Animal form and function [part 2]

IF3211 Domain Specific Computation

School of Electrical Engineering and Informatics ITB

Content

- Neurons, Synapses, and Signaling
- Nervous and Sensory Systems
- Motor Mechanisms and Behavior

Campbell Biology in Focus

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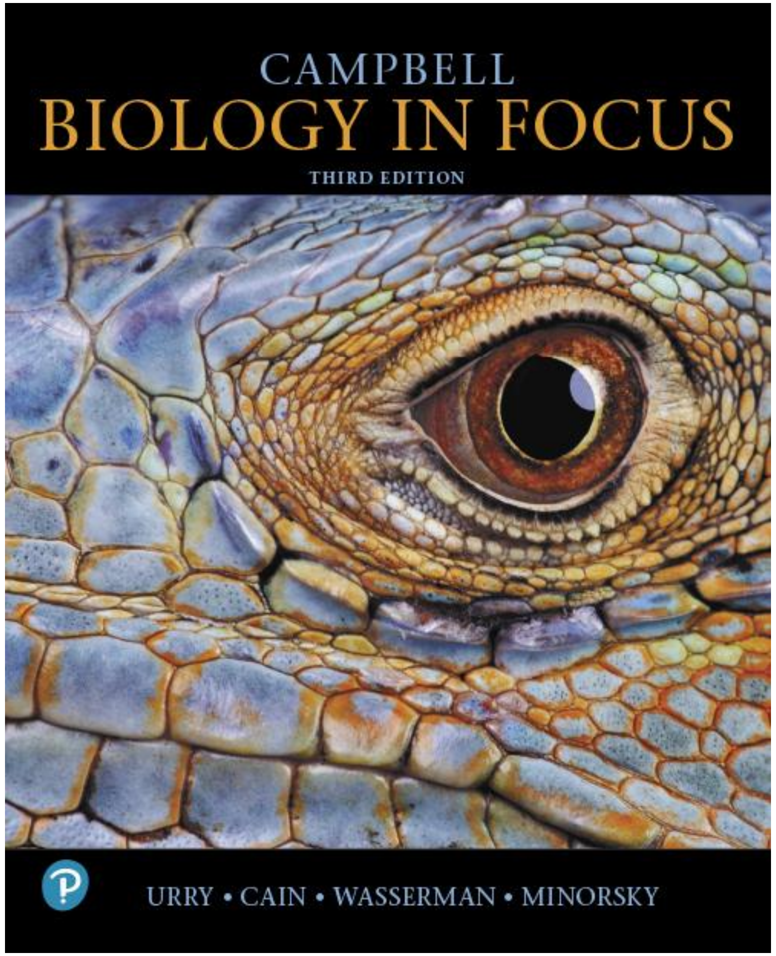


Chapter 37

Neurons, Synapses, and Signaling

Lecture Presentations by
Kathleen Fitzpatrick and Nicole Tunbridge,
Simon Fraser University

Overview: Lines of Communication

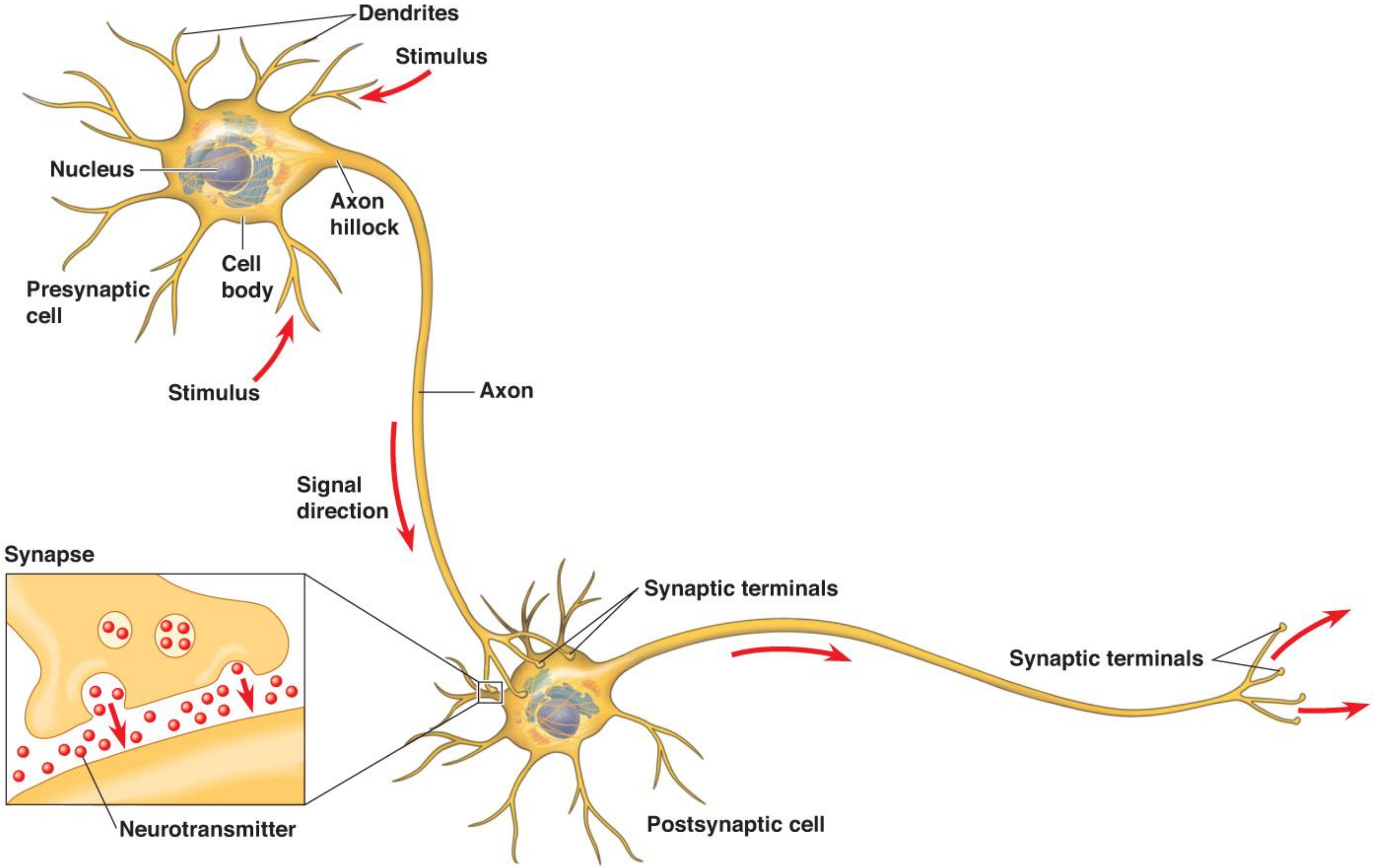
- The tropical cone snail kills prey with venom that disables neurons
- **Neurons** are nerve cells that transfer information within the body
- Communication by neurons largely consists of two types of signals: electrical signals (long distance) and chemical signals (short distance)
- The neuron is a cell type that exemplifies the close fit of form and function that often arises over the course of evolution

Neuron Structure and Function

- Most of a neuron's organelles are in the **cell body**
- Most neurons have **dendrites**, highly branched extensions that receive signals from other neurons
- The single **axon**, a much longer extension, transmits signals to other cells
- The cone-shaped base of an axon, where signals are generated, is called the axon hillock
- The branched ends of axons transmit signals to other cells at a junction called the **synapse**
- The part of each axon branch that forms this specialized junction is called a synaptic terminal
- At most synapses, chemical messengers called **neurotransmitters** pass information from the transmitting neuron to the receiving cell

Figure 37.2

Neuron Structure



Introduction to Information Processing (1 of 3)

- Nervous systems process information in three stages
  - Sensory input
  - Integration
  - Motor output

Introduction to Information Processing (2 of 3)

- **Sensory neurons** transmit information about external stimuli or internal conditions
- **Interneurons** integrate (analyze and interpret) the sensory input
  - They form local circuits connecting neurons in the brain or ganglia
- **Motor neurons** transmit signals to muscle cells, causing them to contract
  - Additional neurons that extend out of the processing centers trigger gland activity

Introduction to Information Processing (3 of 3)

- The neurons that carry out integration are often organized in a **central nervous system (CNS)**
- The neurons that carry information into and out of the CNS form the **peripheral nervous system (PNS)**
- PNS neurons, bundled together, form **nerves**
- Depending on its role, the shape of a neuron can vary considerably

Concept 37.2: Ion Pumps and Ion Channels Establish the Resting Potential of a Neuron

- The inside of a cell is negatively charged relative to the outside
- This charge difference, or voltage, is a source of potential energy, termed **membrane potential**
- The **resting potential** is the membrane potential of a neuron not sending signals
- Changes in membrane potential, action potentials, act as signals, transmitting and processing information

Formation of the Resting Potential

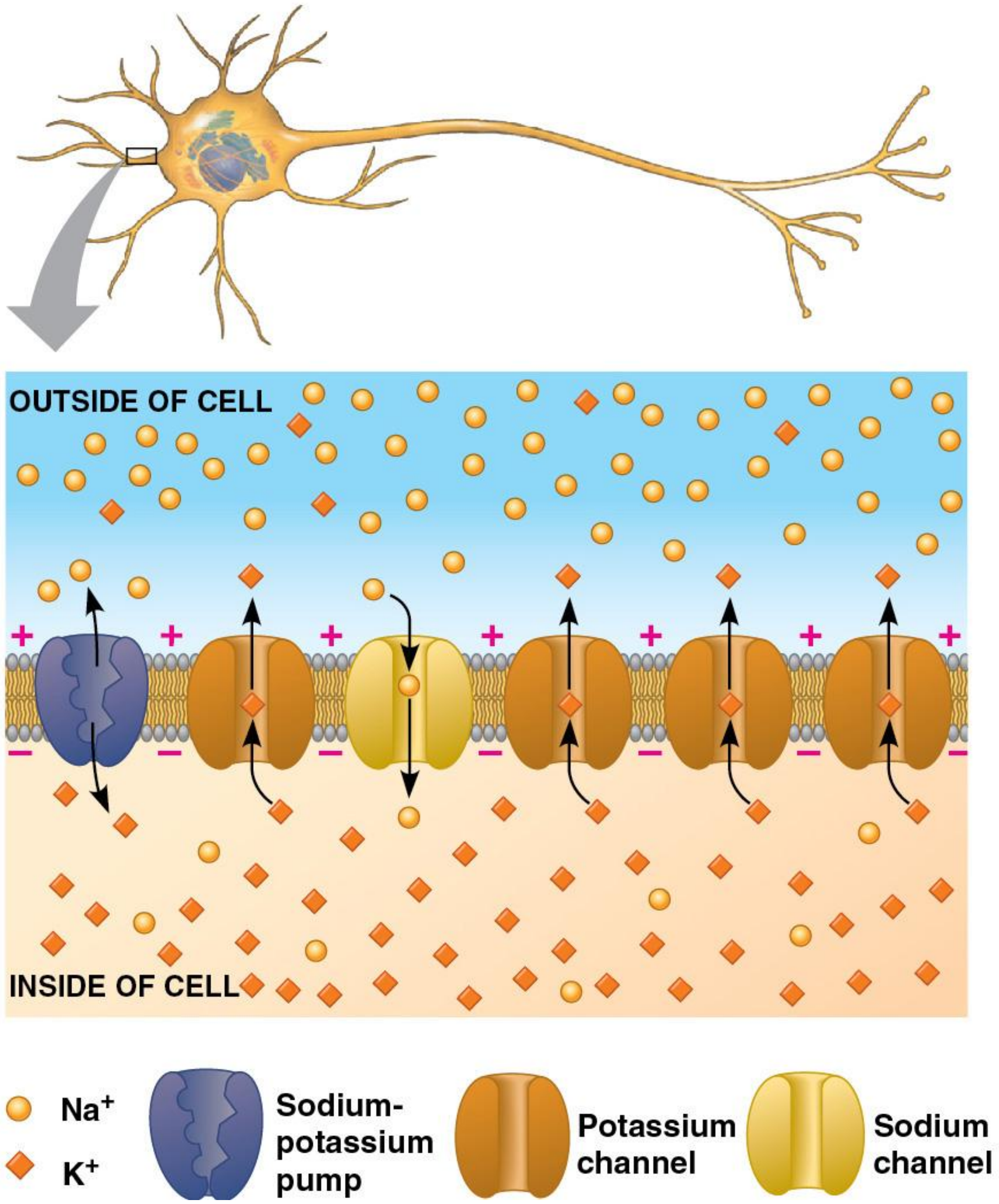
- Potassium ions (K^+) and sodium ions (Na^+) play an essential role in forming the resting potential
- In most neurons, the concentration of K^+ is higher inside the cell, while the concentration of Na^+ is higher outside the cell
- **Sodium-potassium pumps** use the energy of ATP to maintain these K^+ and Na^+ gradients across the plasma membrane

