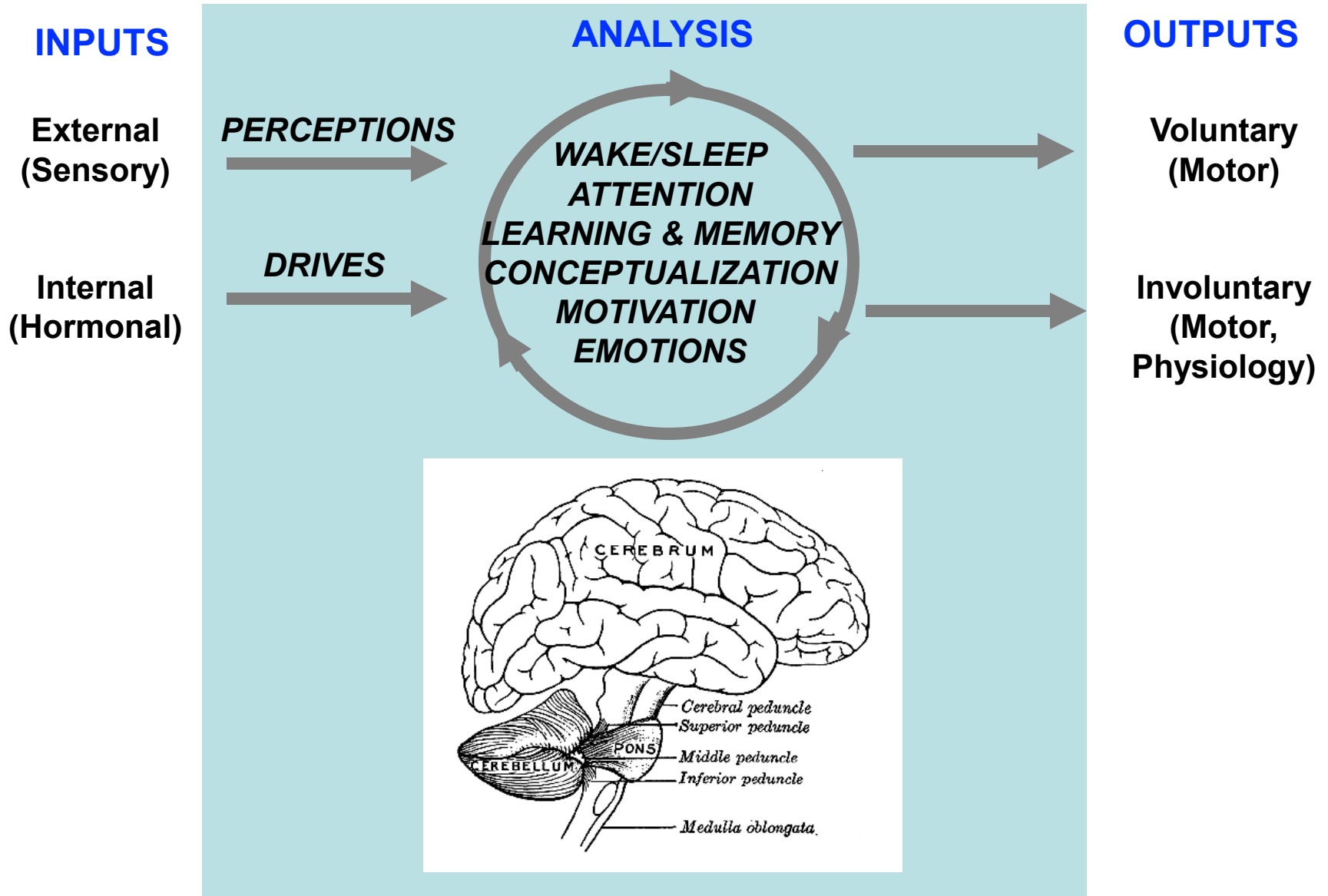


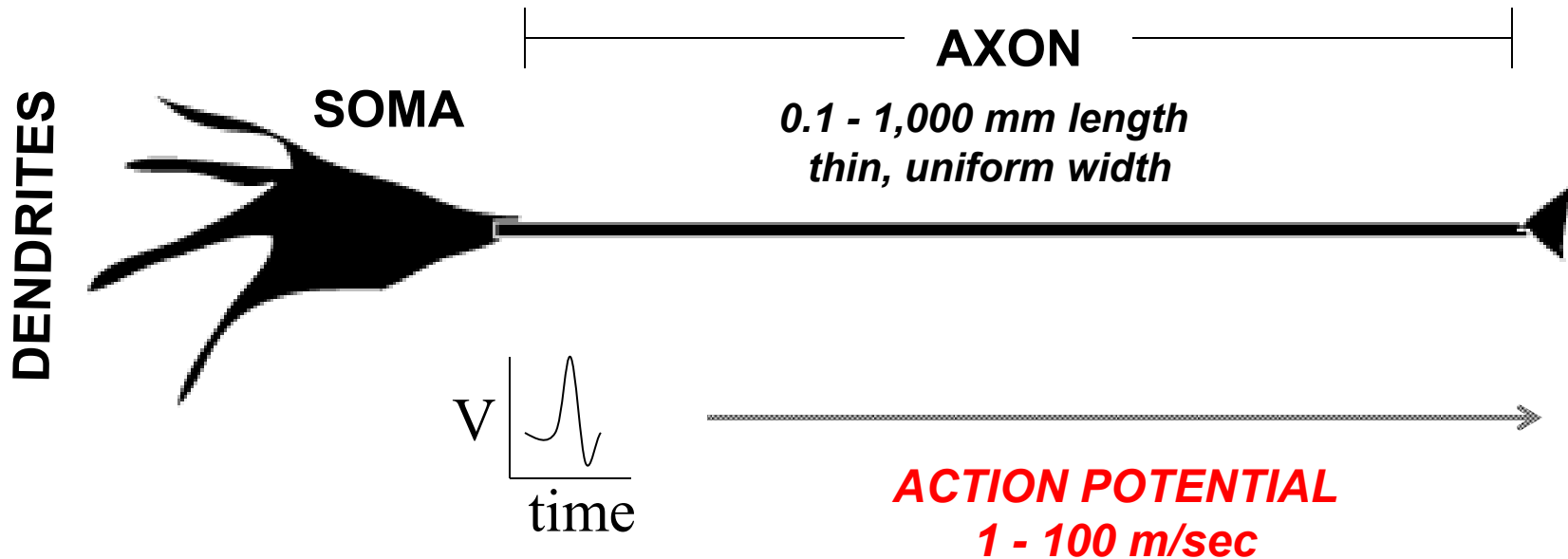
# THE NERVOUS SYSTEM

AN EXQUISITE AND COMPLEX INFORMATION PROCESSING SYSTEM



# THE NEURON

## ELECTRICAL CELL OF THE NERVOUS SYSTEM



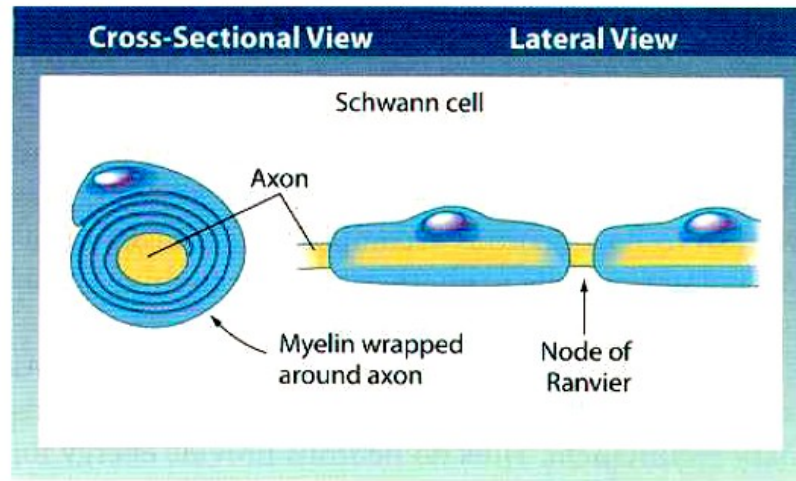
**Action potential** is a digital *one-way* electrical pulse from axon initial segment to axon terminus

Neurons can fire action potentials repetitively at frequencies up to 200 pulses/sec

