

COGS500/CMPE489

Introduction to Cognitive Science

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Emre Uğur
Computer Engineering
Bogazici University

With slides adapted from Albert Ali Salah

Today

- Psychology
- Nervous system

Last Week

- Introduction to Cognitive Science
- Some philosophical background
- Artificial Intelligence lecture by Cem Say

Cognitive View

- Human mind, complex system,
 - Receives, stores, retrieves, transforms, transmits
 - Operations on information: Computations and information processes.
- The view of mind: computational or information-processing view.

The idea of algorithm and computation

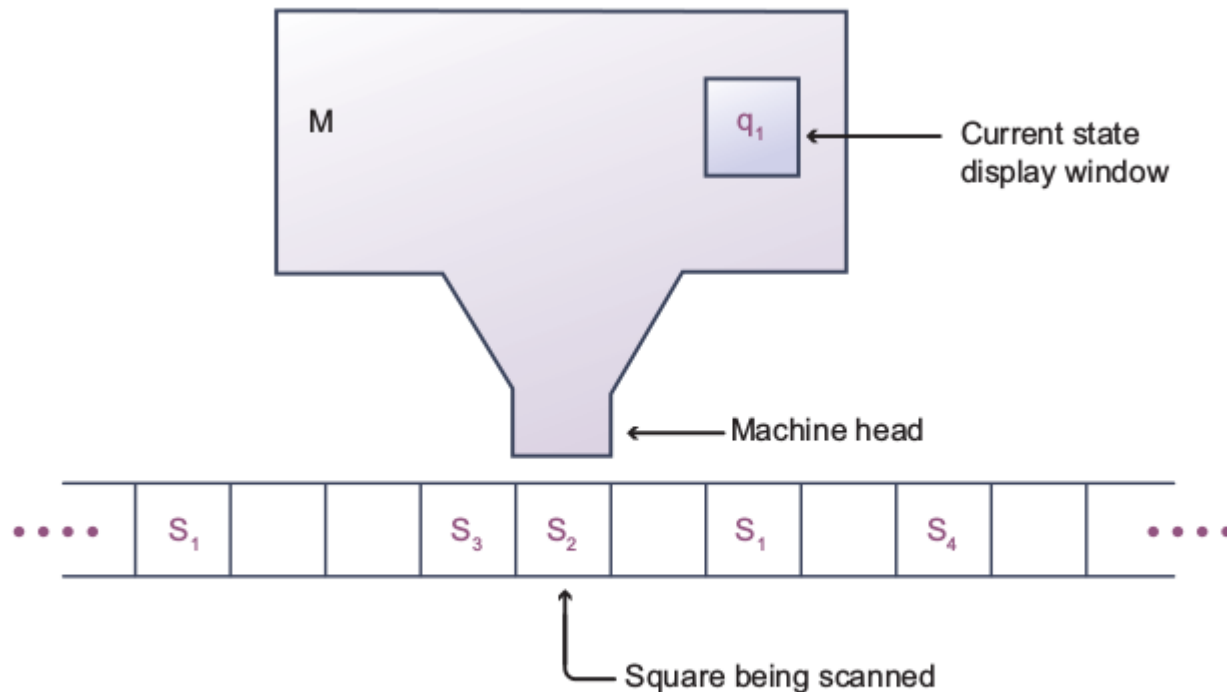


Figure 1.4 Schematic representation of a Turing machine. (Adapted from Cutland 1980)

- delete the symbol in the cell
- write a new symbol in the cell
- move the tape one cell to the left
- move the tape one cell to the right

