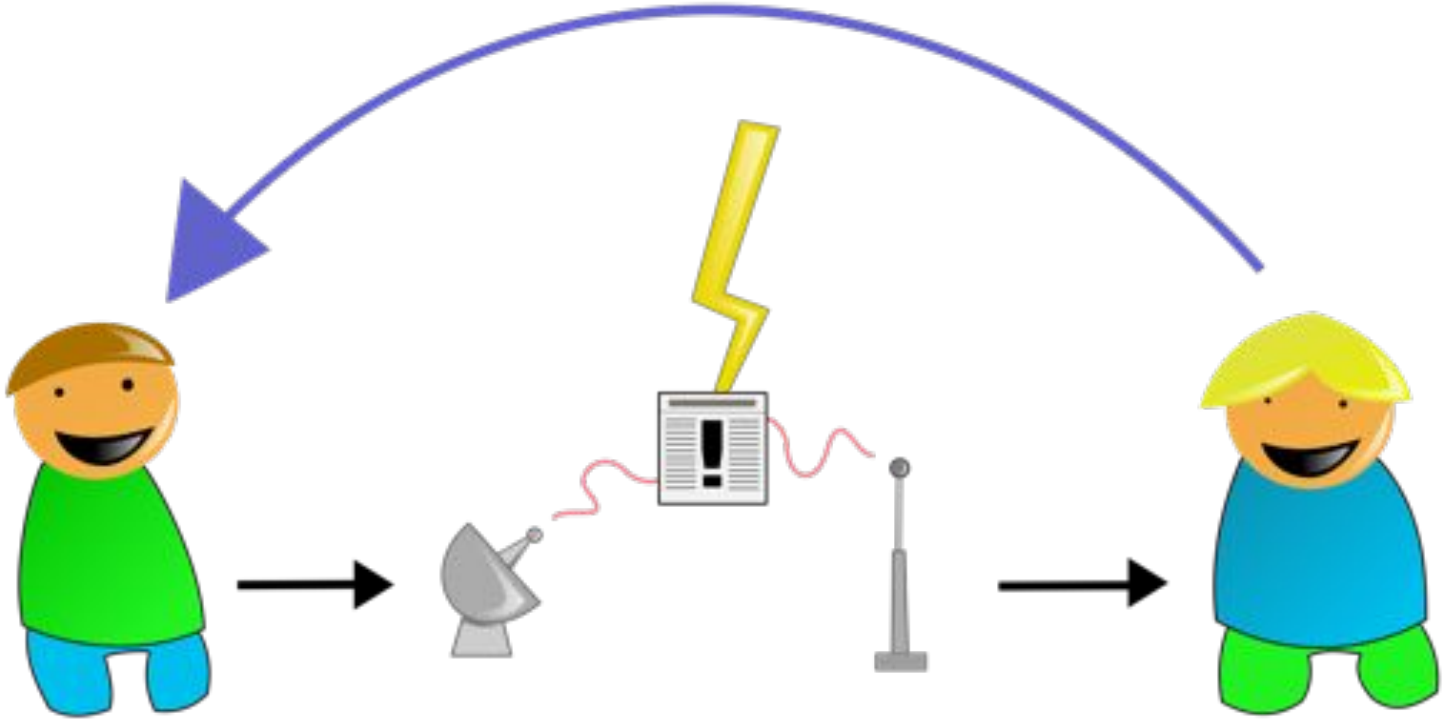
Domain 6: Communication

6.1: Cell communication processes share common features that reflect a shared evolutionary history.

1. INTRODUCTION TO COMMUNICATION.

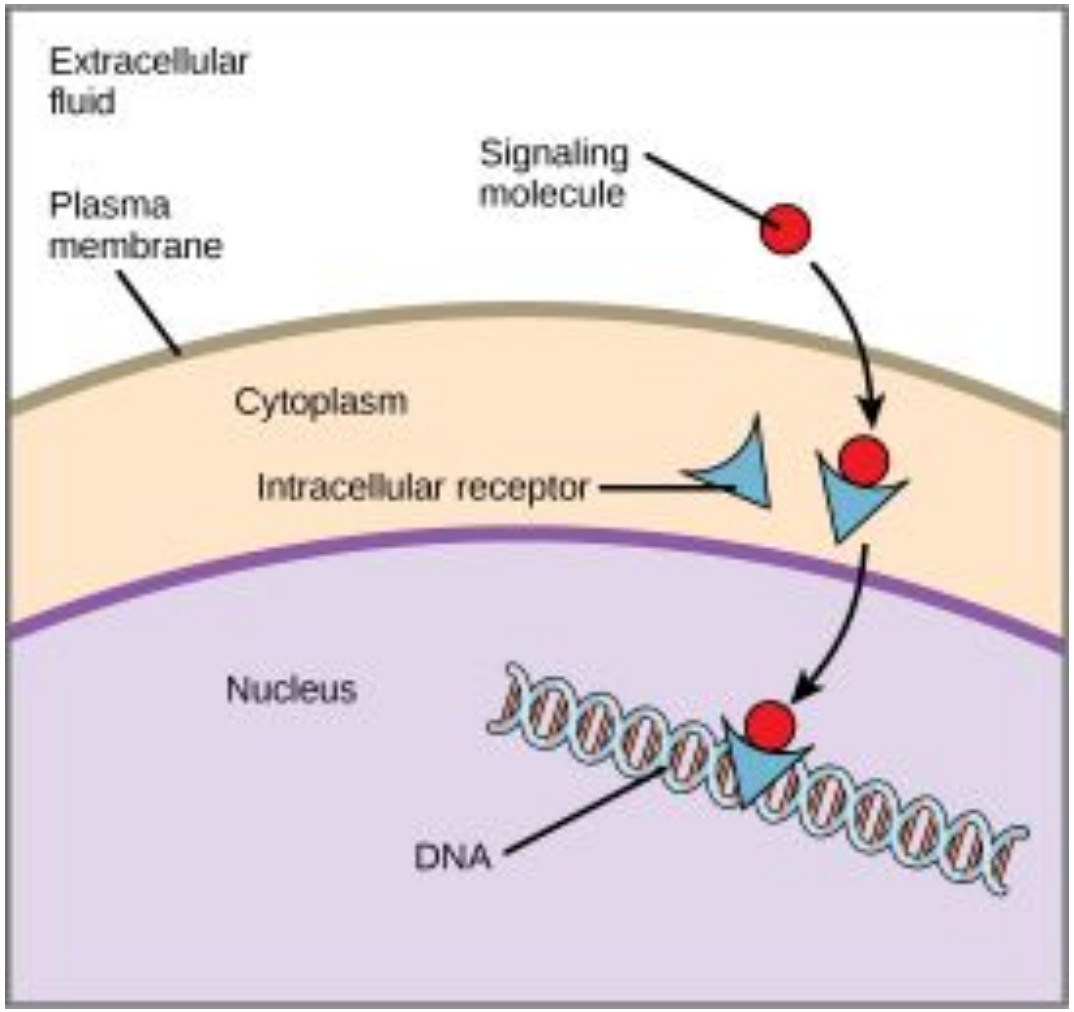
How Does Communication Happen?

Communication requires the generation, transmission, and reception of a signal.



In cellular systems, signals are generally chemical molecules (e.g. **hormones**), but can also include direct detection of environmental conditions (e.g. light).

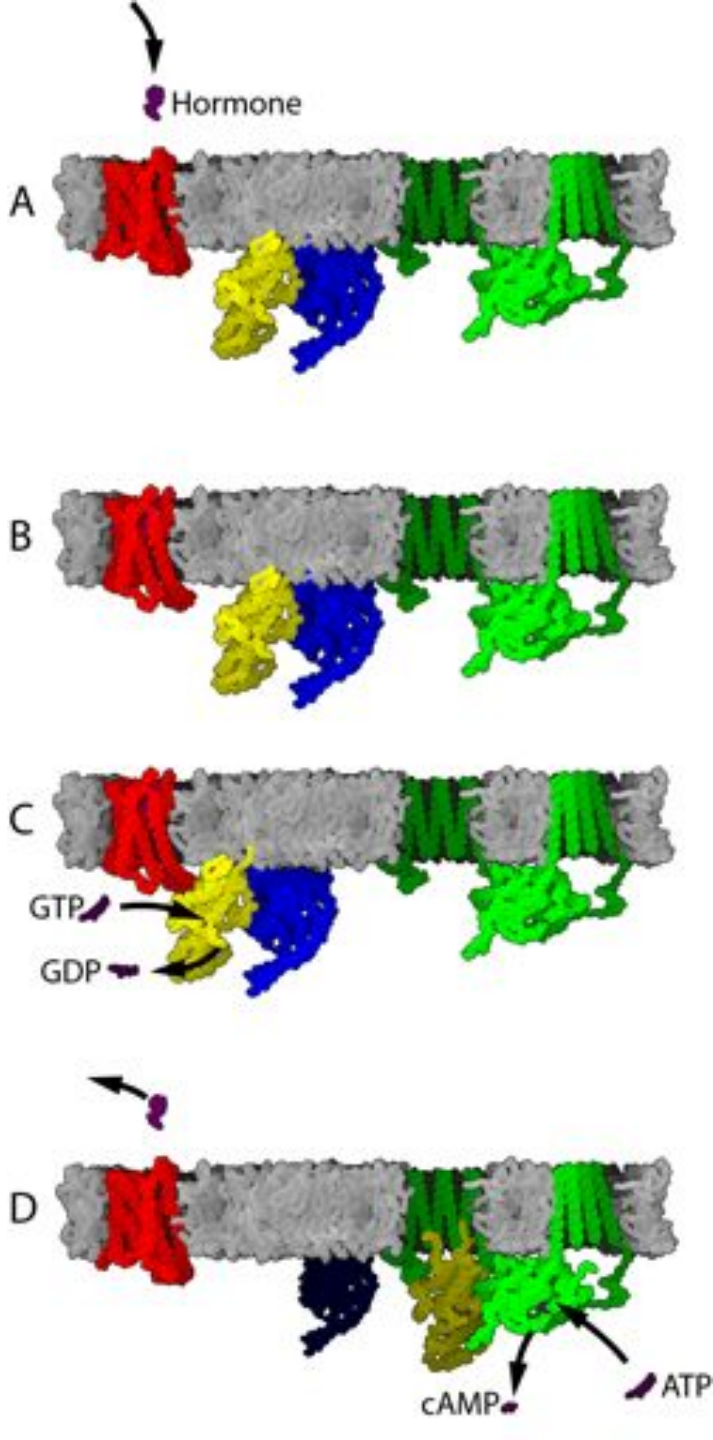
Pathways involved in communication are called "**signal transduction pathways**".



Signal Transduction is Universal

All organisms have signal transduction pathways.

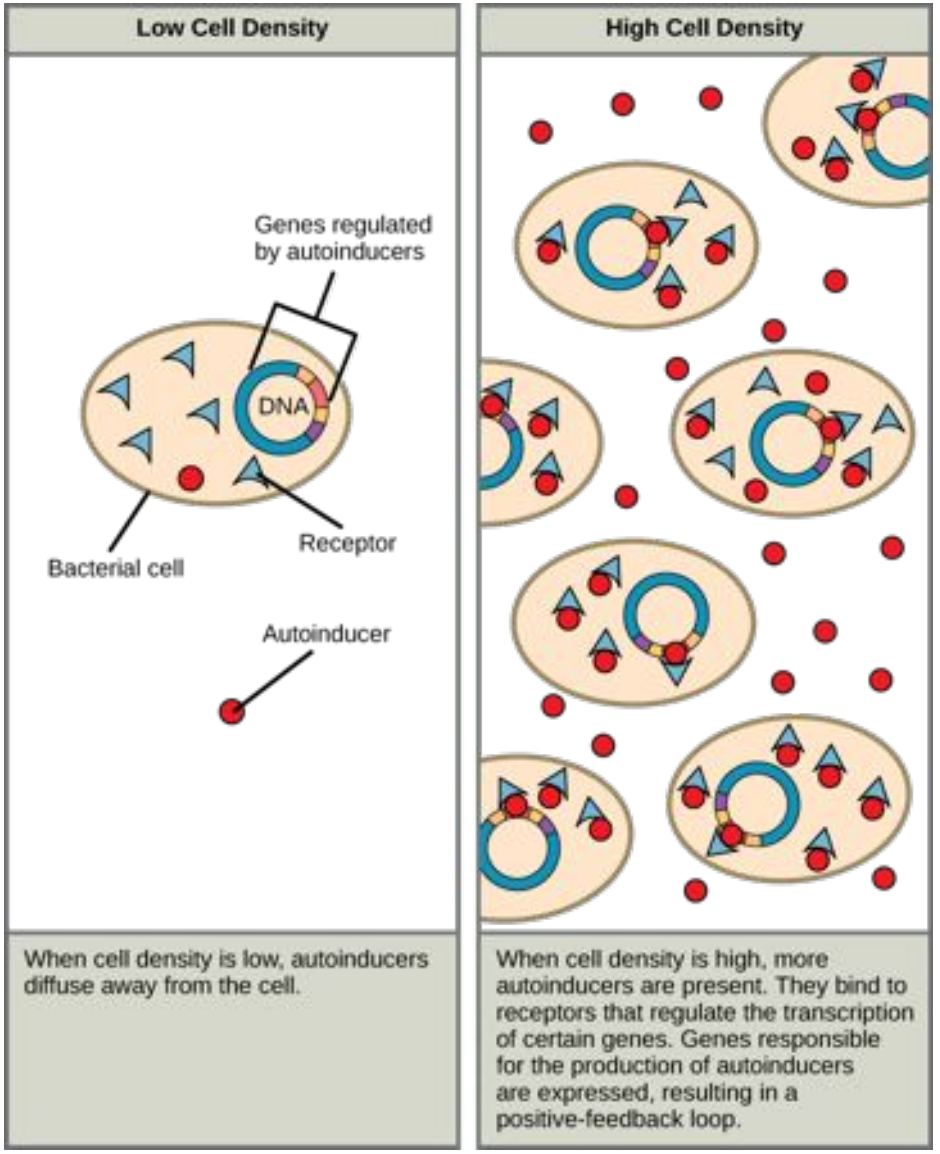
The protein-based nature of signal transduction, along with its adaptive significance makes signal transduction a major area of evolution.



Unicellular Signaling Pathways

Signaling pathways allow unicellular organisms to receive information from the environment and respond to that information.

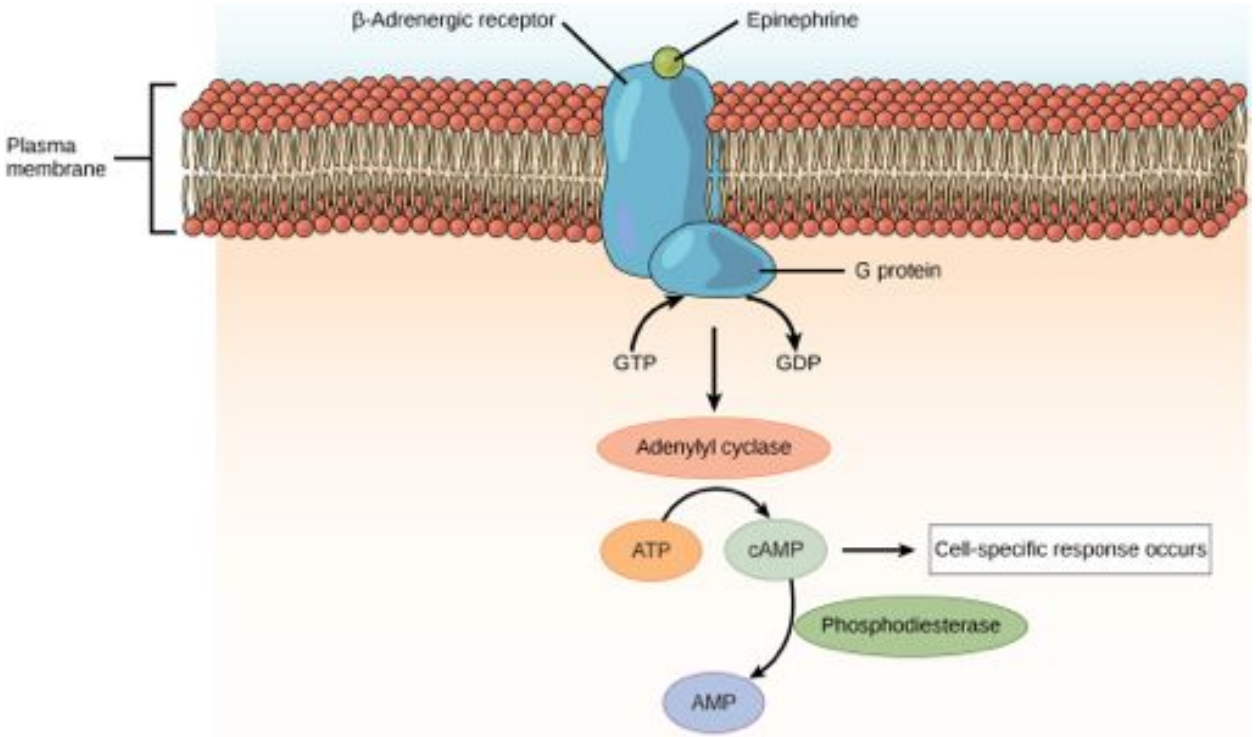
Ex. Quorum Sensing



Multicellular Signaling Pathways

Signaling pathways allow multicellular organisms to receive information, and coordinate all of the cells of the organism in responding to that information

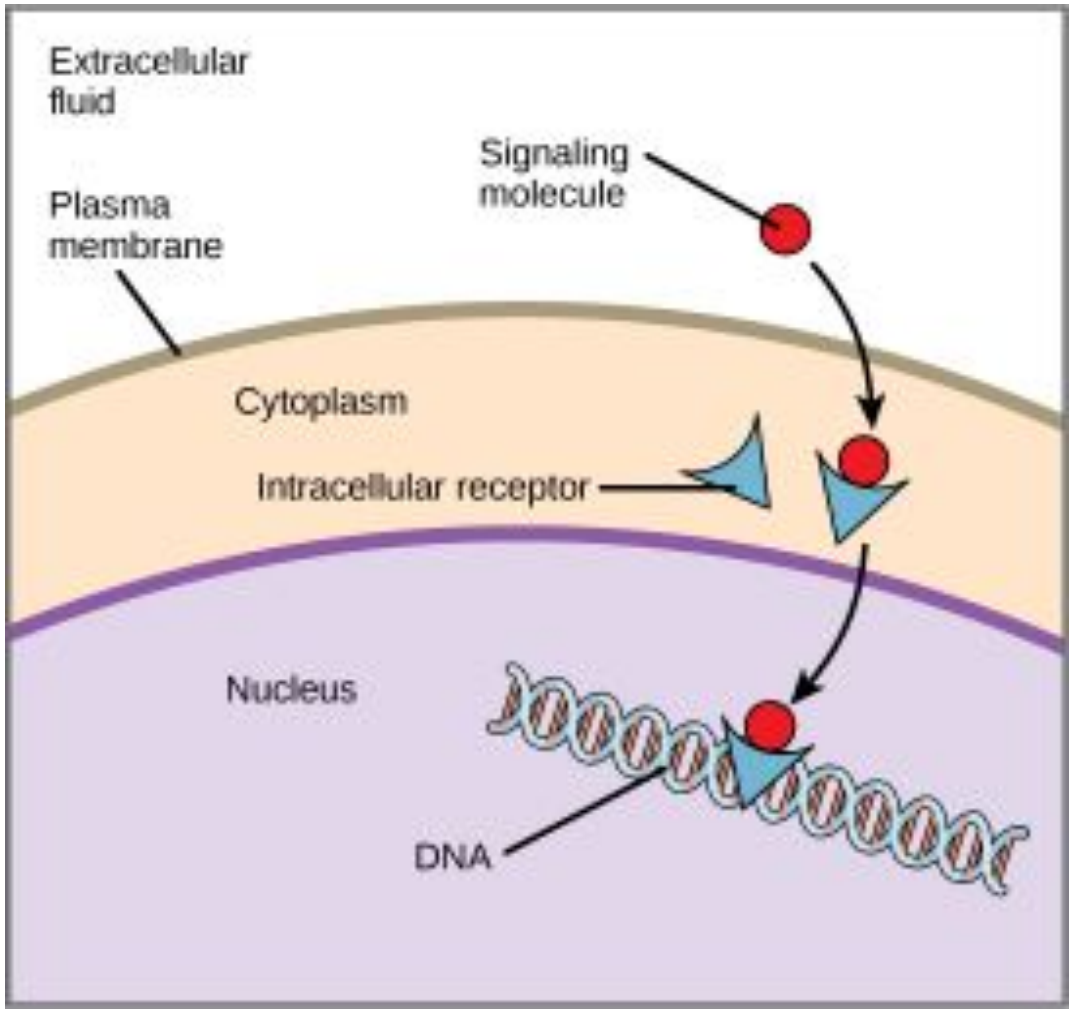
Ex. Epinephrine Signaling



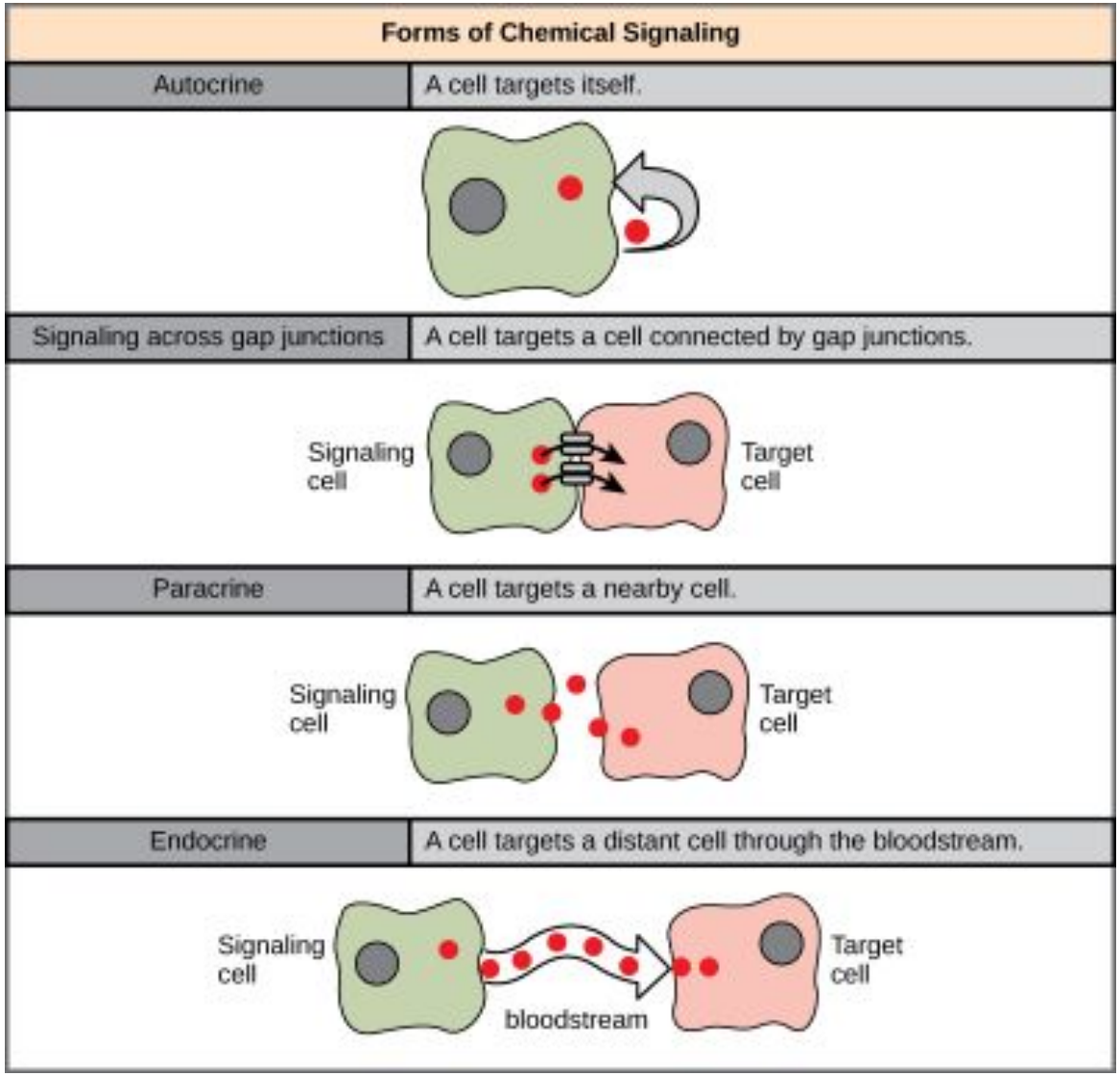
6.2: Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling

1. TYPES OF CELLULAR SIGNALS

Cellular Communication always involves the production, exchange, and receipt of chemical messages (“**ligands**”)



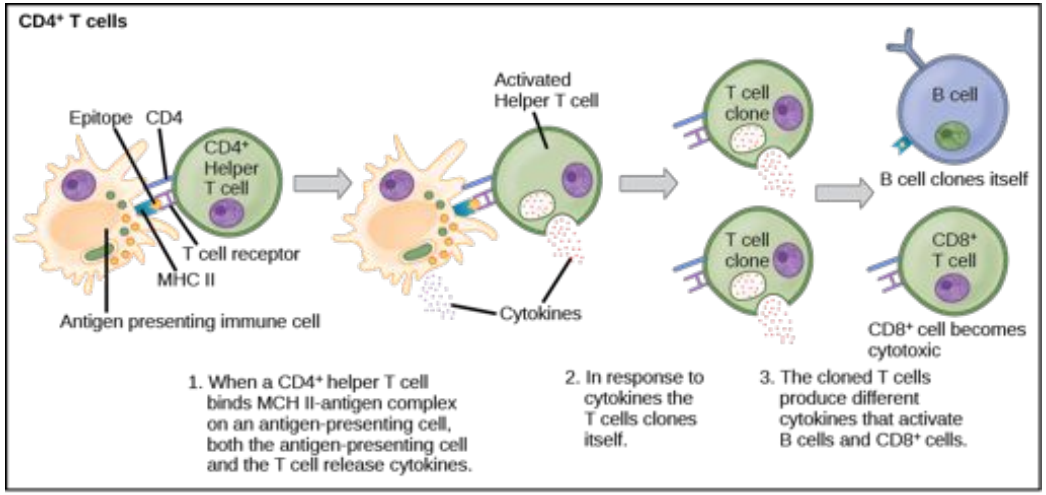
There are a variety of ways that ligands can be exchanged between cells

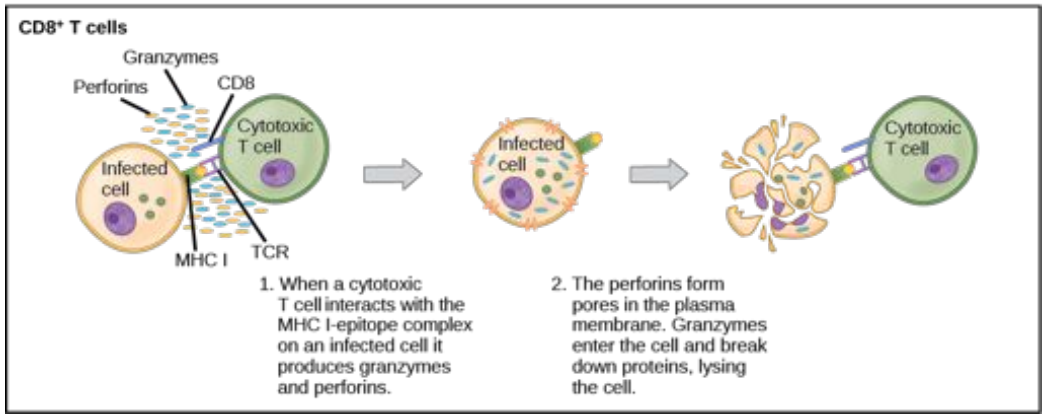


Cell-Cell Contact

Exactly what it sounds like.

