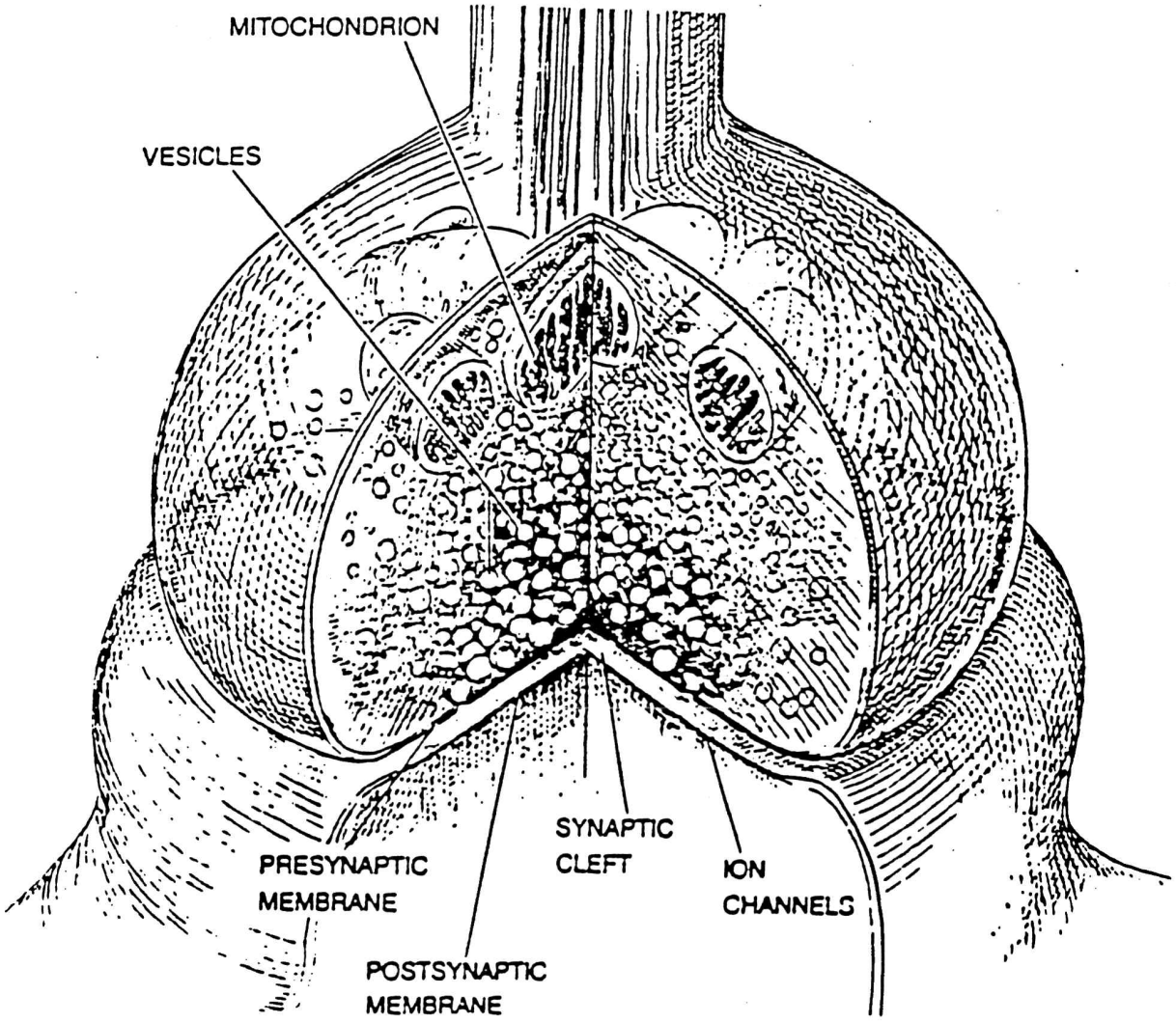
Pre-synaptic Action potential initiates at synapse (through allowing passage of Ca++) - unidirectional

Causes vesicle passage
~300 vesicles per action potential containing chemical transmitter (excitatory or inhibitory) (i.e. ACH acetylcholine or GABA)
Each vesicle contains ~10,000 ACH and are passed to post-synaptic site through exocytosis in < 100 microsec.
Transmitter causes change in post-synaptic membrane permeability leading to firing (excitation) or hyperpolorization (inhibition) depending on type of transmitter at synapse.
Can amplify up to 100x