AI vs. Cognitive Science

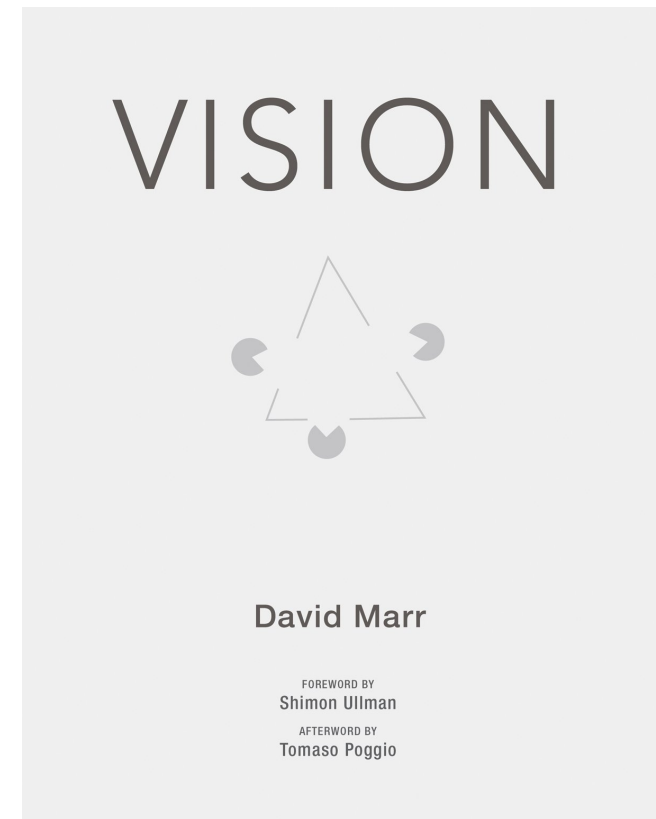
- **CogSci** asks questions of cognitive psychology
 - Use insights/hypothesis/theories from CogSci to build better Artificial Intelligent systems
- **AI** creates machines that reason and act intelligently
 - Use AI methods to construct models and validate them in CogSci

Cognitive Models

- What do we model?
 - A cognitive phenomenon (system output)
 - Dynamics (representation and processing)
 - Physical structure (architecture)
 - Descriptive model: To explain a cognitive phenomenon (cognitive science proper)
 - Prescriptive model: To use some of the principles of cognitive phenomenon to realize other goals (AI proper)
-

Model of vision

- Mind can be studied in different levels:
 - Bottom-up
 - Top-down
- Earliest systematic approach: David Marr's model of human visual system (1982)
- Integrated results from psychology, artificial intelligence, and neurophysiology into new models of visual processing.
- His work was very influential in computational neuroscience



Three levels of description (David Marr, 1982)

Computational

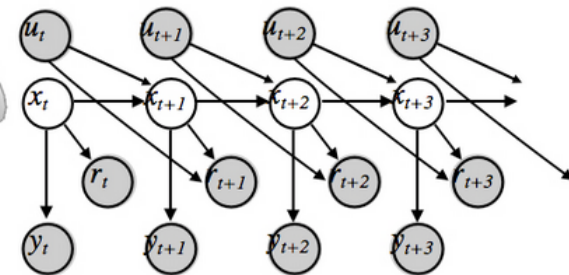
Why do things work the way they do?
What is the goal of the computation?
What are the unifying principles?

maximize:

$$R_t = r_{t+1} + r_{t+2} + \dots + r_T$$

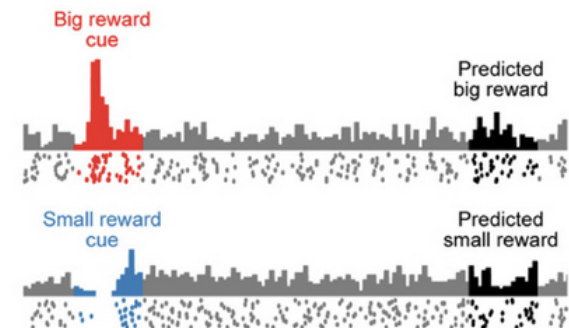
Algorithmic

What representations can implement
such computations?
How does the choice of representations
determine the algorithm?



Implementational

How can such a system be built in
hardware?
How can neurons carry out the
computations?