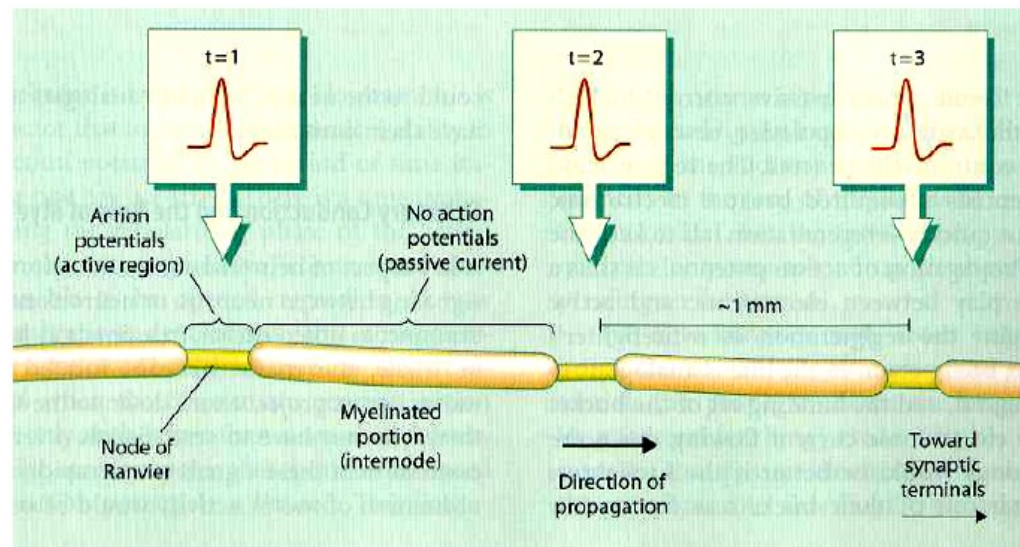
There are *10 billion neurons* in the human nervous system

# MYELIN ON AXONS

AN INSULATING SHEATH TO SPEED AND ENSURE  
LONG-DISTANCE ACTION POTENTIAL PROPOGATION

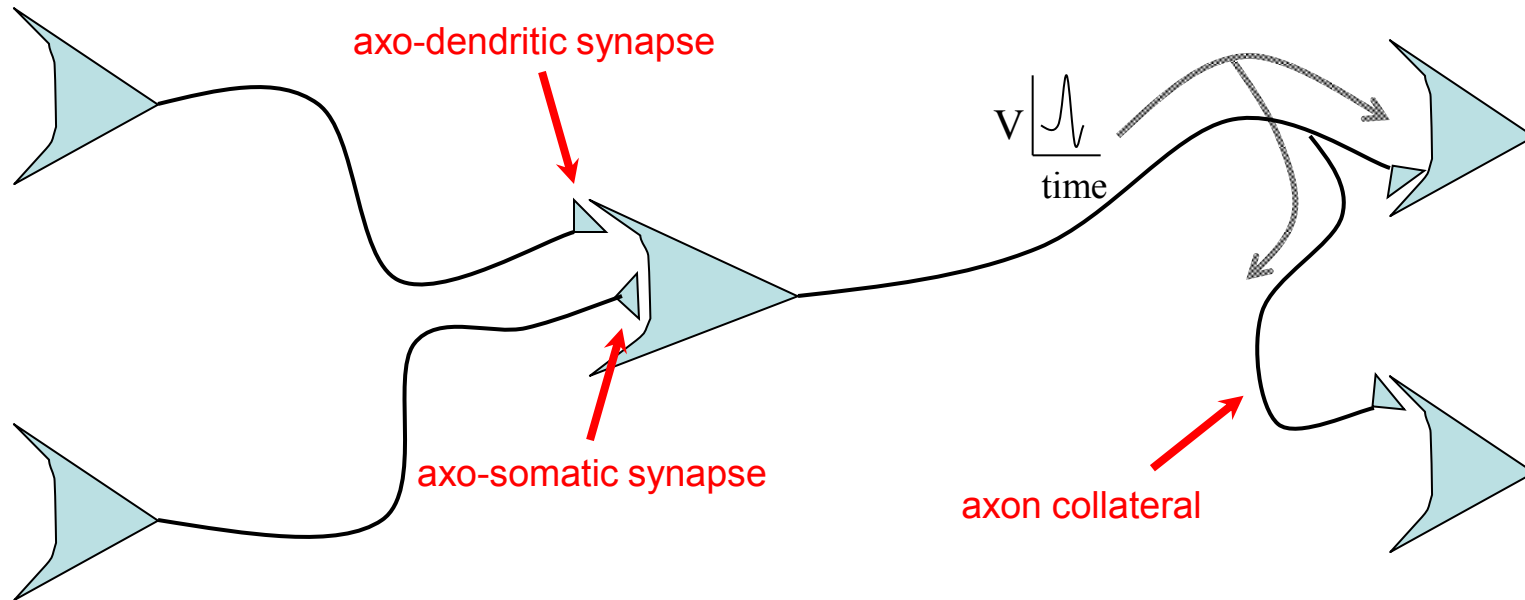


Action potentials occur at nodes of Ranvier  
Myelin sheath insulates axon  
“saltatory” propagation is faster



# THE SYNAPSE

CONTACT BETWEEN NEURONS THAT MEDIATES COMMUNICATION



A neuron can receive synaptic inputs from many other neurons  
*(pyramidal neuron in cerebral cortex can have **1,000** synaptic inputs)*

A neuron's axon can have collateral branches which synapse on  
different neurons  
*(the action potential will propagate down all branches)*

# GENERATION OF ELECTRICAL CURRENTS AT SYNAPSES AND ALONG AXONS

**Neurons are *BATTERIES* that store energy in the form of *ION GRADIENTS* and *ELECTRICAL POTENTIALS* across cell surface membrane**

<i>outside</i>	$[Na^+]_o = 130 \text{ mM}$	$[K^+]_i = 5 \text{ mM}$
----------------	-----------------------------	--------------------------

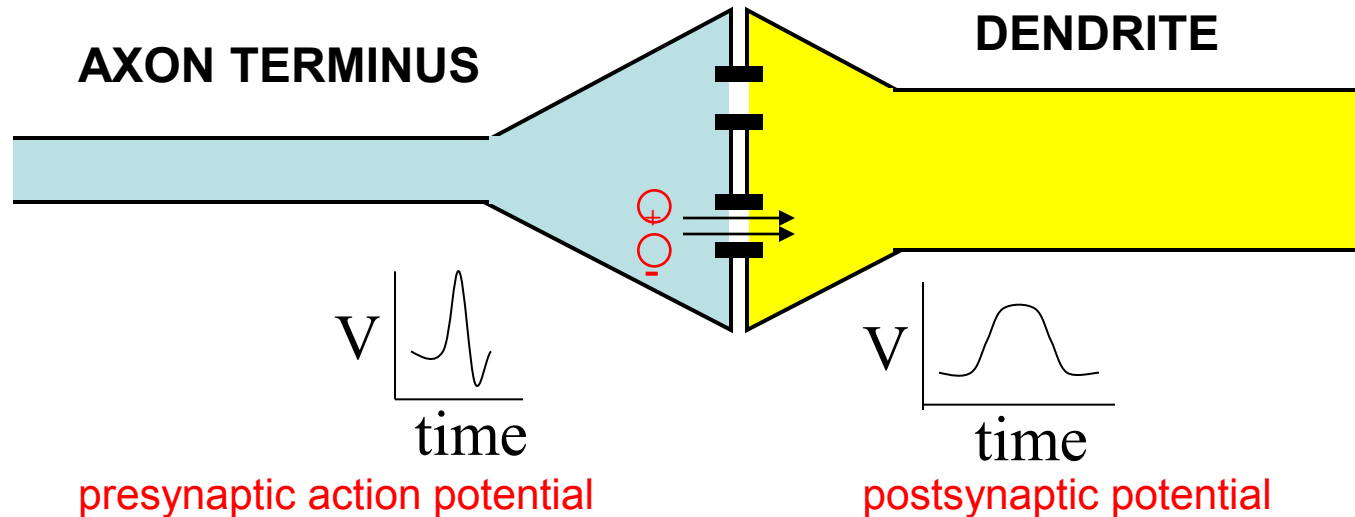
<i>AXON</i>	$[Na^+]_i = 5 \text{ mM}$	$[K^+]_i = 130 \text{ mM}$
-------------	---------------------------	----------------------------

***ION PUMPS* transport ions against their concentration gradients to create *ION GRADIENTS* batteries  
Pumps are driven by energy from ATP hydrolysis**

***ELECTRICAL CURRENTS* are generated by the opening of *ION-SELECTIVE CHANNELS*, allowing flow of current as ions down their concentration and electrical potential gradients**