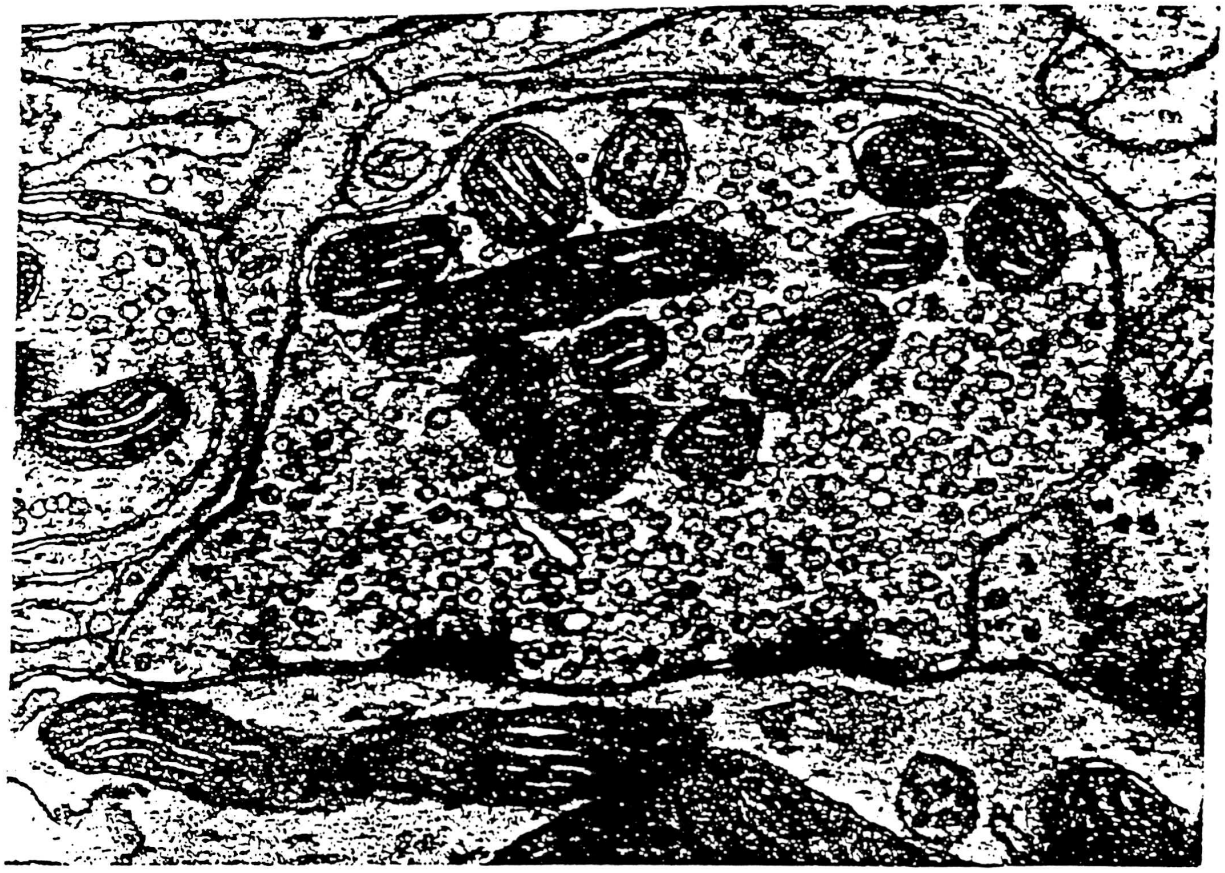
Post-synaptic site may sum from number of synapses - diversity: slow synaptic transmitters, etc.

Somatic summation dependent on closeness of synapse sites and dendrites, size and shape of soma and connecting neurites, etc. If sufficient depolarization, it will cause an action potential down its axon.