Turing machine example

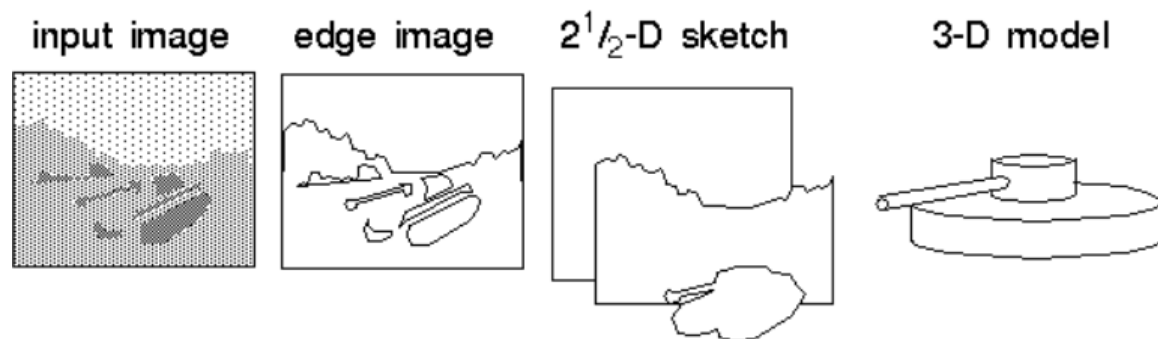
- Computational
 - Characterization of multiplication function
 - Algorithmic
 - Turing machine table
 - Implementational
 - Construction of a physical Turing machine
-

Visual perception model of Marr

- Computational
 - Derive a representation of the 3-d shape and spatial arrangement of an object in a form that allow that object to be recognized.
 - Object centric view.

- Algorithmic
 - How exactly input/output encoded. Representational primitives, what sort of operations on those primitives
 - Intensity of light reaching retina,

- Implementation level
Actual implementation



The computer

- Use of computer models
 - Confirm that a particular algorithm works
 - Predict behaviour
 - Simulate and analyse different conditions
 - Gain useful insight
 - Support empirical evidence
-

The computer

- Unsuccessful computer model
 - ❑ Bad programming? Insufficient training data?
 - ❑ Does not prove that computers cannot do it.
 - ❑ Cannot show “the limits of (*connectionist*) models”
 - Successful computer model
 - ❑ Does not prove that the brain does it that way.
 - ❑ Overuse of simplifying assumptions?
 - ❑ Proves(?) that computers can do it.
-

PSYCHOLOGY

Definition of Psychology

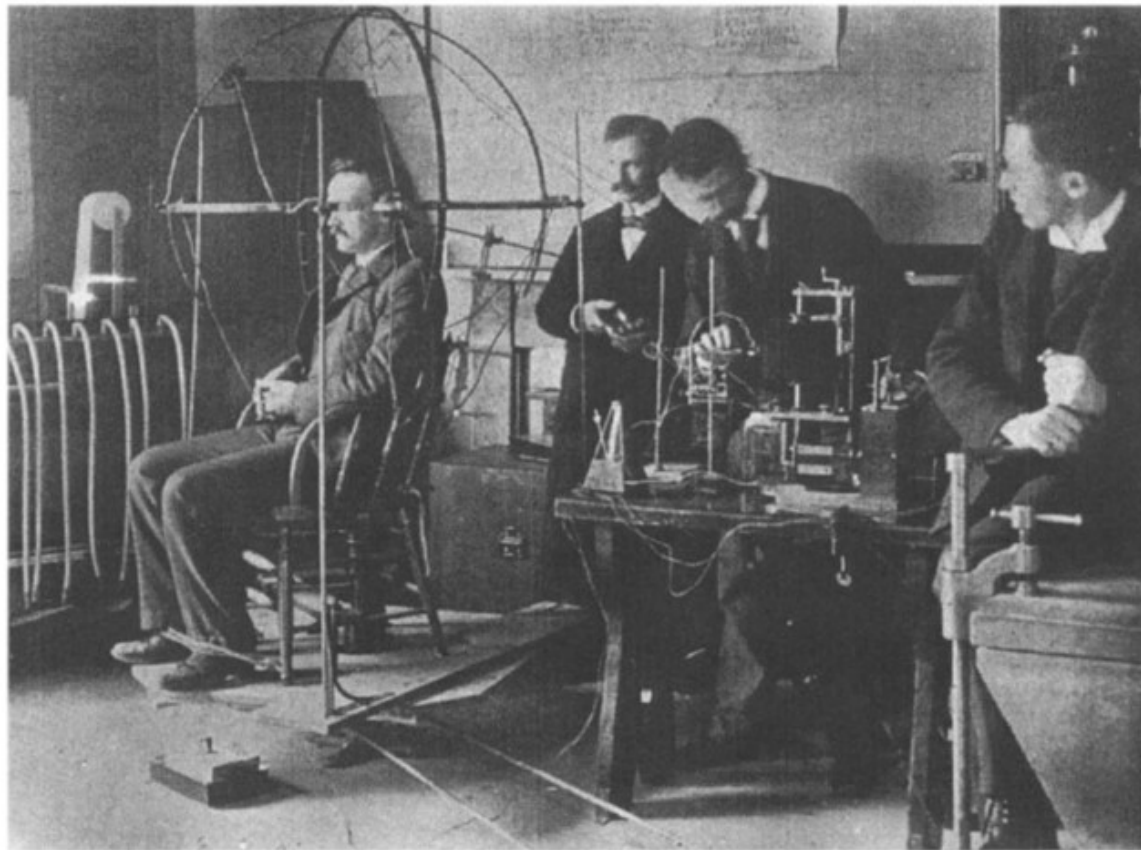
- “The scientific study of behavior and mental processes.” (Atkinson et al.)
- It should be objective: Repeatability
- It should be unbiased: No hypothesis is favored