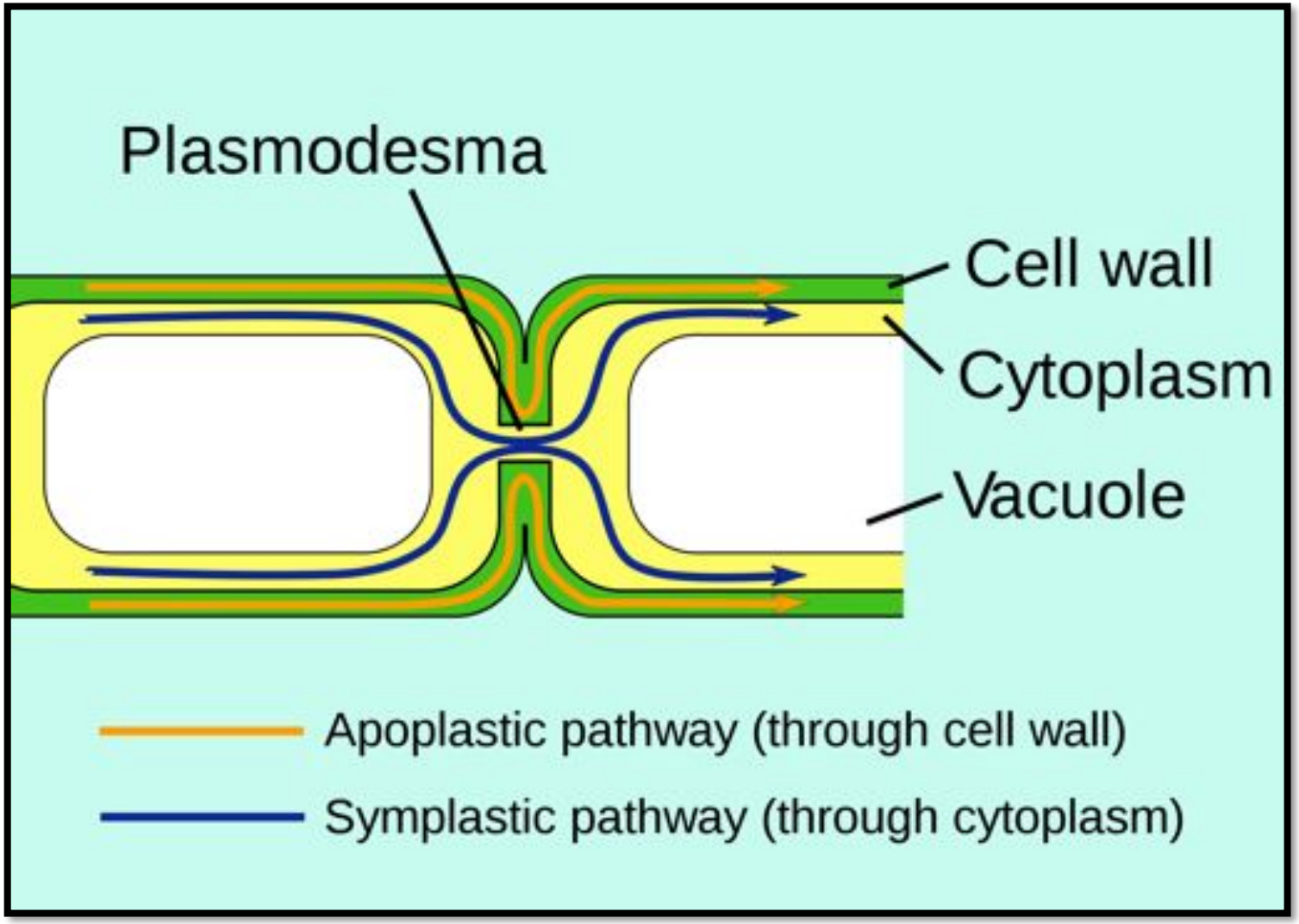
Ex. Lymphocyte Communication





Cell-Cell Contact

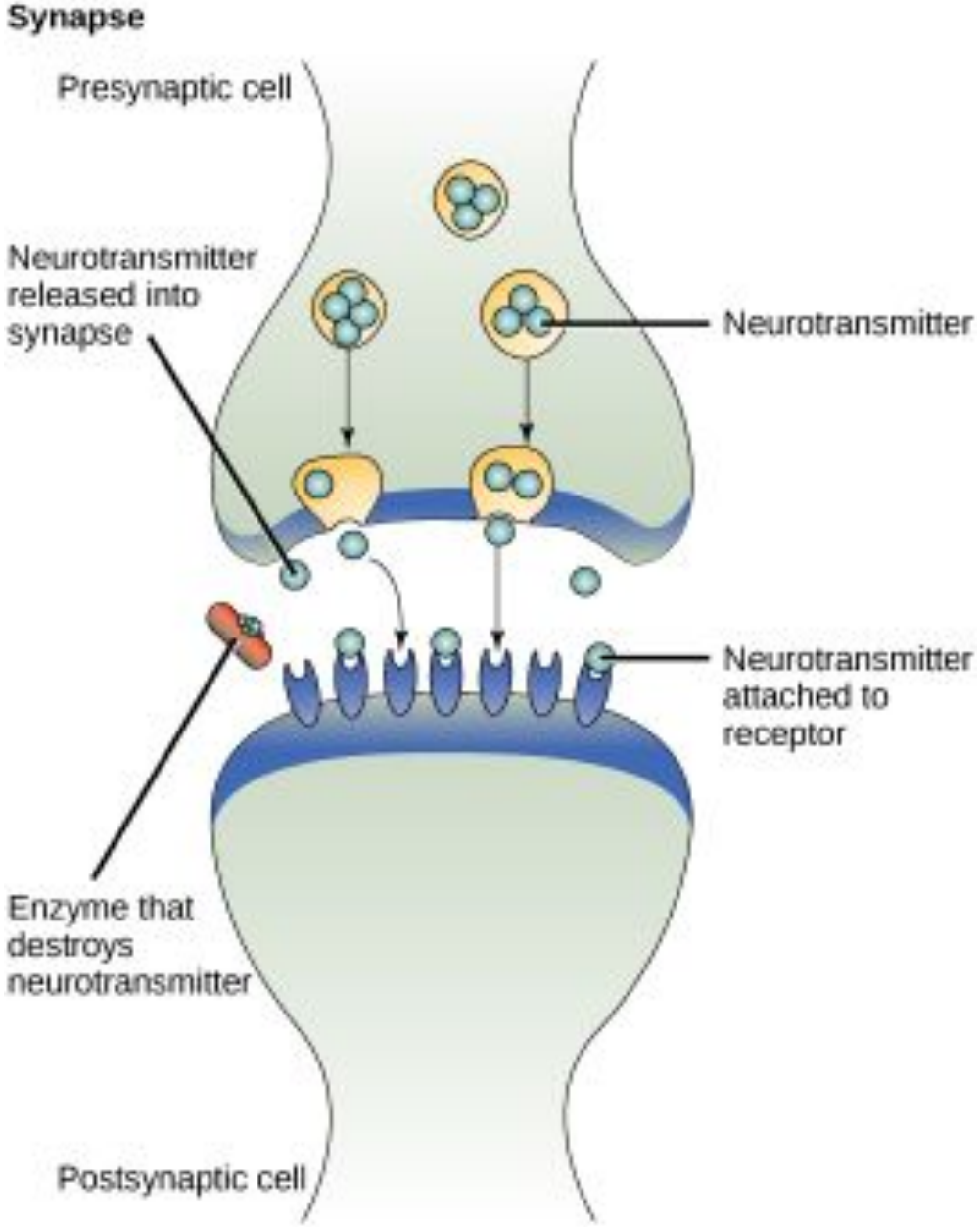
Ex. Communication via Plasmodesmata



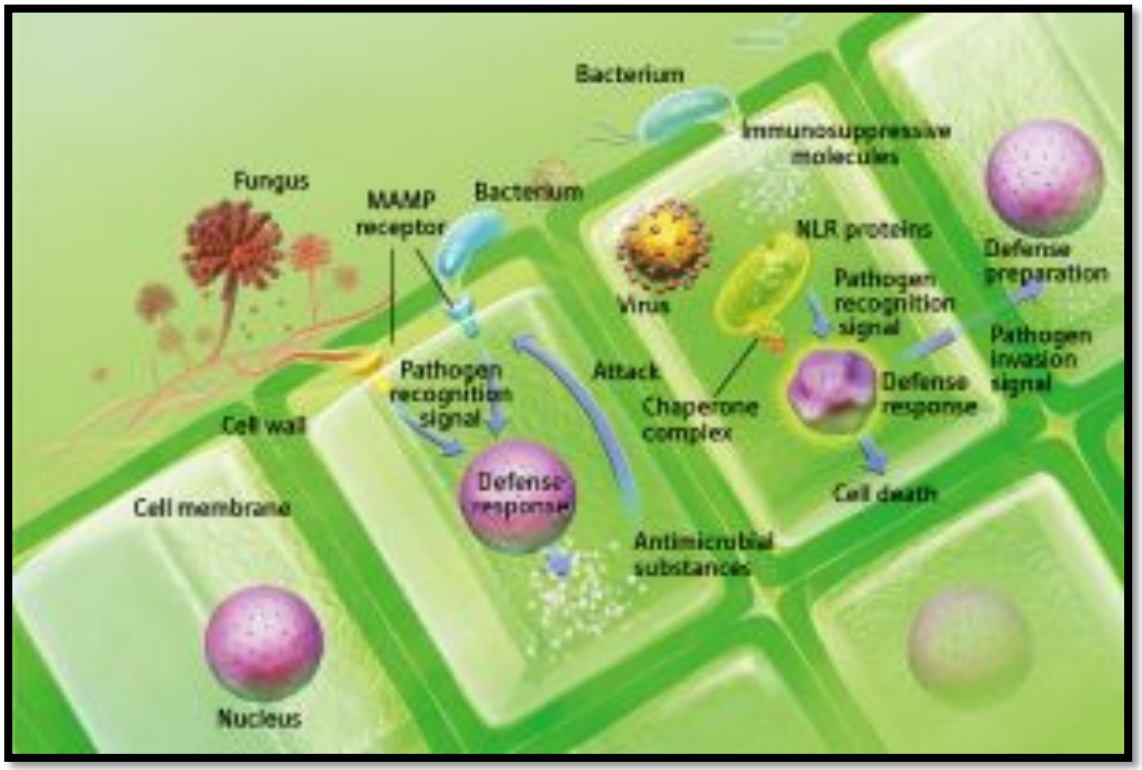
Local Signaling

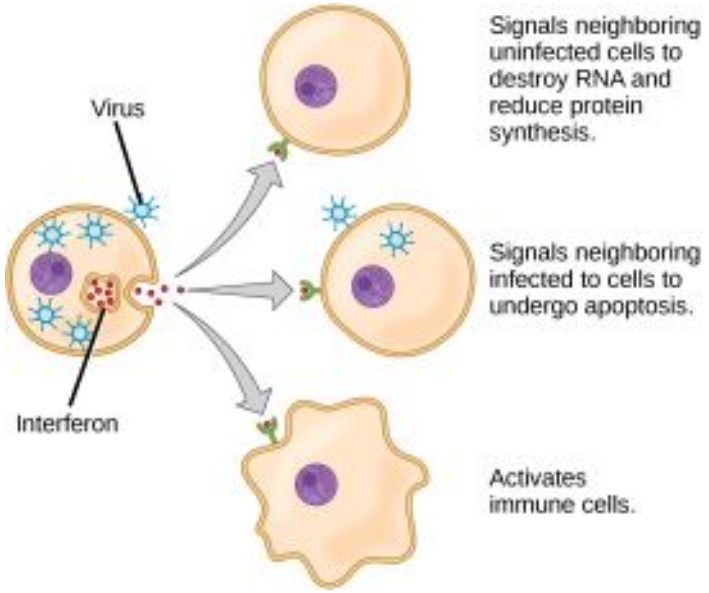
Ligands are produced by cells and diffuse to local target cell populations.

Ex. Neurotransmitters



Ex. Immune System Signaling

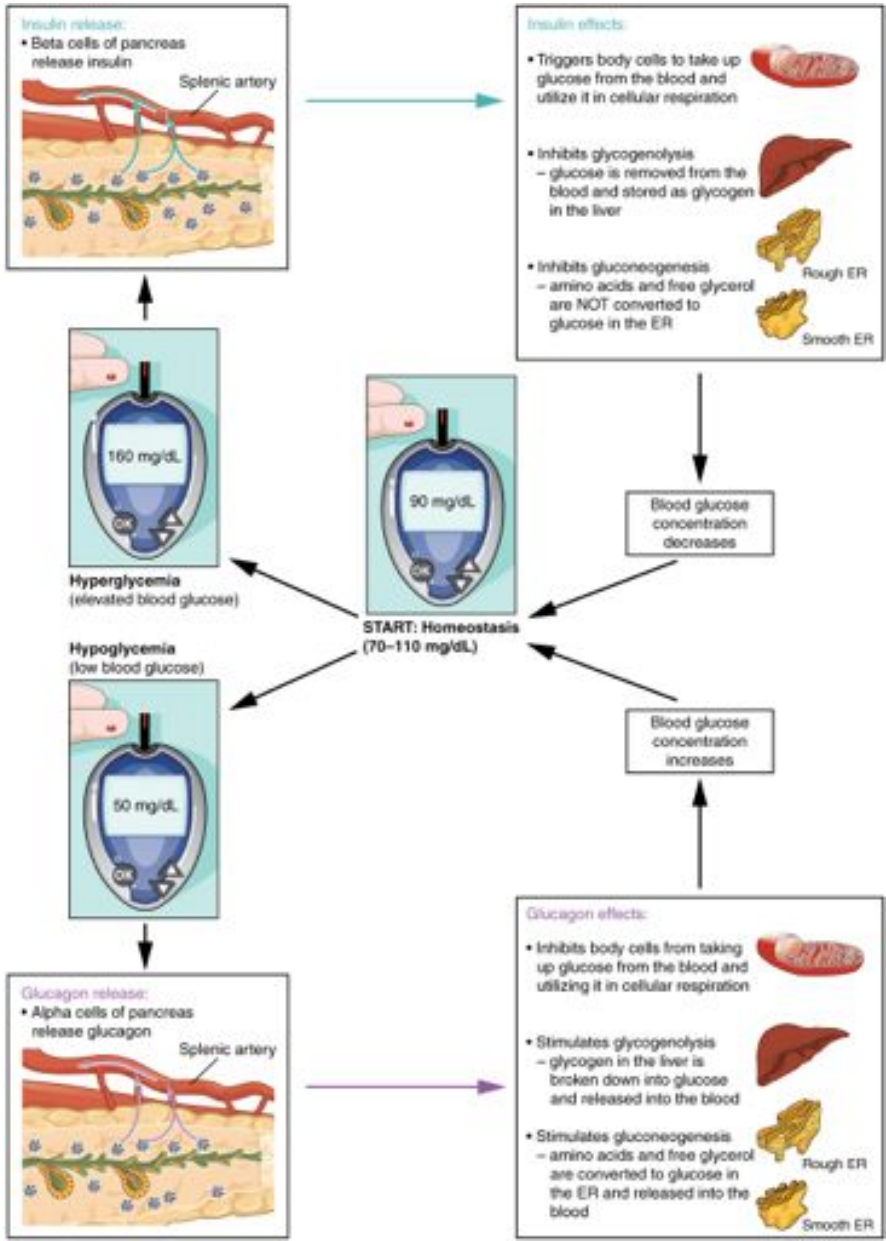




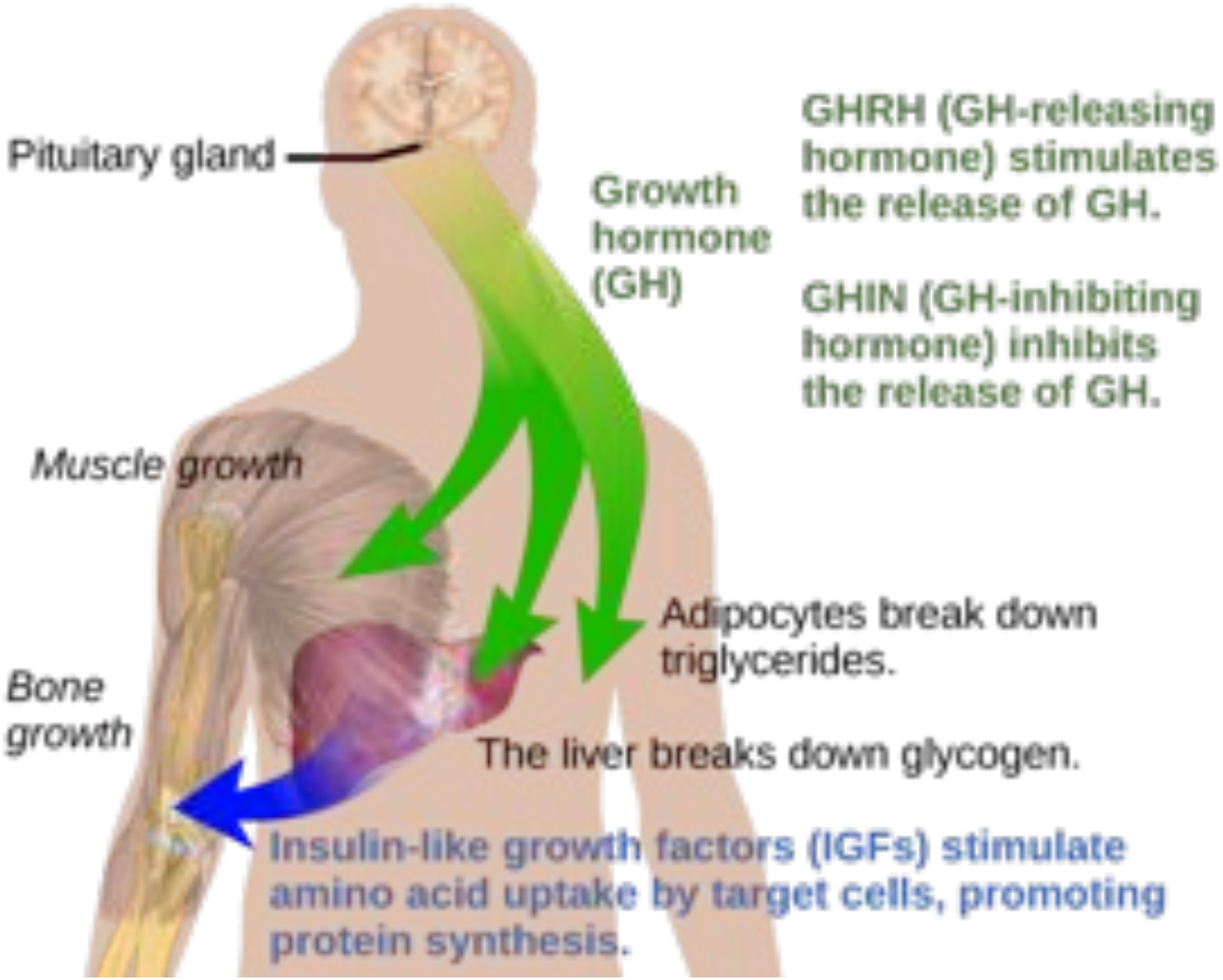
Distance Signaling

Endocrine system: The production of hormones by glands, which travel through the circulatory system to reach target cells.