# The Synapse


MITOCHONDRION
VESICLES
PRESYNAPTIC MEMBRANE
POSTSYNAPTIC MEMBRANE
SYNAPTIC CLEFT
ION CHANNELS

# Synaptic Terminal



# Brain and Nervous System Structure

Much consistent identifiable structure

Invertebrate vs. Vertebrate

Many parallel aspects -
- Somatic - voluntary
- Autonomic - Involuntary

Nerve Bundles, Spinal Cord, Ganglia and reflexes

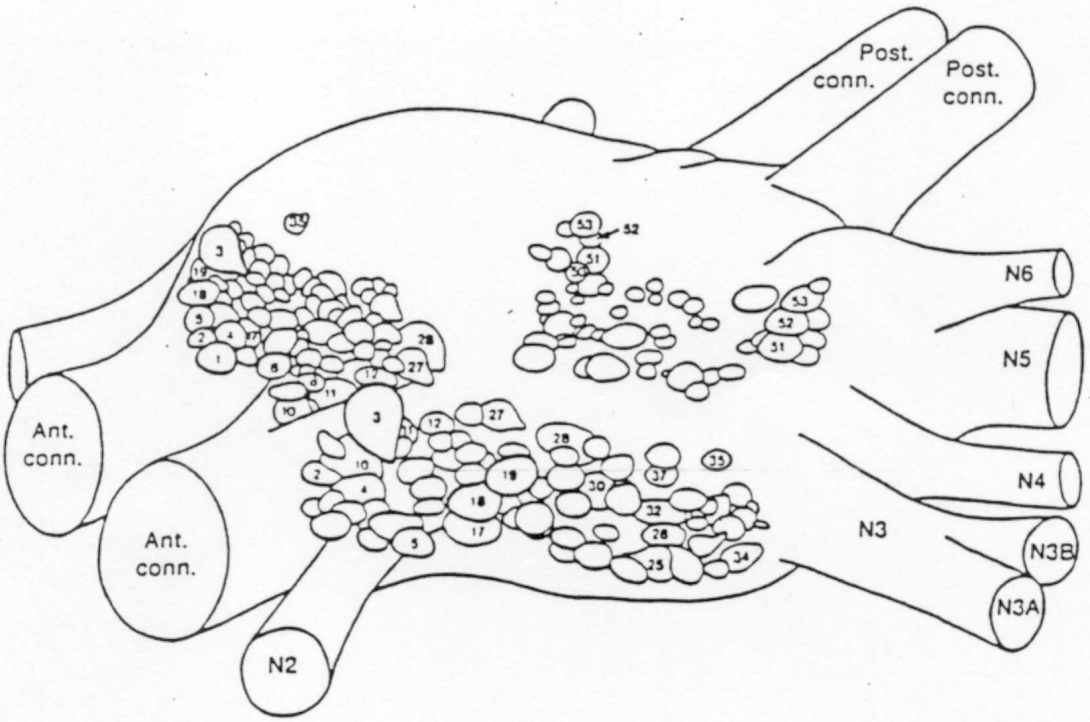
Methods of function postulation

Human Brain

EEG

# Motor Neurons in Cockroach Ganglion

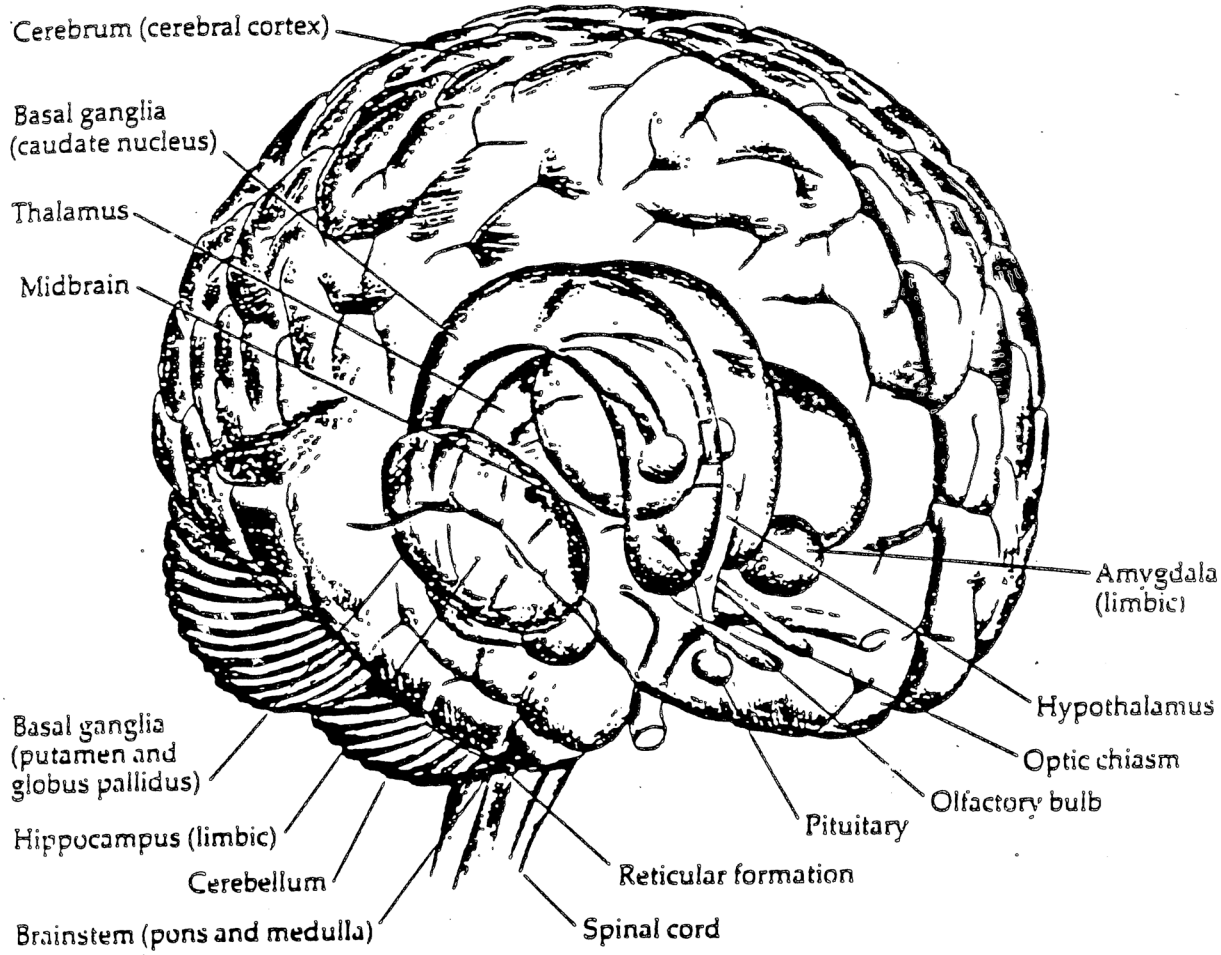
## (Consistency)



## Human Brain

Brainstem - Pons and Medulla - Respiratory, heart, etc.
Midbrain - Tectum -sight, sound, Red Nucleus -- Movement
Cerebellum - Motor coordination, convoluted, regular
Thalamus - Sensory system
Hypothalamus - Hormone control - emotions - Endocrine System
Amygdala - Emotions
Hippocampus - Long term memory?
Basal Ganglia - Movement
Cerebral Cortex - Sensory, voluntary motor skills, Intelligence?
convoluted, 3mm neurons, 6 layers in columns

Corpus Collosum - Hemispheres
Left - Analytical and Verbal Skills, logical, sequential
Right - Holistic, images