Table 37.1

Ion Concentrations Inside and Outside of Mammalian Neurons

Ion	Intracellular Concentration (m*M*)	Extracellular Concentration (m*M*)
Potassium (K^+)	140	5
Sodium (Na^+)	15	150
Chloride (Cl^-)	10	120
Large anions (A^-) inside cell, such as proteins	100	Not applicable

Figure 37.6
The Basis of the Membrane Potential



Modeling the Resting Potential

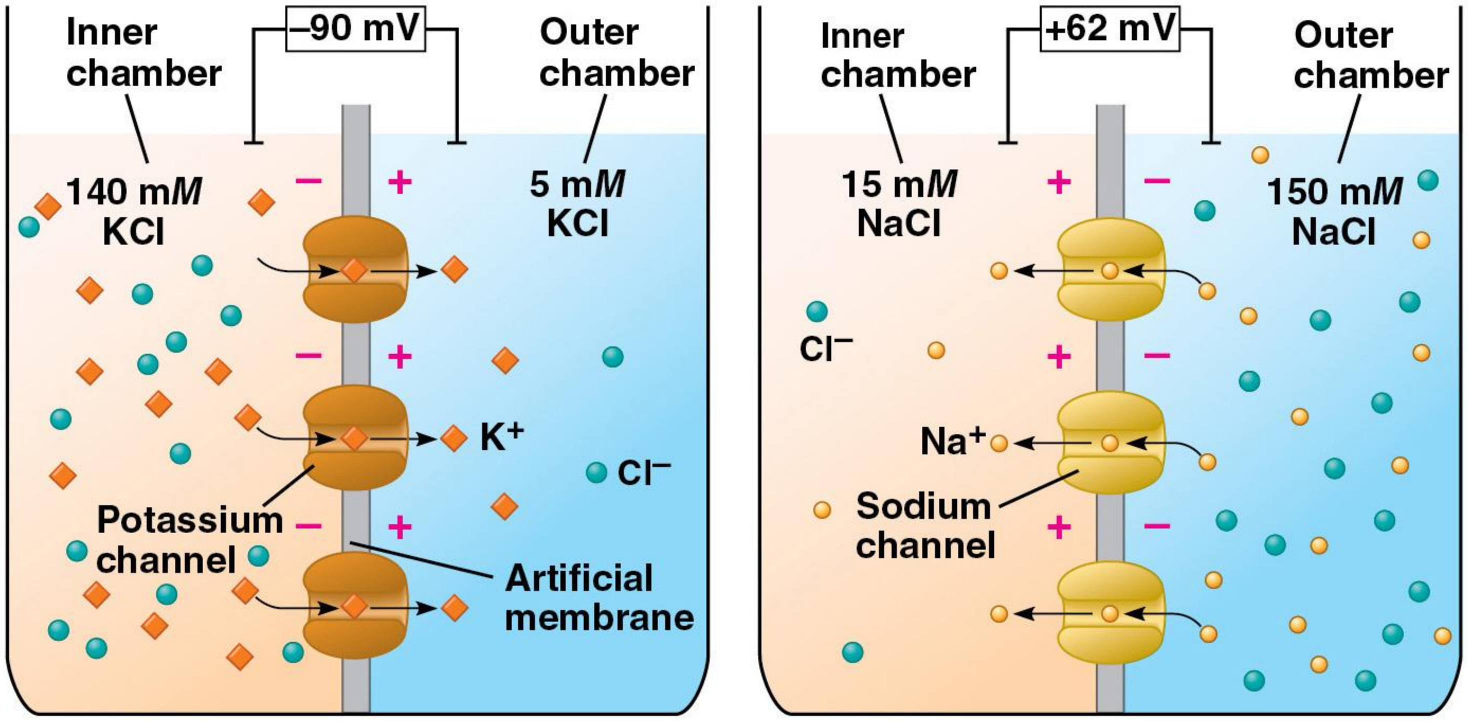
- The **equilibrium potential** (E_{ion}) is the membrane voltage for a particular ion at equilibrium and can be calculated using the Nernst equation

$$E_{ion} = 62\ \text{mV}\left(\log\frac{[\text{ion}]_{\text{outside}}}{[\text{ion}]_{\text{inside}}}\right)$$

- The equilibrium potential for K^+ is -90 mV
- The resting potential of an actual neuron is about −60 to −80 mV because a small amount of Na^+ diffuses into the cell

Figure 37.7

Modeling a Mammalian Neuron



(a) Membrane selectively permeable to K^+

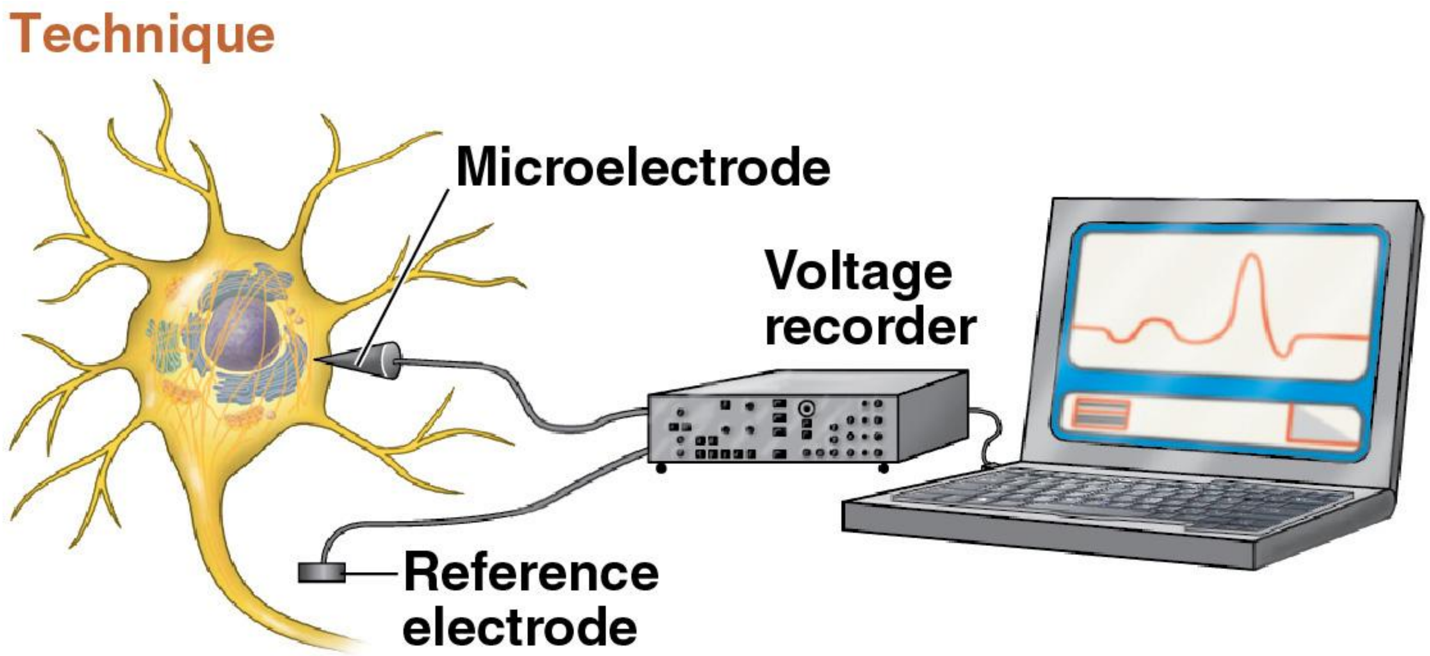
$$E_K = 62 \text{ mV}\left(\log \frac{5 \text{ m}M}{140 \text{ m}M}\right) = -90 \text{ mV}$$

(b) Membrane selectively permeable to Na^+

$$E_{Na} = 62 \text{ mV}\left(\log \frac{150 \text{ m}M}{15 \text{ m}M}\right) = +62 \text{ mV}$$

Figure 37.9

Research Method, Researchers can record the changes in membrane potential when a neuron responds to a stimulus