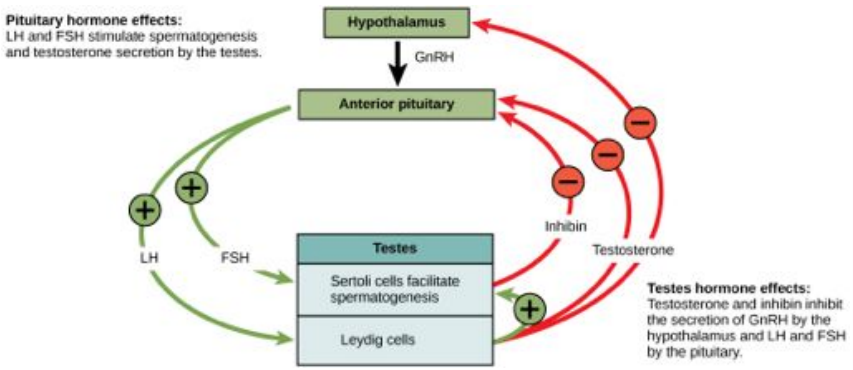
Ex. Insulin/Glucagon

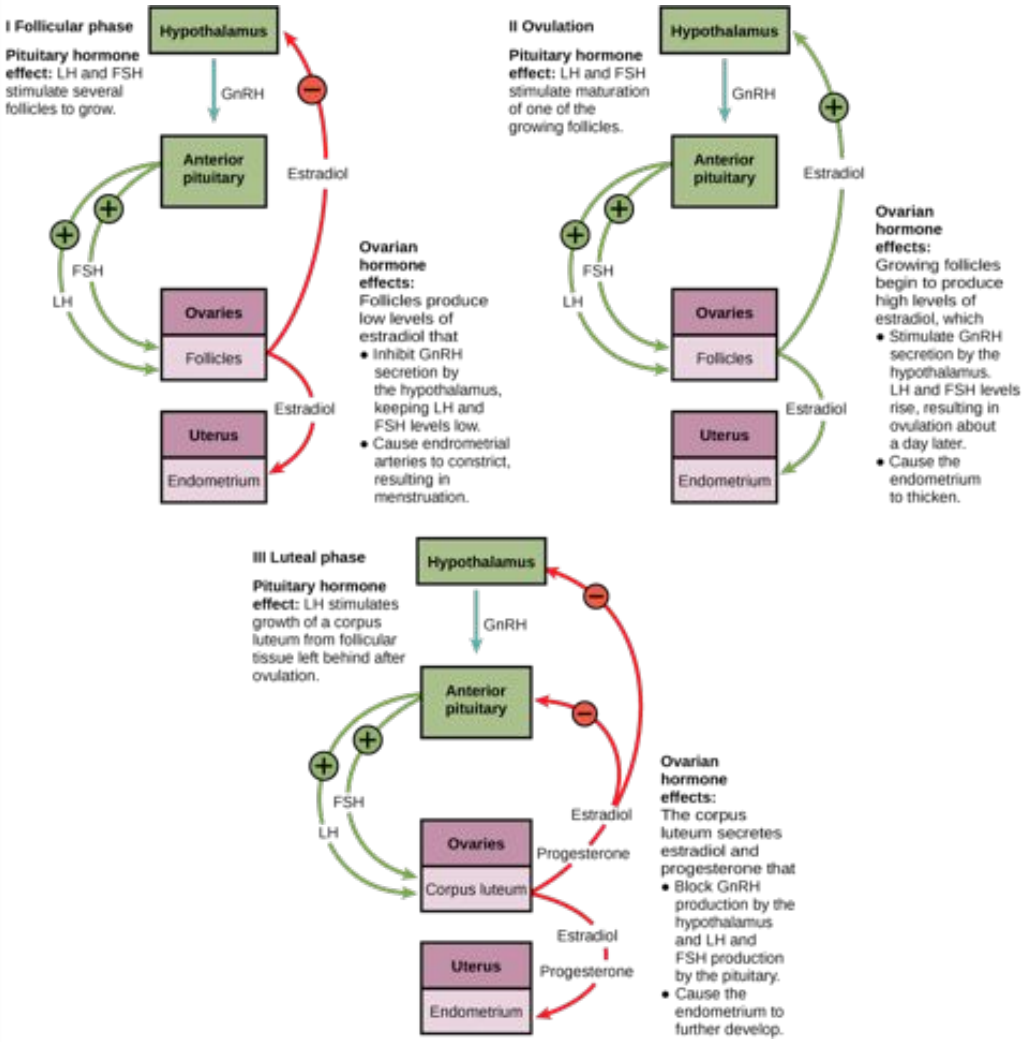


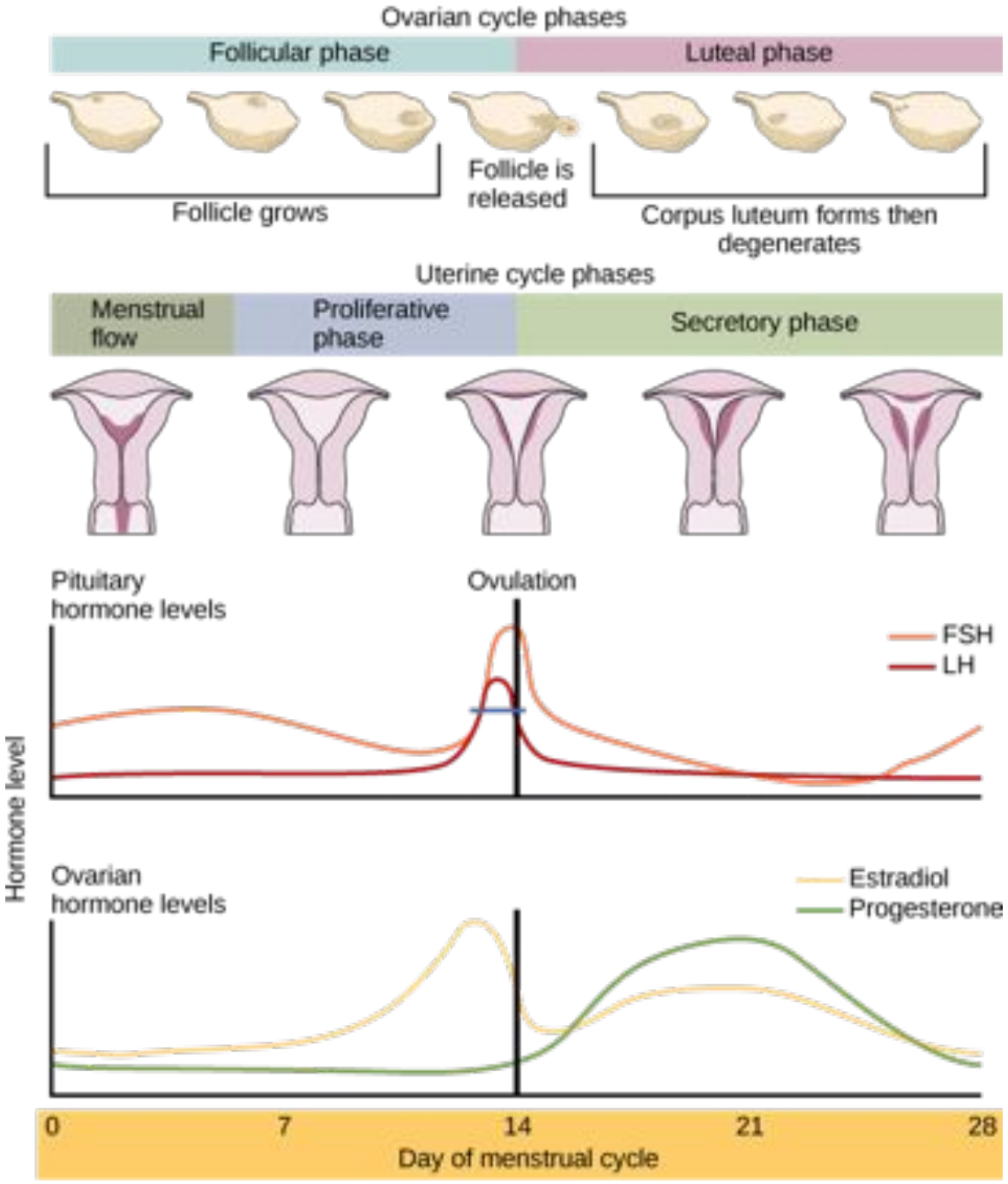
Ex. Human Growth hormone



Ex. Sex Hormones






Ovarian cycle phases
Follicular phase
Luteal phase
Follicle grows
Follicle is released
Corpus luteum forms then degenerates
Uterine cycle phases
Menstrual flow
Proliferative phase
Secretory phase
Pituitary hormone levels
Ovulation
FSH
LH
Hormone level
Ovarian hormone levels
Estradiol
Progesterone
0
7
14
21
28
Day of menstrual cycle

6.3: Signal transduction pathways link signal reception with cellular response.

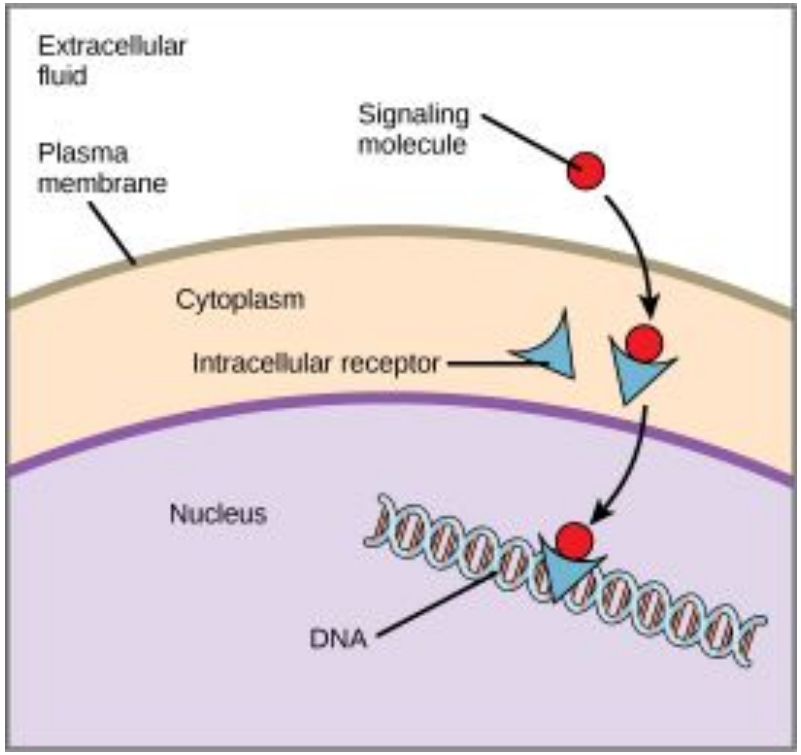
SIGNAL TRANSDUCTION PATHWAYS

Overview

Signal Transduction pathways differ in specific details, but have certain, unifying characteristics.

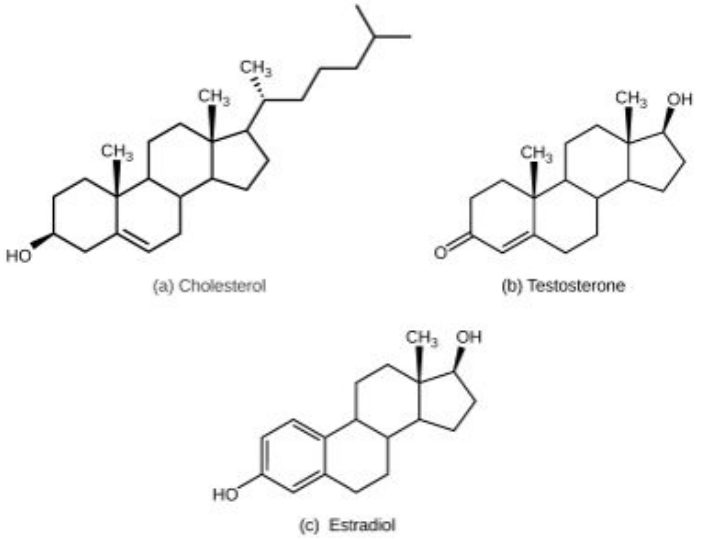
All pathways follow a sequence:

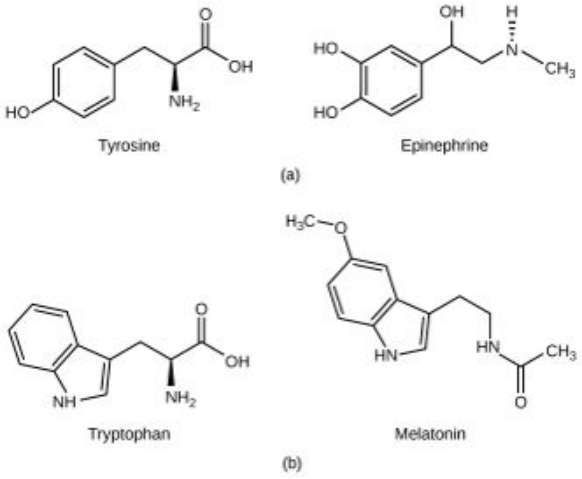
Reception → Transduction → Response

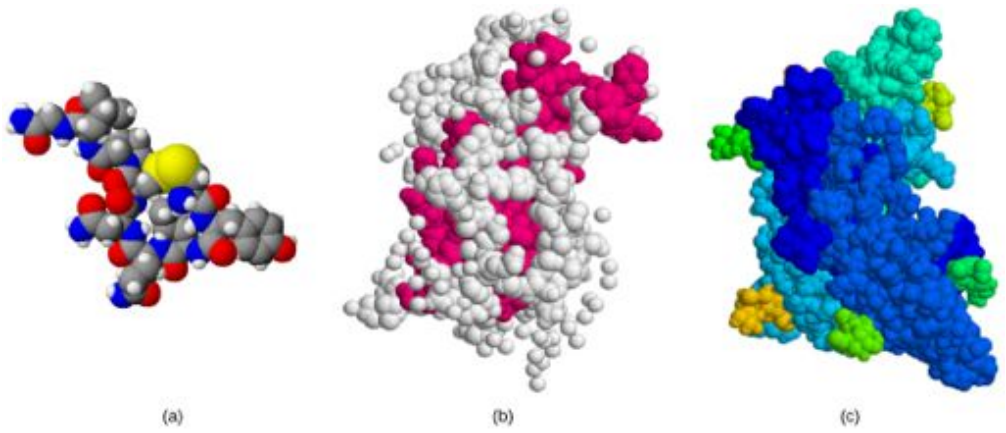


Ligand Chemistry

The chemistry of the ligand determines if it will be received at the cell membrane (proteins and amines) or intracellularly (steroid hormones)



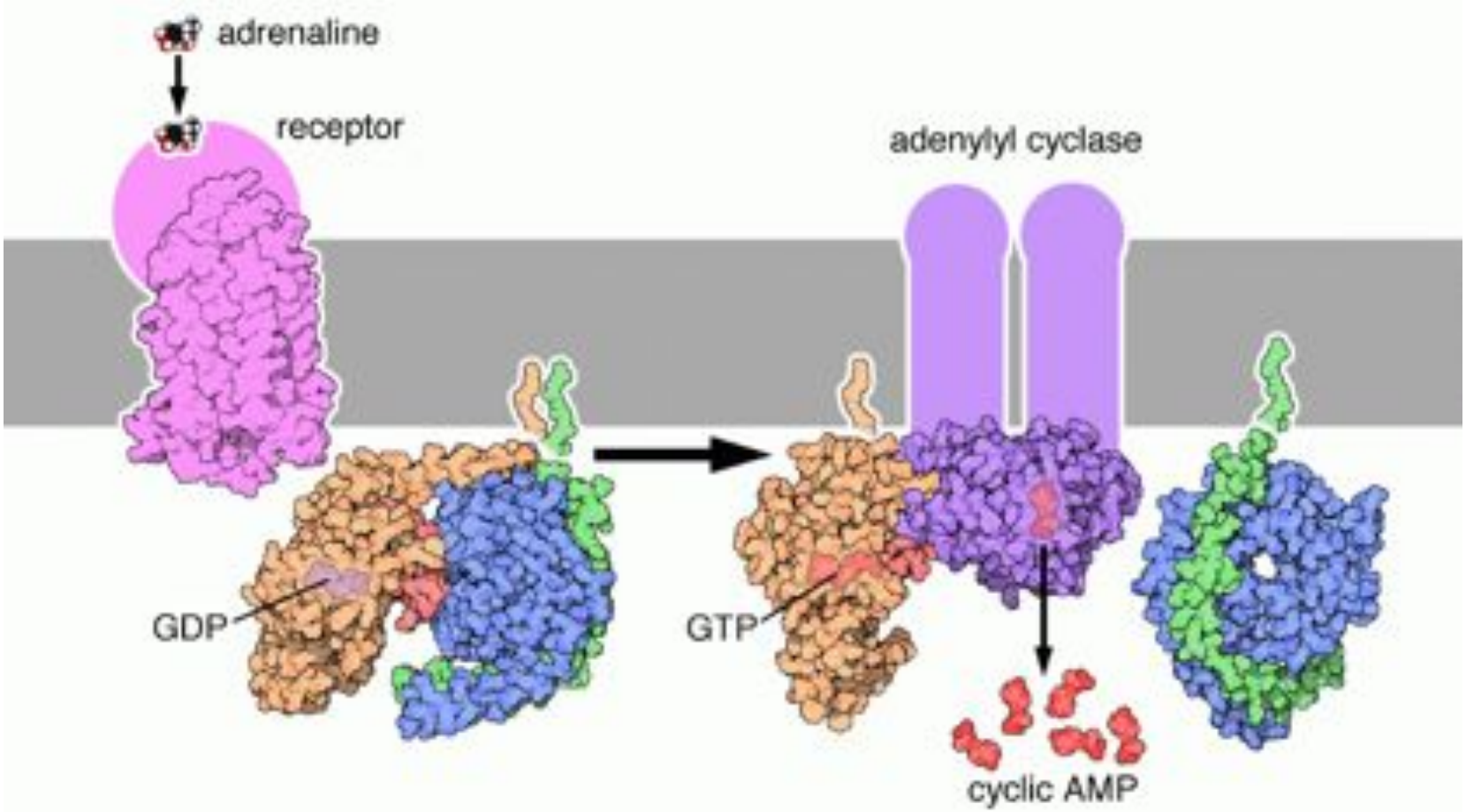




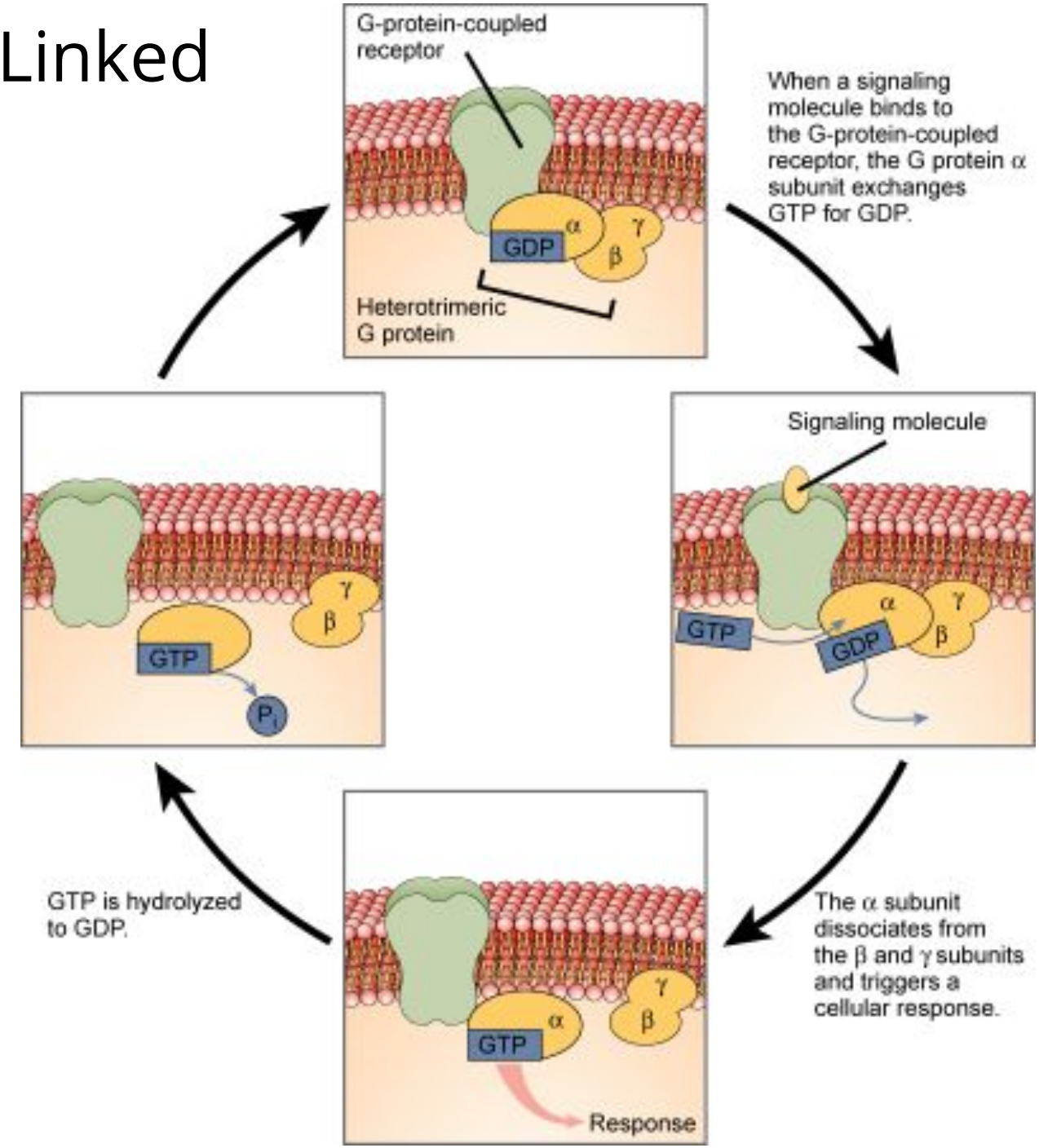
Receptor Proteins

Receptor proteins have a diversity of structures, but there are some general features:

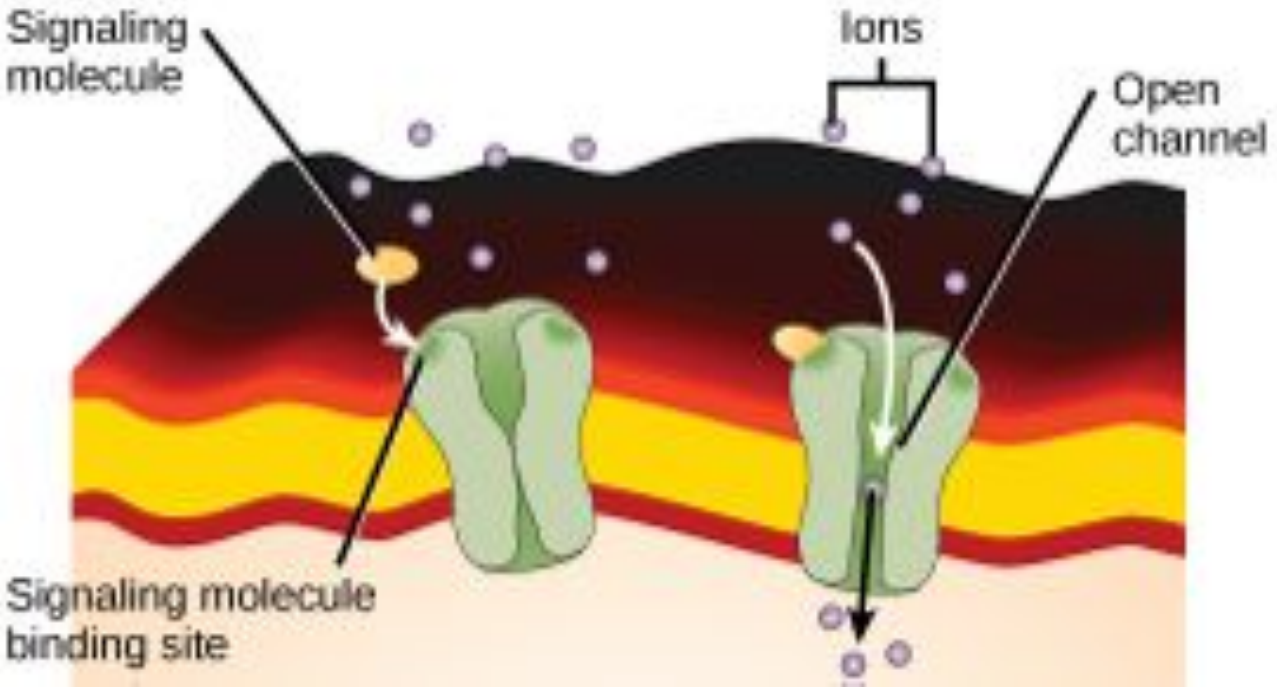
- An area of the protein that interacts with the ligand
- An area of the protein that transmits the signal to another protein.
- Signal transmission is accomplished through conformational change.



Ex. G-Protein Linked Receptor



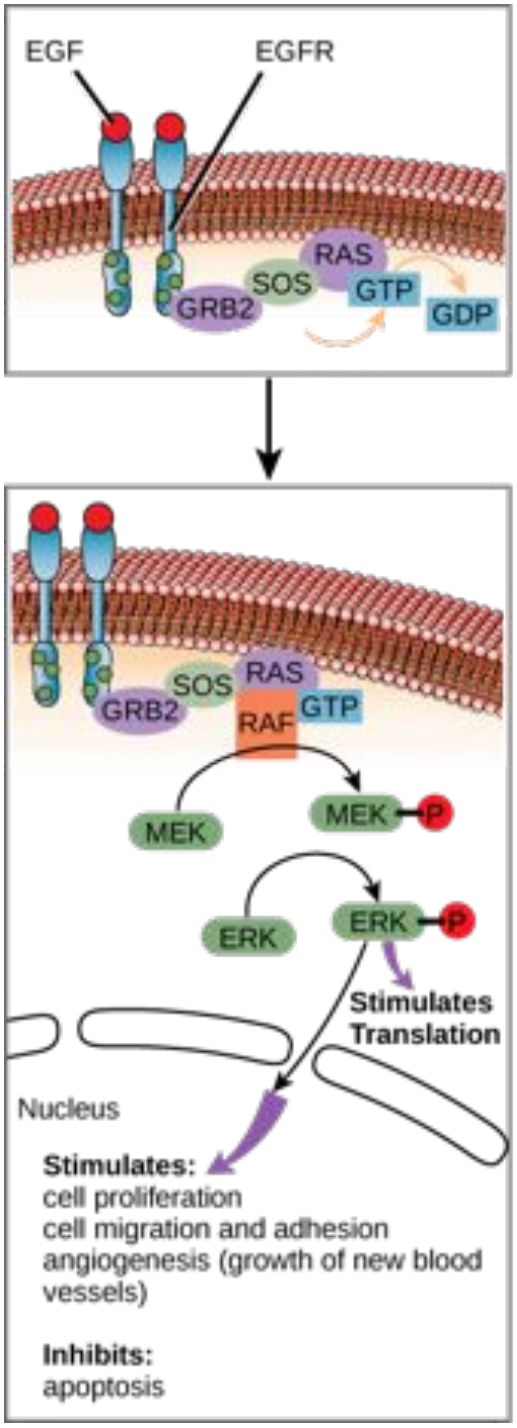
Ex. Ligand Gated Ion Channels



Transduction

Transduction converts signal reception in to cellular response.