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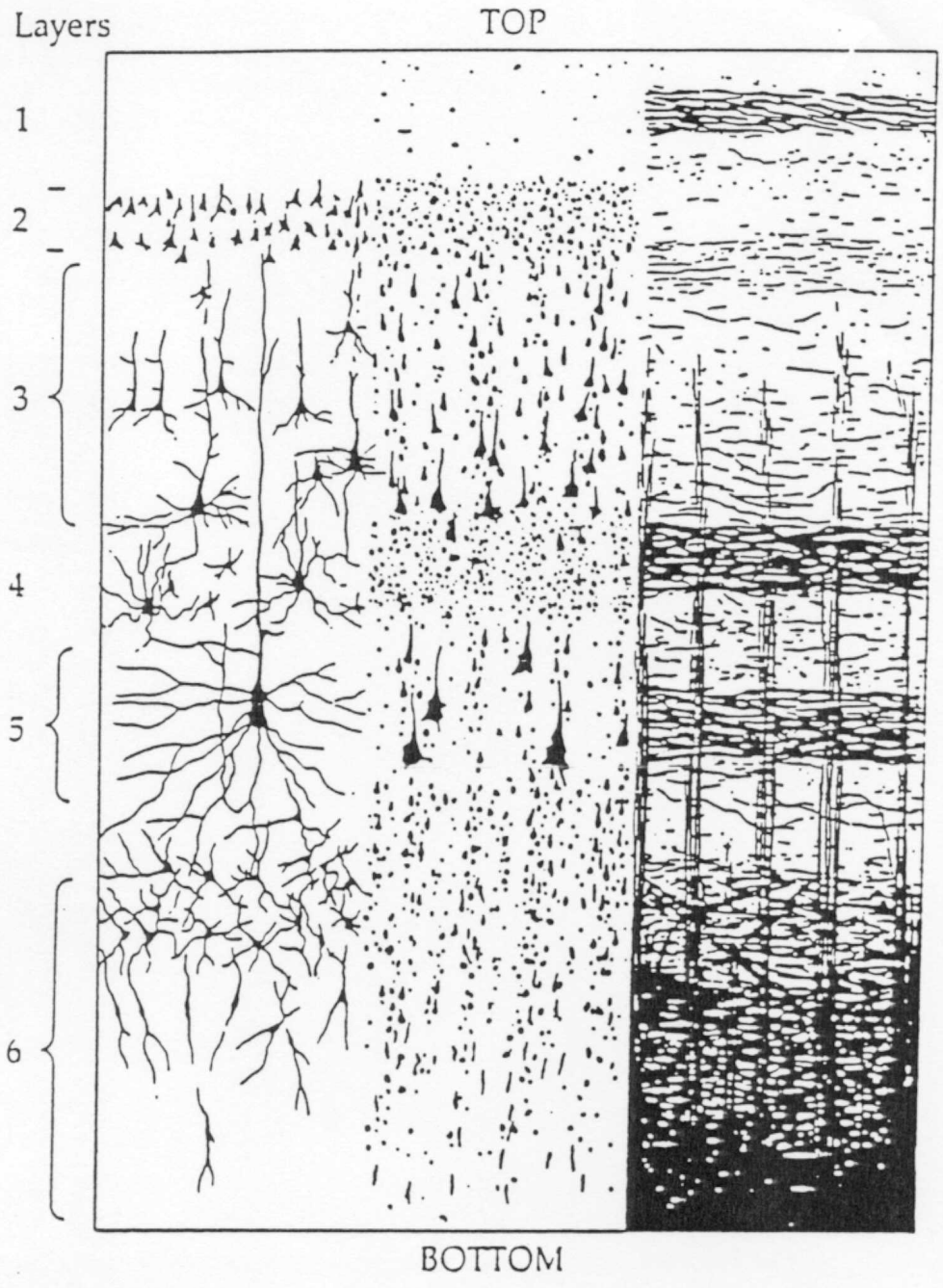
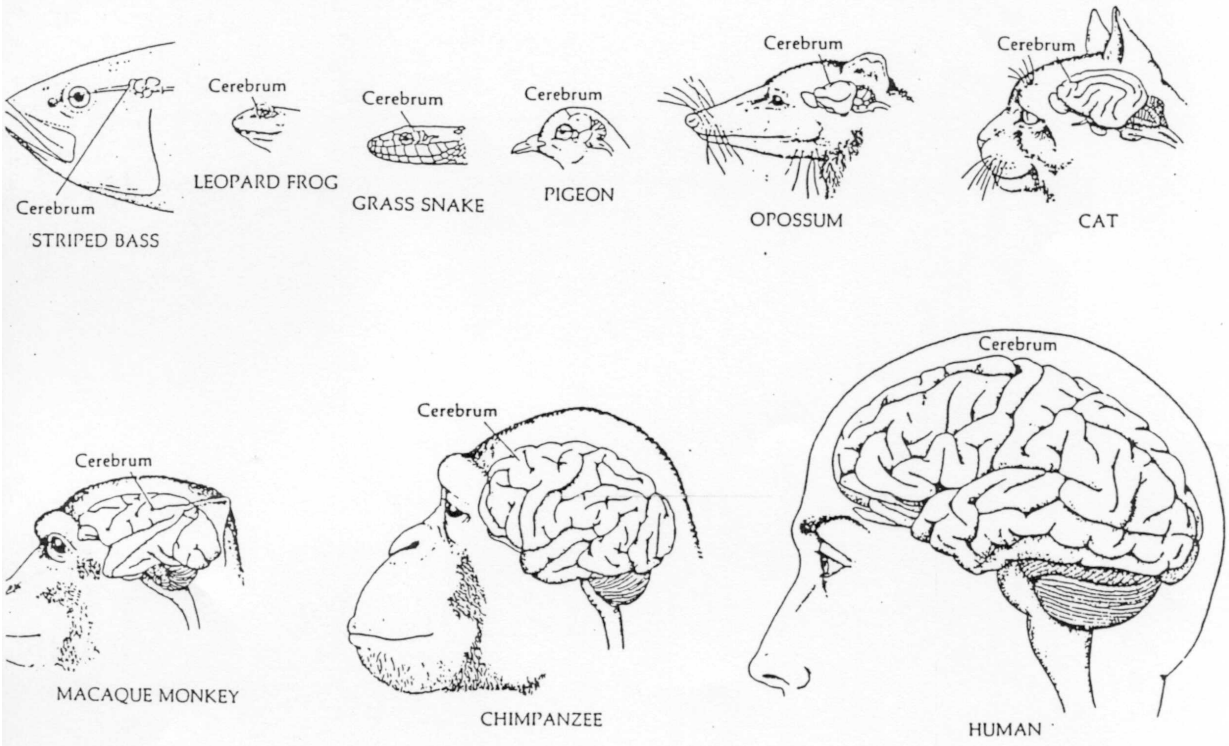
## Layers and Convolution