# THE ELECTRICAL SYNAPSE

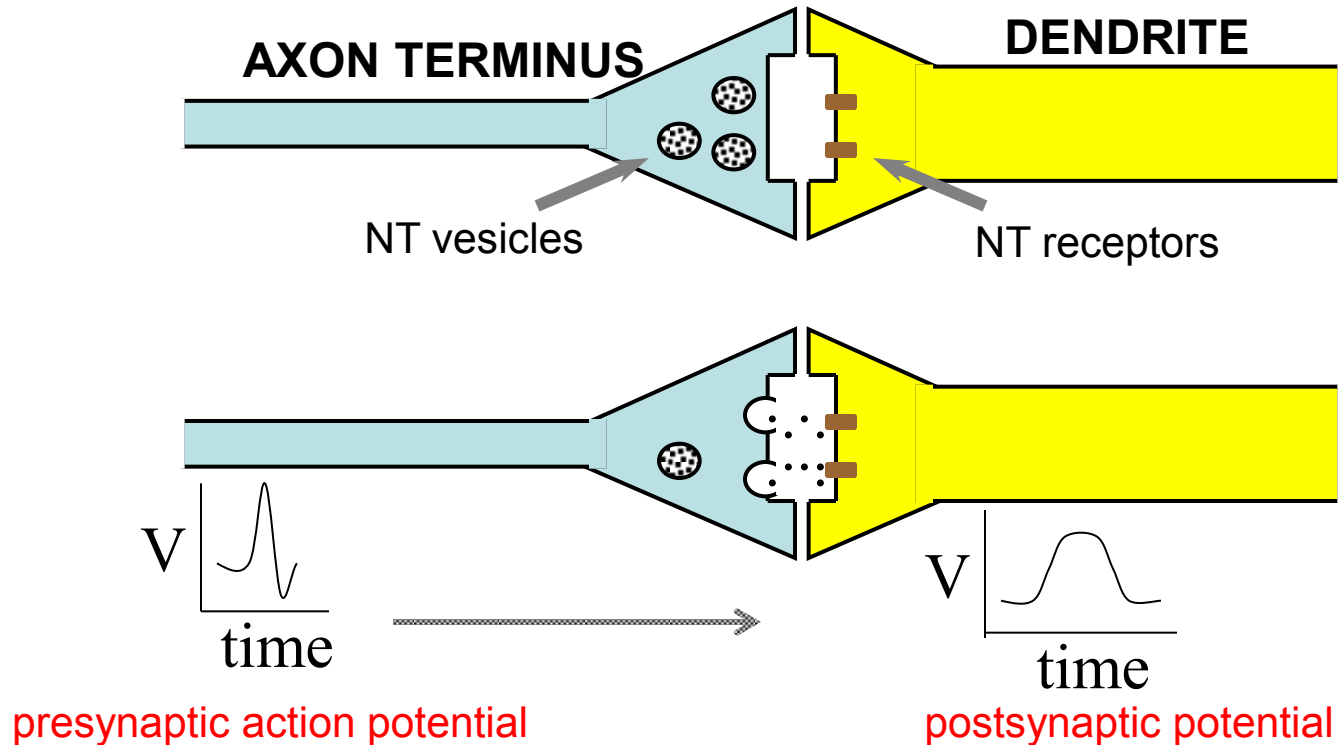
## DIRECT ELECTRICAL TRANSMISSION THROUGH GAP JUNCTIONS



Gap junctions allow free diffusion of ions between cells  
Electrical current from action potential travels through synapse

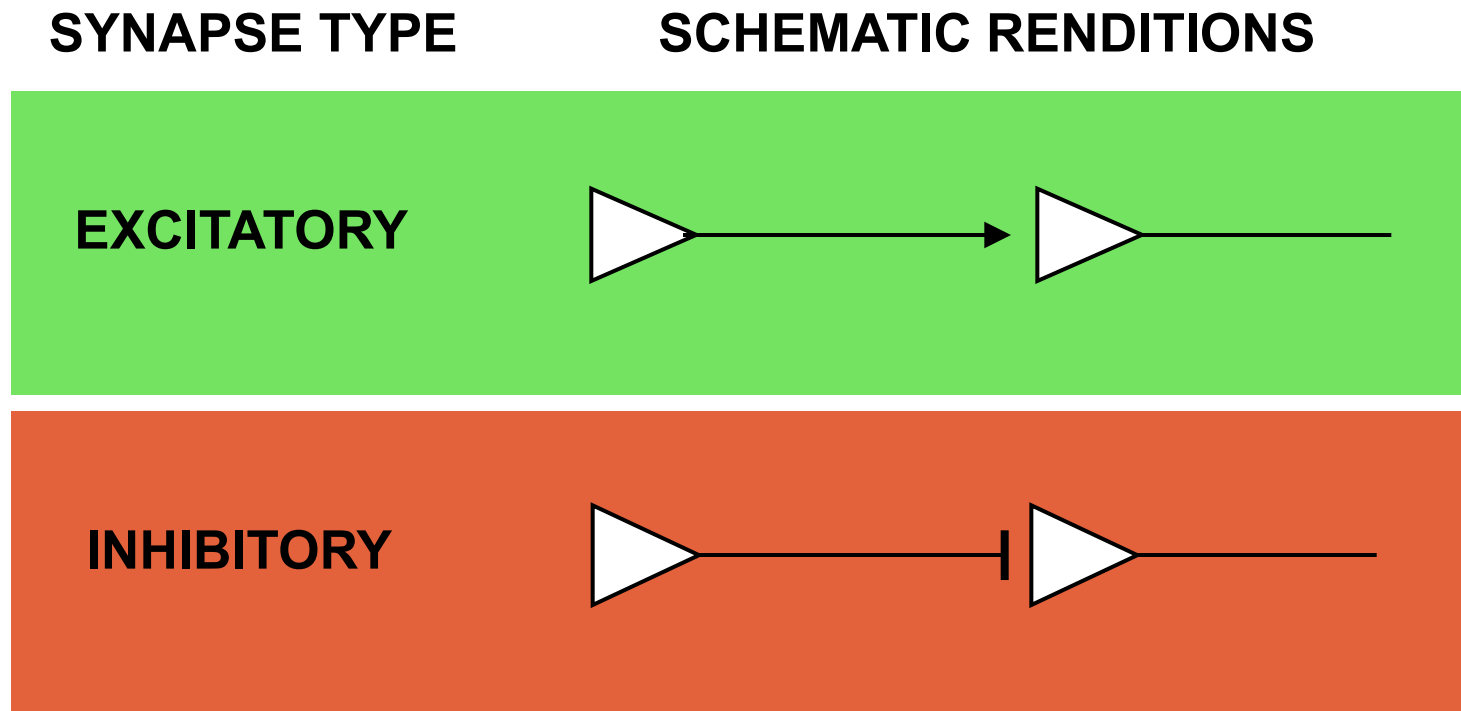
# THE CHEMICAL SYNAPSE

## NEUROTRANSMITTER RELEASE FROM PRESYNAPTIC TERMINAL INTO SYNAPTIC CLEFT



Action potential triggers vesicle exocytosis  
Neurotransmitter binding to post-synaptic receptors  
triggers post-synaptic electrical response

# EXCITATORY VS. INHIBITORY CHEMICAL SYNAPSES



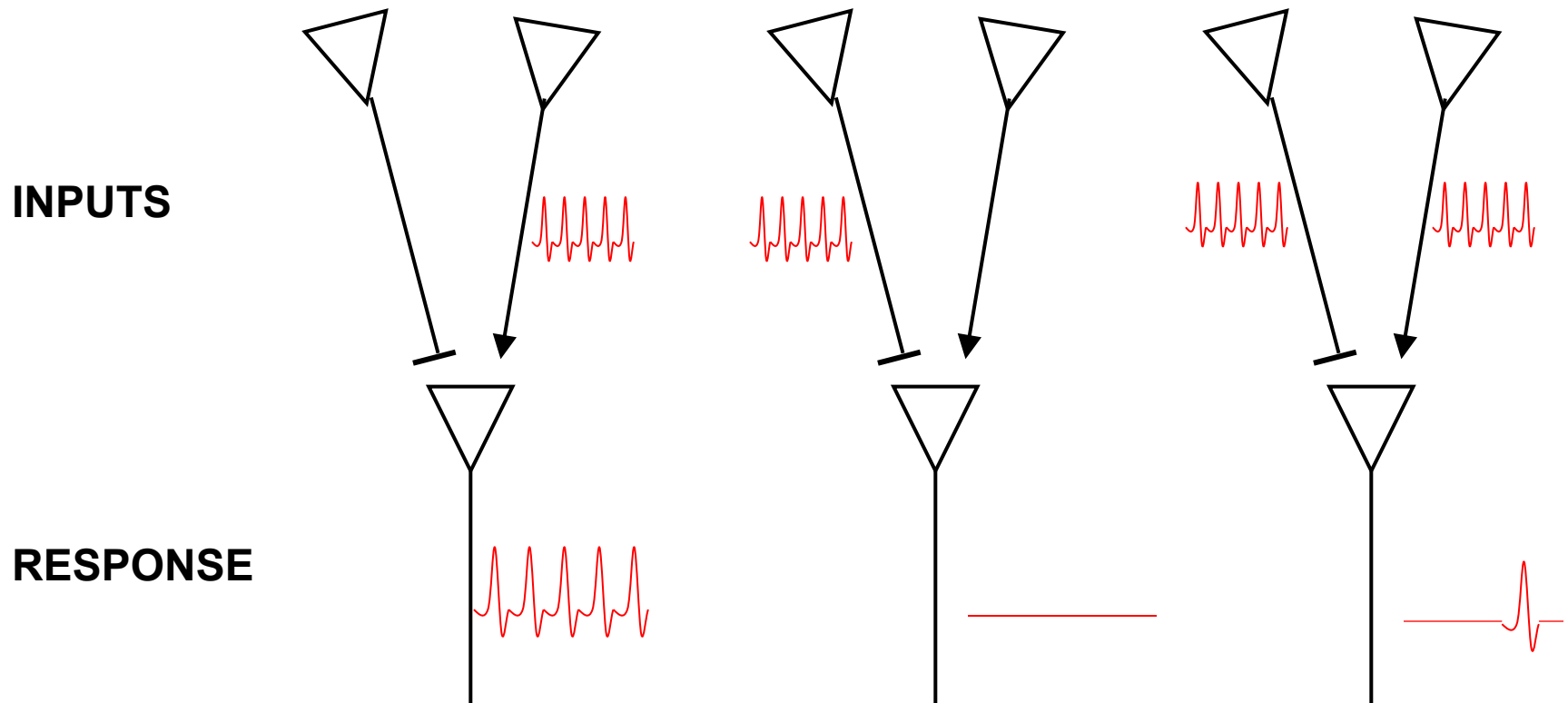
Neurotransmitter release at **excitatory** synapse *favors* action potential generation in post-synaptic cell