Hyperpolarization and Depolarization

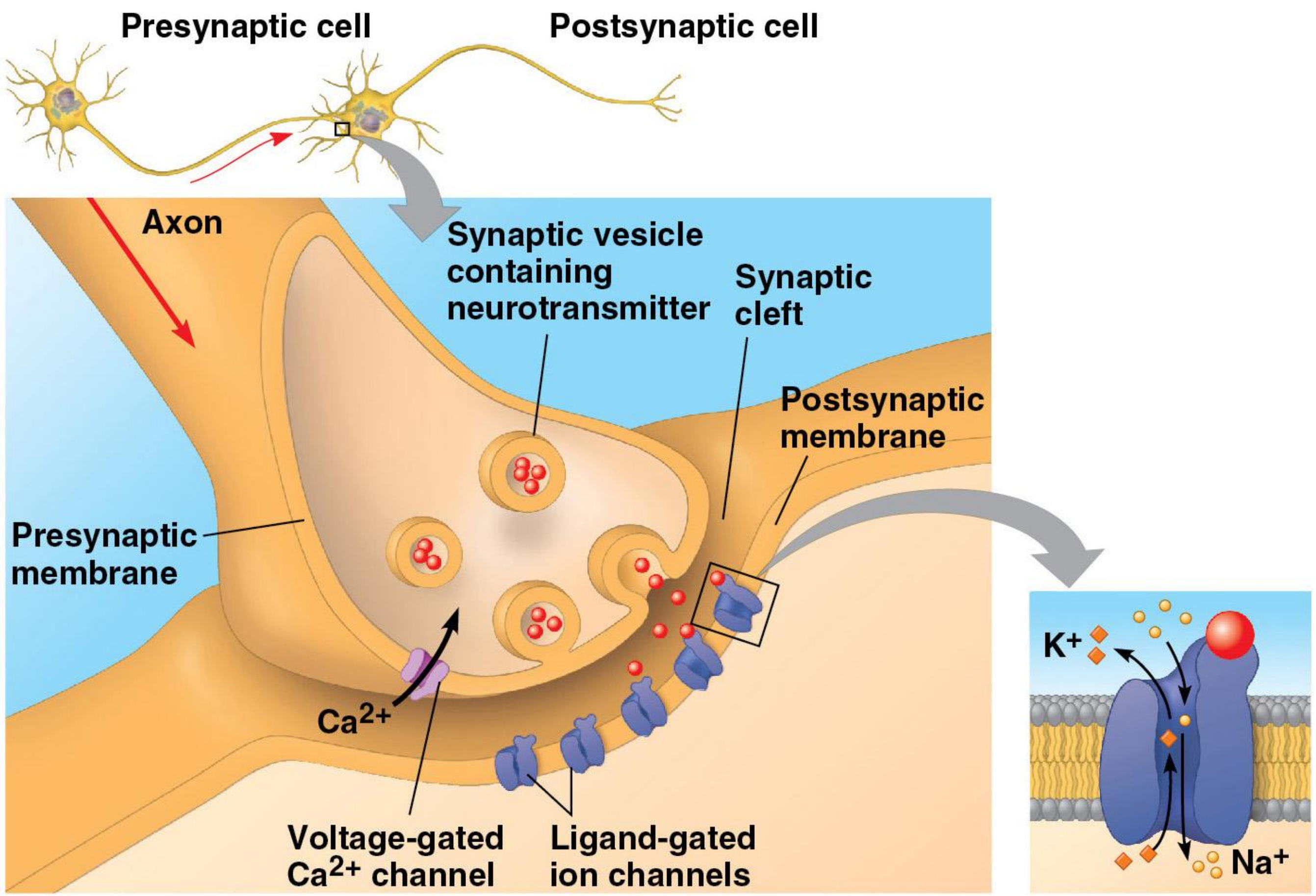
- When gated K^+ channels open, K^+ diffuses out, making the inside of the cell more negative
- This is **hyperpolarization**, an increase in magnitude of the membrane potential
- Opening other types of ion channels triggers a **depolarization**, a reduction in the magnitude of the membrane potential

Concept 37.4: Neurons Communicate with Other Cells at Synapses

- In most cases, action potentials are not transmitted from neurons to other cells
- Information is transmitted, however, at synapses
- Most synapses are chemical synapses, in which a chemical neurotransmitter carries information from the presynaptic neuron to the postsynaptic cell

Figure 37.16

A Chemical Synapse



Generation of Postsynaptic Potentials

- Postsynaptic potentials fall into two categories
    - **Excitatory postsynaptic potentials (EPSPs)** are depolarizations that bring the membrane potential toward threshold
    - **Inhibitory postsynaptic potentials (IPSPs)** are hyperpolarizations that move the membrane potential farther from threshold

Neurotransmitters

- Signaling at a chemical synapse brings about a response that depends on both the neurotransmitter from the presynaptic cell and the receptor on the postsynaptic cell
- A single neurotransmitter may have more than a dozen different receptors
- **Acetylcholine** is a common neurotransmitter in both invertebrates and vertebrates

Acetylcholine

- Acetylcholine is vital for functions involving muscle stimulation, memory formation, and learning
- Vertebrates have two major classes of acetylcholine receptor, one that is ligand gated and one that is metabotropic

Amino Acids

- Glutamate is the most common neurotransmitter in the CNS
- Glycine also acts at inhibitory synapses in the CNS that lies outside of the brain
- Gamma-aminobutyric acid (GABA) is the neurotransmitter at most inhibitory synapses in the brain

Biogenic Amines

- Biogenic amines include
  - Norepinephrine and the chemically similar ephinephrine act in the autonomic nervous system
  - Dopamine and serotonin affect sleep, mood, attention, and learning
- Some psychoactive drugs produce hallucinatory effects by binding receptors for these neurotransmitters
- Biogenic amines have a central role in a number of nervous system disorders and treatments

Neuropeptides

- Several **neuropeptides**, relatively short chains of amino acids, also function as neurotransmitters that operate via G protein-coupled receptors
- Neuropeptides include substance P and **endorphins**, which both affect our perception of pain
- Opiates bind to the same receptors as endorphins and produce the same physiological effects

Gases

- Gases such as nitric oxide (NO) and carbon monoxide (CO) are local regulators in the PNS
- Unlike most neurotransmitters, these are not stored in vesicles but are instead synthesized as needed

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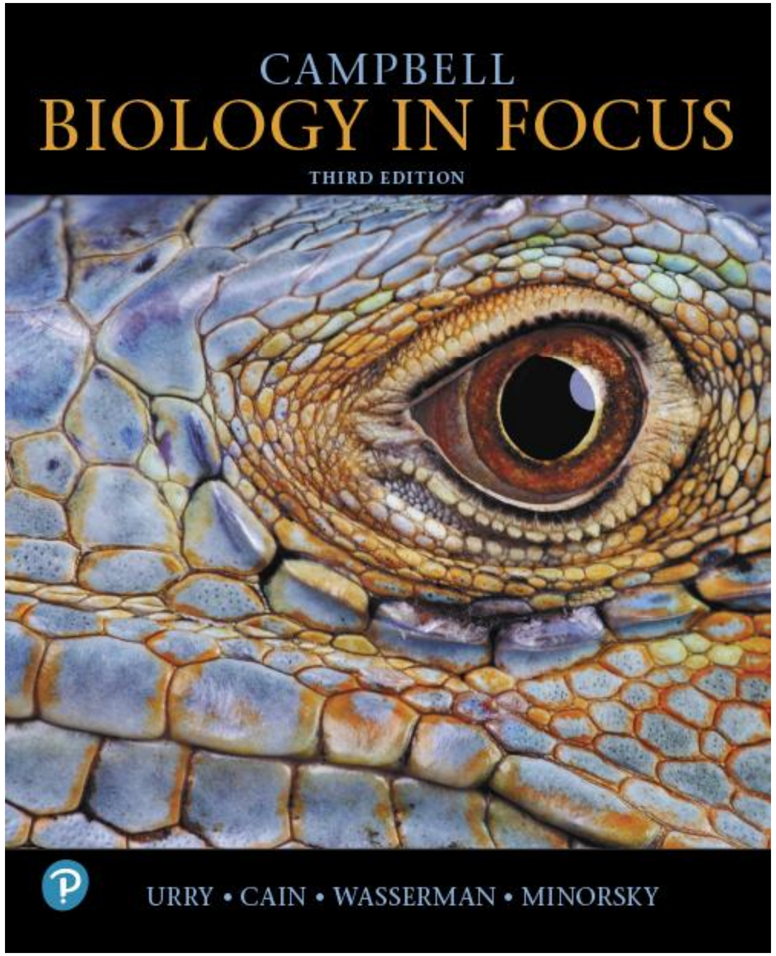


Chapter 38

Nervous and Sensory Systems

Lecture Presentations by
Kathleen Fitzpatrick and Nicole Tunbridge,
Simon Fraser University

Pearson

Overview: Command and Control Center

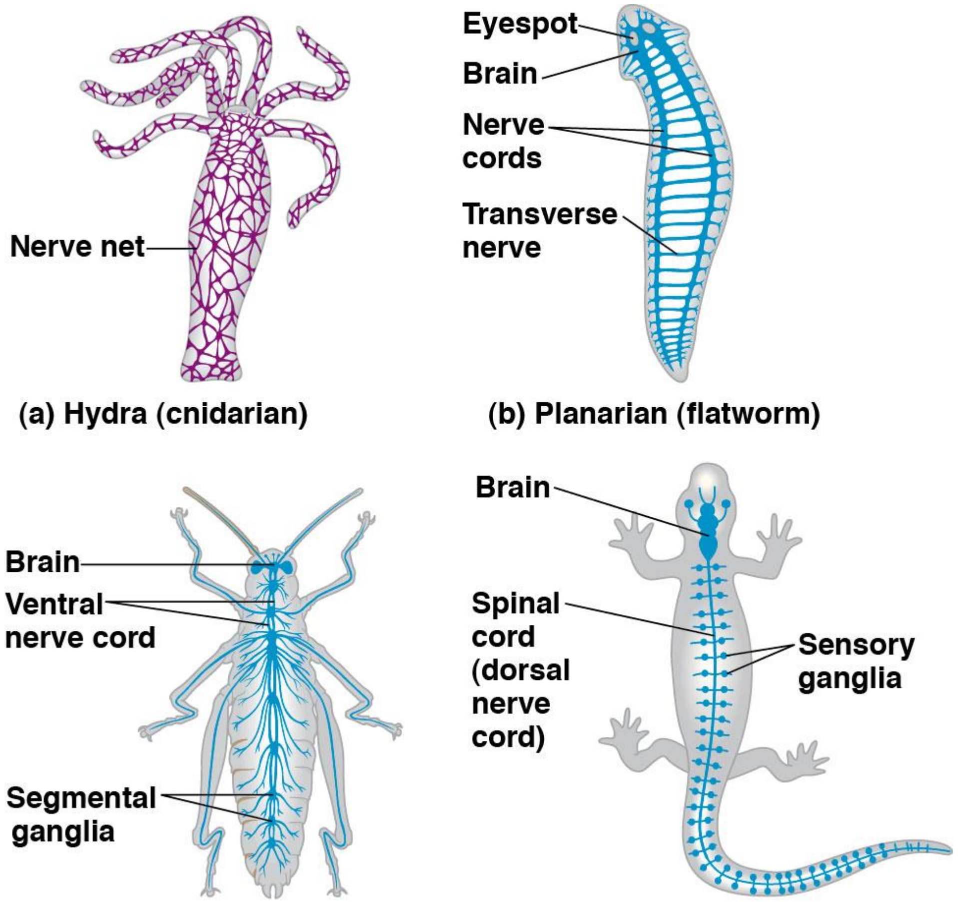
- The human brain contains an estimated 100 billion neurons organized into circuits
- Connections between regions of the brain are mapped using the expression of random combinations of colored proteins in neurons
- Gathering, processing, and organizing information are essential functions of all nervous systems

Concept 38.1: Nervous Systems Consist of Circuits of Neurons and Supporting Cells

- In most cnidarians, interconnected neurons form a **nerve net**, which controls contraction and expansion of the gastrovascular cavity
- In more complex animals, the axons of multiple neurons are often bundled together into **nerves**
- These fibrous structures channel and organize information flow through the nervous system
- Nonsegmented worms have the simplest clearly defined **central nervous system** (**CNS**), consisting of a small brain and longitudinal nerve cords
- Neurons that carry information into and out of the CNS form a **peripheral nervous system** (**PNS**)

Figure 38.2

Nervous System Organization



(a) Hydra (cnidarian)

(b) Planarian (flatworm)

(c) Insect (arthropod)