## Cerebral Cortex



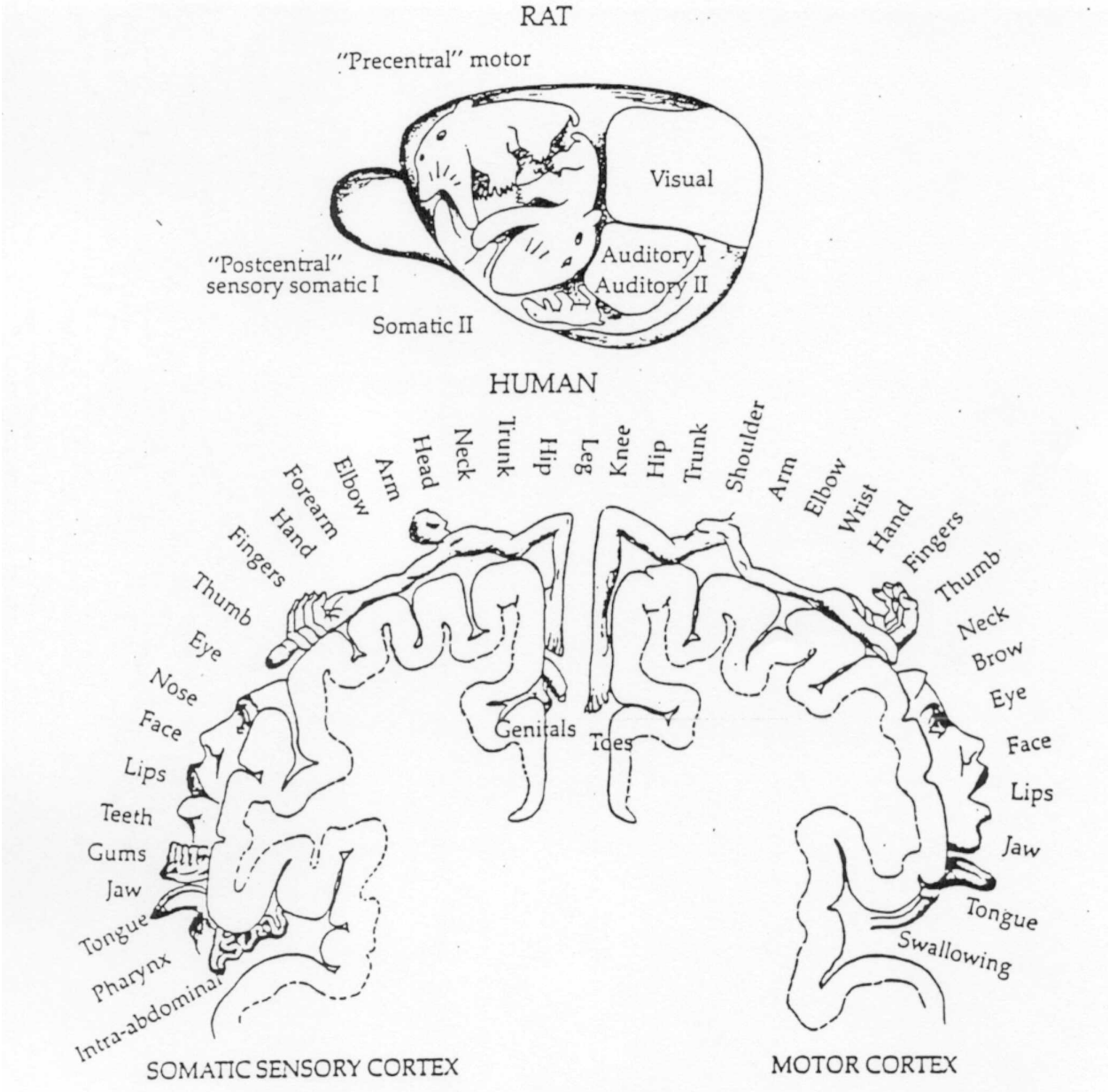
## Cerebrum Comparisons

## (Thinking Centers?)



# Homonculus

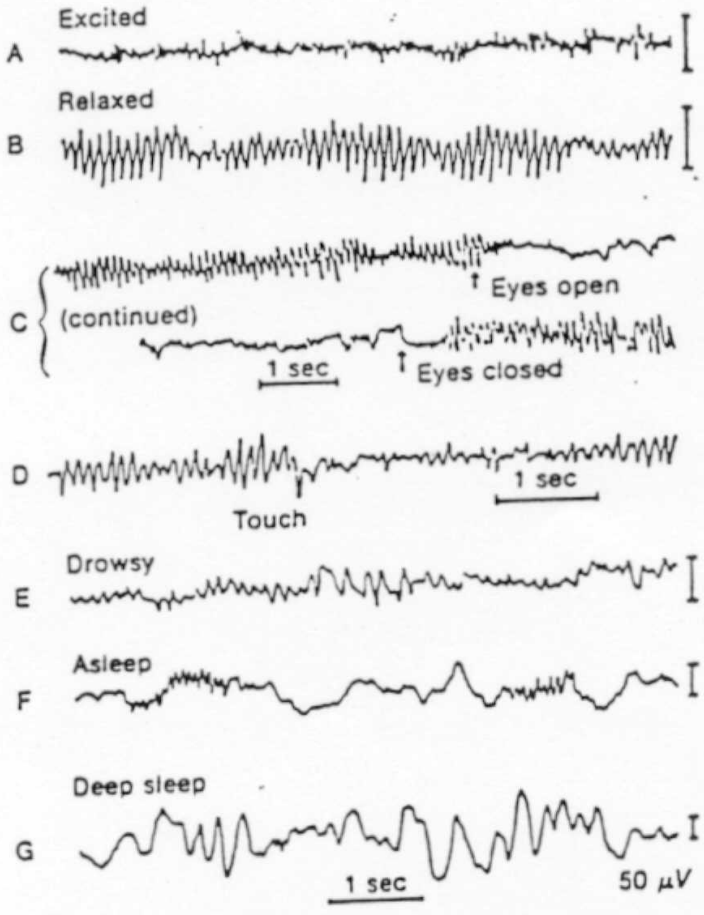
## Symmetricity, Allocation



# EEG - Electroencephalogram

## Brain Waves

## Predictable, Not understood



## Structure and Mechanism

Cerebellar Cortex - Example of highly structured area

Lateral Inhibition - Ubiquitous

Descussation

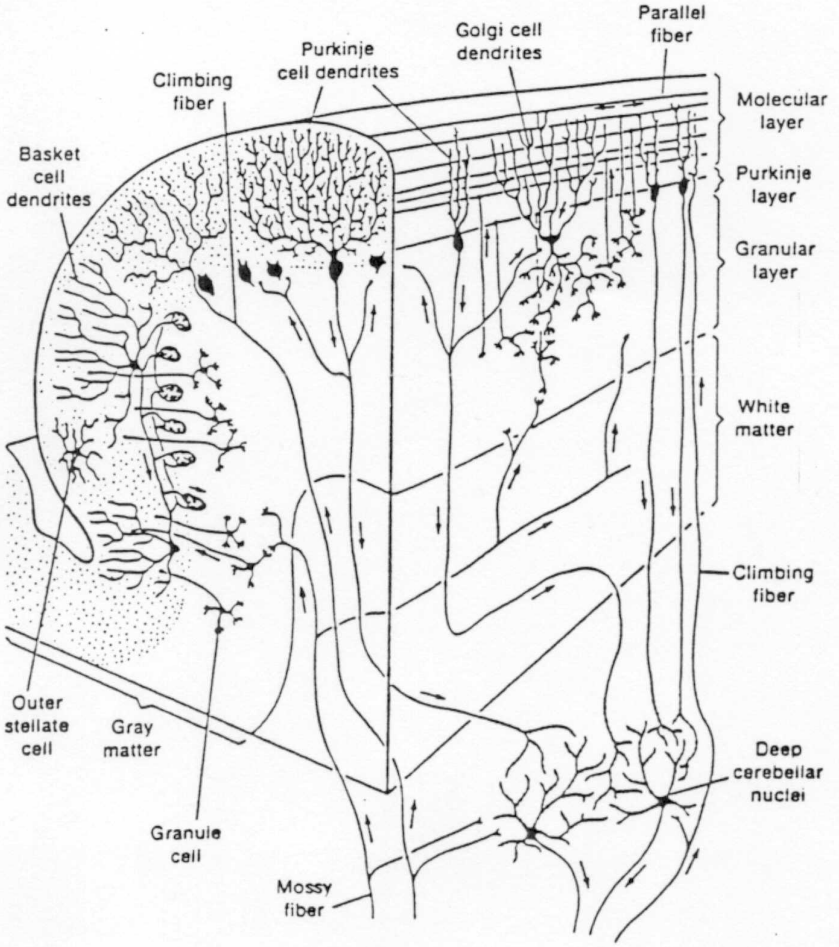
Habituation - Milder reactions to repeated stimuli

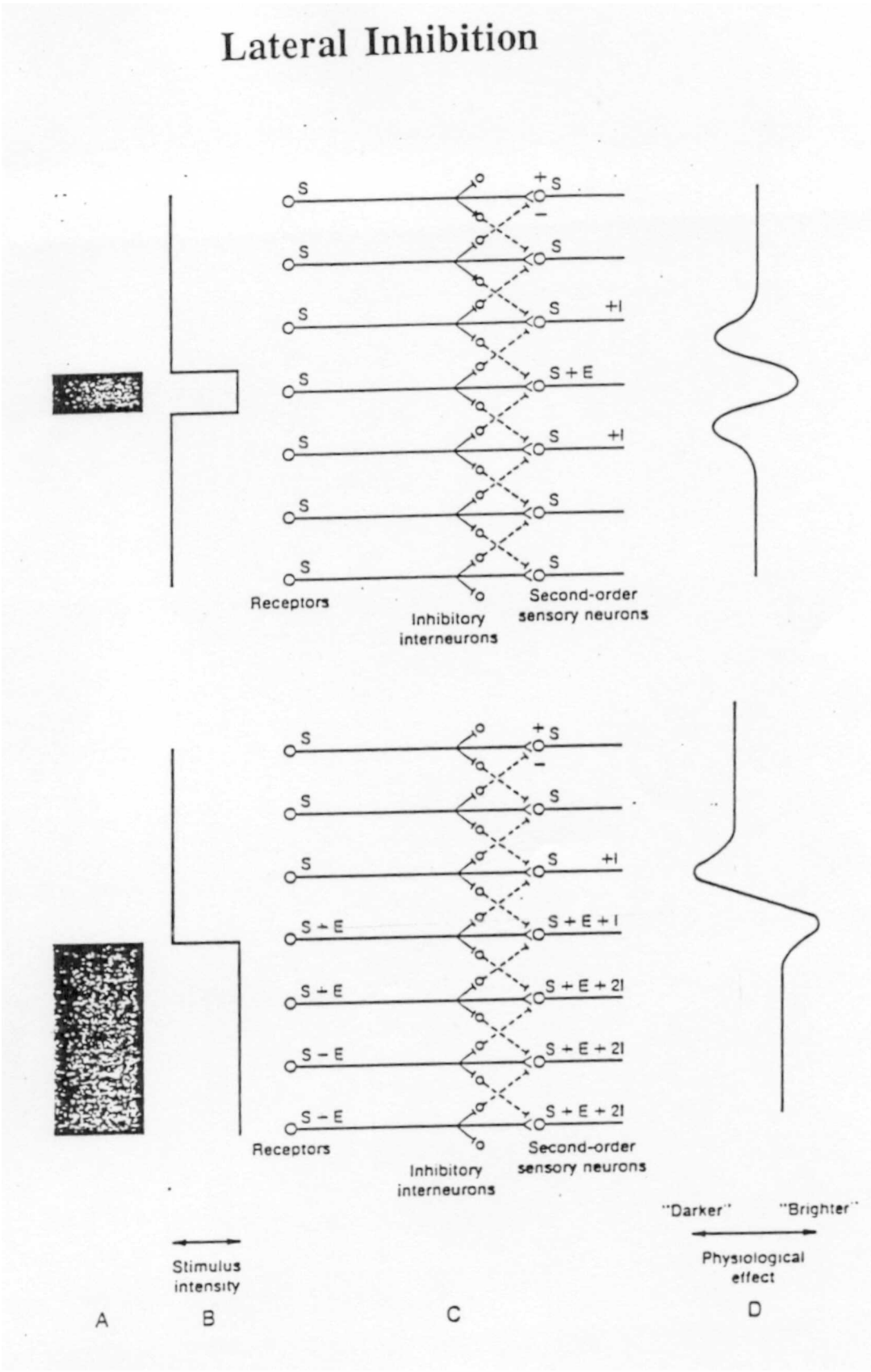
Attention - Short term awareness for events

Hierarchical

## Cerebellar Cortex - Example of Complex Regularity

Each Purkinje has inhibitory output into inner cerebellum
Climbing fiber excitatory on purkinje 1 to 1
mossy fiber - excites purkinje and ~900 granule cells each
each granule cell receives from 4-5 mossy fibers
10 ** 10 granule cells - 7000/purkinje cell
parallel fibers ~250,000 - from granule cells, Each synapses with ~1/5 of purkinjes, excite purkinje, (also stellate, basket, and golgi cells which in turn are mutually inhibitory)
Golgi inhibits granule
Only purkinje outputs lead back into cerebellum