Neurotransmitter release at **inhibitory** synapse *discourages* action potential generation in post-synaptic cell



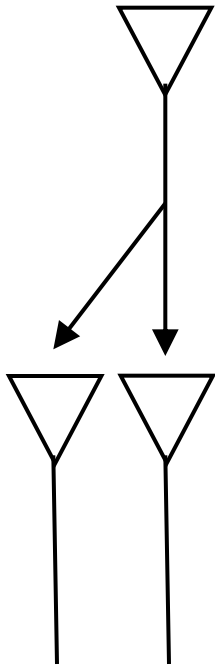
# A NEURON MAY RECEIVE BOTH EXCITATORY AND INHIBITORY INPUTS

MULTIPLE SYNAPTIC INPUTS ARE *INTEGRATED* TO SET  
THE FREQUENCY OF ACTION POTENTIAL GENERATION



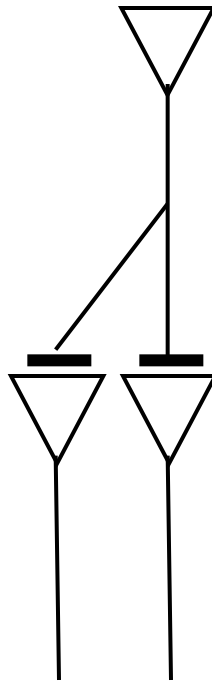
# ONLY ONE NEUROTRANSMITTER IS SYNTHESIZED AND USED BY A NEURON

**NEURON PRODUCING  
EXCITATORY NT**



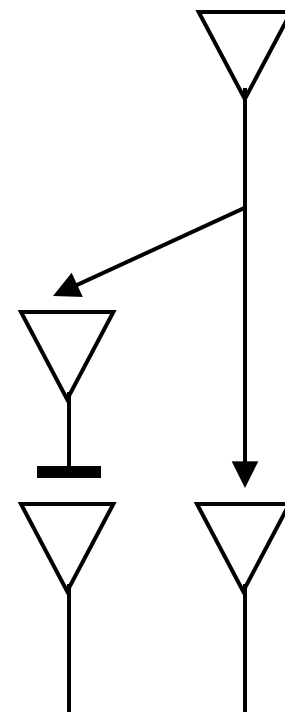
**TWO STIMULATED  
NEURONS**

**NEURON PRODUCING  
INHIBITORY NT**



**TWO INHIBITED  
NEURONS**

**NEURON PRODUCING  
EXCITATORY NT**



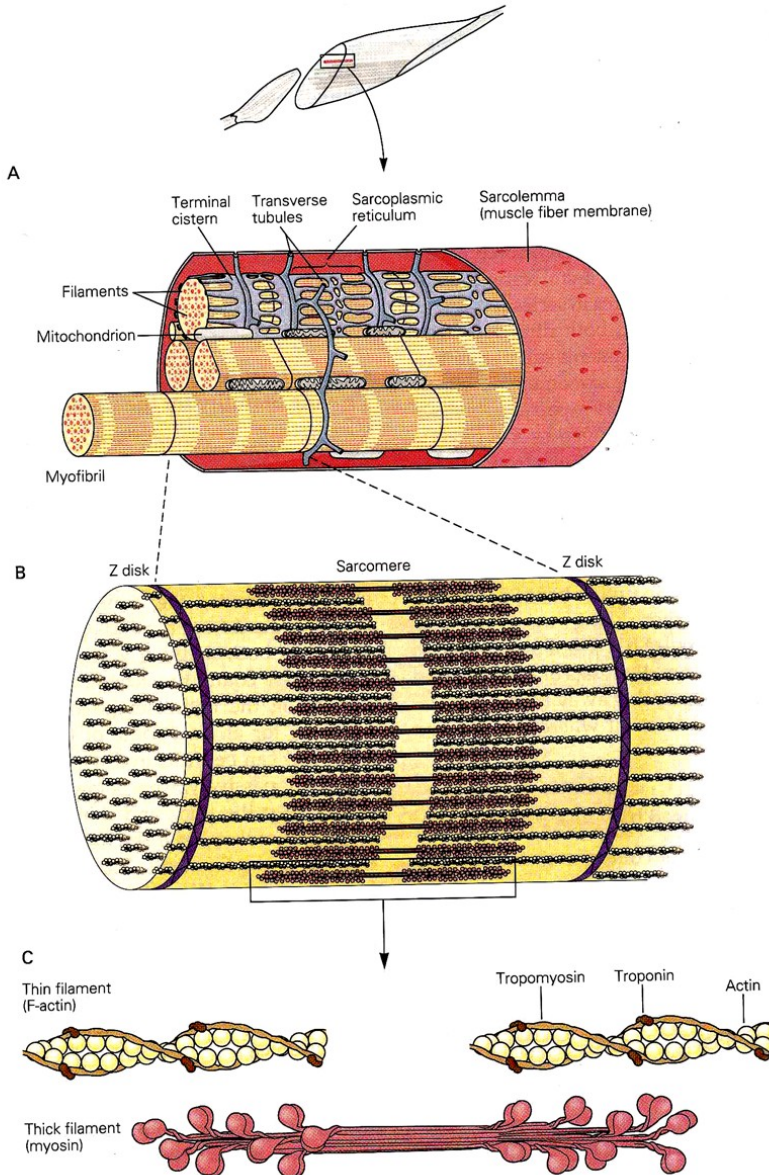
**INHIBITED**

**STIMULATED**

**ONE NEURON CAN INDIRECTLY MEDATE BOTH  
EXCITATORY AND INHIBITORY RESPONSES**

# MUSCLE FIBERS, LIKE NEURONS, ARE EXCITABLE

## MUSCLE ACTION POTENTIALS TRIGGER CONTRACTION

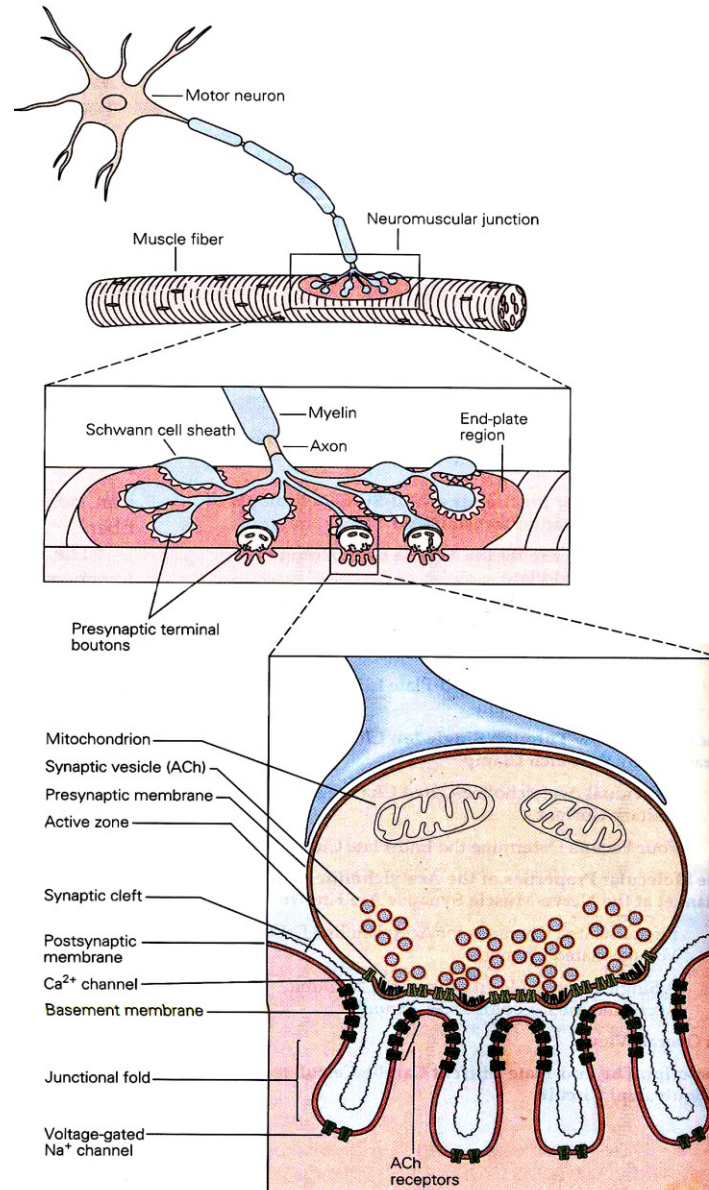


**Action potential**  
traveling through  
muscle fiber induces  
**elevation** in cytosolic  
**Ca<sup>2+</sup>** ion concentration