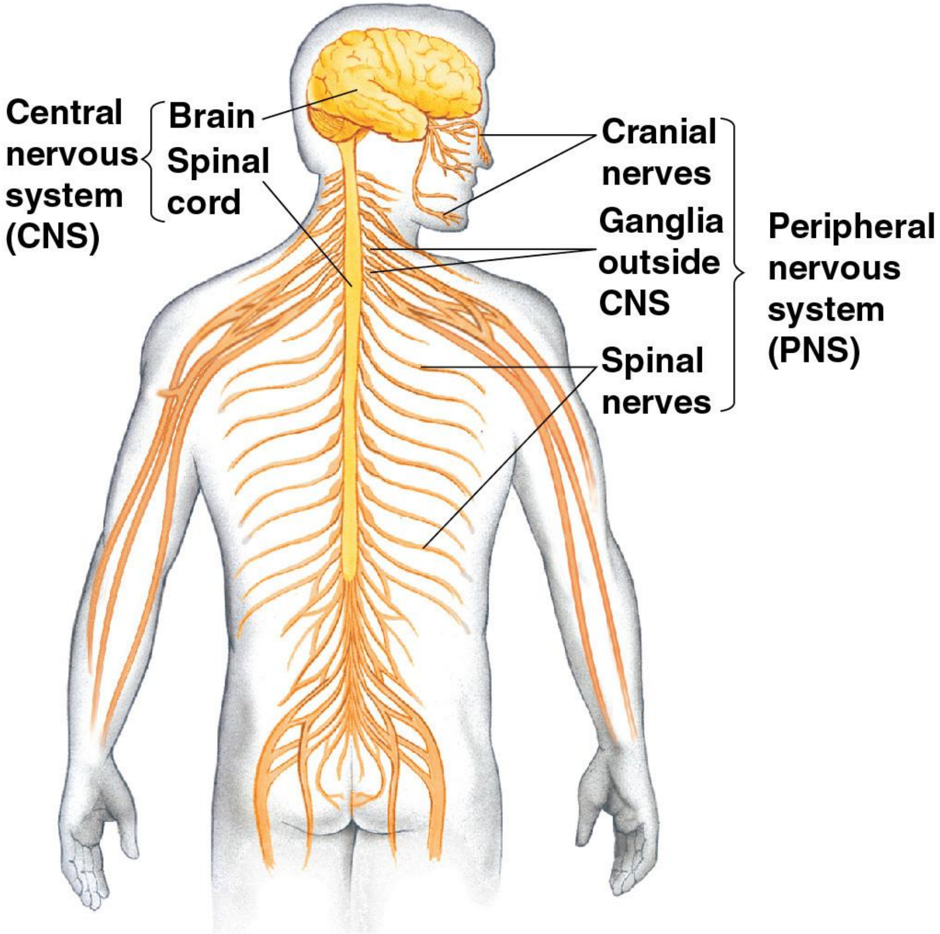
(d) Salamander (vertebrate)

Glia

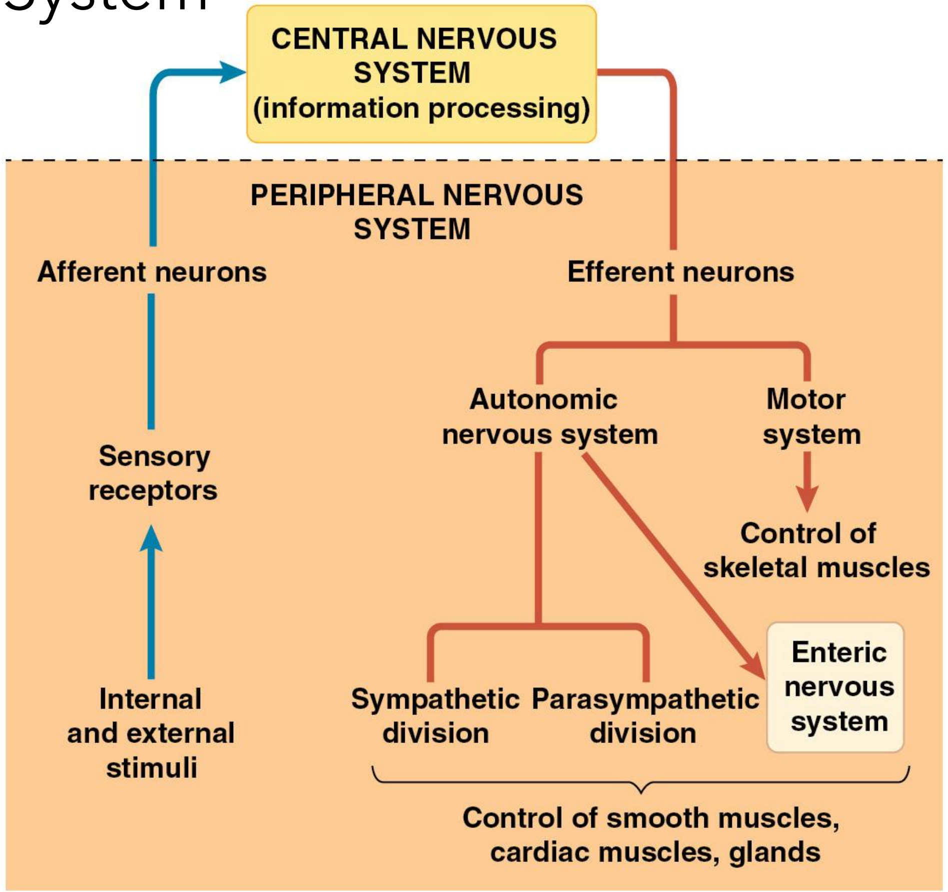
- Vertebrates and most invertebrates have **glial cells**, or **glia**, in addition to neurons
- Glia have numerous functions in nourishing, supporting, and regulating neurons
  - Embryonic radial glia form tracks along which newly formed neurons migrate
  - Astrocytes (star-shaped glial cells) participate in formation of the blood-brain barrier, which prevents many substances in blood from entering the CNS

Figure 38.4

The Vertebrate Nervous System



Functional Hierarchy of the Vertebrate Peripheral Nervous System



The Peripheral Nervous System

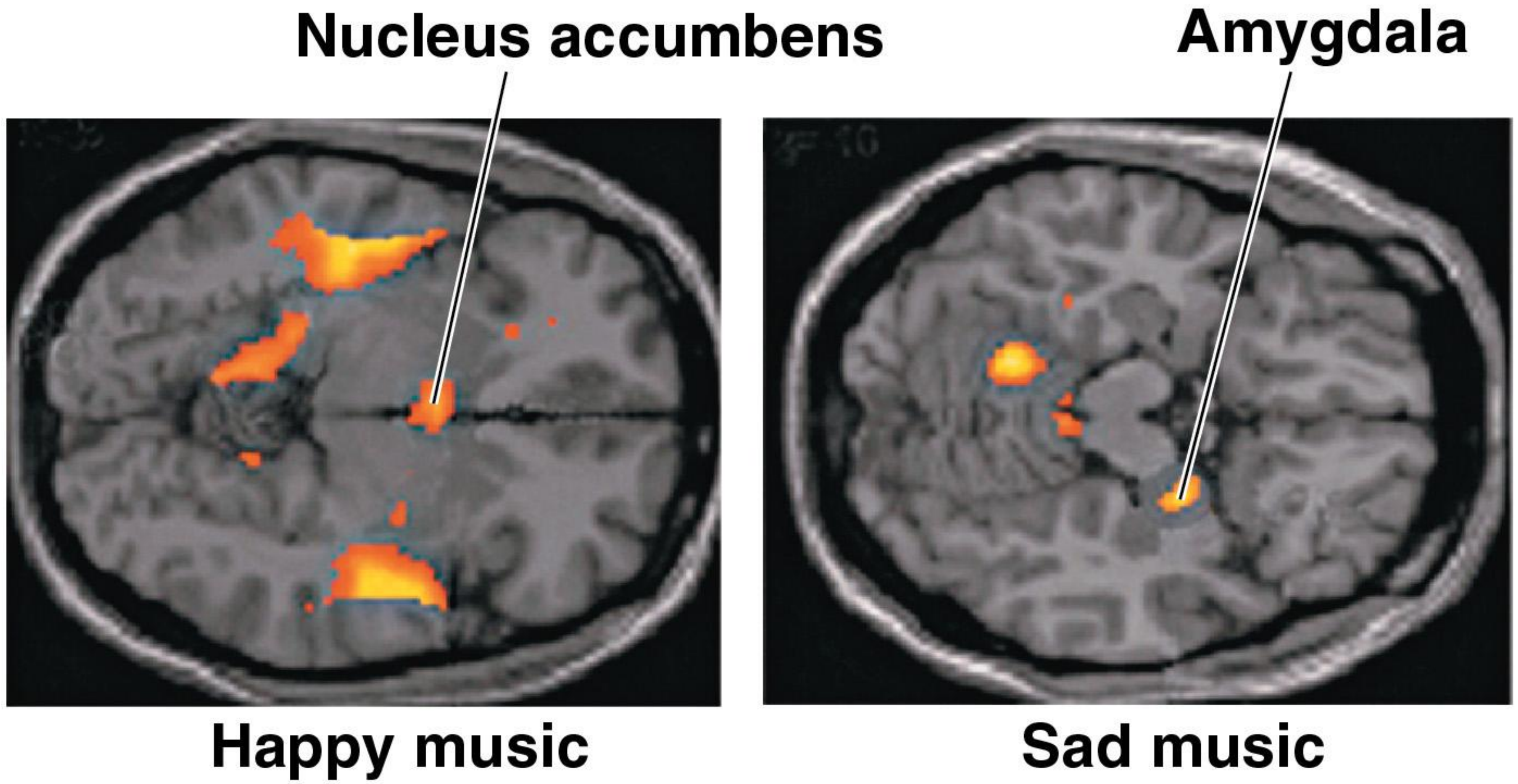
- The PNS has two efferent components: the motor system and the autonomic nervous system
- The **motor system** carries signals to skeletal muscles, and can be voluntary or involuntary
- The **autonomic nervous system** regulates smooth and cardiac muscles and is generally involuntary

Functional Imaging of the Brain

- Functional imaging methods enable researchers to match particular functions with activity in specific brain areas
- In positron-emission tomography (PET), an injection of radioactive glucose enables a display of metabolic activity
- In functional magnetic resonance imaging (fMRI), the subject lies with his or her head in the center of a large, doughnut-shaped magnet. Brain activity is detected by changes in local oxygen concentration

Figure 38.6

Functional Brain Imaging in the Working Brain



Arousal and Sleep

- Arousal is a state of awareness of the external world
- Sleep is a state in which external stimuli are received but not consciously perceived
- Arousal and sleep are controlled by clusters of neurons in the midbrain and pons

Biological Clock Regulation

- Cycles of sleep and wakefulness are an example of a circadian rhythm, a daily cycle of biological activity
- Such rhythms rely on a **biological clock**, a molecular mechanism that directs periodic gene expression and cellular activity
- Biological clocks are typically synchronized to light and dark cycles and maintain a roughly 24-hour cycle

Emotions

- Generation and experience of emotions depend on many brain structures, including the amygdala, hippocampus, and parts of the thalamus
- These structures are grouped as the limbic system

The Brain's Reward System and Drug Addiction

- The brain's reward system provides motivation for activities that enhance survival and reproduction
- Inputs to the reward system are received by neurons in a region of the brain called the ventral tegmental area (VTA)
- The brain's reward system is dramatically affected by drug addiction
- Drug addiction is characterized by compulsive consumption of a drug and loss of control in limiting intake