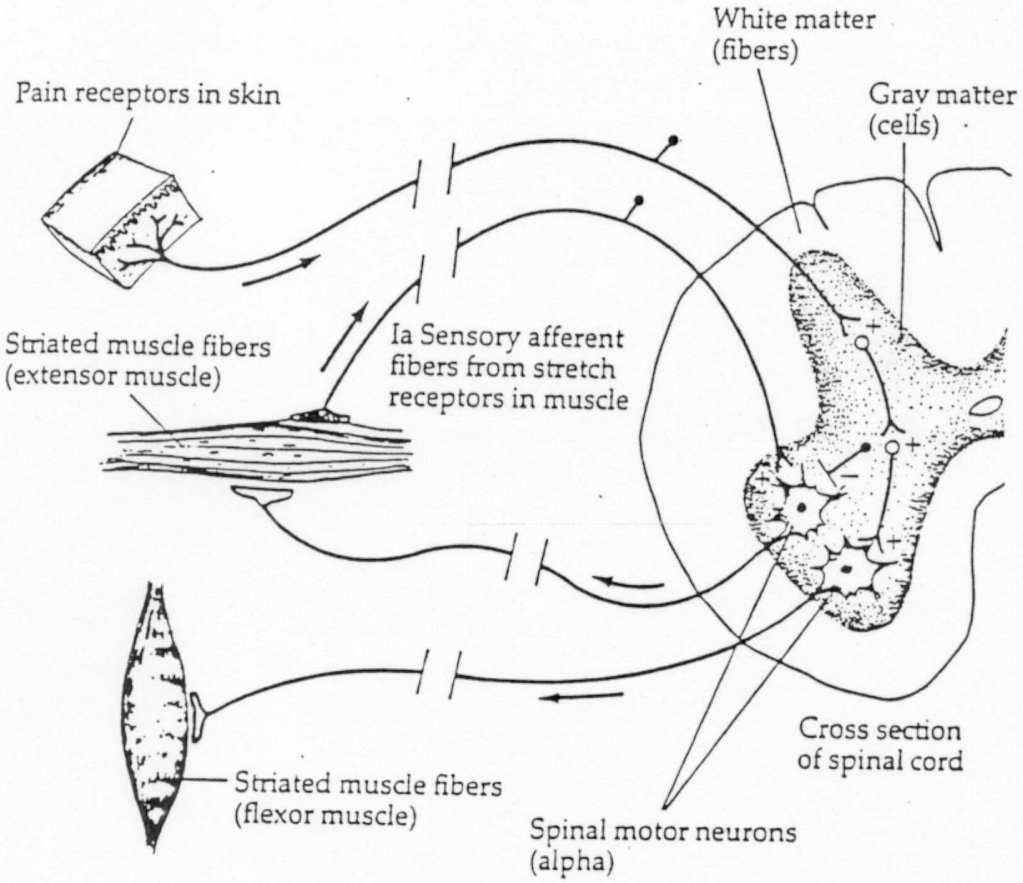



Lateral Inhibition
S
+S
−
S
+I
S + E
S + E + I
S + E + 2I
S − E
Receptors
Inhibitory interneurons
Second-order sensory neurons
"Darker"
"Brighter"
Physiological effect
Stimulus intensity
A
B
C
D

# Reflexes

## Normal Loop when Stretching

## Pain Input will override and cause corrective effect



## Development of Nervous System

Not well understand, perhaps most fascinating

Human - 250,000 neurons per/minute - in embryo - no division later

Divide and migrate - many theories

Differentiation - initially similar, change into proper diversity

Overpopulation and Pruning - Extra limbs, etc.

More plasticity in more complex species - also less initial instinct

Diverse hardware allocation - Hawk's eye

Critical learning periods - Cat's eye 4-6 weeks, monkey 1-4 months, human 0-4 years
chemically stimulated? - nore-pinephrene

Effect of environment on arborization, weight, dendritic complexity, etc.

Learning - synaptic change, neurite change, (existence, size, functionality

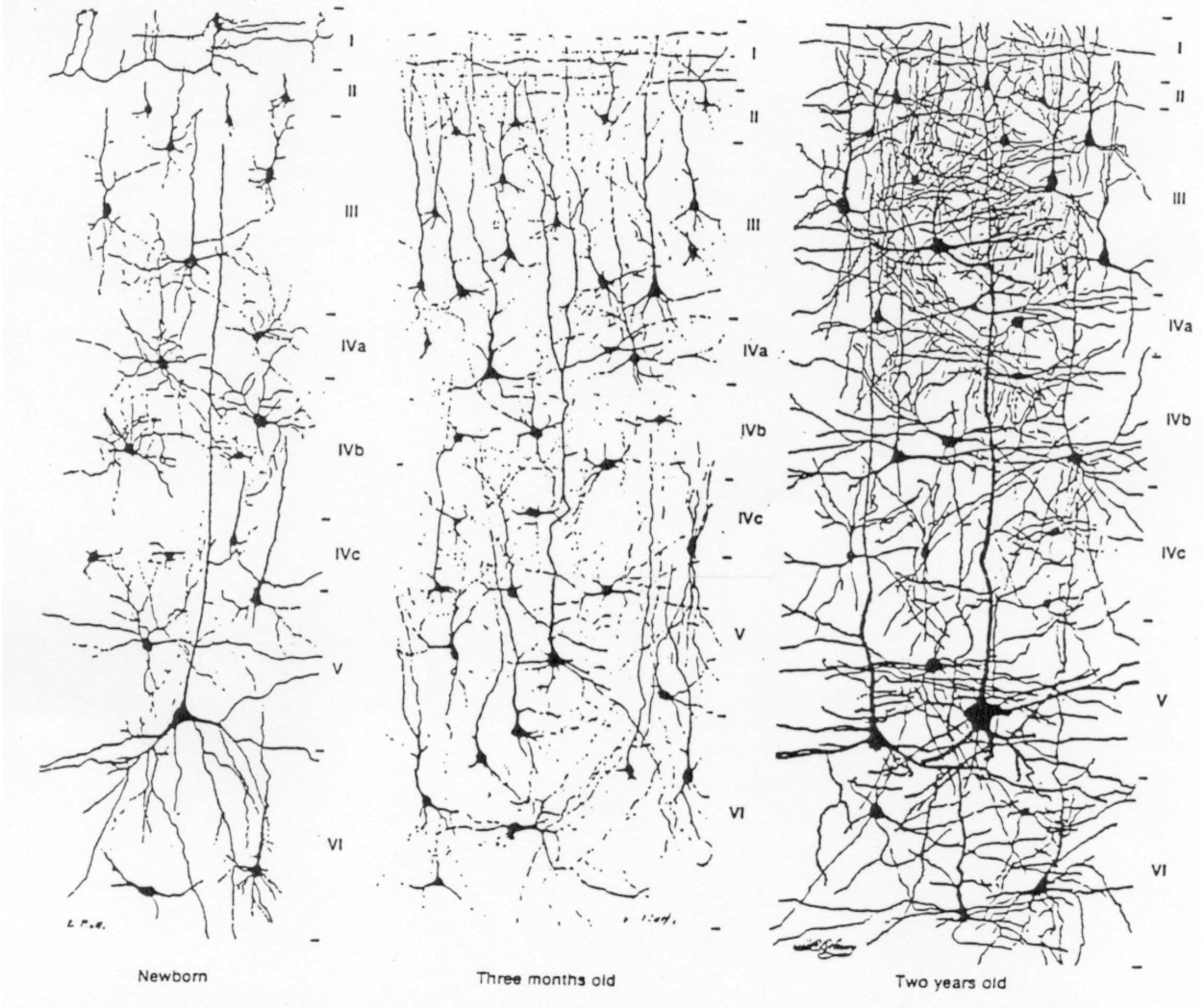
Memory - Short term - theories (synaptic facilitation, accommodation, fatigue), reverberations