**Ca<sup>2+</sup>** and ATP drive  
the sliding of **myosin**  
filaments along **actin**  
filaments, thereby  
causing contraction

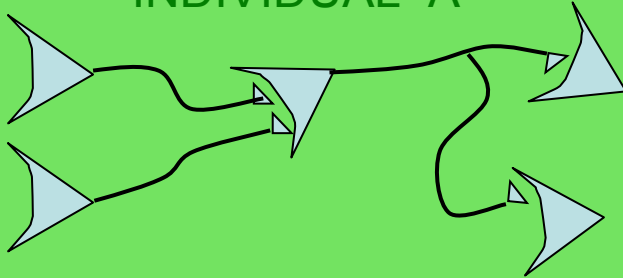
# THE NEUROMUSCULAR JUNCTION

## EXCITATORY SYNAPSE BETWEEN MOTOR NEURON AXON AND MUSCLE FIBER

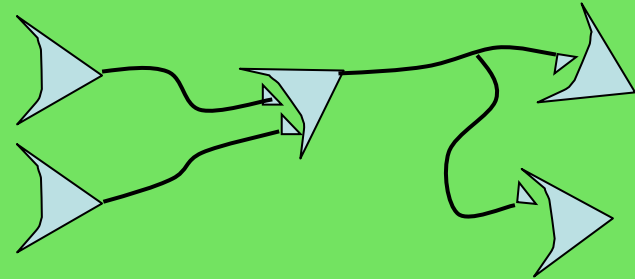


# THE NERVOUS SYSTEM IS HARD-WIRED WITH ADAPTABLE FUNCTION

INDIVIDUAL "A"

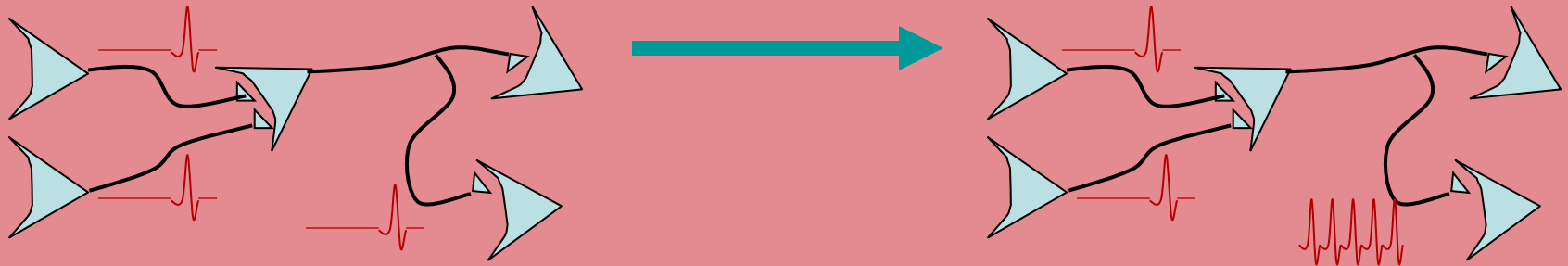


INDIVIDUAL "B"



EACH PERSON HAS ALMOST THE SAME NEURAL WIRING

EXPERIENCE

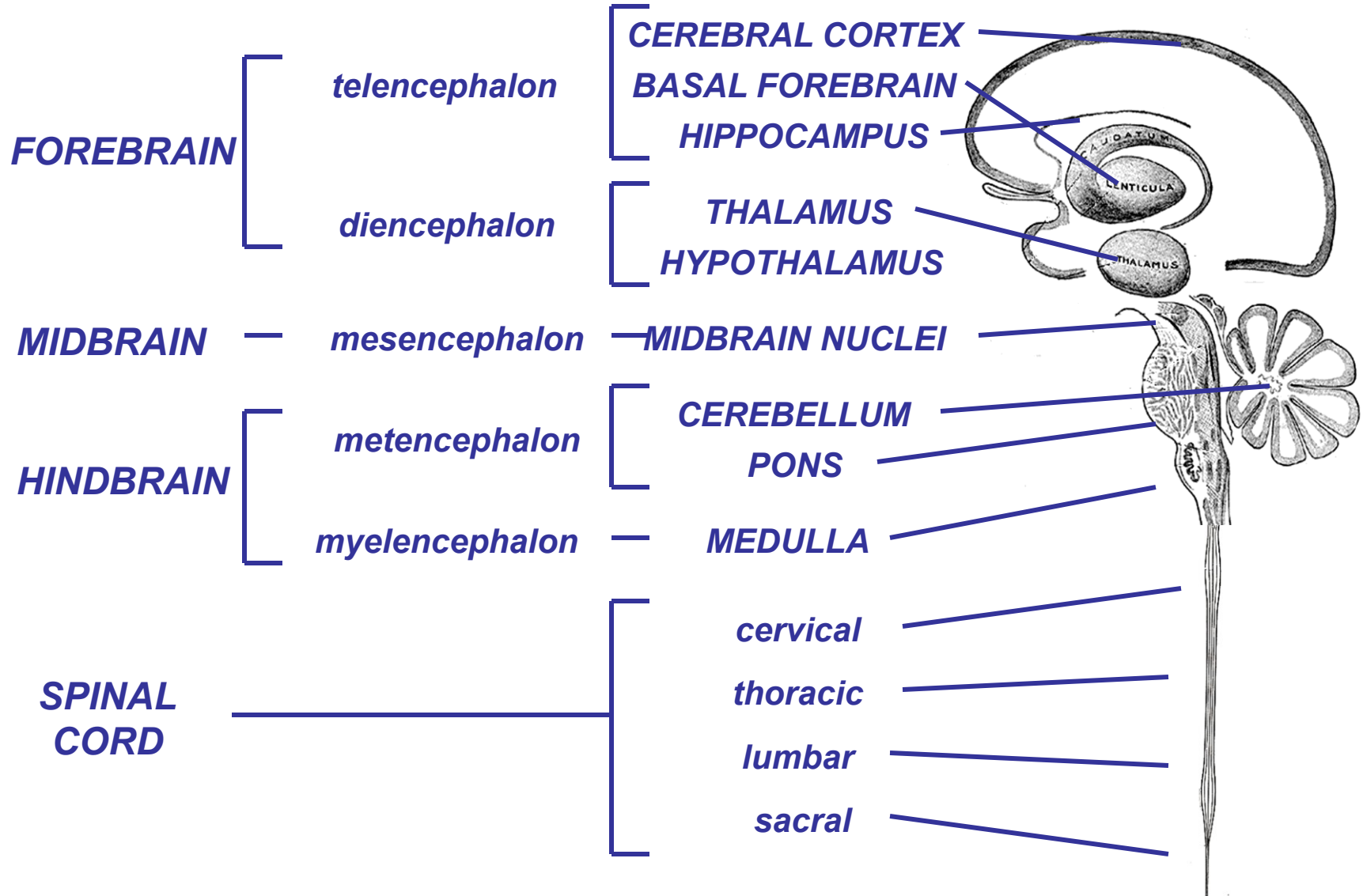


EXPERIENCE CHANGES STRENGTH OF SYNAPTIC CONNECTIONS  
BASIS OF LEARNING AND MEMORY?