Language and Speech

- The mapping of cognitive functions within the cortex began in the 1800s
- Broca's area, in the left frontal lobe, is active when speech is generated
- Wernicke's area, in the posterior of the left temporal lobe, is active when speech is heard

Information Processing

- The cerebral cortex receives input from sensory organs and somatosensory receptors
- Somatosensory receptors provide information about touch, pain, pressure, temperature, and the position of muscles and limbs
- The thalamus directs different types of input to distinct locations
- Once processed, sensory information passes to the prefrontal cortex, which helps plan actions

Frontal Lobe Function

- Frontal lobe damage may impair decision making and emotional responses but leave intellect and memory intact
- The frontal lobes have a substantial effect on “executive functions”

Evolution of Cognition in Vertebrates

- In nearly all vertebrates, the brain has the same basic structures
- The hypothesis that higher order reasoning requires a highly convoluted cerebral cortex has been experimentally refuted
- The anatomical basis for sophisticated information processing in birds (without a highly convoluted neocortex) appears to be a cluster of nuclei in the top or outer portion of the brain (pallium)

Neuronal Plasticity

- Much of the reshaping of the nervous system occurs at synapses
- Changes can strengthen or weaken signaling at a synapse
- **Neuronal plasticity** is the capacity of the nervous system to be remodeled, especially in response to its own activity

Memory and Learning

- Neuronal plasticity is essential to formation of memories
- **Short-term memory** is accessed via temporary links formed in the hippocampus
- When information is transferred to **long-term memory**, these links are replaced by connections within the cerebral cortex
- Some consolidation of memory is thought to occur during sleep

Perception

- **Perception** is the brain’s construction of stimuli
- Action potentials from sensory receptors travel along neurons that are dedicated to a particular stimulus
- The brain thus distinguishes stimuli, such as sight or sound, solely by the path along which the action potentials have arrived

Amplification and Adaptation

- **Amplification** is the strengthening of a sensory signal during transduction
- **Sensory adaptation** is a decrease in responsiveness to continued stimulation

Types of Sensory Receptors

- Based on stimuli transduced, sensory receptors fall into five categories
  - Mechanoreceptors: sense physical deformation caused by stimuli such as pressure, touch, stretch, and motion
  - Electromagnetic receptors: detect electromagnetic energy such as light, electricity, and magnetism
  - Thermoreceptors: detect heat and cold
  - Pain receptors: detect stimuli that reflect conditions that could damage animal tissues
  - Chemoreceptors: transmit information about the total solute concentration of a solution

Sensing of Gravity and Sound in Invertebrates

- Most invertebrates sense gravity and maintain equilibrium using mechanoreceptors located in organs called **statocysts**
- Statocysts contain ciliated receptor cells that detect the movement of granules called statoliths
- Most insects sense sounds with body hairs that vibrate at different frequencies; many others detect sound by means of vibration-sensitive organs

Hearing

- Vibrating objects create pressure waves in the air, which are transduced by the ear into nerve impulses, perceived as sound in the brain
- To hear sounds in our environment, we rely on hair cells, sensory cells with hairlike projections that detect motion
- The tympanic membrane vibrates in response to vibrations in air

Equilibrium

- Several organs of the inner ear detect body movement, position, and equilibrium
  - The **utricle** and **saccule** contain granules called otoliths that allow humans to perceive position relative to gravity or linear movement
  - Three semicircular canals connected to the utricle contain fluid and can detect angular movement in any direction

Evolution of Visual Perception

- Light detectors in animals range from simple clusters of cells that detect direction and intensity of light to complex organs that form images
- Light detectors all contain **photoreceptors**, sensory cells that contain light-absorbing pigment molecules

Light-Detecting Organs

- Most invertebrates have a light-detecting organ
- One of the simplest light-detecting organs is that of planarians
- A pair of ocelli called eyespots are located in the head region
- These allow planarians to move away from light and seek shaded locations

Compound Eyes

- Insects, crustaceans, and some polychaete worms have **compound eyes**, which consist of up to several thousand light detectors called **ommatidia**
- Compound eyes are very effective at detecting movement

Single-Lens Eyes

- **Single-lens eyes** are found in some jellies, polychaetes, spiders, and many molluscs
- They work on a camera-like principle: the **iris** changes the diameter of the **pupil** to control how much light enters
- The eyes of all vertebrates have a single lens

Processing of Visual Information in the Retina

- Processing of visual information begins in the retina
- In the dark, rods and cones release the neurotransmitter glutamate into synapses with neurons called bipolar cells
- Bipolar cells are either hyperpolarized or depolarized in response to glutamate

Processing of Visual Information in the Brain

- The two optic nerves meet at the optic chiasm near the cerebral cortex
- Sensations from the left visual field of both eyes are transmitted to the right side of the brain
- Sensations from the right visual field are transmitted to the left side of the brain
- It is estimated that at least 30% of the cerebral cortex takes part in formulating what we actually “see”

Color Vision

- Among vertebrates, most fish, amphibians, and reptiles, including birds, have very good color vision
- Humans and other primates are among the minority of mammals with the ability to see color well

The Visual Field

- The brain processes visual information and controls what information is captured
- Focusing occurs by changing the shape of the lens
- The **fovea** is the center of the visual field and contains no rods but a high density of cones

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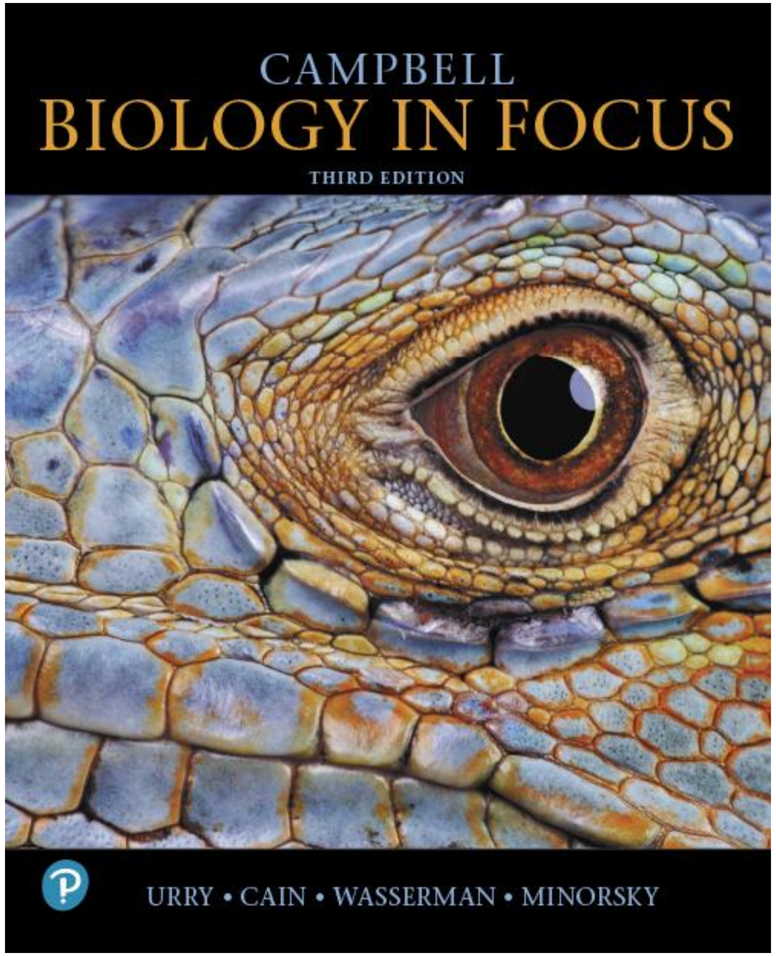


Chapter 39

Motor Mechanisms and Behavior

Lecture Presentations by

Kathleen Fitzpatrick and Nicole Tunbridge,

Simon Fraser University

Overview: The How and Why of Animal Activity

- A **behavior** is an action carried out by muscles under control of the nervous system
- Behavior is an essential part of acquiring food, finding mates, and homeostasis
- Behavior is subject to natural selection and influences the evolution of animal anatomy

Concept 39.1: The Physical Interaction of Protein Filaments Is Required for Muscle Function

- Muscle cell contraction relies on the interaction between protein structures
  - **Thin filaments** consist of two strands of actin coiled around one another
  - **Thick filaments** are staggered arrays of myosin molecules
- Muscle contraction is powered by chemical energy; muscle extension is passive

Vertebrate Skeletal Muscle

- Vertebrate **skeletal muscle** moves individual bones and the whole body
- A skeletal muscle consists of a bundle of fibers running the length of the muscle
- Each fiber is a single cell containing multiple nuclei
- **Myofibrils** are bundles of thick and thin filaments surrounding the nuclei

The Sliding-Filament Model of Muscle Contraction

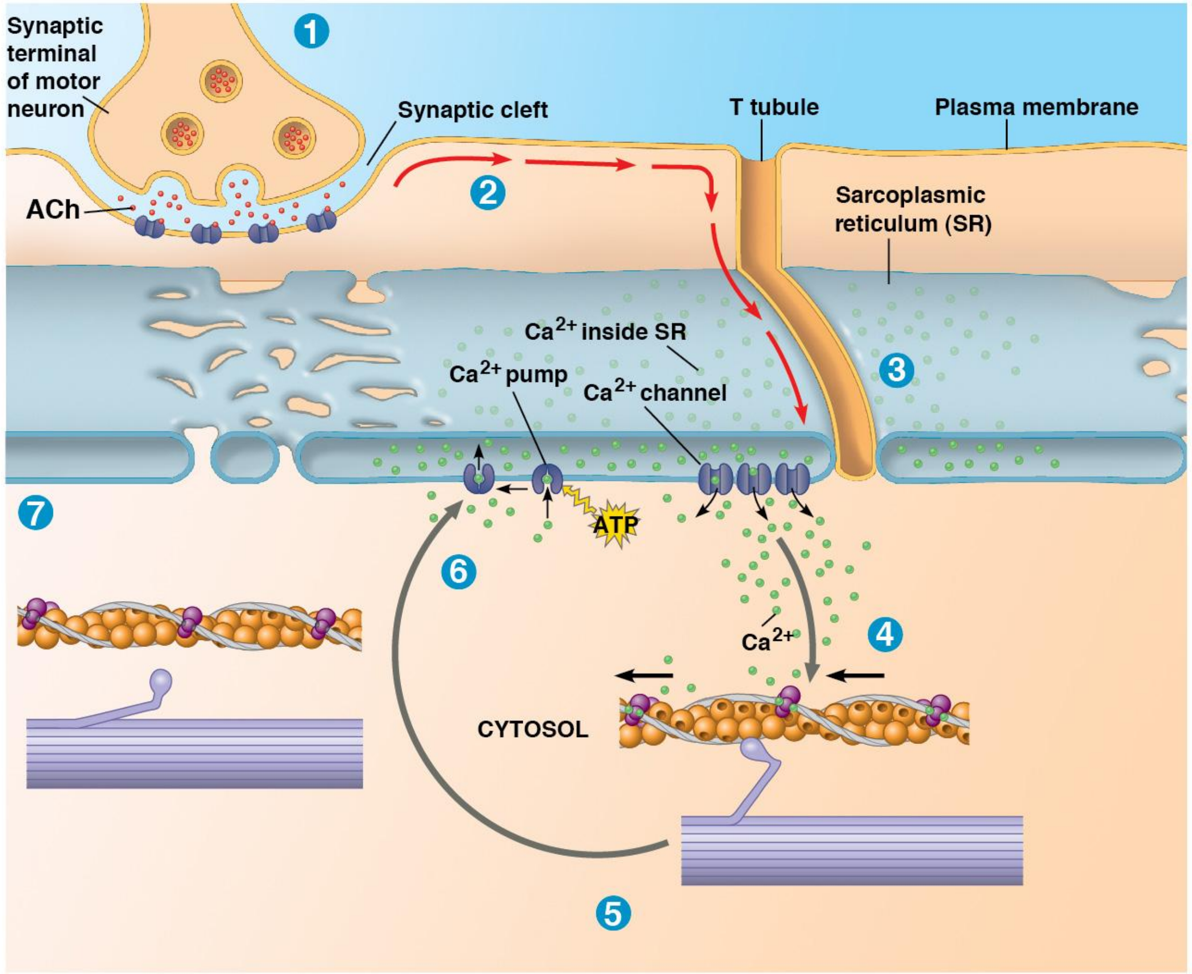
- According to the **sliding-filament model**, muscle filaments slide past each other longitudinally, causing an overlap between thin and thick filaments
- The contracting muscle shortens, but the filaments stay the same length