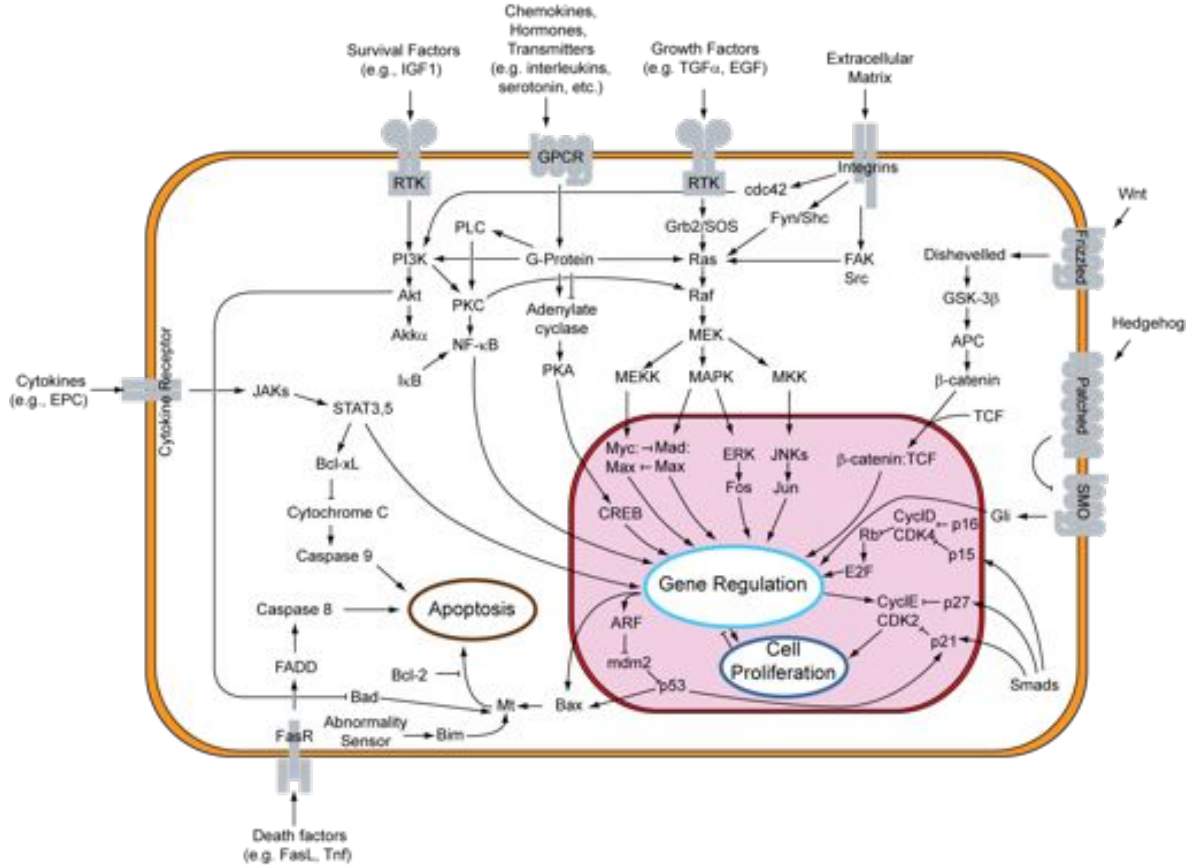
Accomplished via activation of proteins through **phosphorylation**, or a change in intracellular conditions.



Amplification & Complexity

The signal of one ligand can be exponentially amplified during transduction.

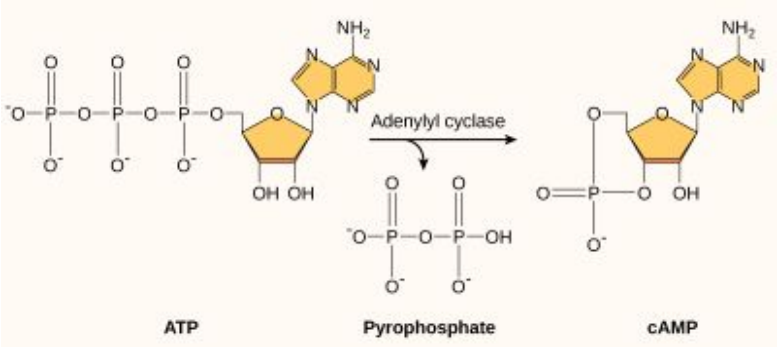
The interconnected network of cellular signaling pathways leads can generate very complex cellular responses.

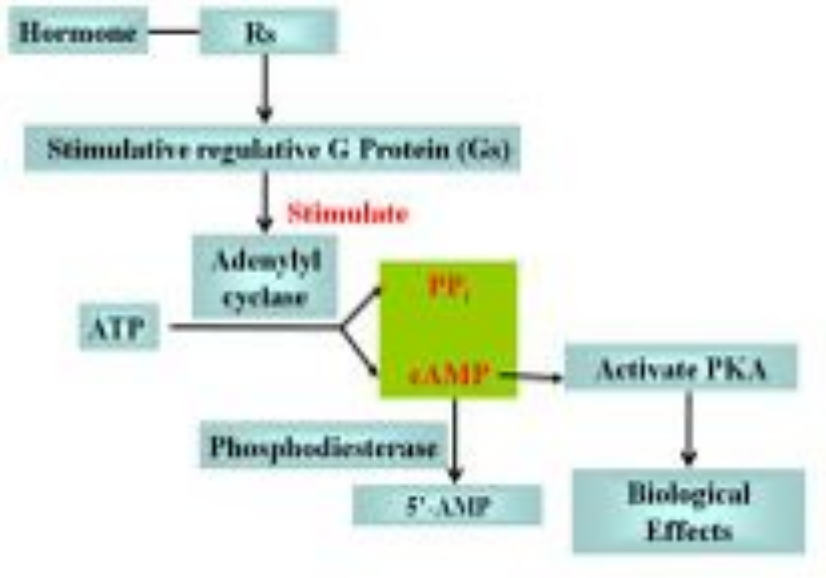


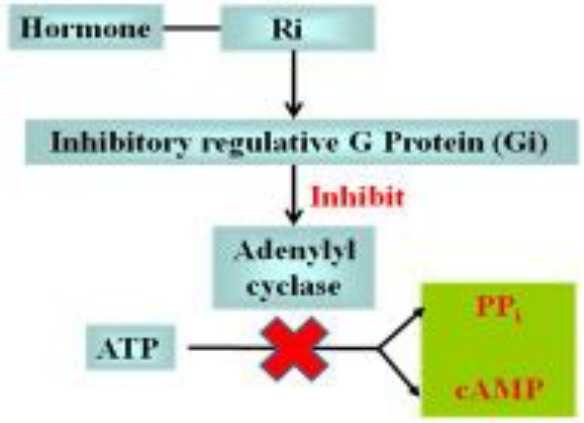
Second Messengers

Internal signaling molecules, often activated by multiple external signals.

Ex. Cyclic AMP

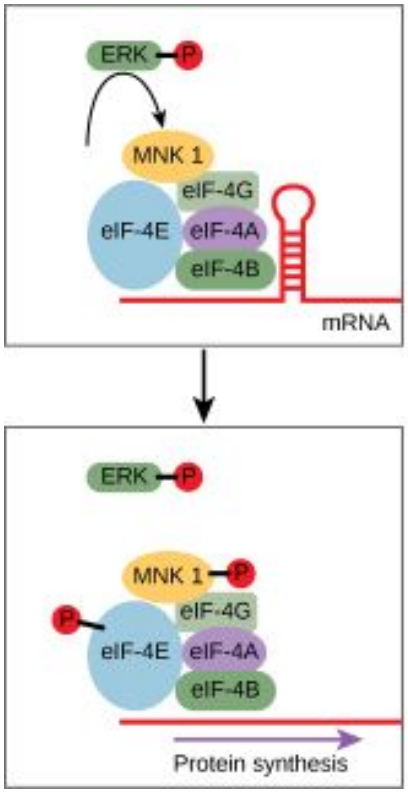




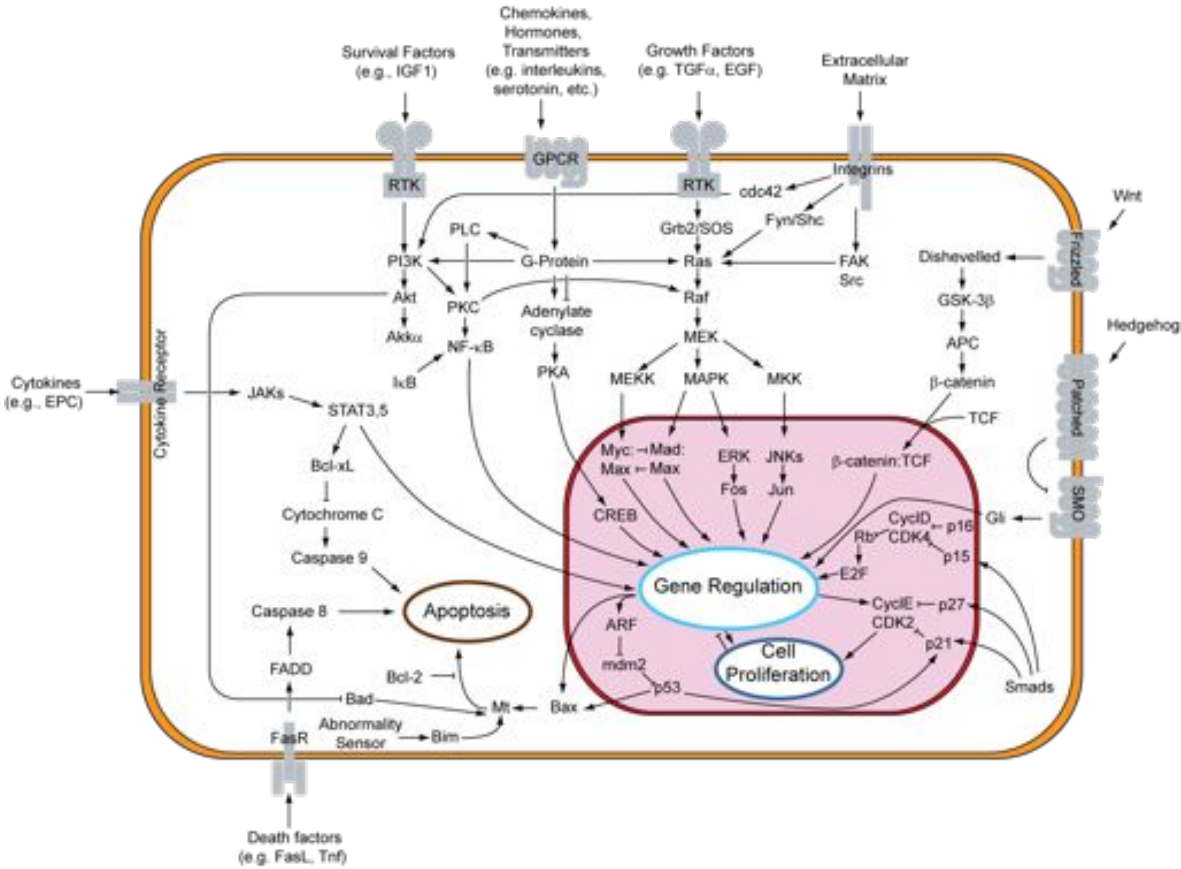


Response

Cellular responses involve changes in gene expression, and the activation of already synthesized, inactive proteins.



The MAP kinase ERK phosphorylates MNK1. MNK1 in turn phosphorylates eIF-4E, which is associated with mRNA. The mRNA unfolds and protein sythesis begins.



6.4: Changes in signal transduction pathways can alter cellular response.

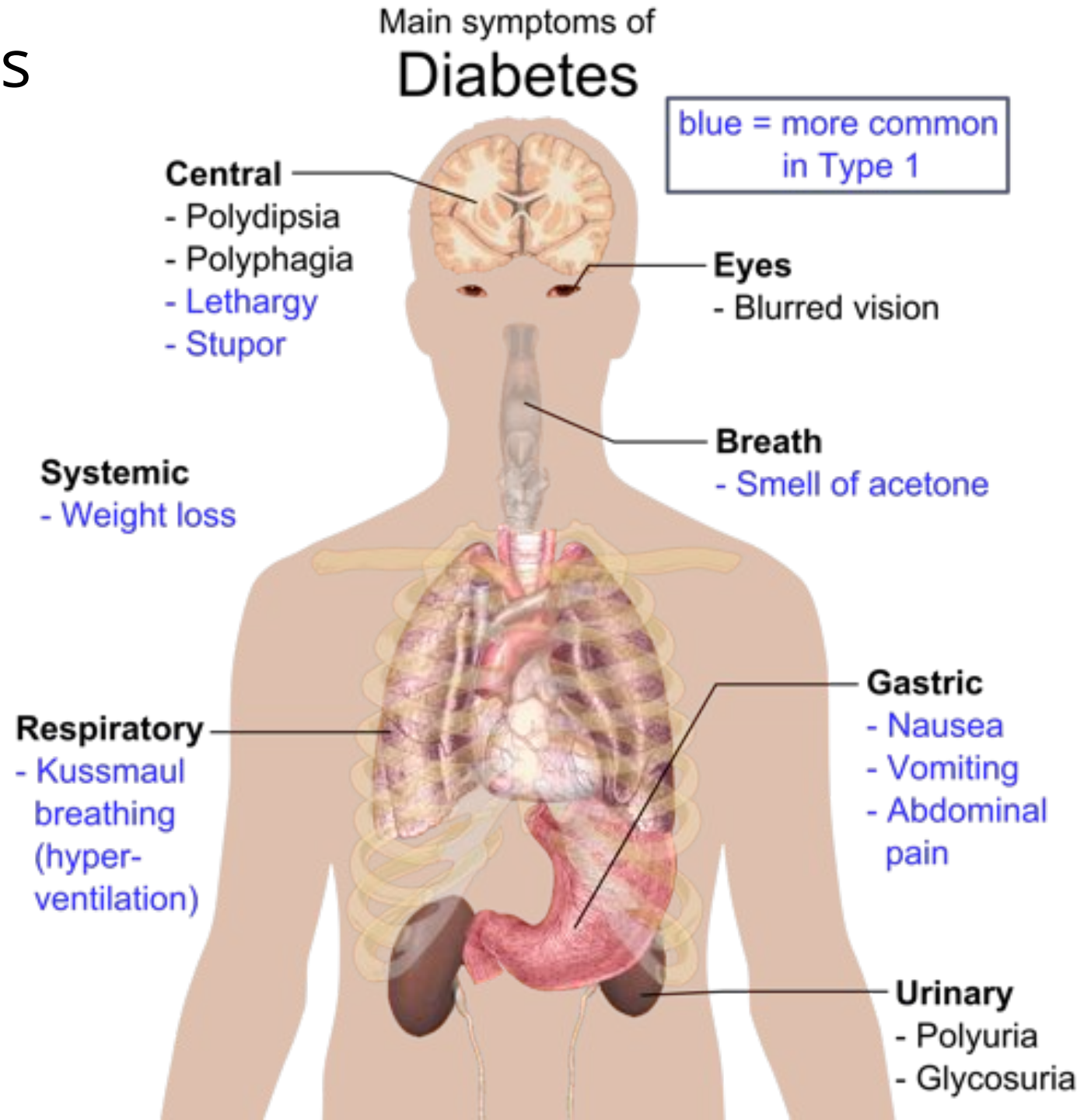
1. ALTERATIONS TO SIGNALING PATHWAYS

Changes Have Effects

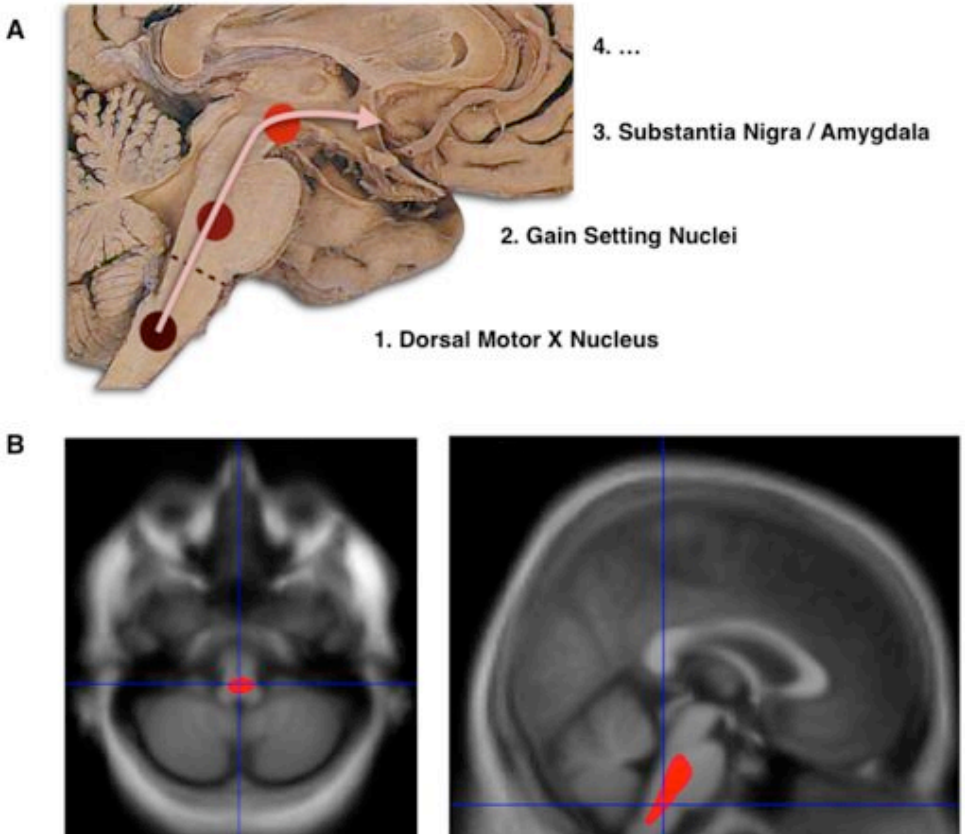
Alterations in signal transduction pathways will affect the functioning of cells, and the homeostasis of the organism.

Many **diseases** result from alterations to signal transduction pathways.

Ex. Diabetes


Main symptoms of
Diabetes
blue = more common in Type 1
Central
- Polydipsia
- Polyphagia
- Lethargy
- Stupor
Eyes
- Blurred vision
Breath
- Smell of acetone
Systemic
- Weight loss
Respiratory
- Kussmaul breathing (hyper-ventilation)
Gastric
- Nausea
- Vomiting
- Abdominal pain
Urinary
- Polyuria
- Glycosuria

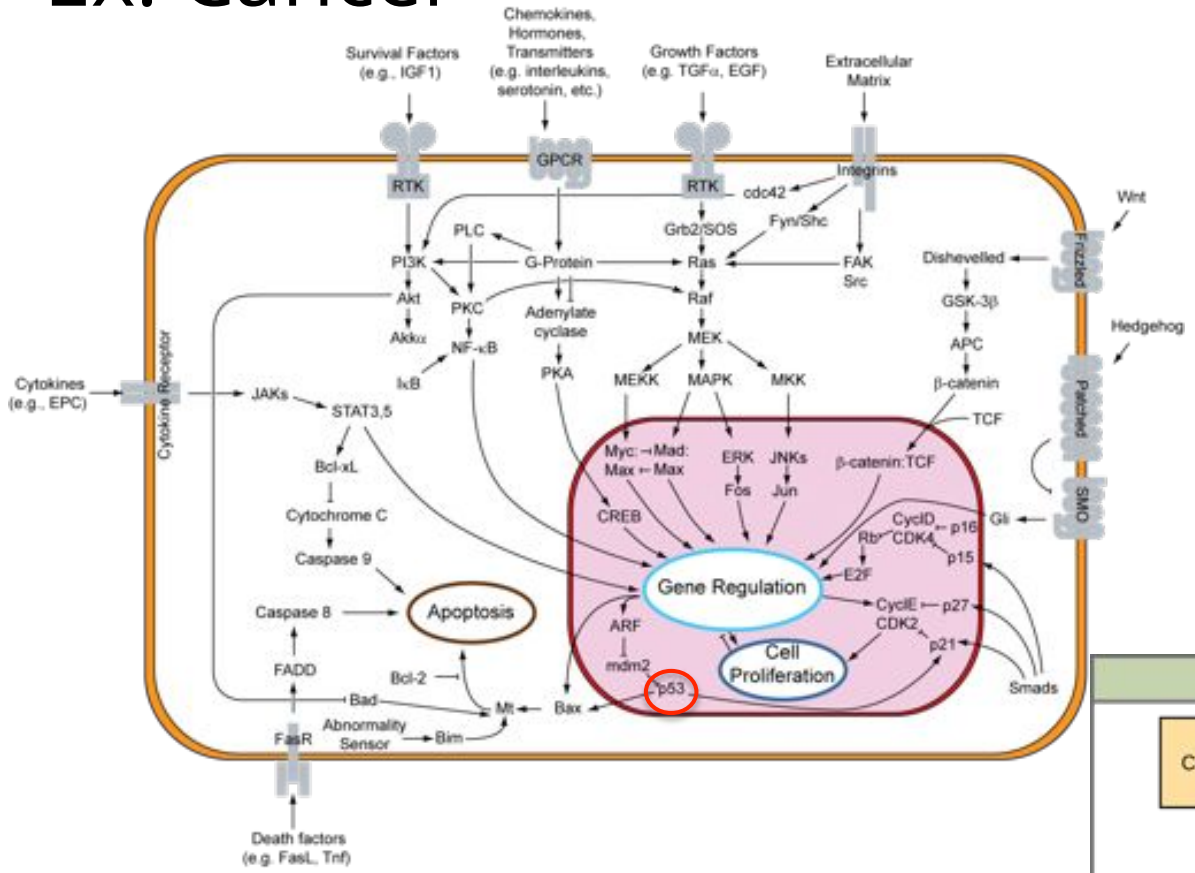
Ex. Neurological Disease

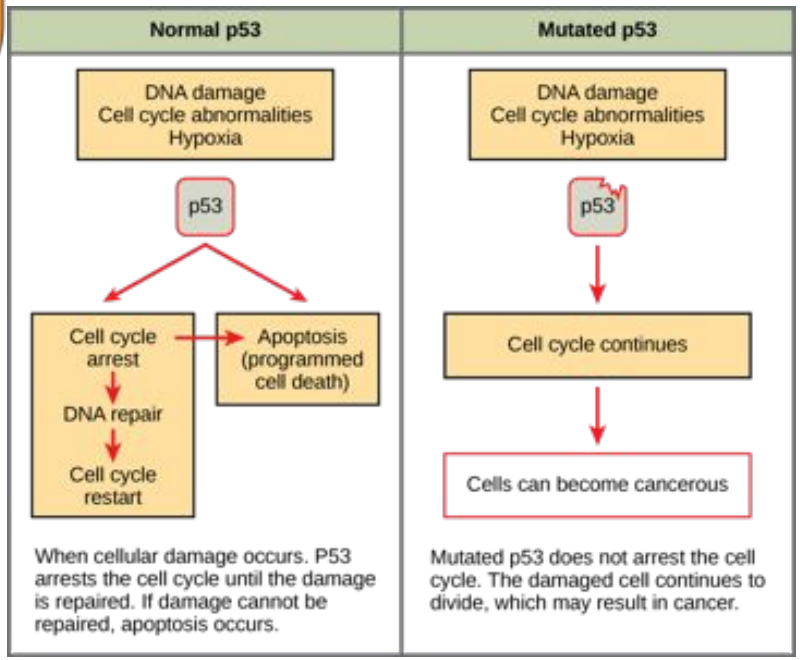


Catherine Metzger

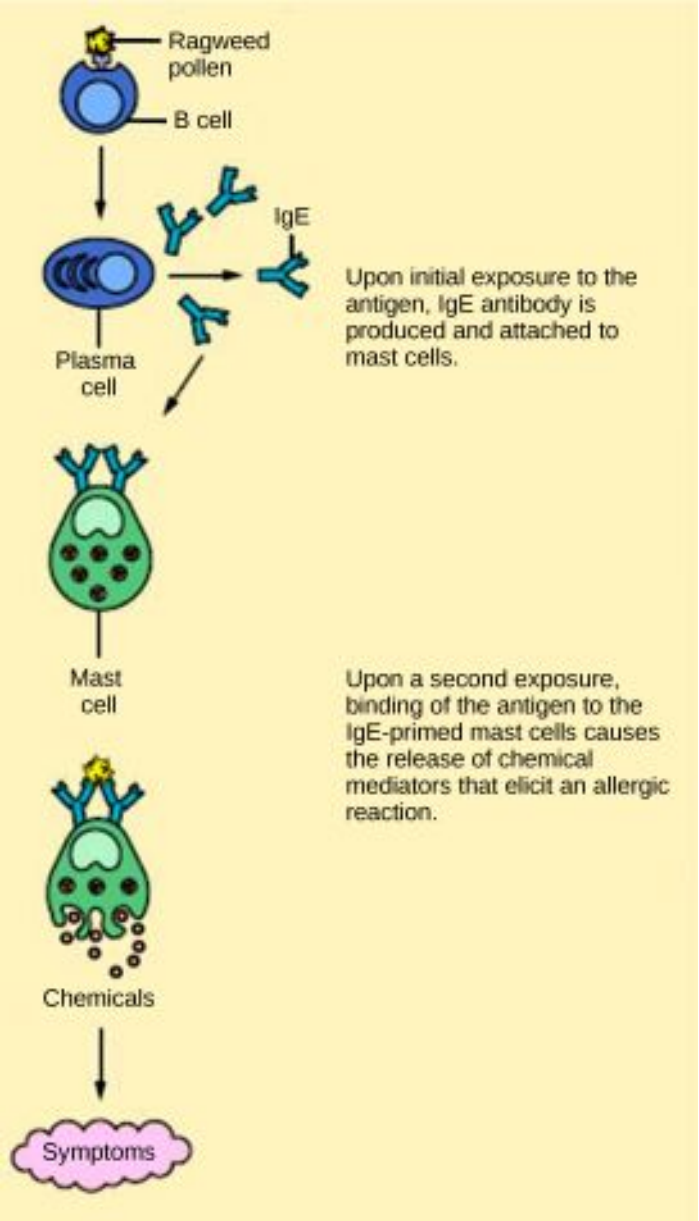
13 Octobre 1869

Ex. Cancer


Survival Factors (e.g., IGF1)
Chemokines, Hormones, Transmitters (e.g. interleukins, serotonin, etc.)
Growth Factors (e.g. TGFα, EGF)
Extracellular Matrix
GPCR
RTK
RTK
Integrins
cdc42
Fyn/Shc
PLC
Grb2/SOS
PI3K
G-Protein
Ras
FAK
Src
Akt
PKC
Adenylate cyclase
Raf
Akkα
NF-κB
MEK
IκB
PKA
MEKK
MAPK
MKK
Cytokines (e.g., EPC)
Cytokine Receptor
JAKs
STAT3,5
Bcl-xL
Cytochrome C
Caspase 9
Caspase 8
Apoptosis
FADD
Bcl-2
Bad
Mt
Abnormality Sensor
Bim
FasR
Death factors (e.g. FasL, Tnf)
Myc: Mad: Max Max
ERK
JNKs
Fos
Jun
β-catenin:TCF
CREB
CyclD
p16
Rb
CDK4
p15
E2F
Gene Regulation
CyclE
p27
CDK2
p21
ARF
mdm2
p53
Cell Proliferation
Bax
Smads
Wnt
Frizzled
Dishevelled
GSK-3β
APC
β-catenin
TCF
Hedgehog
Patched
SMO
Gli


Normal p53
Mutated p53
DNA damage
Cell cycle abnormalities
Hypoxia
p53
Cell cycle arrest
DNA repair
Cell cycle restart
Apoptosis (programmed cell death)
When cellular damage occurs. P53 arrests the cell cycle until the damage is repaired. If damage cannot be repaired, apoptosis occurs.
DNA damage
Cell cycle abnormalities
Hypoxia
p53
Cell cycle continues
Cells can become cancerous
Mutated p53 does not arrest the cell cycle. The damaged cell continues to divide, which may result in cancer.