# CENTRAL NERVOUS SYSTEM (CNS)

## A HIERARCHY OF DOMAINS

*lower* ----- *higher*



# THE CEREBRAL CORTEX

## THE HOME OF CONSCIOUSNESS

**CONSCIOUSNESS** --- Property of self-awareness and awareness of one's place in the environment

**CEREBRAL CORTEX** --- The highest brain center; different portions perform different functions, but the **SUM** of these activities defines conscious state

**ELECTROENCEPHALOGRAPH (EEG)** --- Measures electrical activity in cerebral cortex.

**FAST ASYNCHRONOUS EEG** --- observed in awake individuals

**SLOW SYNCHRONOUS EEG** --- observed in deep sleep and coma

# PERIPHERAL NERVOUS SYSTEM COMPONENTS

***PNS = all parts of nervous system outside of CNS  
including:***

***MOTOR NERVES:*** Motor neurons are in CNS, but their axons bundle into nerves and travel peripherally to skeletal muscles (VOLUNTARY & REFLEXIVE motor system)

***SENSORY NERVOUS SYSTEM:*** Neuron soma clustered in ganglia near CNS; axons bundled into nerve fibers projecting to periphery and into CNS

***ENTERIC NERVOUS SYSTEM:*** Neuron soma and axons form plexus surrounding gut (INVOLUNTARY motor system)

***SYMPATHETIC & PARASYMPATHETIC NERVOUS SYSTEM:*** Neuron soma clustered in ganglia near CNS; axons project to visceral organs, blood vessel smooth muscle, hair follicles, and sweat glands (INVOLUNTARY motor system)



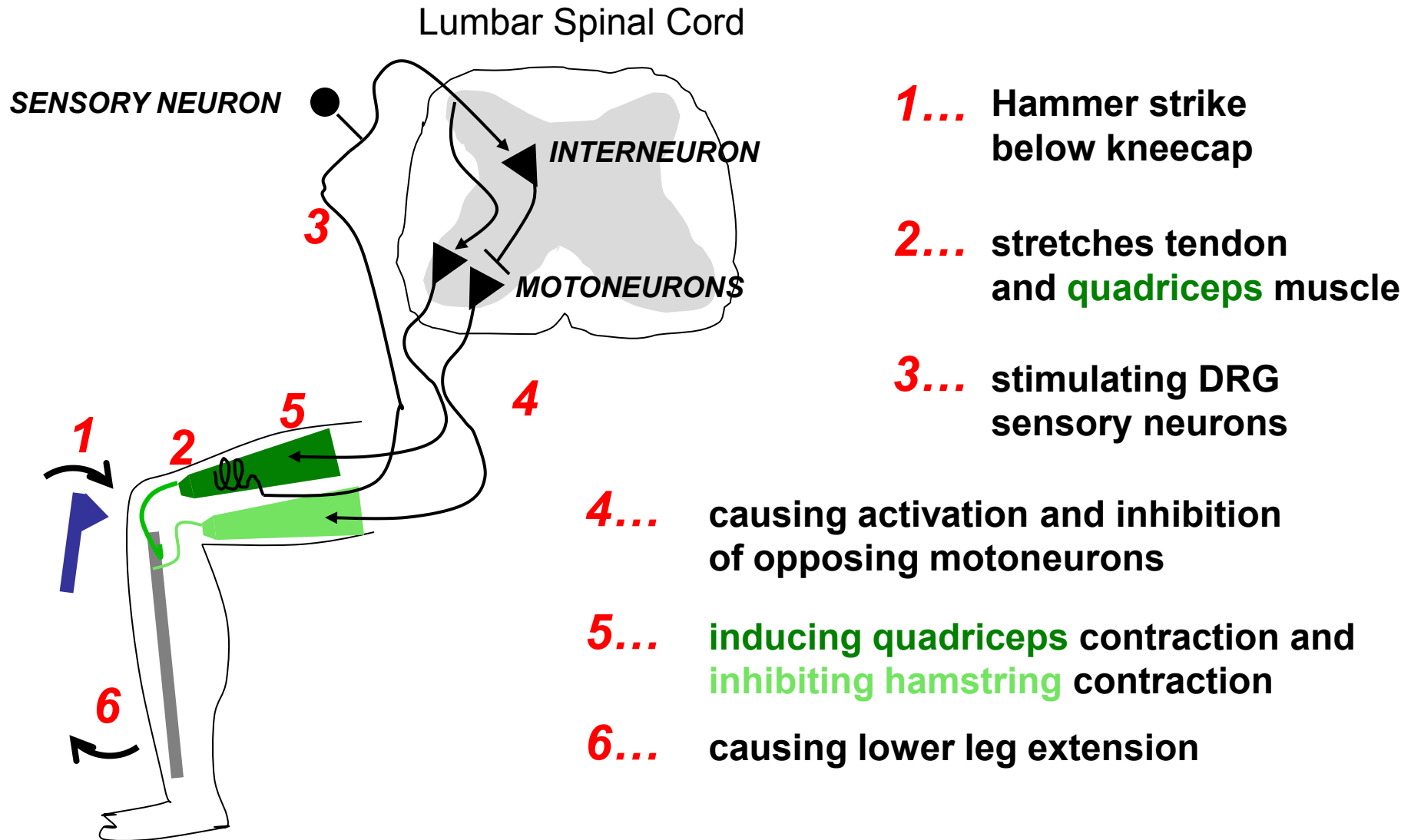
# SENSATIONS

Sensory System	Modality	Stimulus Energy	Receptor Class	Receptor Cell Types
Visual	Vision	Light	Photoreceptor	Rods, cones
Auditory	Hearing	Sound	Mechanoreceptor	Hair cells (cochlea)
Vestibular	Balance	Gravity	Mechanoreceptor	Hair cells (vestibular labyrinth)
Somatosensory	Somatic senses:			Dorsal root ganglia neurons
	Touch	Pressure	Mechanoreceptor	Cutaneous mechanoreceptors
	Proprioception	Displacement	Mechanoreceptor	Muscle & joint receptors
	Heat/cold	Thermal	Thermoreceptor	Cold & warm receptors
	Itch	Chemical	Chemoreceptor	Chemical nociceptor
	Pain	Chemical, thermal mechanical	Chemoreceptor Thermoreceptor Mechanoreceptor	Various nociceptors
Gustatory	Taste	Chemical	Chemoreceptor	Taste buds
Olfactory	Smell	Chemical	Chemoreceptor	Olfactory sensory neurons