The Role of Calcium and Regulatory Proteins

- In a muscle fiber at rest, actin strands of thin filaments are bound to **tropomyosin** and the **troponin complex**
- These regulatory proteins cover the myosin-binding sites, preventing actin and myosin from interacting

Figure 39.7

Summary of Contraction in a Skeletal Muscle Fiber

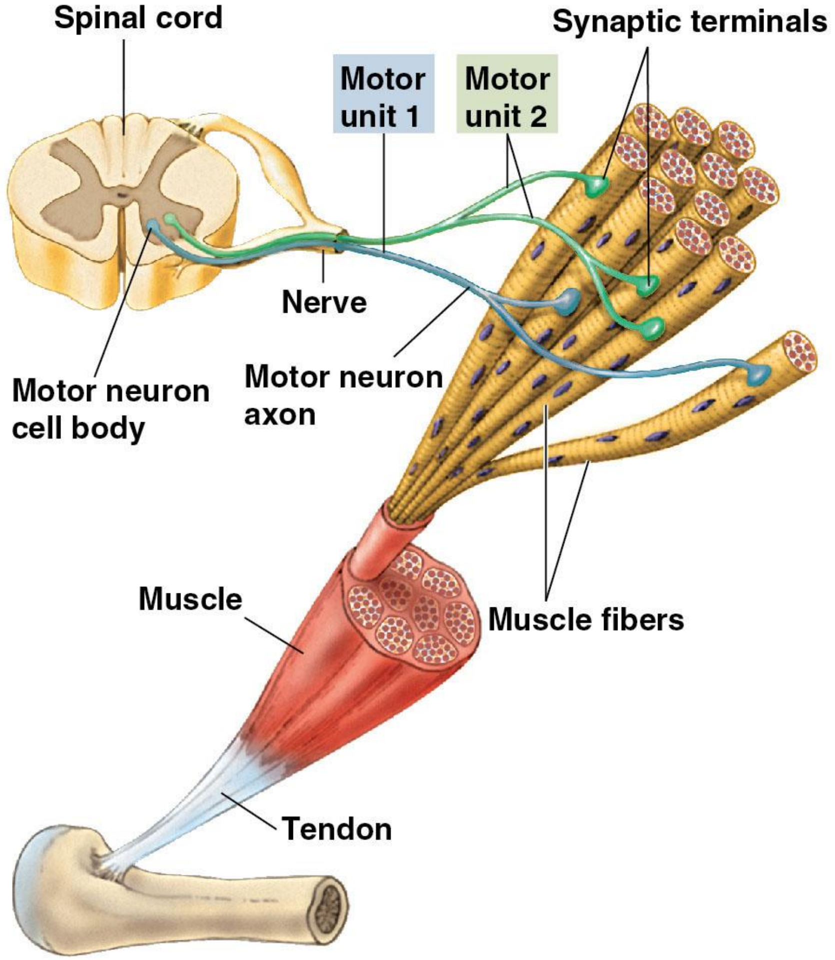


Nervous Control of Muscle Tension

- Contraction of a whole muscle is graded; the extent and strength of its contraction are under voluntary control
- The nervous system can produce graded contractions by varying
  - The number of muscle fibers that contract
  - The rate at which muscle fibers are stimulated
- In vertebrates, a **motor unit** consists of a single motor neuron and all the muscle fibers it controls
- Each motor neuron synapses with multiple muscle fibers, but each fiber is controlled by only one motor neuron

Figure 39.8

Motor Units in a Vertebrate Skeletal Muscle



Other Types of Vertebrate Muscle

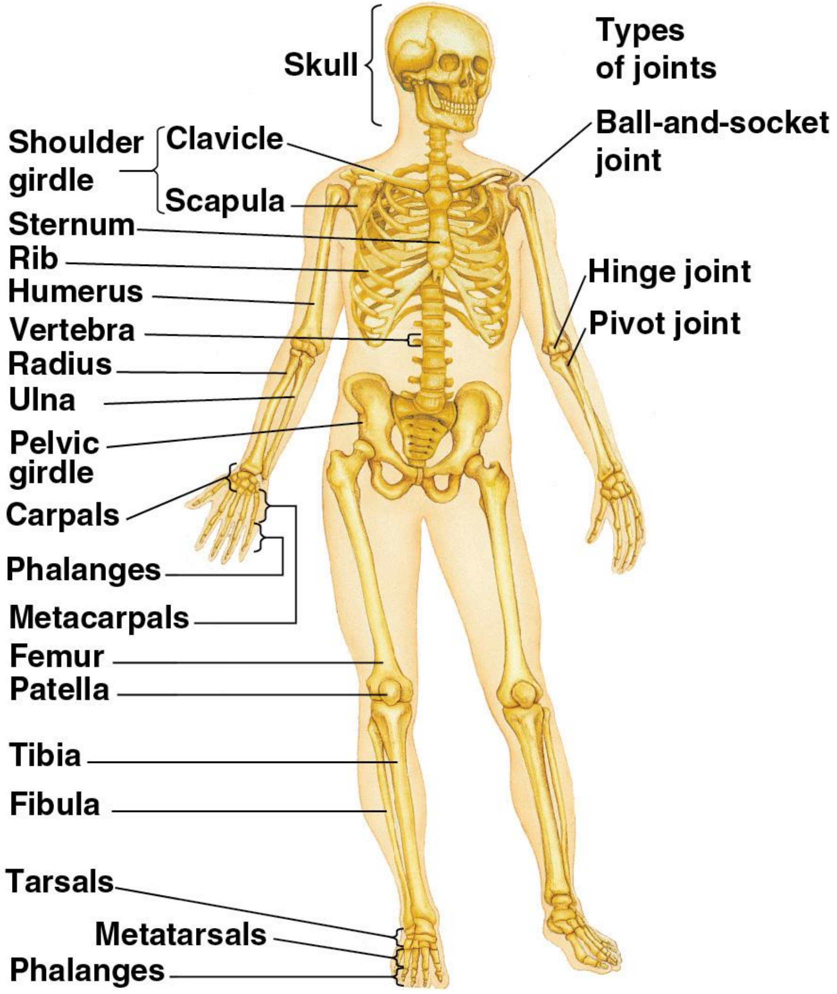
- In addition to skeletal muscle, vertebrates have cardiac muscle and smooth muscle
- **Cardiac muscle**, found only in the heart, consists of striated cells electrically coupled by intercalated disks
- Cardiac muscle cells can initiate rhythmic depolarization and contraction without neural input
- **Smooth muscle** cells lack striations and are found in the walls of hollow organs of the circulatory, digestive, and reproductive systems

Types of Skeletal Systems

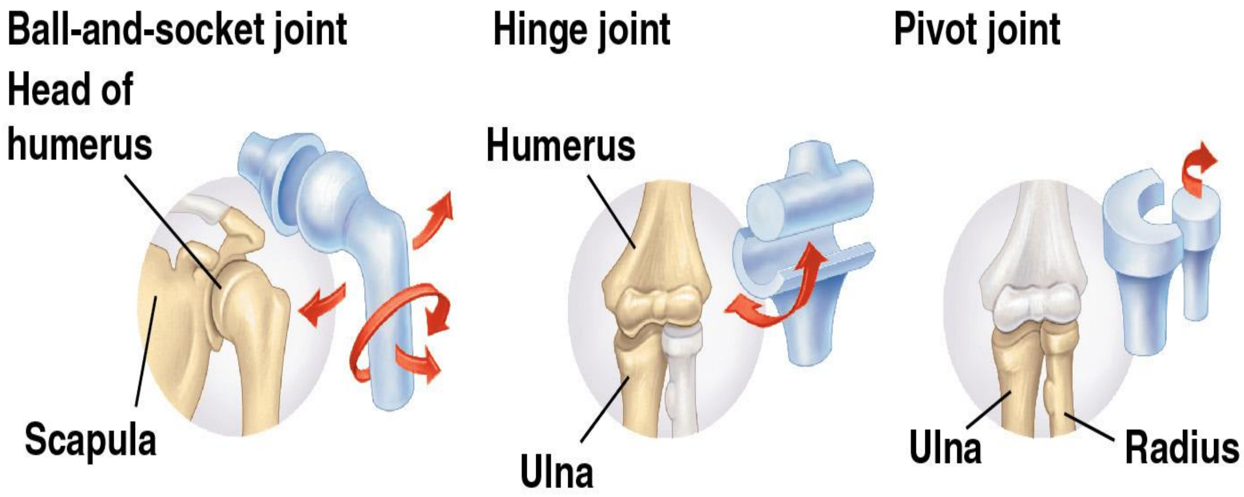
- The three main types of skeletons are
  - Hydrostatic skeletons (lack hard parts): A **hydrostatic skeleton** consists of fluid held under pressure in a closed body compartment
  - Exoskeletons (external hard parts): An **exoskeleton** is a hard encasement deposited on the surface of animals including arthropods and most molluscs
  - Endoskeletons (internal hard parts): An **endoskeleton** consists of a hard internal skeleton, buried in soft tissue

Figure 39.13

Bones and Joints of the Human Skeleton



Types of Joints



Types of Locomotion

- Most animals are capable of **locomotion**, or active travel from place to place
- In locomotion, energy is expended to overcome friction and gravity

Swimming

- In water, friction is a bigger problem than gravity
- Fast swimmers usually have a sleek, fusiform (torpedo-like) shape that minimizes
- Animals swim in diverse ways
  - Paddling with their legs as oars
  - Jet propulsion
  - Undulating their body and tail from side to side or up and down

Flying

- Active flight requires that wings produce enough lift to overcome the downward force of gravity
- Wings are shaped to act as airfoils; fusiform body shape reduces drag
- Many flying animals have adaptations that reduce body mass
    - For example, birds have large, air-filled bones and they lack teeth and a urinary bladder

Migration

- Environmental stimuli can provide cues that animals use to carry out behaviors
- Many animals use such cues to guide **migration**, a regular, long-distance change in location
- These cues allow animals to find their way through environments they have not previously encountered