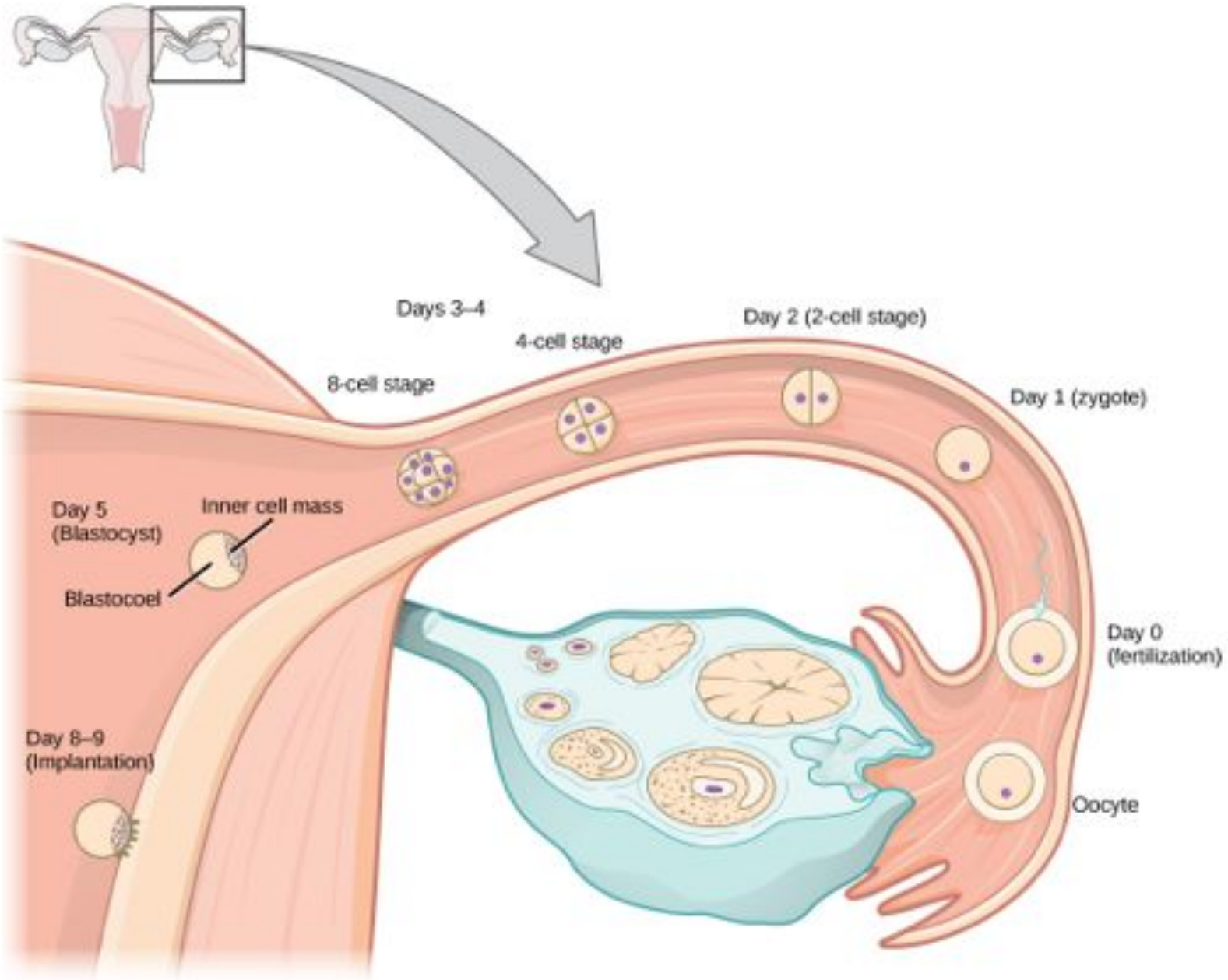
Cell Signaling And Drugs



Many drugs work by altering signal transduction pathways.

Ex. Antihistamines

Ex. Birth Control Pills



6.5: Individuals can act on information and communicate it to others.

1. COMMUNICATION BETWEEN ORGANISMS

Organisms Communicate

All organisms are able to acquire information about their environment.

Most are able to exchange that information with other organisms

Stimulus & Response

Anything in the environment that elicits a response from an organism.

The ability of organisms to respond to stimuli will contribute to fitness.

Ex. Predator Warnings

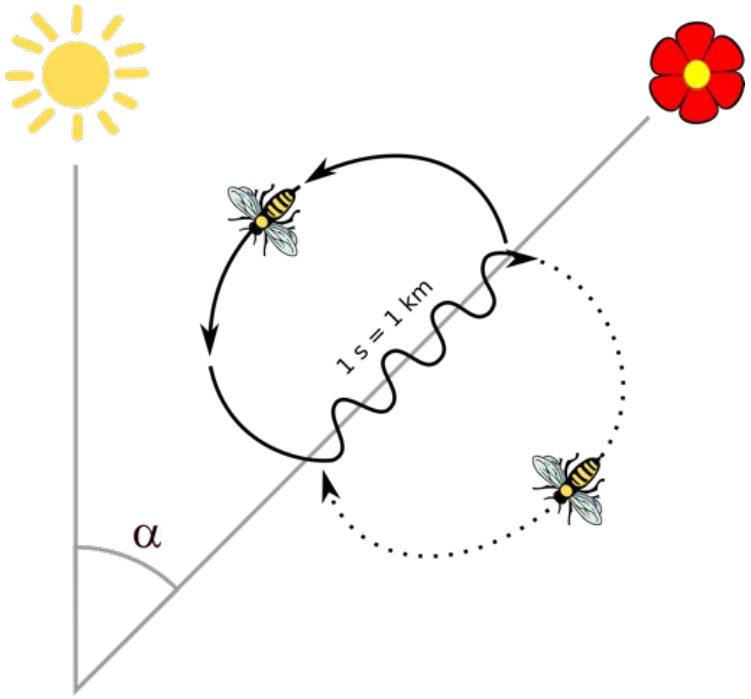
Ex. Plant Responses to Herbivory

Animal Responses

Animals have highly developed **sensory systems**, and **muscular-skeletal systems** that allow for fast responses to environmental stimuli.

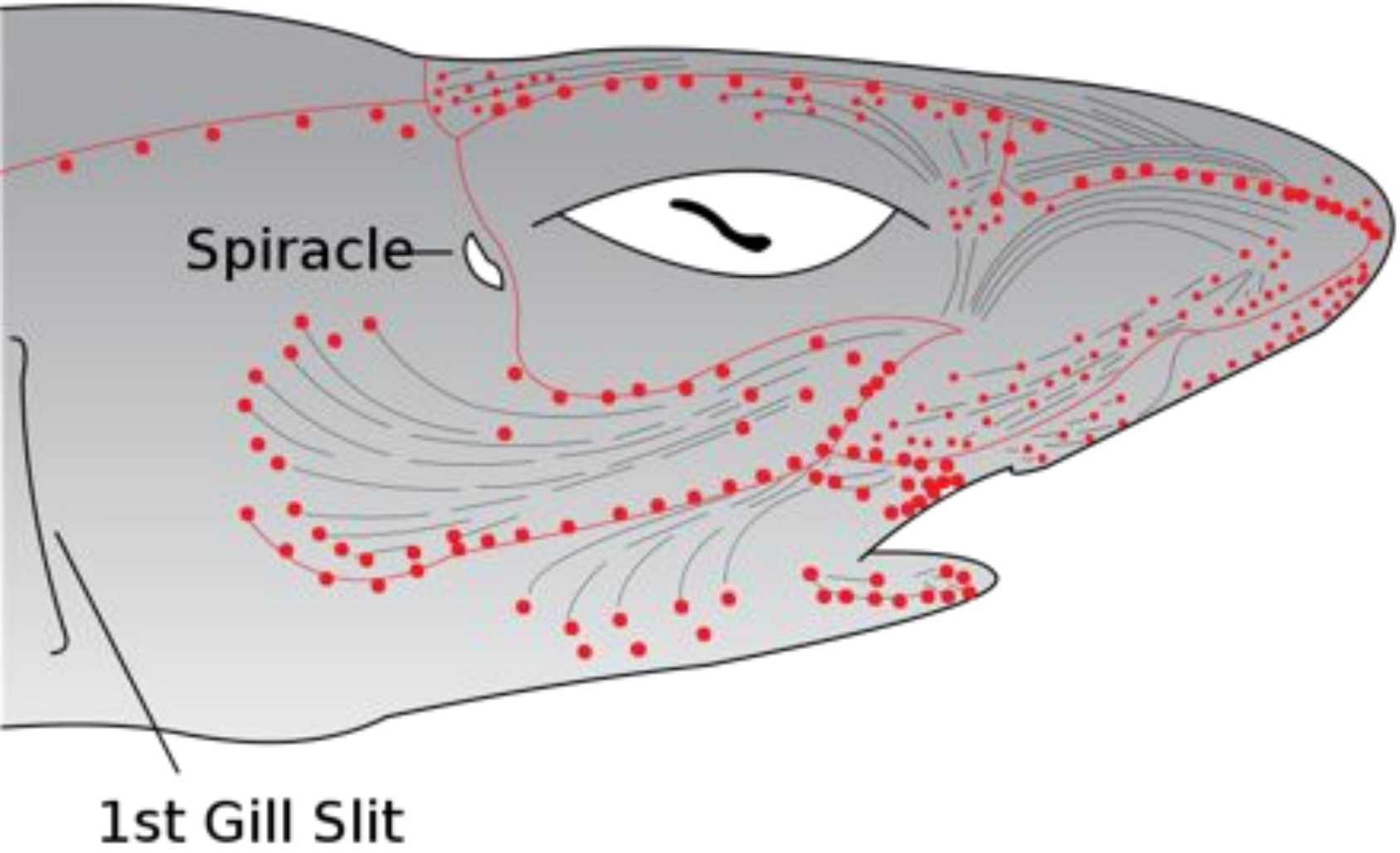
Different Animal lineages can communicate using visual, auditory, tactile, chemical, and electrical signals from the environment.

Ex. Bee Waggle Dances



Ex. Swarming Behavior

Ex. Electroreception



Communication and Natural Selection

Organisms who are best adapted at communicating and responding to information from their environment will be at a selective advantage.

Natural selection will favor the evolution of any behavior that increases survival and reproductive success.

Ex. Mating Rituals

Ex. Foraging

Communication and Cooperation

If cooperation benefits the organisms who cooperate, they will be at an adaptive advantage.

Natural selection will allow for the evolution of cooperative behavior if it increases the fitness of the individual OR genetically related individuals.

Ex. Social Behavior

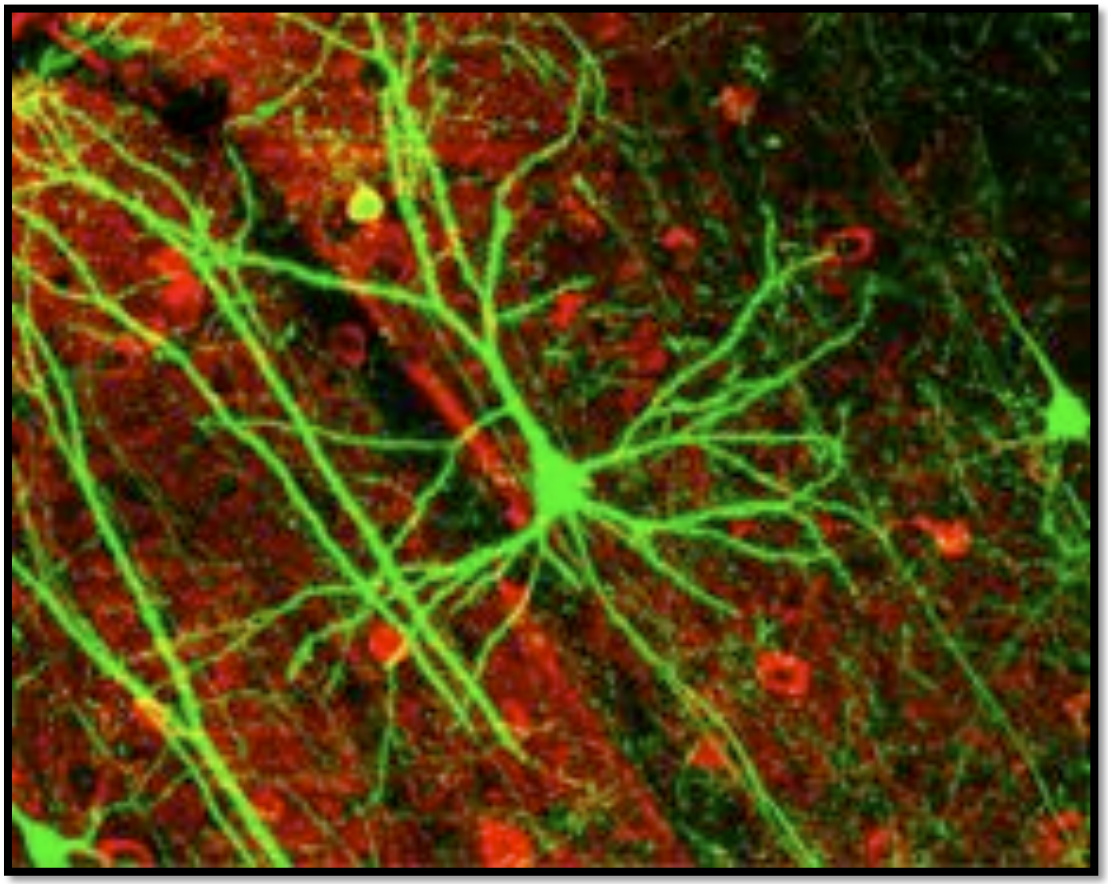
Ex. Schooling/Flocking Behavior

6.6: Animals have nervous systems that detect external and internal signals, transmit and integrate information, and produce responses.

1. NEURONS

All About Neurons

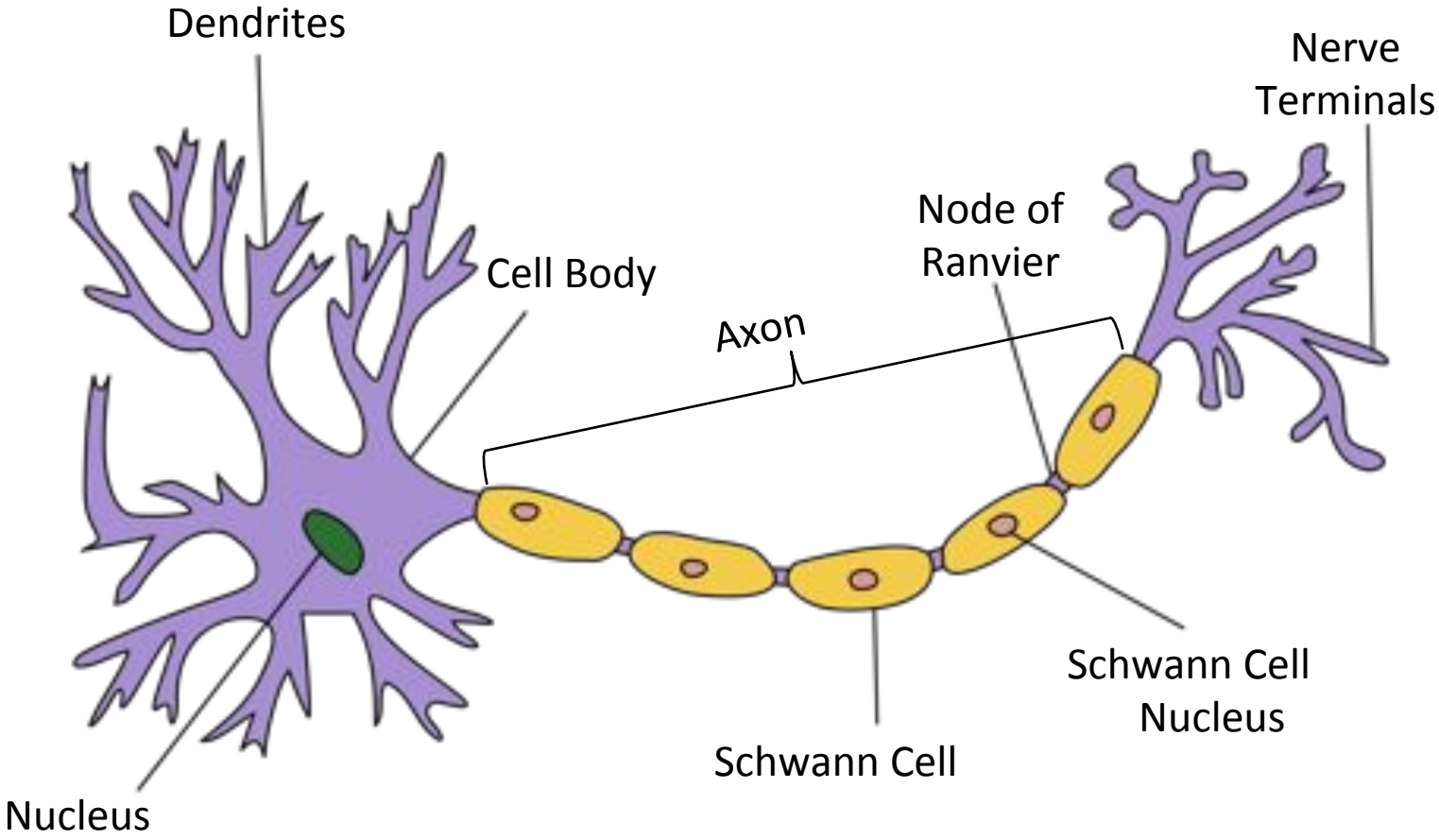
Neurons are highly-specialized cells used by the nervous system to detect signals and transmit them to other neurons or response **effectors** (muscles or glands)



Neuron Anatomy

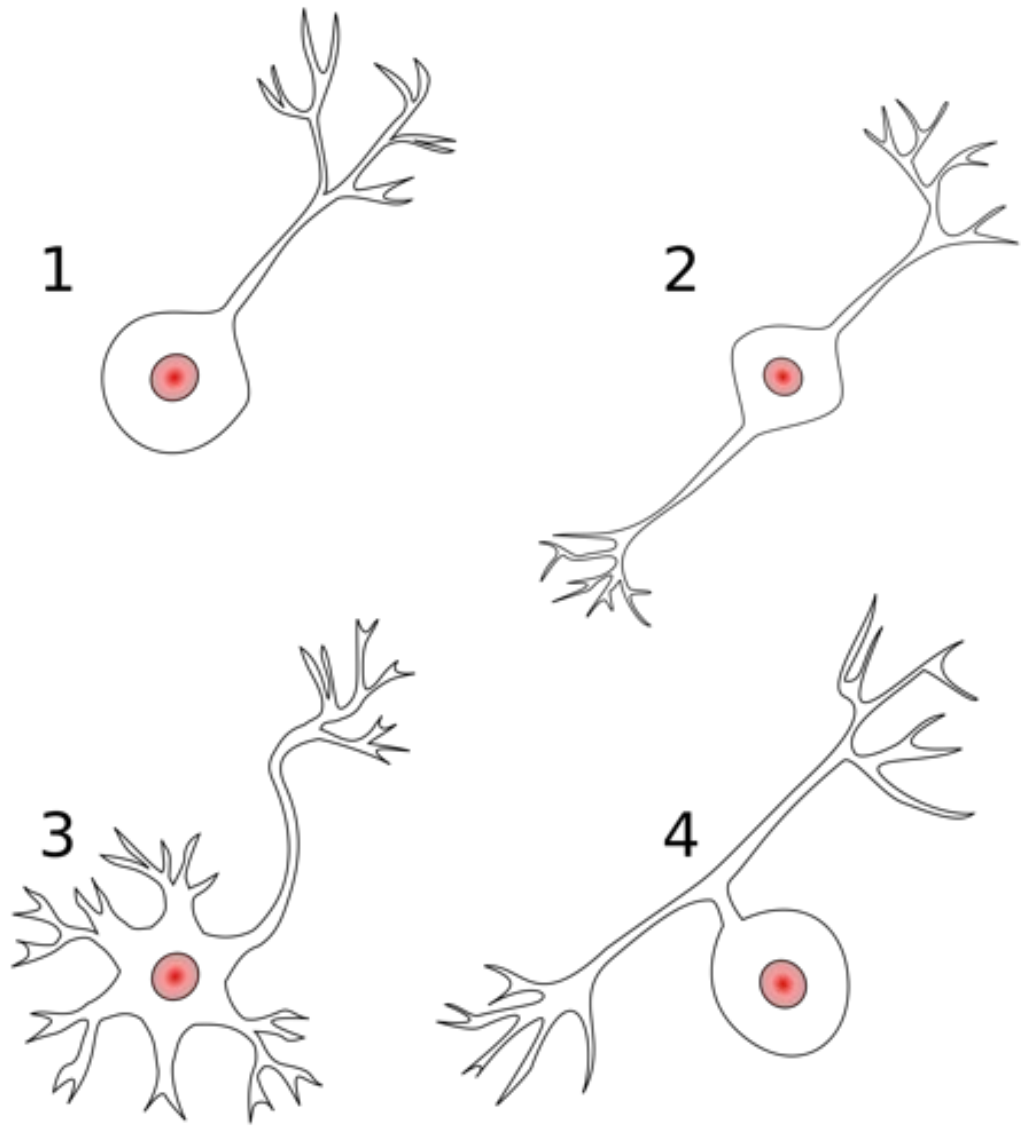
Neurons allow for signals to generated, detected, transmitted and integrated by animals.