*TABLE Adapted from Kandel et al., Principles of Neuroscience*

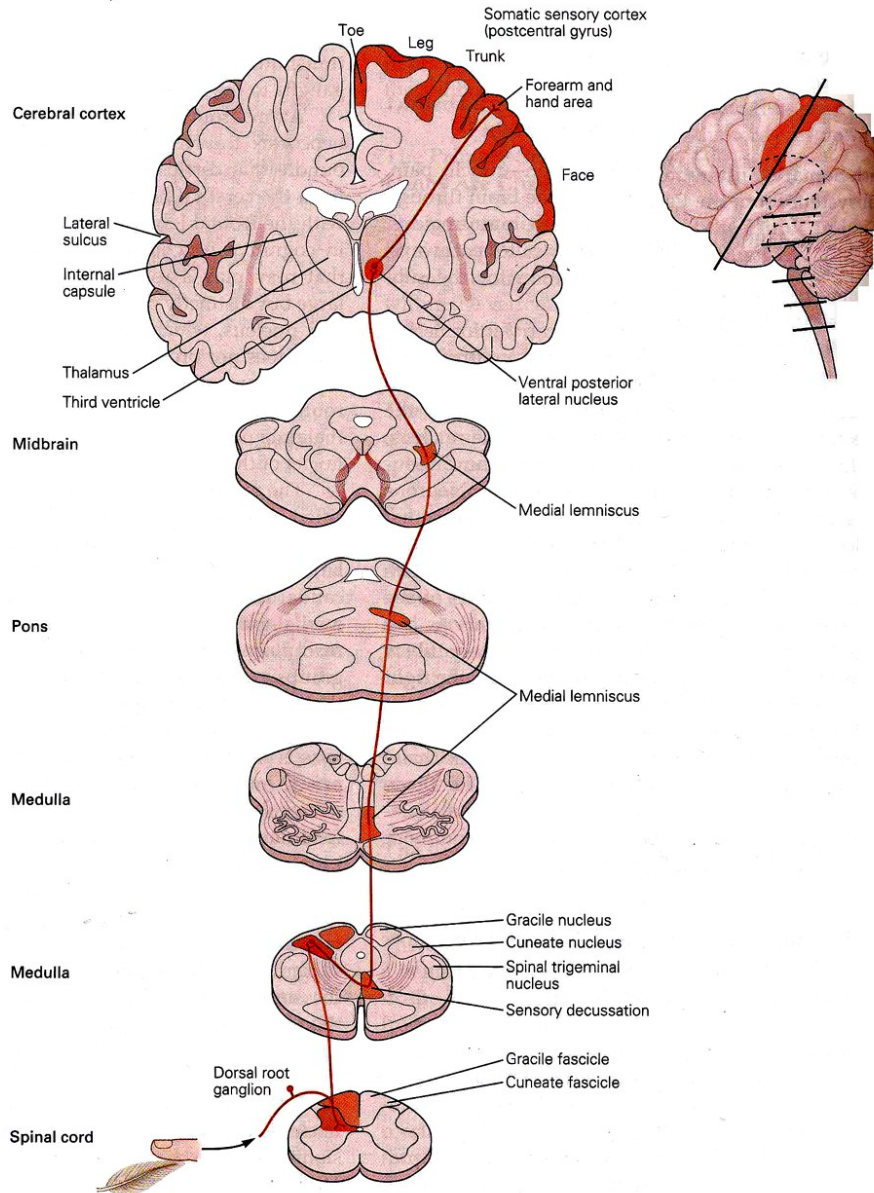
# AN EXAMPLE OF RESPONSE TO SENSATION

## THE TENDON STRETCH REFLEX

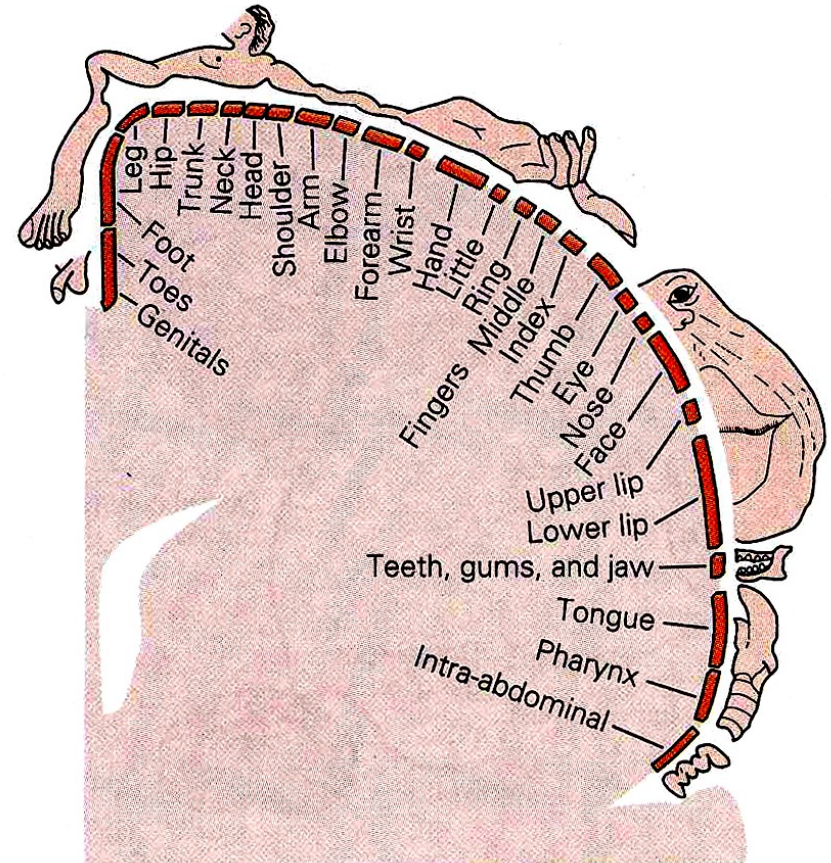


# ASCENDING SENSORY PATHWAYS

## A SOMATOTOPIC REPRESENTATION OF THE BODY IN THE CEREBRAL CORTEX



## Sensory homunculus



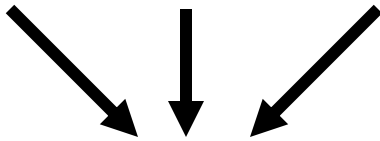
# REFINEMENT OF SENSORY INFORMATION

NEURONS AT EACH RELAY INTEGRATE INPUTS FROM  
MANY PRECEDING SENSORY SIGNALS

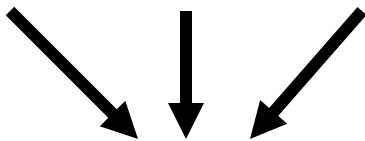
## VISUAL PROCESSING

### CELL TYPE

Retina Rod-type Photoreceptor



Retinal Ganglion Cell



Neuron in Primary Visual Cortex

### FIRES IN RESPONSE TO:

Photon of Light



Point of Light Contrast

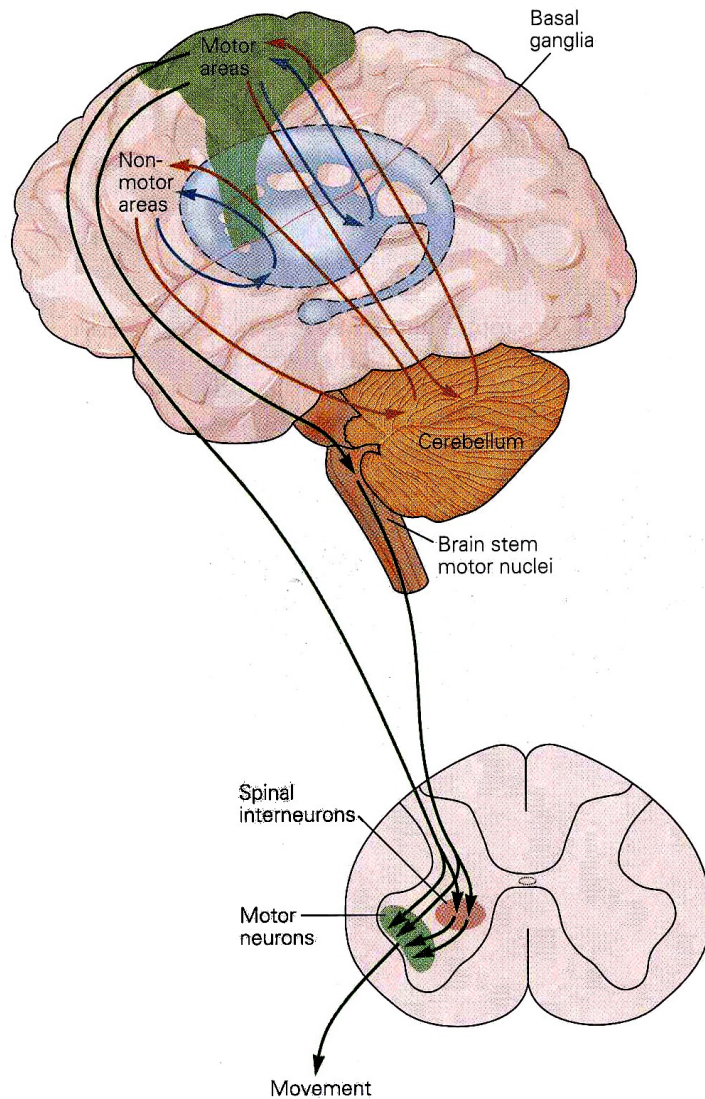


Lines and Other Borders  
or  
Motion

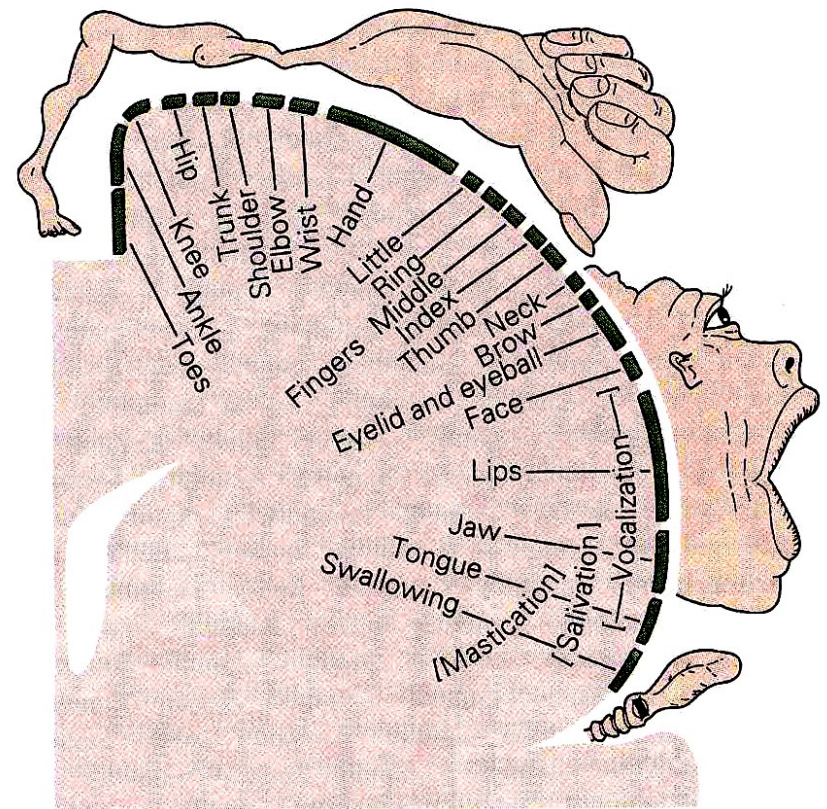


# DESCENDING PATHWAYS FROM THE MOTOR CORTEX

## SOME CORTICAL NEURONS PROJECT AXONS THAT SYNAPSE ON SPINAL MOTOR NEURONS



### Motor homunculus



# THE CEREBELLUM AND BASAL FOREBRAIN

## COORDINATION AND CONSISTENCY OF MOTOR TASKS

### **CEREBELLUM --- BRAIN'S "INTERNAL GUIDANCE SYSTEM" FOR MOTOR TASKS**

- 1) receives input on motor task to be performed and progress of ongoing task, and provides corrective signals to keep task on target
- 2) adapts with repetition to provide better guidance