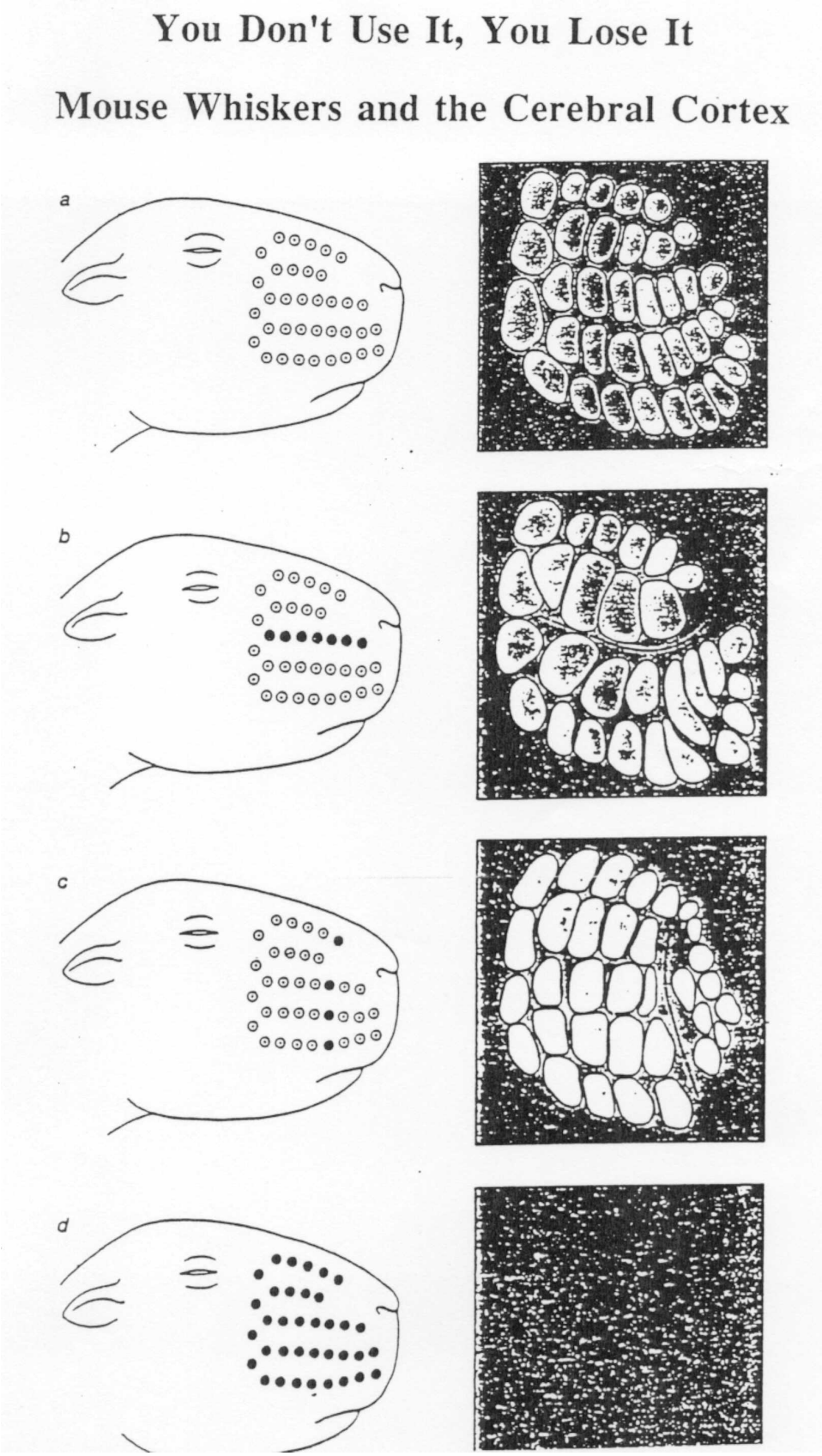
Long term - Synaptic (weight) changes, synaptic and neurite physical changes, Localist vs. distributed, more there than we can get at? - examples

## Dendritic Arborization in Human Visual Cortex

## Newborn, 3 Month, 2 Year Old

## Environment and Arborization (Rats)




You Don't Use It, You Lose It
Mouse Whiskers and the Cerebral Cortex
a
b
c
d