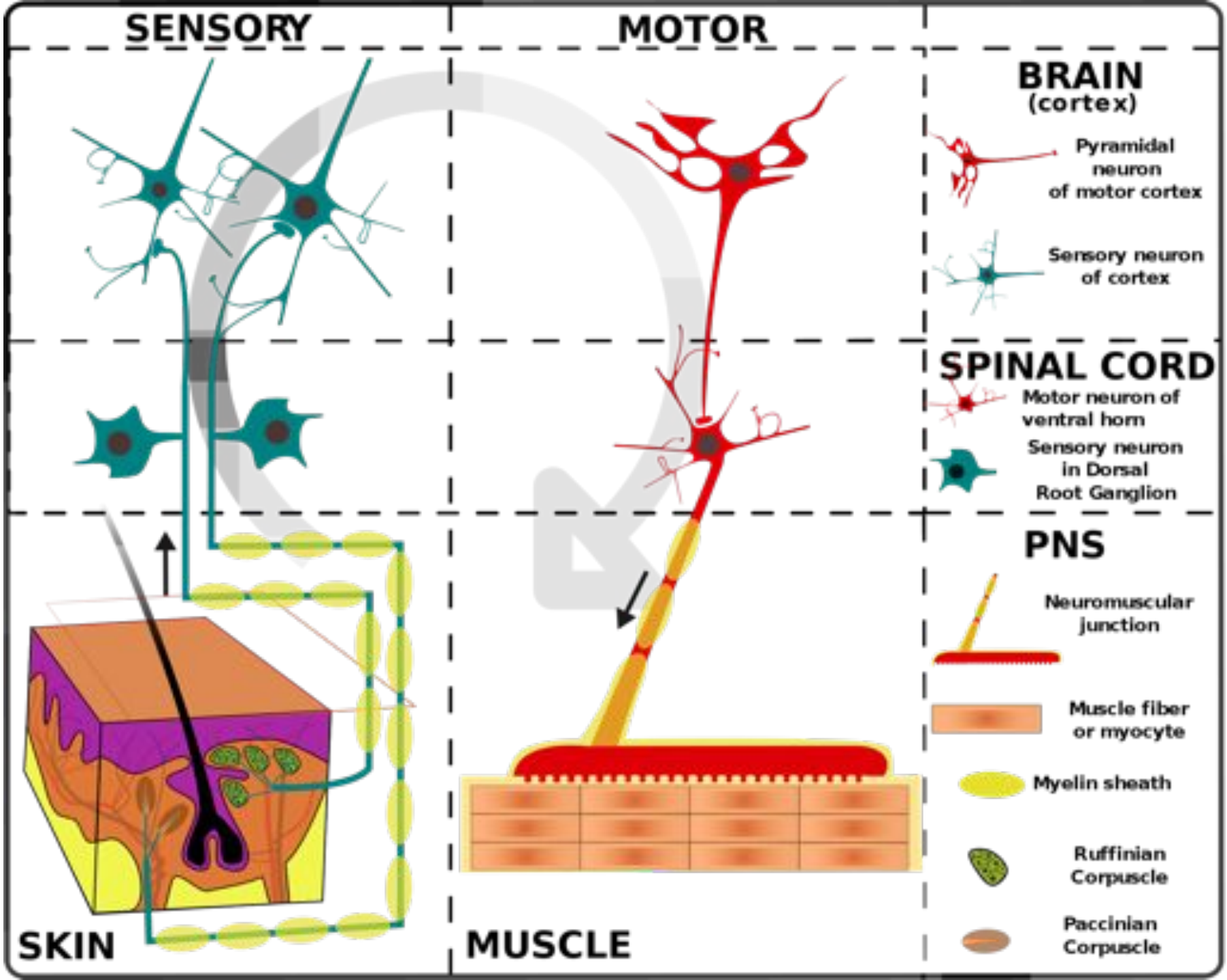
Neuron signals move from **dendrites** to **axon** to **nerve terminals**.



Neuron Diversity

Neuron structure varies depending on the role of the neuron in the nervous system.




SENSORY
MOTOR
BRAIN
(cortex)
Pyramidal neuron of motor cortex
Sensory neuron of cortex
SPINAL CORD
Motor neuron of ventral horn
Sensory neuron in Dorsal Root Ganglion
PNS
Neuromuscular junction
Muscle fiber or myocyte
Myelin sheath
Ruffinian Corpuscle
Paccinian Corpuscle
SKIN
MUSCLE

Action Potentials

Neuron signals are electrochemical "**action potentials**".

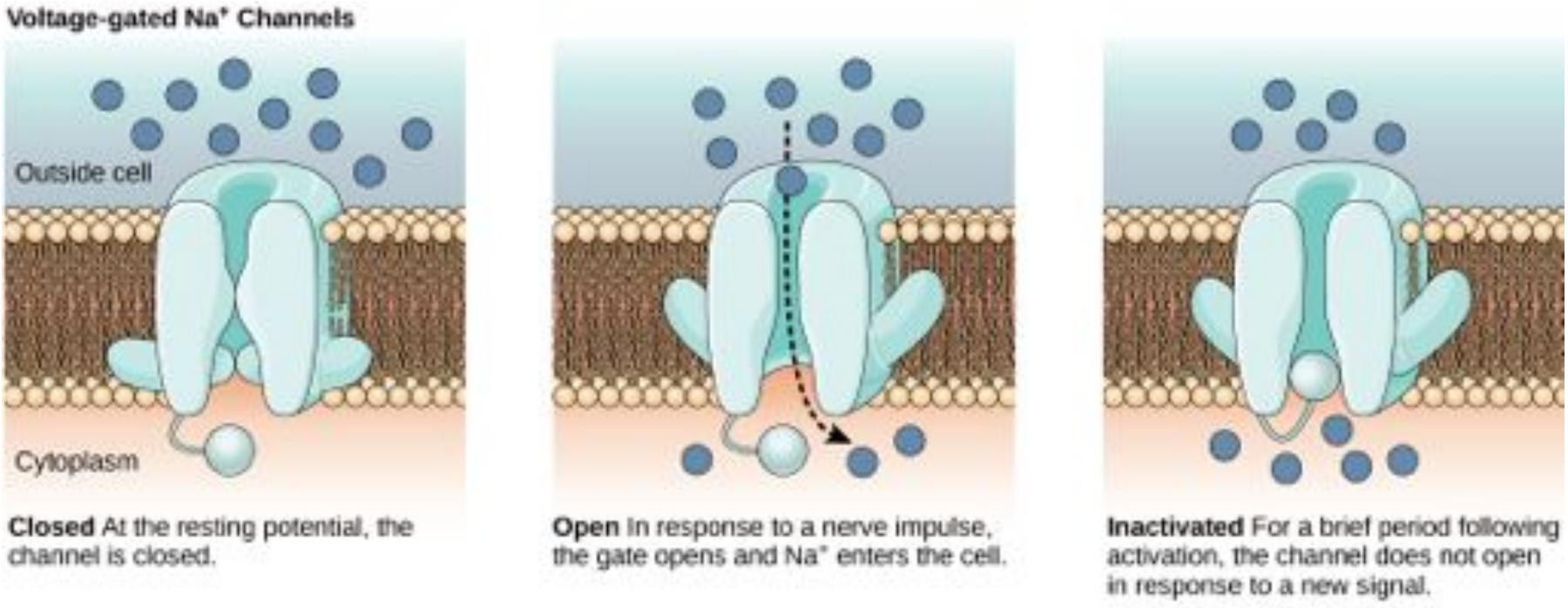
At rest, the membrane of a neuron is **polarized**, with active maintenance of different concentrations of ions inside and outside of the cell (the "**resting potential**").

Na^+ is at a higher concentration outside the cell.

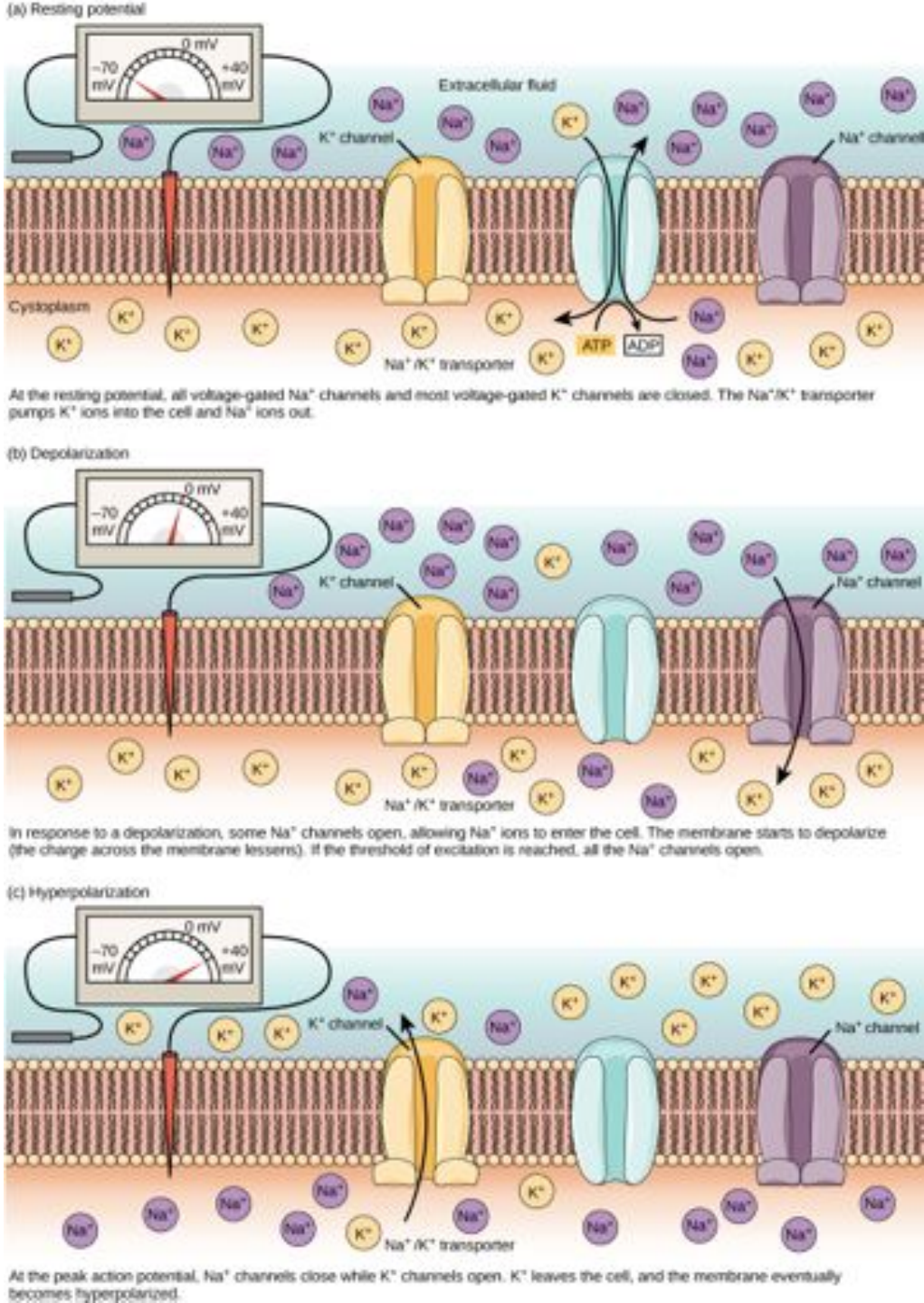
K^+ is at a higher concentration inside the cell.

An action potential results from the depolarization of a neuronal membrane's resting potential.

When the membrane is depolarized to a "**threshold potential**", voltage gated channels in the axon open, and a rapid exchange of ions occurs:

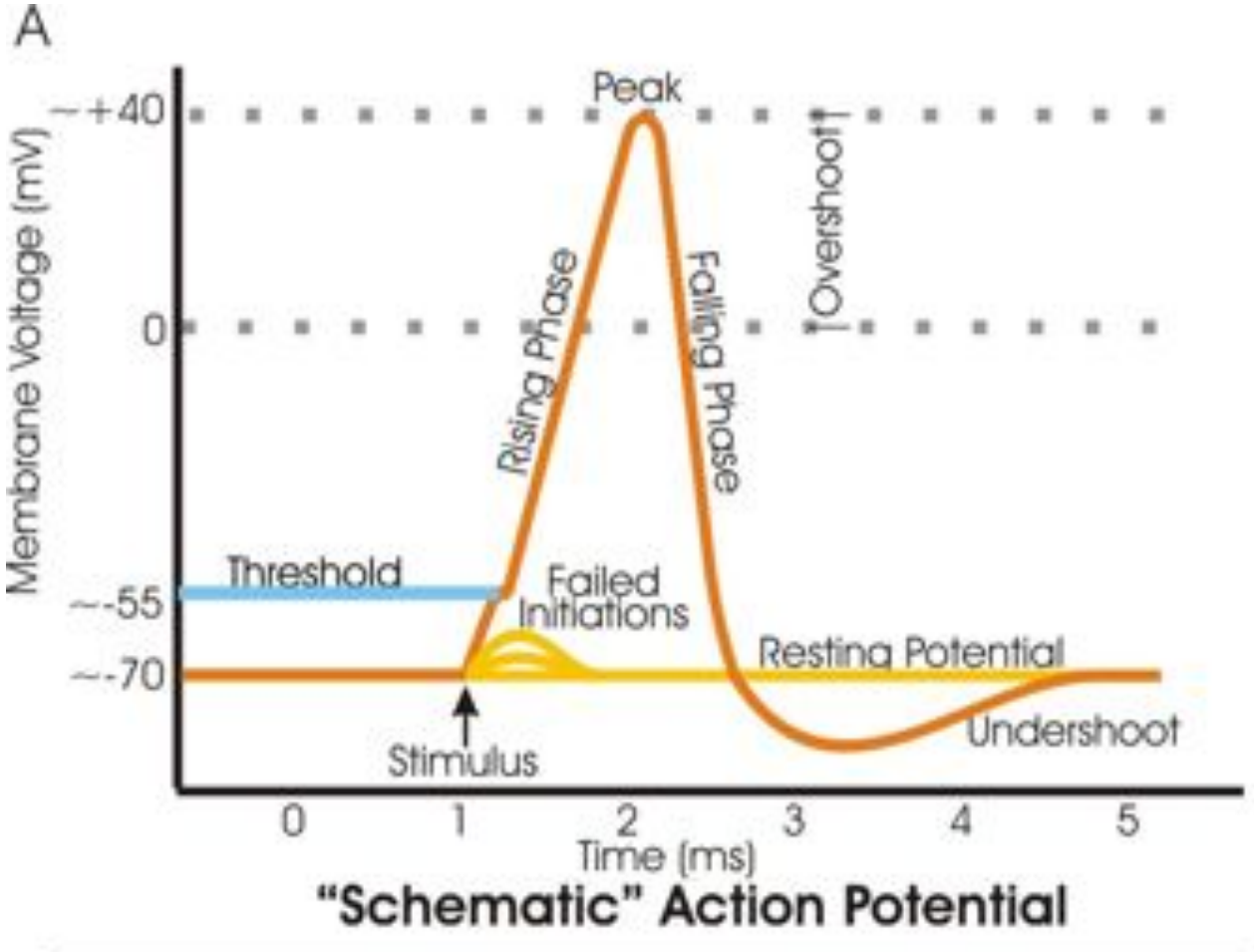


1. At threshold, **Na^+ moves in** to the cell, triggering a massive depolarization.
2. At peak depolarization, K^+ ion channels also open**, K^+ ions to move out** of the cell.
3. Peak depolarization triggers the closing of the Na^+ channels, K^+ ion channels remain open. As K^+ continues to move out of the cell, the membrane becomes hyperpolarized.
4. The action of **Na^+/K^+ pump proteins** restores the polarization of the membrane back to the resting potential.
5. Once the resting potential is restored, the neuron can send another action potential.



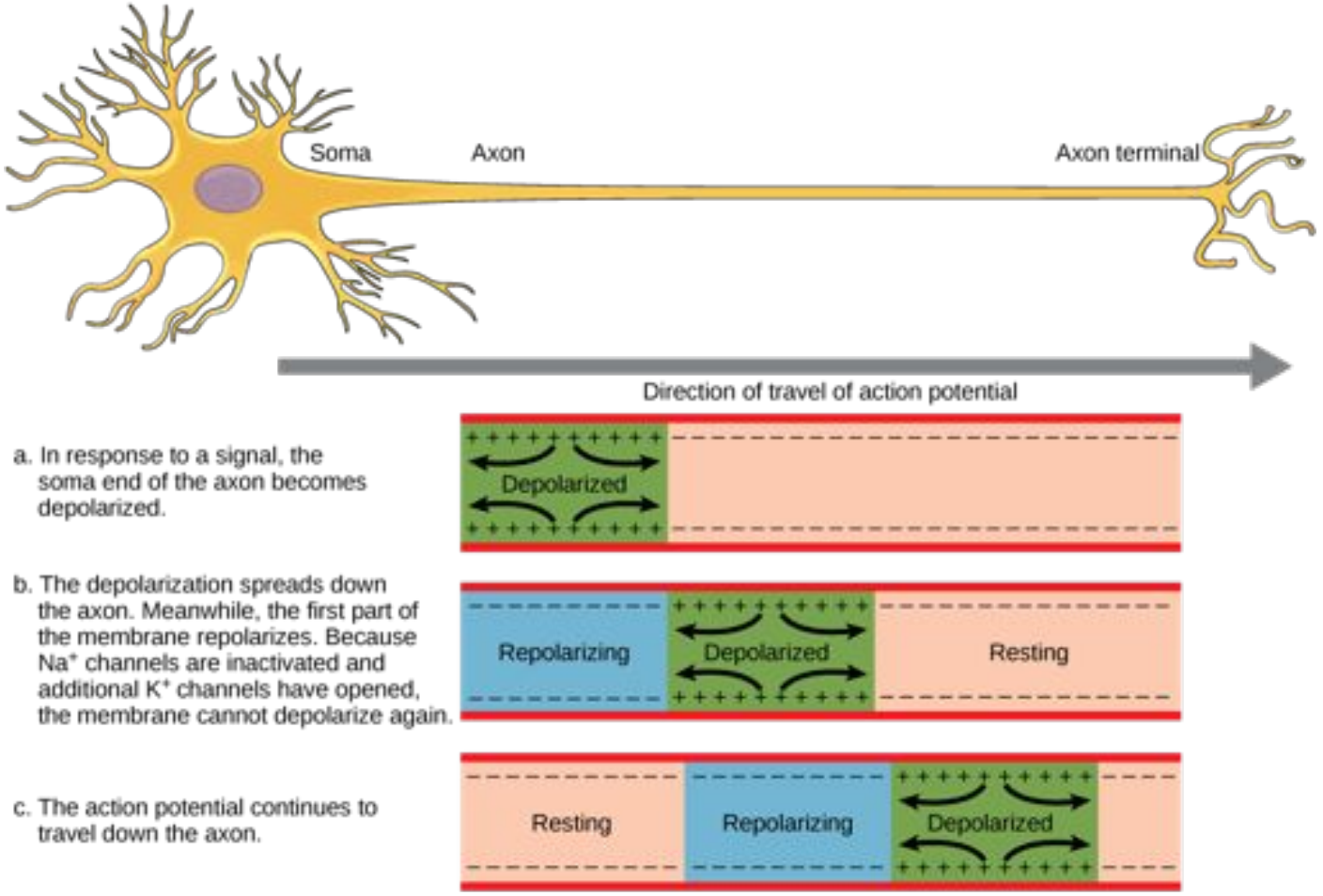
Action potentials are:

- binary (“all or nothing”)
- self-propagating
- unidirectional

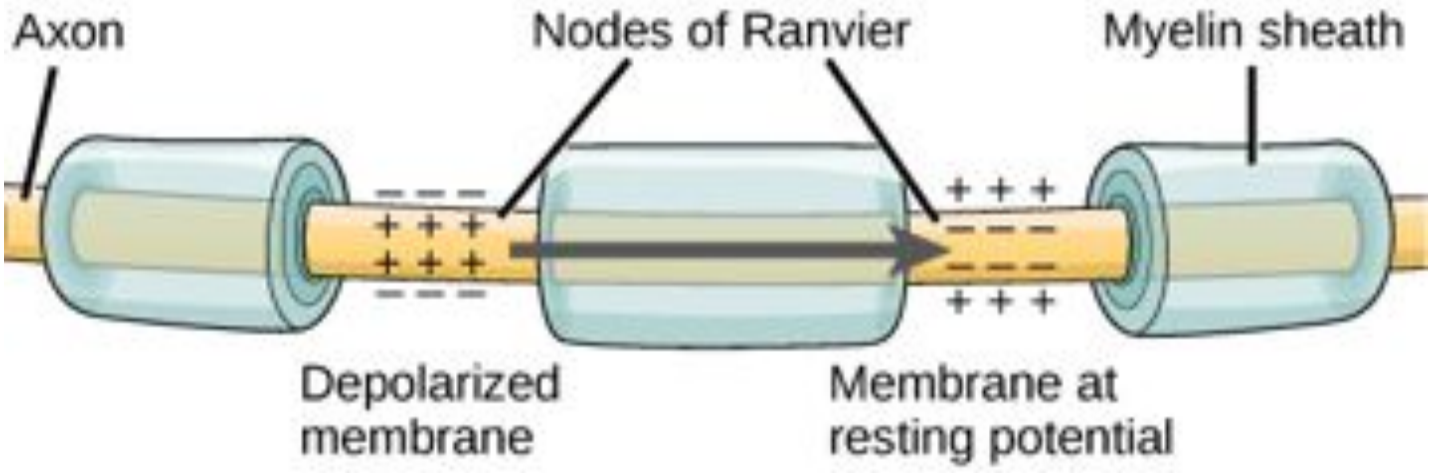


“Schematic” Action Potential

The initial depolarization of the membrane triggers the depolarization of the next area of the membrane. The hyperpolarization following an action potential prevents the action potential from moving backwards along the axon.



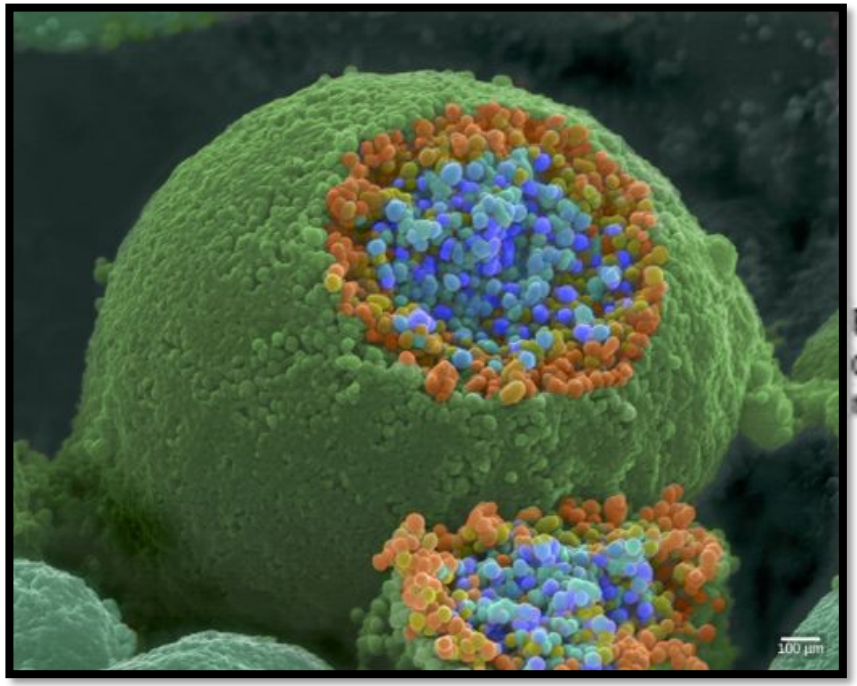
Myelination greatly increases the speed of action potential transmission, as the signal moves along nodes ("**saltatory conduction**").