Animal Signals and Communication

- In behavioral ecology, a **signal** is a stimulus that is transmitted from one organism to another
- **Communication** is the transmission and reception of signals between animals
- Communication often has a role in the proximate cause of behavior
- Animals communicate using visual, chemical, tactile, and auditory signals
- Fruit fly courtship follows a three-step stimulus-response chain

Pheromones

- Animals that communicate through odors or tastes emit chemical substances called **pheromones**
- Pheromones are often used in reproductive behavior
    - For example, pheromones are the basis for communication in fruit fly courtship

Experience and Behavior

- Cross-fostering studies help behavioral ecologists to identify the contribution of environment to an animal’s behavior
- A **cross-fostering study** places the young from one species in the care of adults from another species

Learning

- **Learning** is the modification of behavior based on specific experiences
- The capacity for learning has a genetic basis, but environmental influence is a critical component of the process of learning

Imprinting

- The ability of offspring to recognize and be recognized by a parent can be essential for survival
- This learning can take the form of **imprinting**, the establishment of a long-lasting behavioral response to a particular individual or object
- Imprinting can only take place during a specific time in development, called the **sensitive period**

Spatial Learning and Cognitive Maps; Associative Learning

- **Spatial learning** is the establishment of a memory that reflects the spatial structure of the environment
- Niko Tinbergen showed how digger wasps use landmarks to find nest entrances
- In **associative learning**, animals associate one feature of their environment with another
  - For example, a blue jay (*Cyanocitta cristata*) will avoid eating butterflies with specific colors after a bad experience with a distasteful butterfly

Cognition and Problem Solving

- **Cognition** is a process of knowing that may include awareness, reasoning, recollection, and judgment
- Although it was once thought only primates and certain marine mammals were capable of cognition, it is now recognized in many other animals
  - For example, honeybees can distinguish "same" from "different"

Mating Behavior and Mate Choice

- Mating behavior includes seeking or attracting mates, choosing among potential mates, competing for mates, and caring for offspring
- Needs of the young are an important factor constraining evolution of mating systems
- Consider bird species where chicks cannot feed or care for themselves
    - A male maximizes his reproductive success by staying with his mate and caring for his chicks (monogamy)

Genetic Basis of Behavior

- Differences at a single locus can sometimes have a large effect on behavior
  - For example, male prairie voles pair-bond with a single female after mating, while male meadow voles remain solitary
  - Which of these behaviors develops depends on the expression of a receptor gene, whose product binds with **antidiuretic hormone (ADH),** or **vasopressin**
- When behavioral variation between populations of a species corresponds to environmental variation, it may reflect natural selection

Altruism

- Natural selection favors behavior that maximizes an individual's survival and reproduction
- These behaviors are often selfish
- On occasion, some animals behave in ways that reduce their individual fitness but increase the fitness of others
- This kind of behavior is called **altruism**, or selflessness

Inclusive Fitness

- Altruism can be explained by inclusive fitness
- **Inclusive fitness** is the total effect an individual has on proliferating its genes by producing offspring and helping close relatives produce offspring

Hamilton’s Rule and Kin Selection

- William Hamilton proposed a quantitative measure for predicting when natural selection would favor altruistic acts among related individuals

Copyright

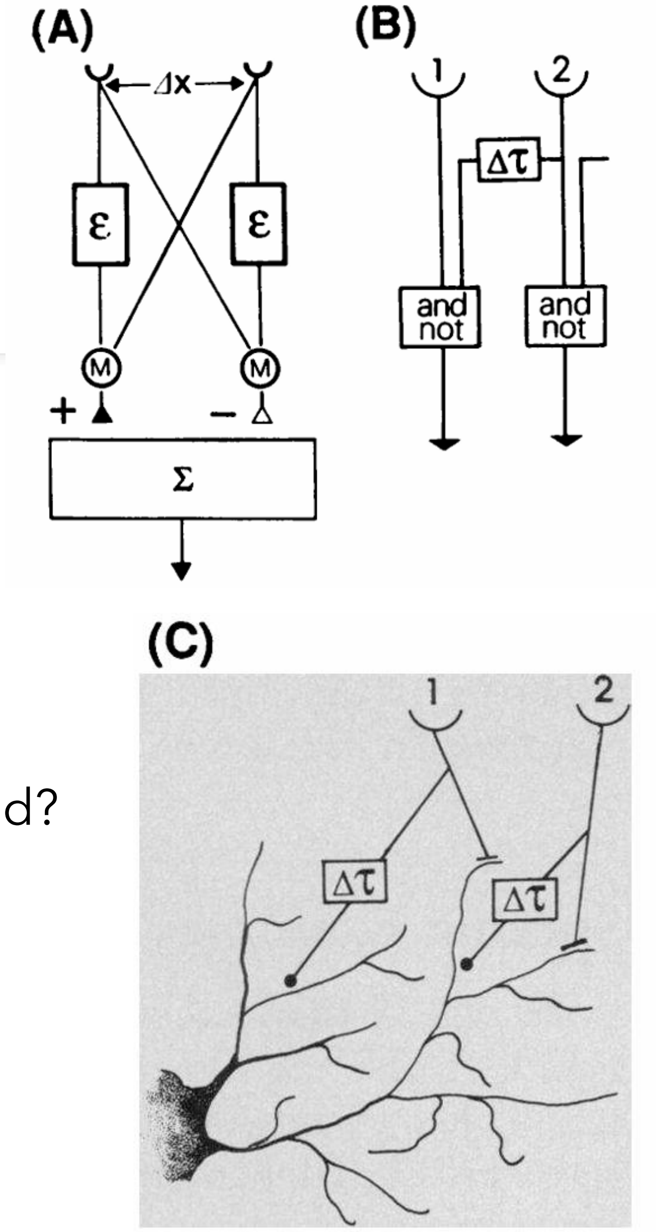
Computational

Computational Neuroscience

- The study of how the brain computes, using mathematical models and computer simulations to understand neural systems.
- It bridges biology, physics, mathematics, and computer science to explain how neural circuits process information.
- Key questions:
  - How do neurons encode and transmit information?
  - How do networks of neurons give rise to perception, action, and cognition?
- Computational models help test hypotheses that are difficult or impossible to address experimentally.
- Sejnowski, T.J., Koch, C., & Churchland, P.S. (1988). Computational Neuroscience. Science, 241(4871), 1299-1306
  - https://klab.tch.harvard.edu/academia/classes/Neuro204/neuro_204_week_7_sejnowski_reading.pdf

Levels of Analysis in Computational Neuroscience

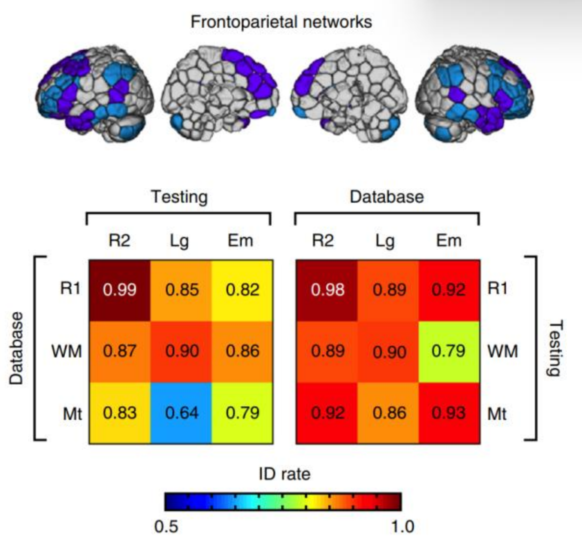
- Marr's Three Levels:
  - **Computational Level:** What is the goal of the computation? (e.g., edge detection in vision)
  - **Algorithmic Level:** What processes and representations are used? (e.g., receptive fields, neural codes)
  - **Implementation Level:** How is the algorithm physically realized? (e.g., ion channels, synapses, neural circuits)
- Example: Visual processing
  - Computational: Identify objects in a scene.
  - Algorithmic: Feature extraction, pattern recognition.
  - Implementation: Retina, LGN, visual cortex.



Impact and Applications of Computational Neuroscience

- **Understanding the Brain:** Models explain how neural circuits generate behavior, learning, and memory.
- **Bridging Scales:** From single neurons (Hodgkin-Huxley model) to large-scale brain networks (connectionist models).
- **Technological Advances:** Insights inspire artificial intelligence, machine learning, and neuroprosthetics.
- **Interdisciplinary Collaboration:** Progress requires integration of experimental data, mathematical theory, and computational tools.
- **Future Directions:**
  - More realistic, data-driven models.
  - Integration with genetics and molecular biology.
  - Applications in medicine (e.g., brain-machine interfaces, disease modeling).

Image Processing and Machine Learning on Brain MRI



- The human brain's functional connectivity pattern—how different regions' activities are correlated—can serve as a unique "fingerprint" for each individual.
- Finn et al. (2015) used resting-state fMRI to measure these patterns in 126 subjects.
- They constructed a functional connectome: a matrix showing correlations between pairs of brain regions.
- Key question: Can we identify a person just by their brain's connectivity pattern?
- Finn, E. S., Shen, X., Scheinost, D., Rosenberg, M. D., Huang, J., Chun, M. M., Papademetris, X., & Constable, R. T. (2015). Functional connectome fingerprinting: identifying individuals using patterns of brain connectivity. *Nature Neuroscience*, 18(11), 1664–1671
  - https://www.researchgate.net/publication/282812326_Functional_connectome_fingerprinting_Identifying_individuals_using_patterns_of_brain_connectivity

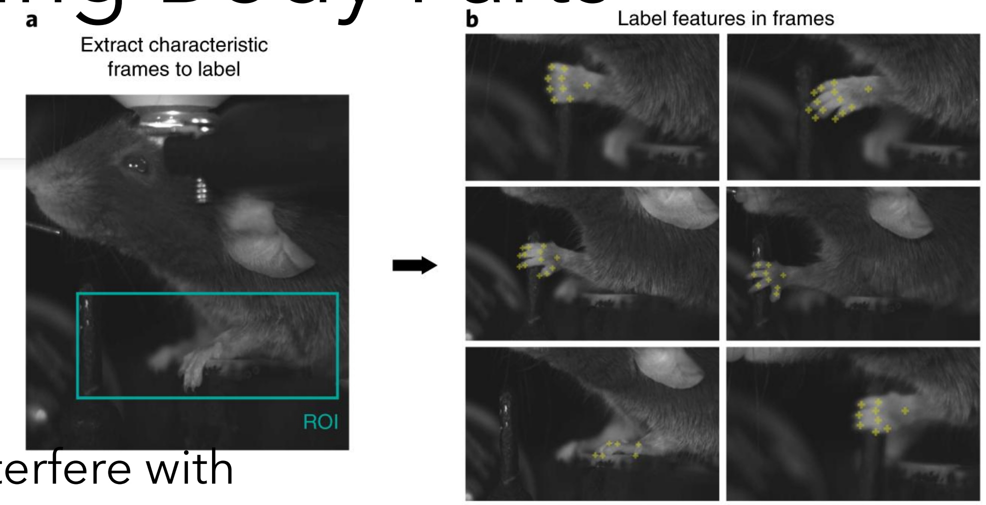
Computational Approach and Key Findings

- **Data Processing:**
  - Extracted time-series data from 268 brain regions for each subject.
  - Computed correlation matrices (connectomes) for each scan session.
- **Identification Algorithm:**
  - Compared each subject's connectome from one session to all connectomes from another session.
  - Used similarity metrics to "match" individuals across sessions.
- **Results:**
  - Achieved over 90% accuracy in identifying individuals.
  - The most distinctive features were in the frontoparietal network (linked to higher cognition).