### **BASAL FOREBRAIN --- ENSURES MOTOR TASKS ARE EXECUTED SMOOTHLY AND AT DESIRED SPEED**

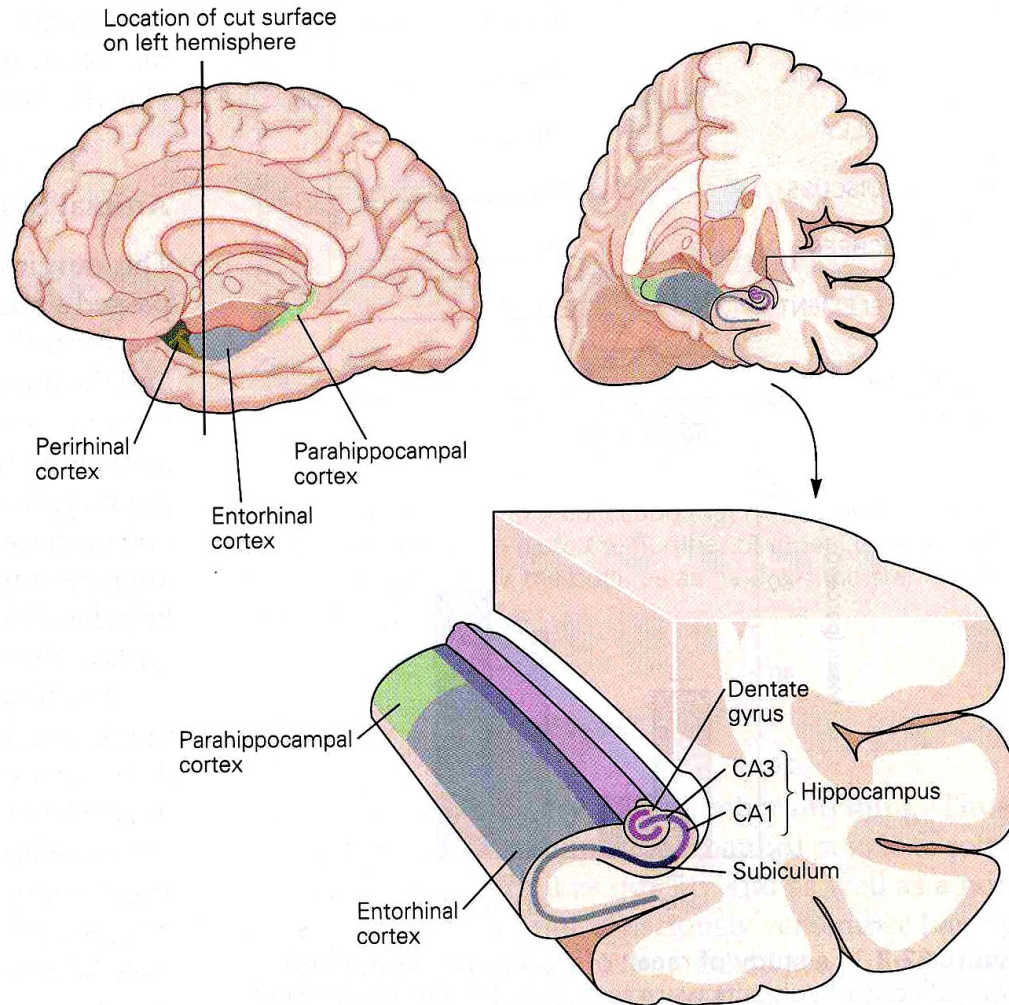
#### DISEASES OF THE BASAL FOREBRAIN:

Parkinson's Disease ..... Slowed movement with tremor

Huntington's Disease ..... Hyperkinesia with tremor

# THE HIPPOCAMPUS

## ESSENTIAL CENTER FOR SPATIAL LEARNING AND MEMORY



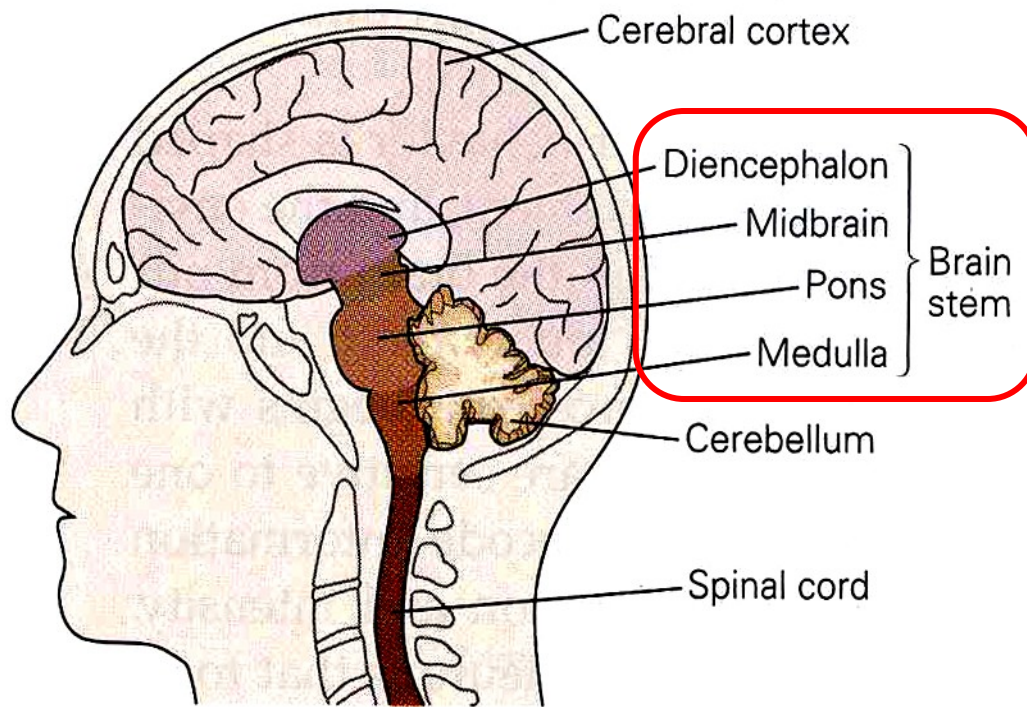
**Lesions in hippocampus result in inability to create new spatial and verbal long-term memories**

**Pyramidal neurons in the dentate gyrus, CA1, and CA3 regions of hippocampus “learn” very well from synaptic experience**



# THE BRAIN STEM

## CONTROL CENTER OF WAKEFULNESS AND REFLEXIVE BEHAVIORS



## Major Divisions of CNS

**Brain stem** serves as **on/off switch** to control cortical activity and consciousness

**Brain stem** and its associated cranial nerves control many stereotyped involuntary motor tasks:

***Rhythmic breathing***

***Heartbeat modulation***

***Swallowing***

***Sneezing***

***Involuntary facial expressions***



# THE HYPOTHALAMUS

SMALL CONTROL CENTER IN BRAIN STEM COORDINATING PHYSIOLOGICAL AND BEHAVIORAL RESPONSES TO PHYSICAL AND EMOTIONAL STATES

## EXAMPLES

1. Thirst and hunger urges are induced by hypothalamus in response to visceral sensory inputs of hyperosmolarity and hypoglycemia
2. Sweating, flushness of skin, and urge to seek out cooler environment are induced by hypothalamus in response to hyperthermia caused by hot weather, exertion or fever
3. Secretion of pituitary hormones which regulate sexual functions and behavior are coordinated by commands from the hypothalamus
4. Physical expression of emotions orchestrated by hypothalamus

# THE LIMBIC SYSTEM

A NETWORK OF BRAIN CENTERS WHICH PRODUCE  
EMOTIONAL, MOTIVATIONAL, AND ADDICTIVE STATES

Best understood limbic center is the **AMYGDALA**

**AMYGDALA** is required for experiencing both  
**fearful and pleasurable** responses and is required  
for generating memories associated with  
emotional experiences

# DEVELOPMENT OF THE NERVOUS SYSTEM ONGOING FROM EARLY EMBRYOGENESIS UNTIL ADOLESCENCE

## ***DEVELOPMENTAL TASKS TO ACCOMPLISH***

Where in body should neurons be formed?

How are the types and shapes of neurons specified?

How do axons grow and project to proper targets?

Is later development shaped by experience?

## ***CELLULAR MECHANISMS USED***

Developing neurons receive instructive signals from other cells.

Instructive signals are specific proteins presented:

- a) by direct cell-to-cell contact
- b) as part of the extracellular matrix
- c) as diffusible factors

Next Lecture: BASIC PRINCIPLES OF ELECTRICITY

**REQUIRED READING:** Kandel text, Appendix Chapter I