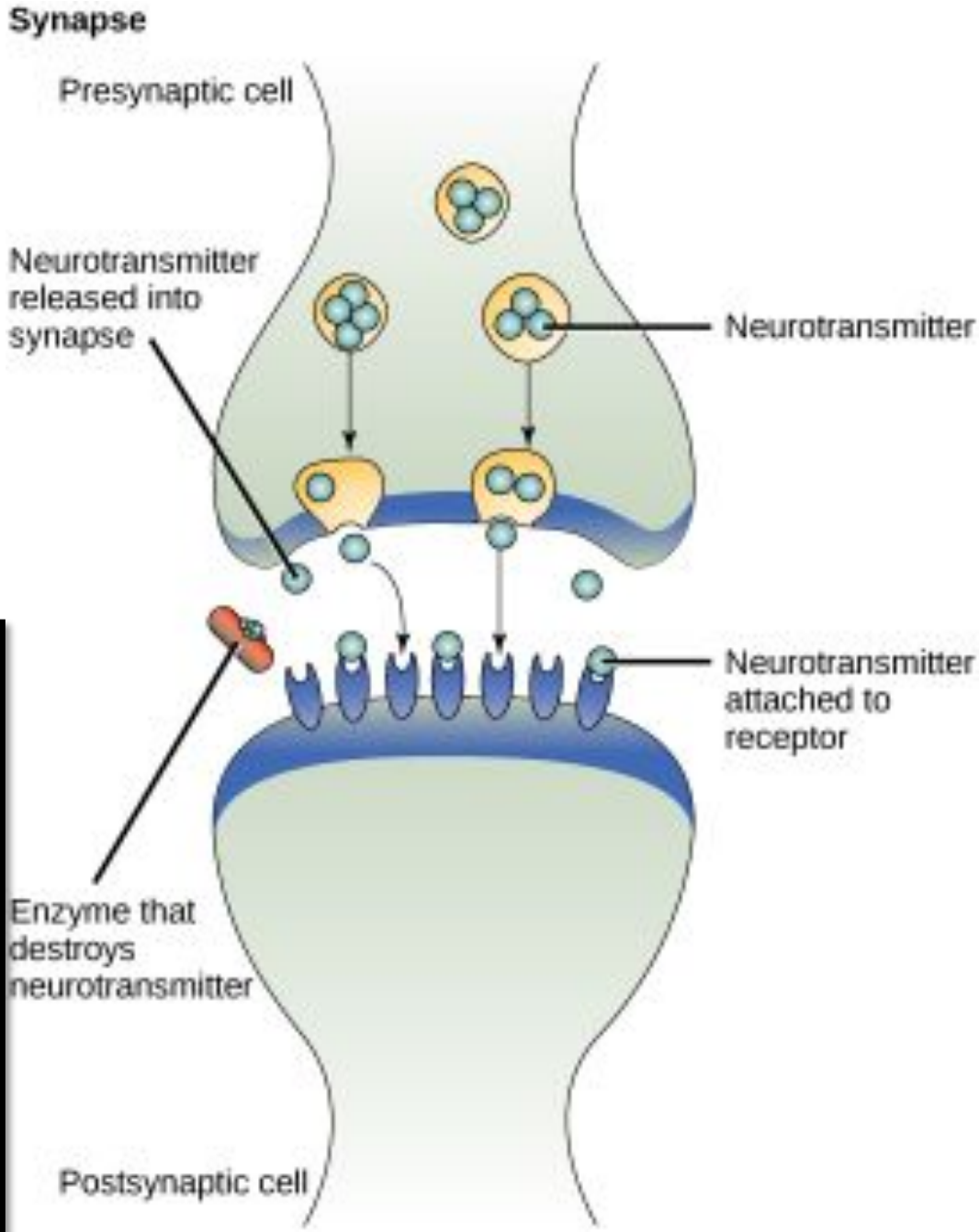


Synapses

Junctions between neurons.

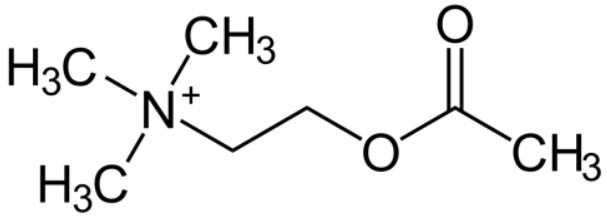
Signals are transmitted as chemicals ("**Neurotransmitters**").



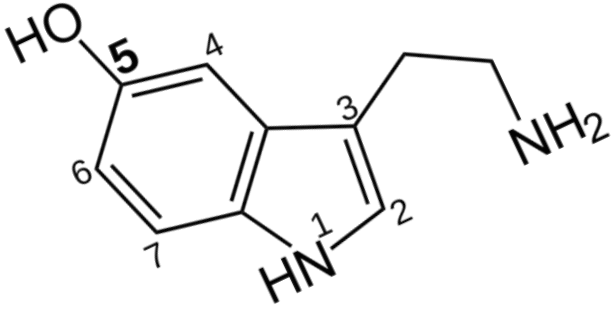


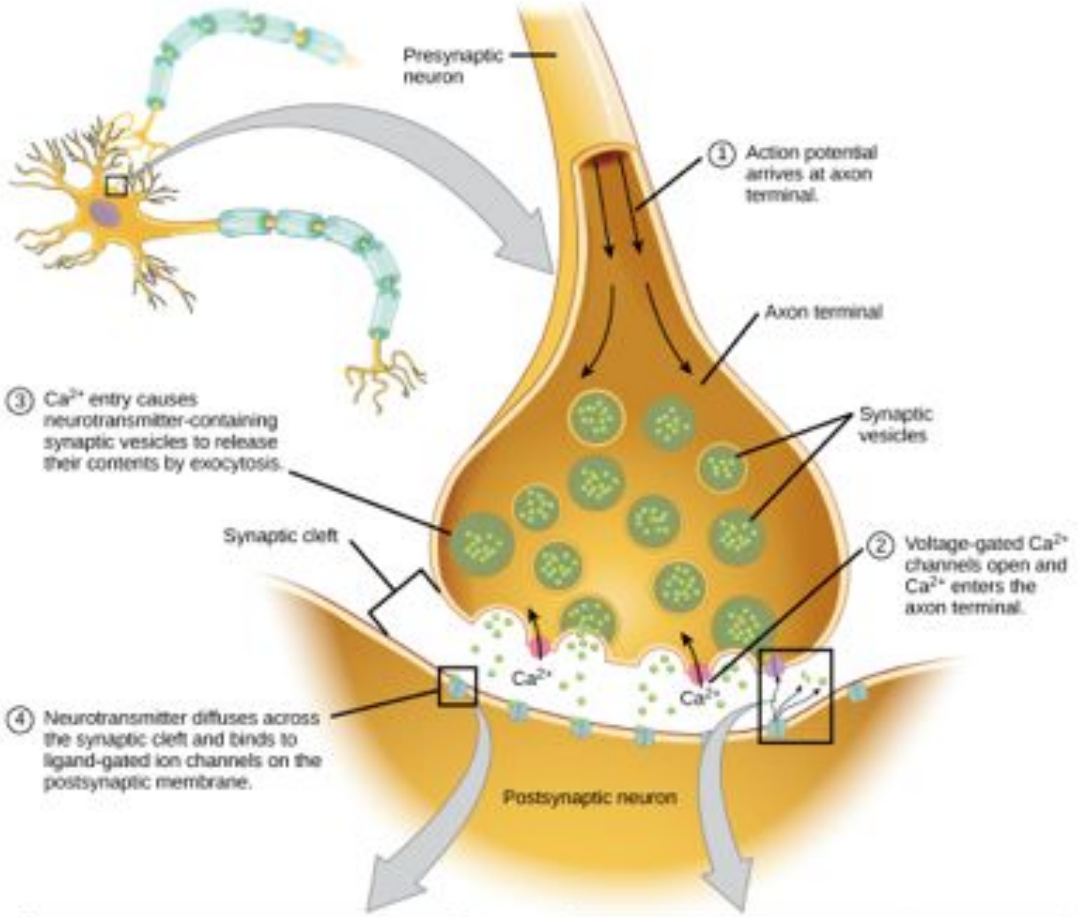
Different neurotransmitters have different uses in the nervous system.

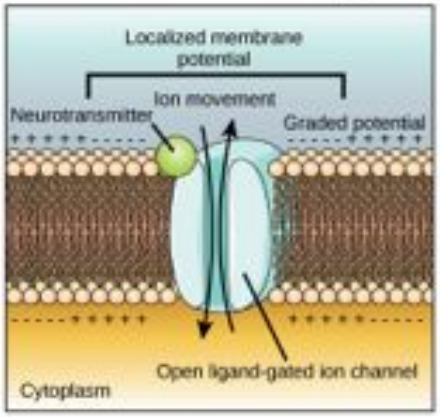
Ex. Acetylcholine: released by motor neurons at the neuromuscular junction.



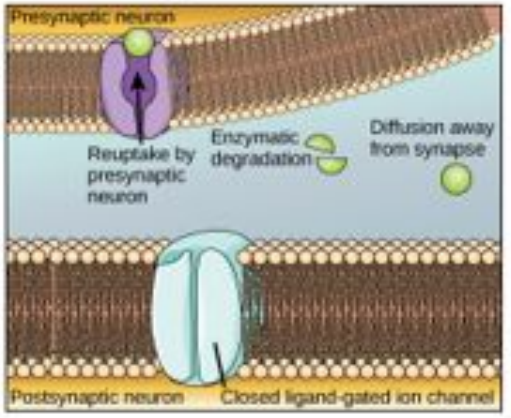
Serotonin: Released by neurons in the brain involved in emotional responses.







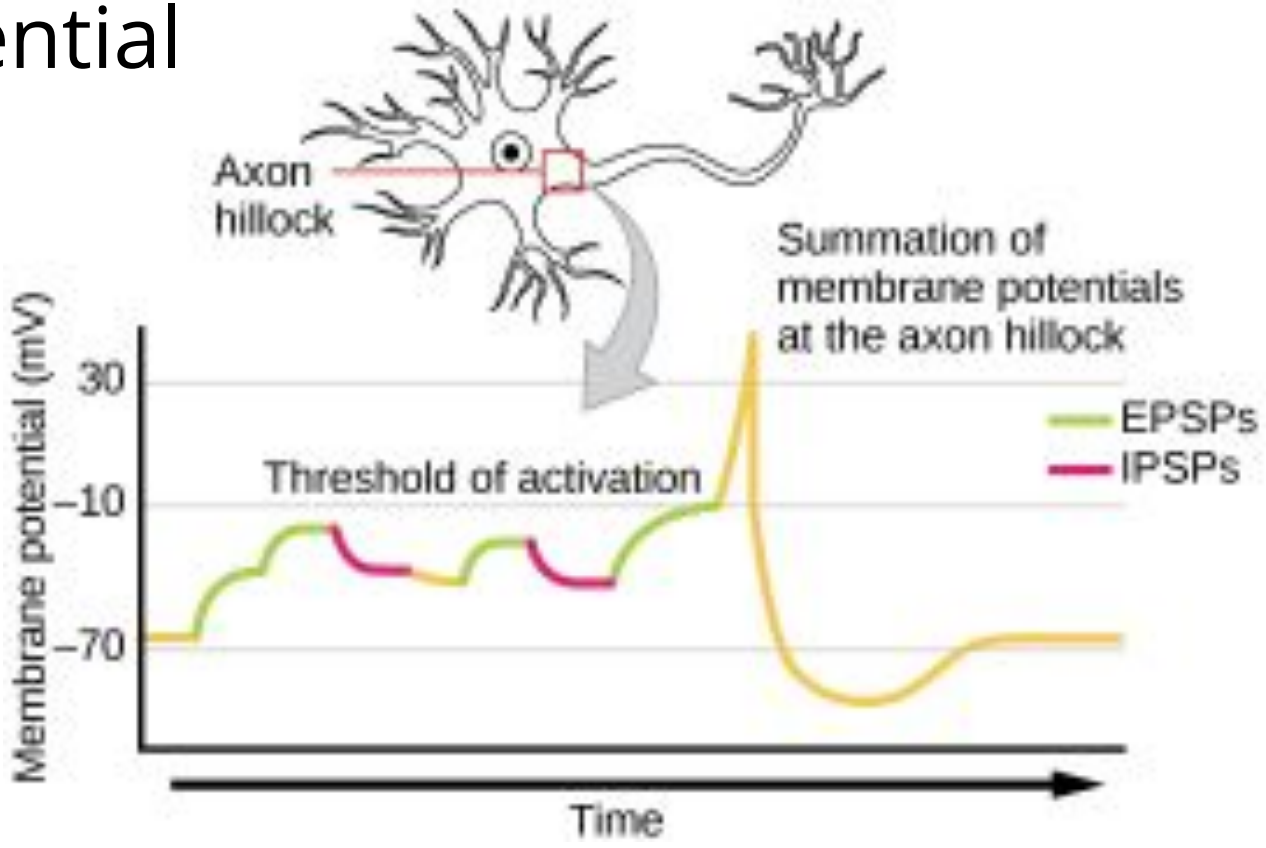
5 Binding of neurotransmitter opens ligand-gated ion channels, resulting in graded potentials.



6 Reuptake by the presynaptic neuron, enzymatic degradation, and diffusion reduce neurotransmitter levels, terminating the signal.

Signal Summation

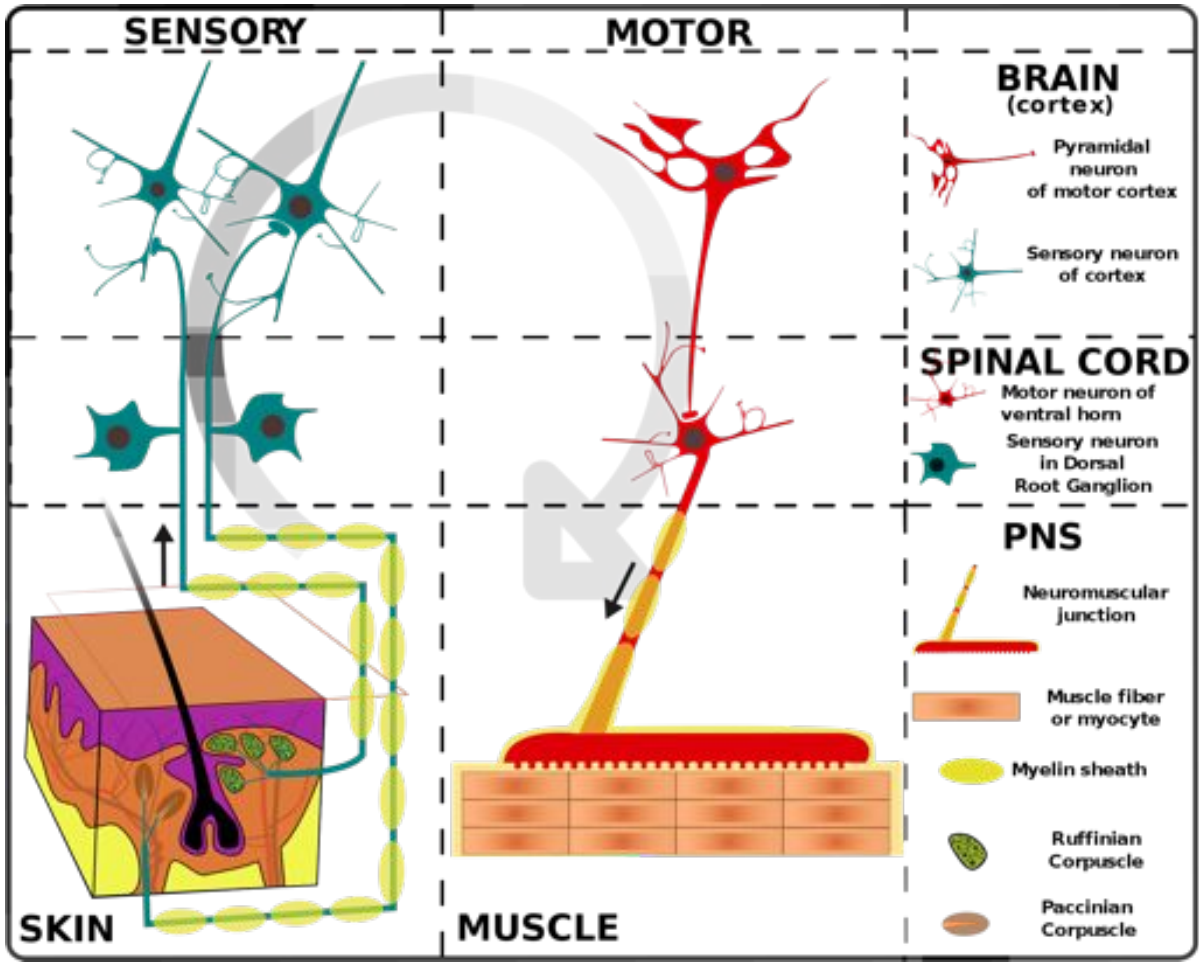
Incoming signals will be **excitatory** or **inhibitory**. The summation of all of the incoming signals will trigger a neuron to send an action potential or not.



Integration and Response

Integration: The spatial and temporal pattern of incoming action potentials will be interpreted by the nervous system as a **sensation**.

Response: the operation of muscles, or the secretion of hormones are the major ways that responses are effected.



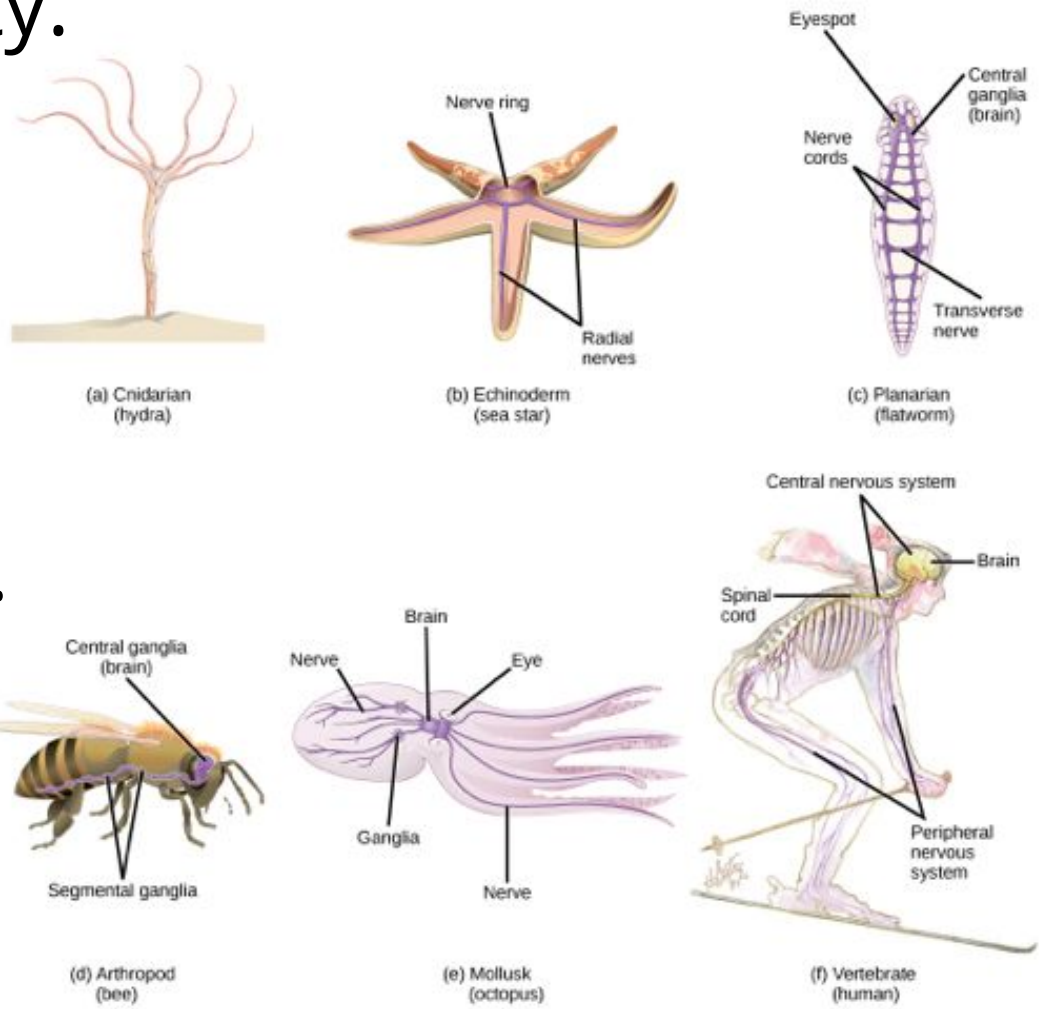
6.6: Animals have nervous systems that detect external and internal signals, transmit and integrate information, and produce responses.

2. NERVOUS SYSTEMS

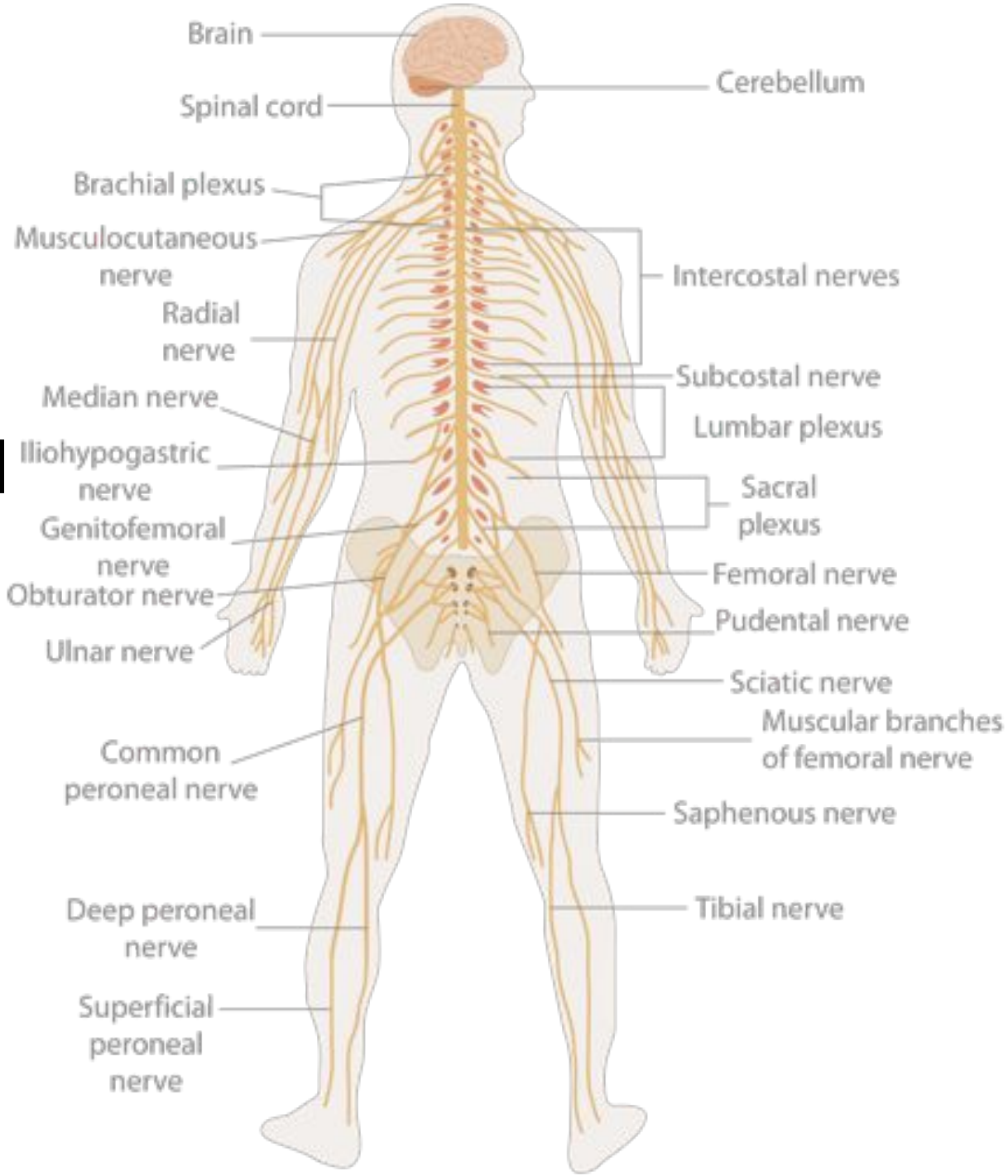
Nervous Systems

Animal Nervous Systems have varying levels of complexity.

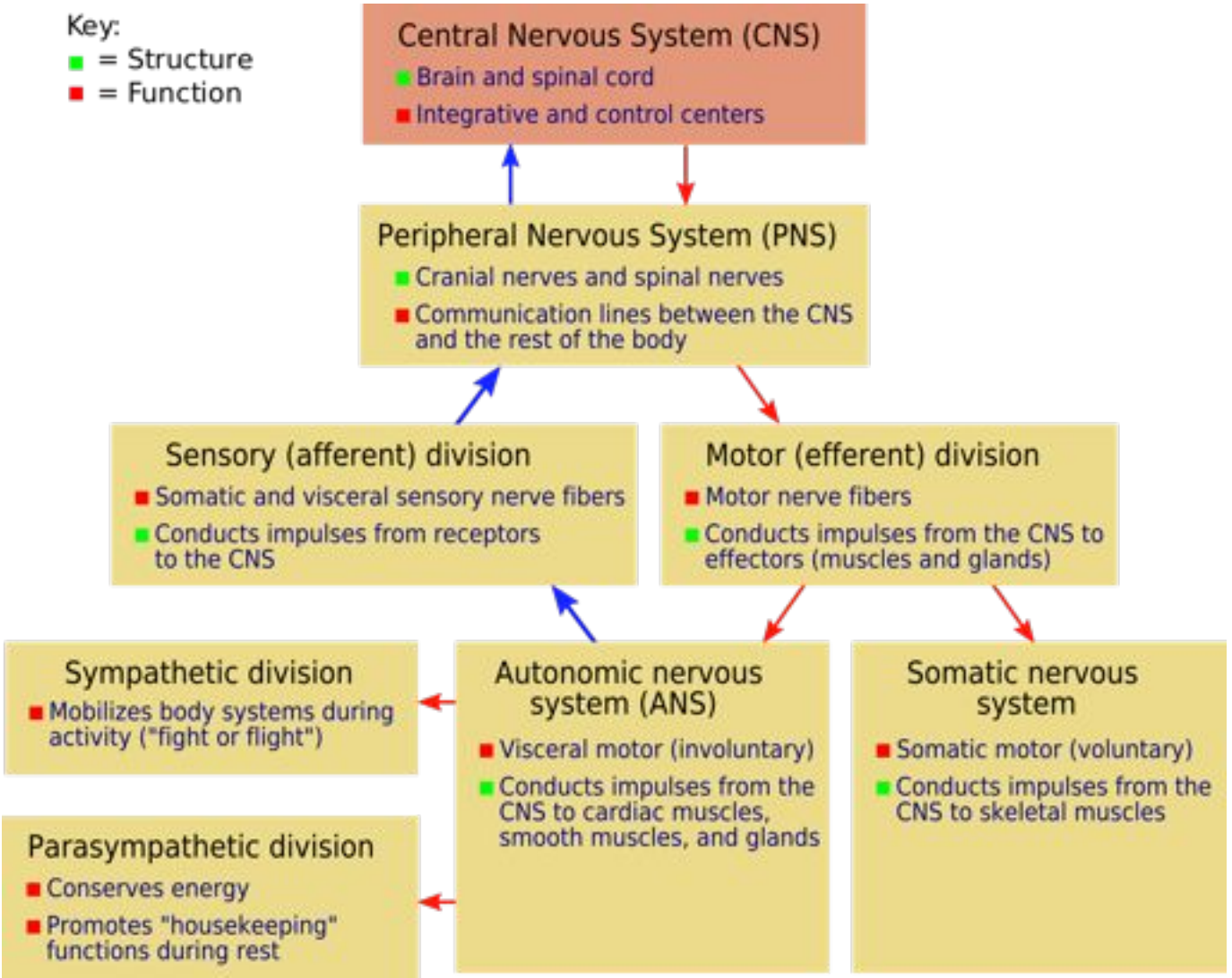
Evolutionary trends towards centralization and "**cephalization**" are demonstrated.