Why Does This Matter? The Role of Computation

- **Demonstrates the power of computational neuroscience:**
  - Large-scale data processing and network analysis are essential for extracting meaningful patterns from brain data.
- **Enables new applications:**
  - Personalized medicine: tracking brain changes over time.
  - Brain-based biometrics: potential for secure identification.
  - Understanding individual differences in cognition and behavior.
- **Highlights the need for advanced algorithms:**
  - Pattern recognition, machine learning, and network science are key tools for modern neuroscience research.

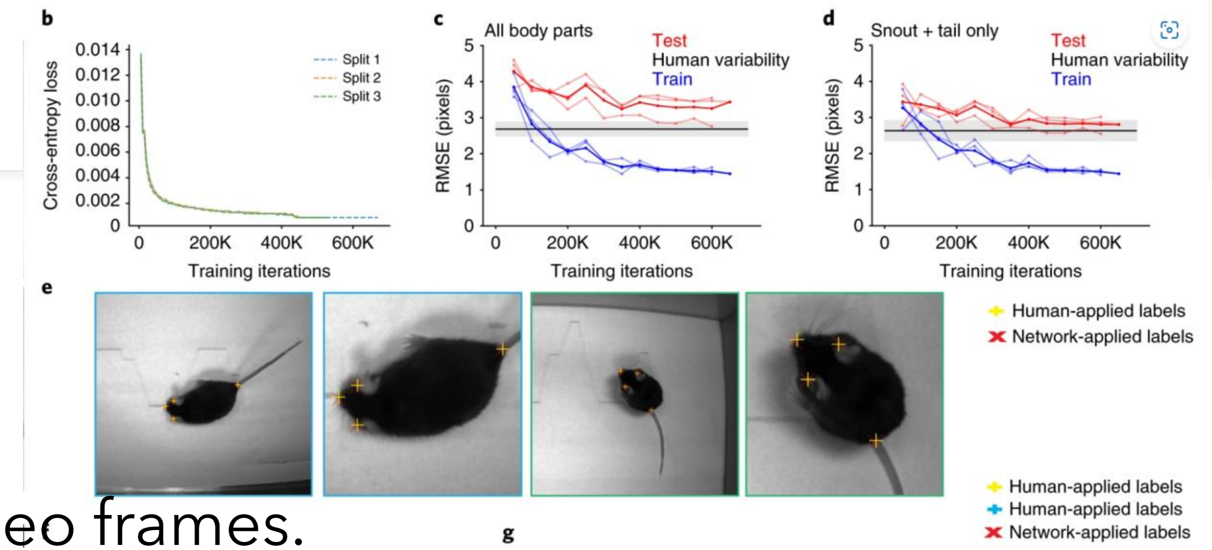
Using Deep Learning in Tracking Body Parts



- Quantifying animal behavior often requires tracking specific body parts over time.
- Traditional methods use physical markers or manual annotation—both are time-consuming and can interfere with natural behavior.
- Need for a flexible, accurate, and markerless solution.

- Mathis, A., Mamidanna, P., Cury, K. M., Abe, T., Murthy, V. N., Mathis, M. W., & Bethge, M. (2018). DeepLabCut: markerless pose estimation of user-defined body parts with deep learning. Nature Neuroscience, 21, 1281–1289.
  - http://catniplab.github.io/journalclub/JCpapers/Mathis_markerless_defined_deep learning.pdf

DeepLabCut – Deep Learning for Markerless Tracking

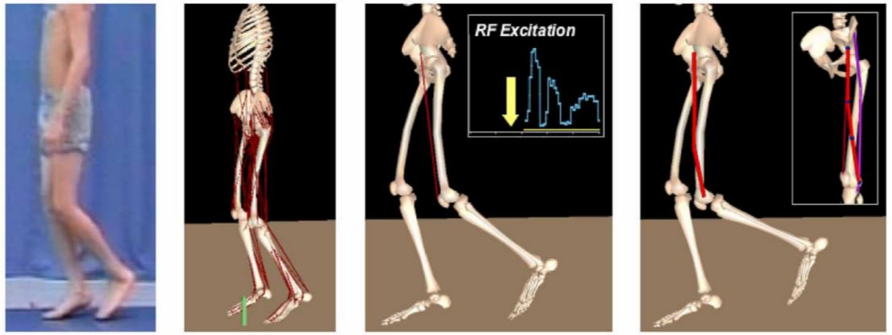


- DeepLabCut uses deep CNN (ResNet) to learn to detect user-defined body parts from video frames.
- Workflow:
  - User labels a small number of frames (e.g., nose, paw, tail).
  - The network is trained on these examples.
  - The trained model predicts body part positions in new, unlabeled frames.
- Works across species (mice, flies, fish, humans) and behaviors.

Impact and Computational Relevance

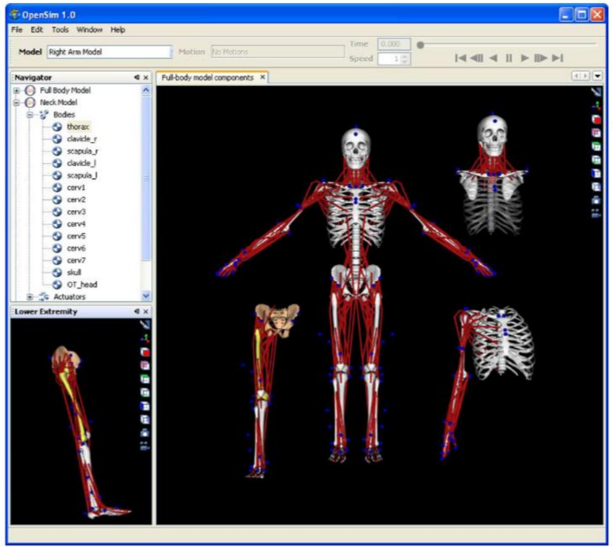
- **High accuracy:** Achieves human-level precision with minimal labeled data.
- **Scalable:** Enables high-throughput behavioral analysis for large datasets.
- **Open-source and customizable:** Researchers can define any body part of interest.
- **Computational significance:**
  - Demonstrates the power of transfer learning and deep neural networks in biological research.
  - Bridges computer vision and neuroscience, making advanced AI accessible to experimentalists.

The Need for Dynamic Movement Simulation



- Understanding how muscles, bones, and joints work together is crucial for biomechanics, rehabilitation, and robotics.
- Experimental measurements alone can't reveal all internal forces or predict the effects of changes (e.g., surgery, injury).
- Computational models and simulations fill this gap, allowing "virtual experiments" on movement.
- Delp, S. L., Anderson, F. C., Arnold, A. S., Loan, P., Habib, A., John, C. T., Guendelman, E. & Thelen, D. G. (2007). OpenSim: open-source software to create and analyze dynamic simulations of movement. IEEE transactions on biomedical engineering, 54(11), 1940-1950.
  - https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=4352056

OpenSim – An Open-Source Platform for Movement Science



- OpenSim provides tools to:
  - Build detailed musculoskeletal models (bones, muscles, tendons).
  - Simulate dynamic movements (walking, running, jumping).
  - Analyze muscle forces, joint torques, and movement efficiency.
- Features:
  - Graphical user interface and scripting (MATLAB, Python).
  - Extensible for custom models and analyses.
  - Community-driven, with shared models and datasets.

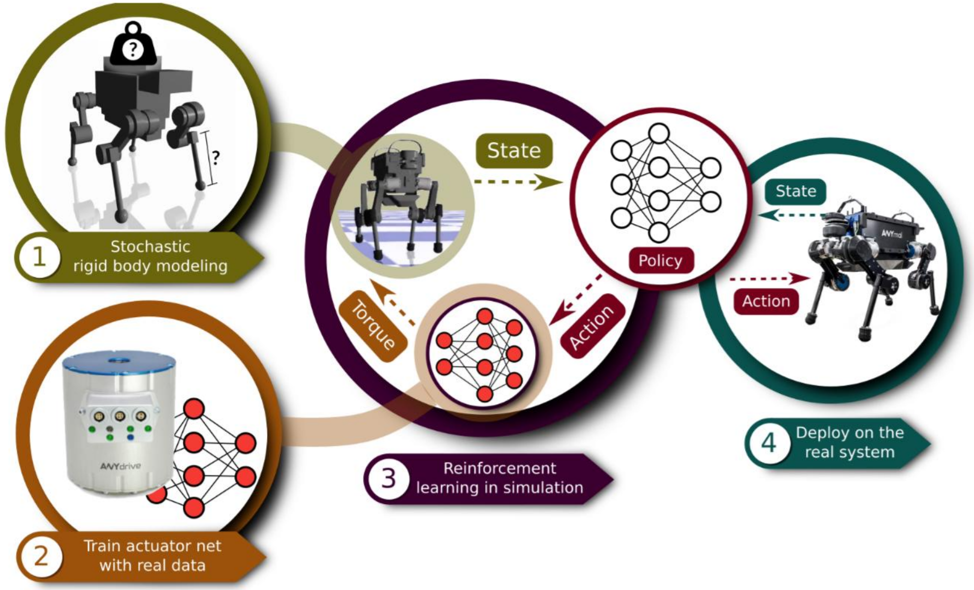
Impact and Computational Relevance

- **Research and clinical impact:**
  - Used to study normal and pathological gait, sports performance, and surgical planning.
  - Helps design assistive devices and prosthetics.
- **Computational significance:**
  - Integrates physics-based modeling, numerical solvers, and optimization algorithms.
  - Enables reproducible, shareable, and extensible research.
  - Bridges biomechanics, neuroscience, and computer science.

The Challenge of Agile Legged Locomotion

- Legged robots must coordinate many joints and muscles to move dynamically and robustly.
- Traditional control methods struggle with complex, unpredictable environments.
- Can we use machine learning to teach robots to move like animals?
- Hwangbo, J., Lee, J., Dosovitskiy, A., Bellicoso, D., Tsounis, V., Koltun, V., & Hutter, M. (2019). Learning agile and dynamic motor skills for legged robots. Science Robotics, 4(26).
  - https://www.research-collection.ethz.ch/bitstream/handle/20.500.11850/319675/2/ScienceRobotics_2019_arxiv(3).pdf

Deep Reinforcement Learning for Motor Skills



- The authors use deep RL to train neural network controllers in simulation.
  - The robot receives sensory input (joint angles, velocities, etc.).
  - The neural network outputs motor commands to achieve walking, trotting, and recovery.
- **Domain randomization**: Varying simulation parameters (e.g., friction, mass) during training helps the policy generalize to the real world.
- After training, the learned policy is transferred to the real ANYmal robot.

Impact and Computational Relevance

- **Results:**
  - ANYmal achieves fast, stable, and agile locomotion on rough terrain and can recover from falls.
  - Outperforms traditional controllers in robustness and adaptability.
- **Computational significance:**
  - Demonstrates the power of deep RL and simulation for real-world robotics.
  - Bridges animal biomechanics, neuroscience, and AI.
  - Opens new possibilities for autonomous robots in search, rescue, and exploration.