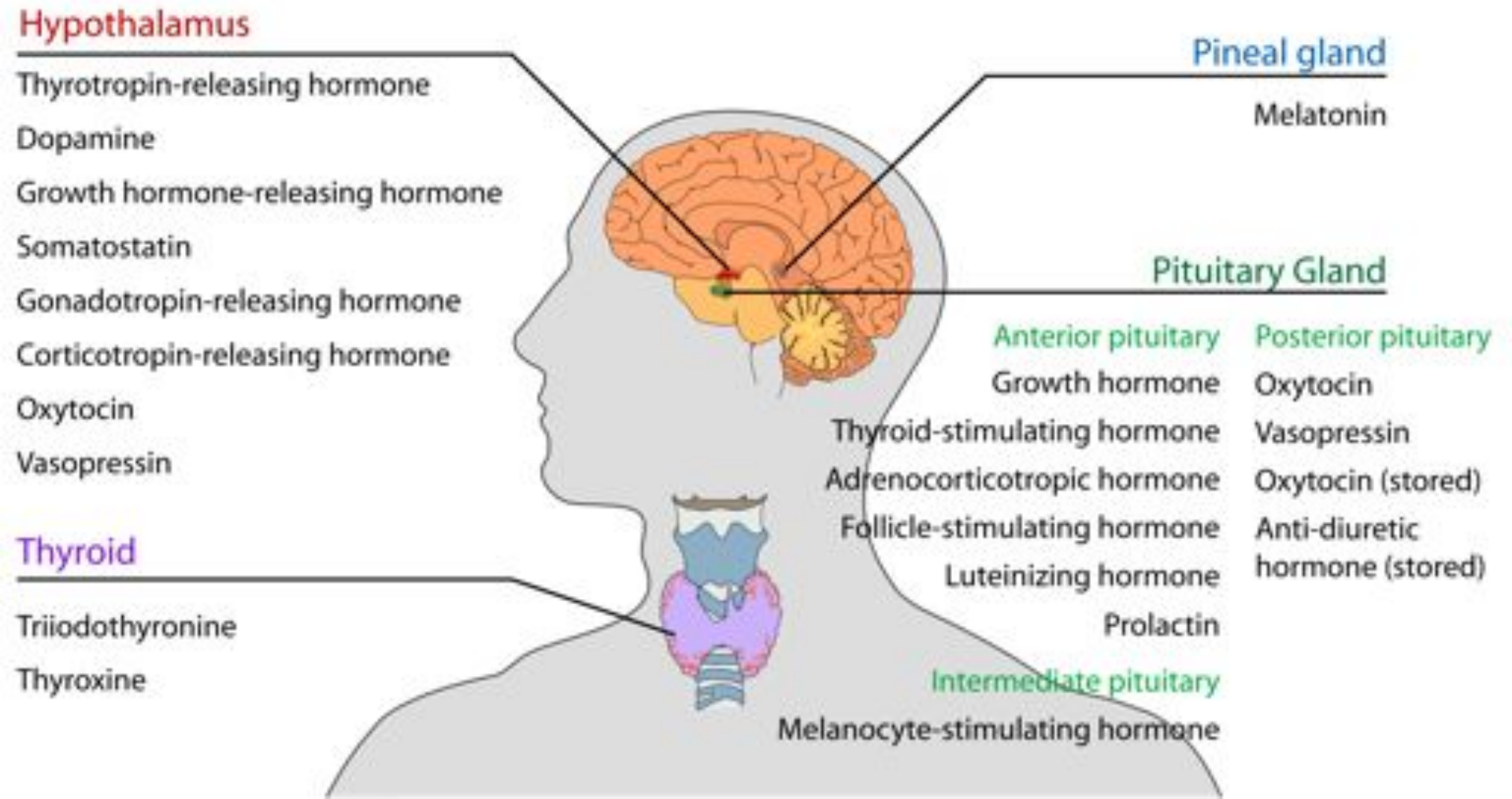
In Vertebrates, the **brain** is the central unit for integrating nervous system information and coordinating responses.



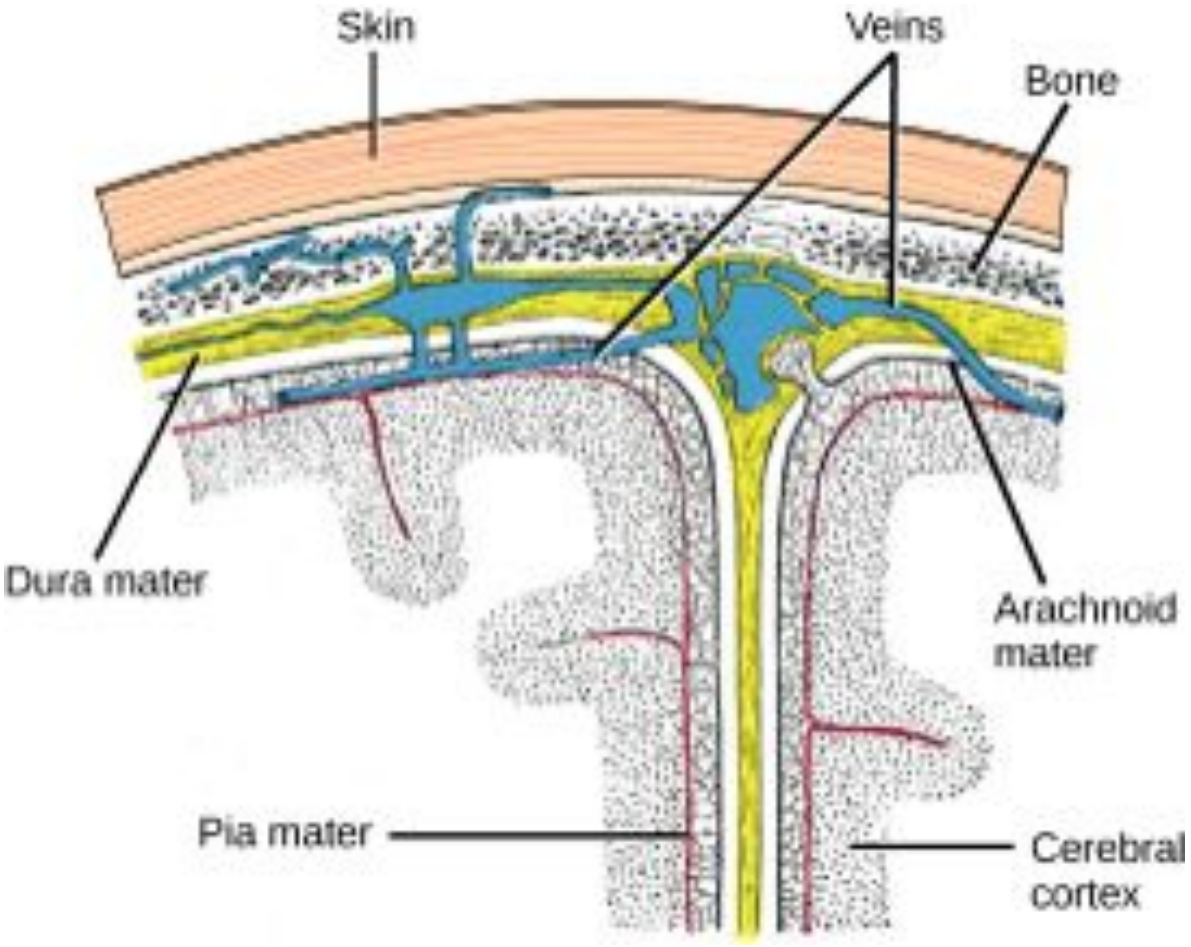
The brain is part of the **central nervous system**, which integrates information from the **peripheral nervous system**.



The brain is also the master regulator for the endocrine system.

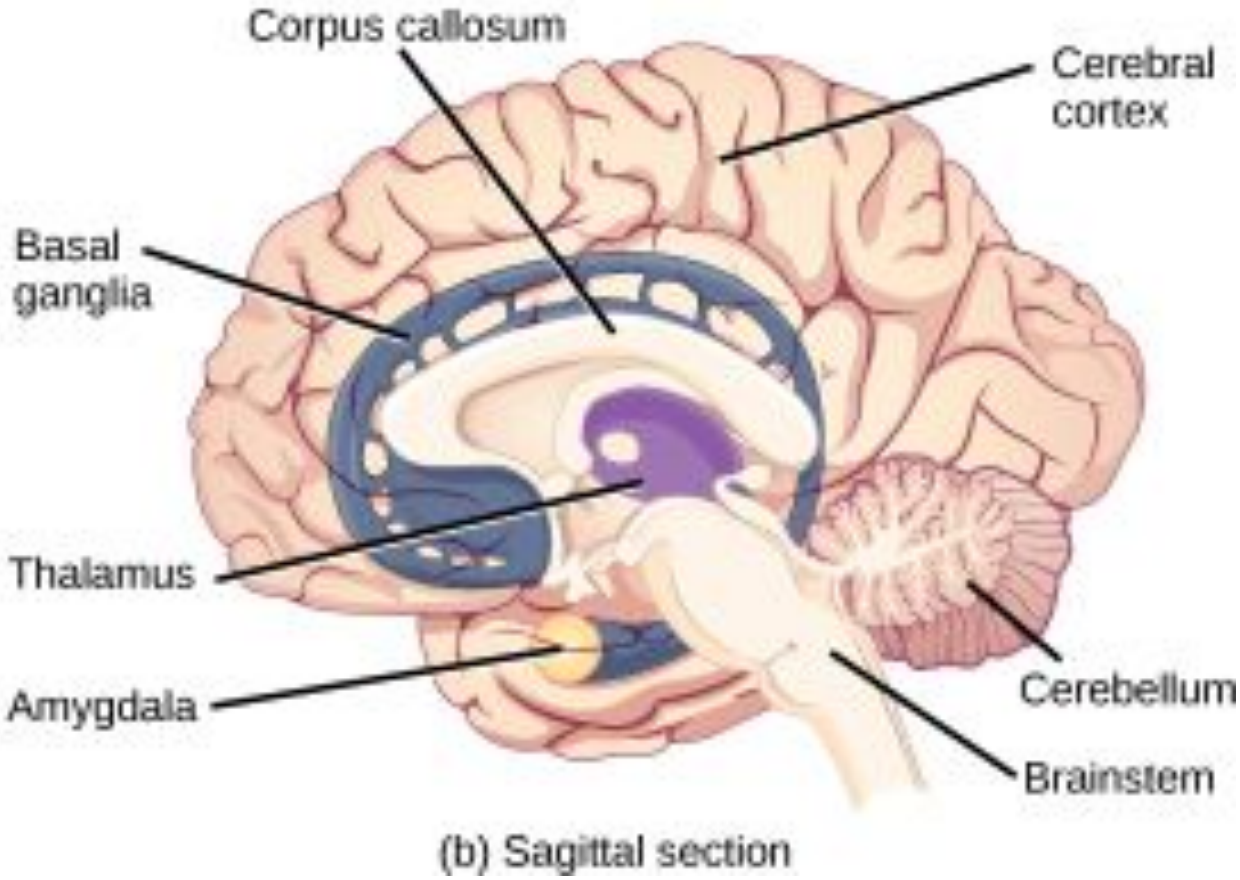


The brain is adapted to maximize connections between neurons.

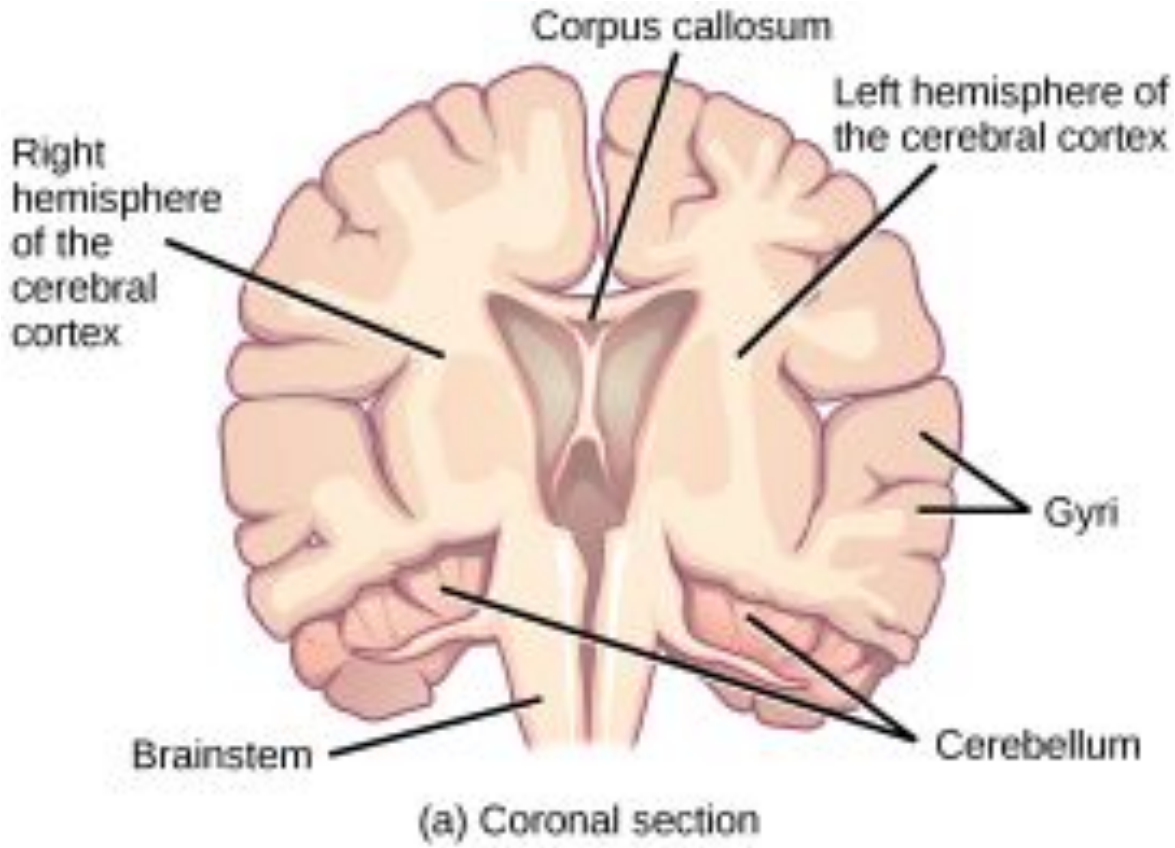


Different regions of the brain have different functions and work together to coordinate the behavior of the organism.

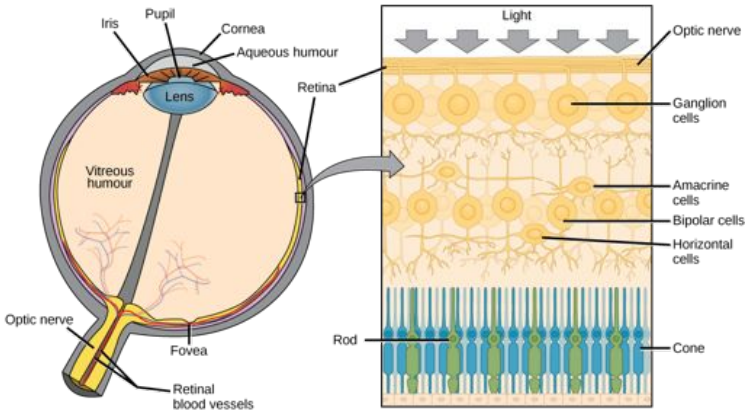
Ex. Medulla/Cerebellum/Cerebrum

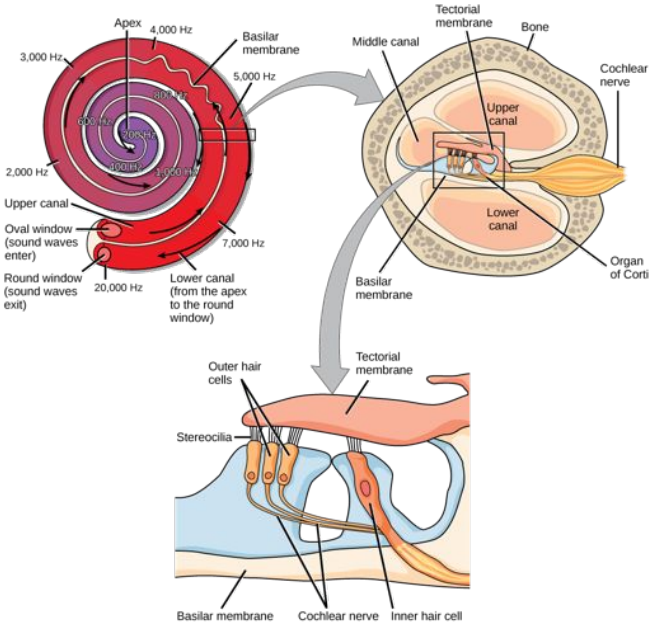


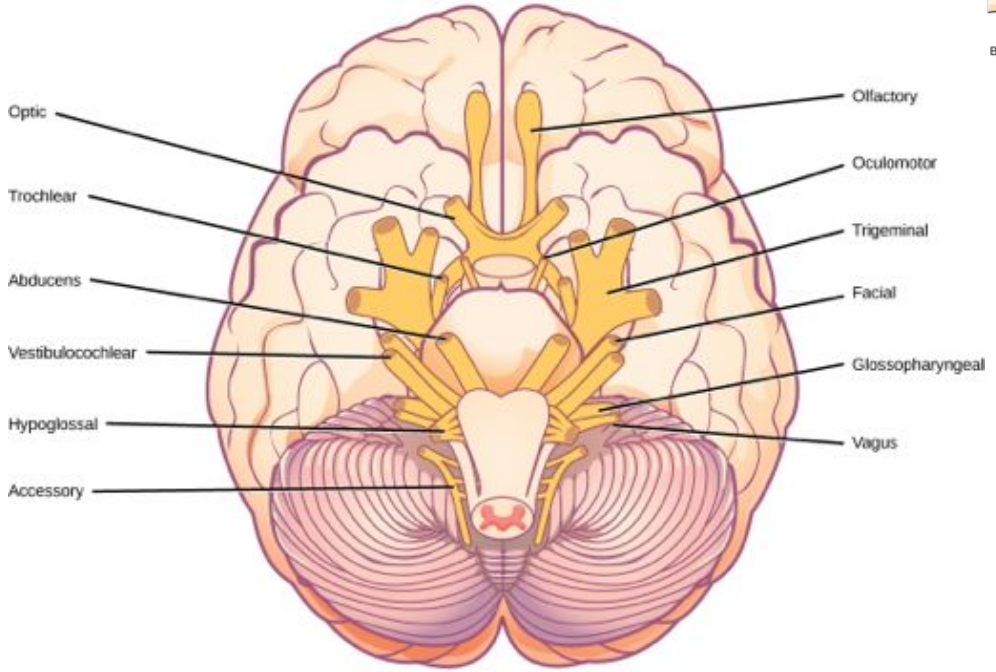
Ex. Right hemisphere/left hemisphere separation.



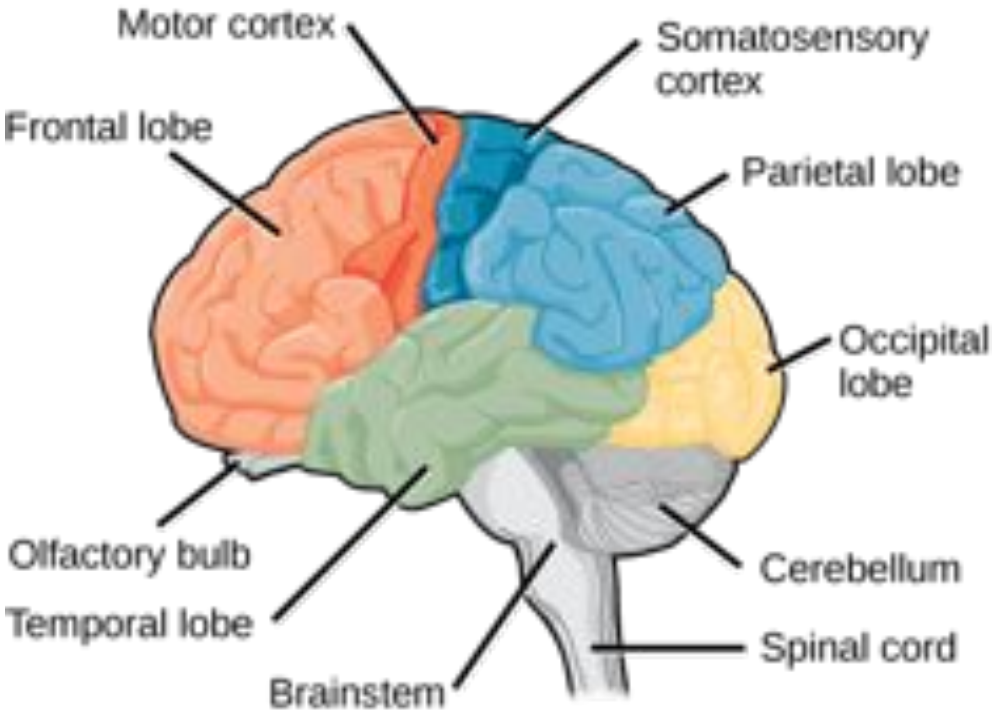
Ex. Vision and Hearing Centers

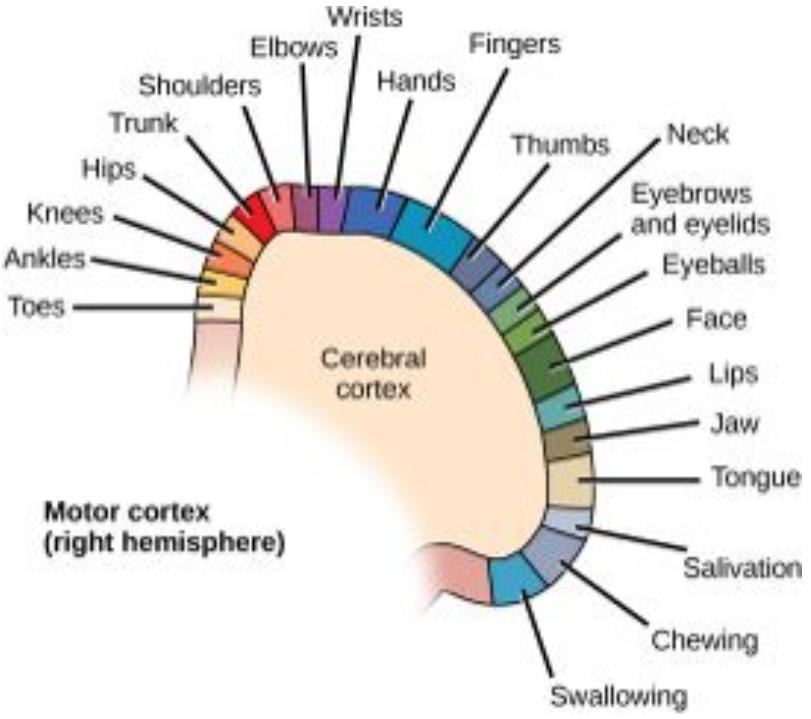






Ex. Cerebrum Functions





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Exceptions: Slide 22- www.pdb.org