Nature–nurture debate

- Nature - nurture debate centers on the question of whether human capabilities are inborn or acquired through experience
- Early philosophers believed that this knowledge and understanding could be accessed through careful reasoning and **introspection**.

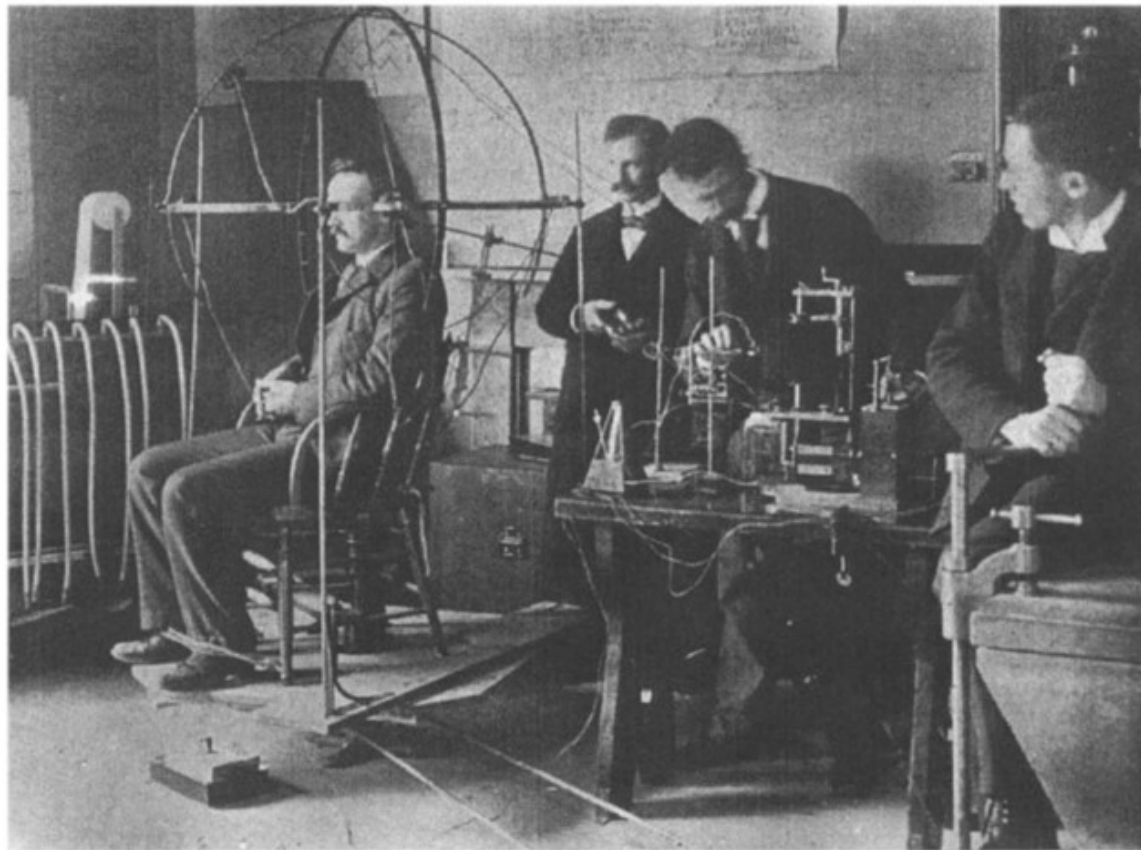
Introspection

- 1879, Wilhelm Wundt established the first psychological laboratory in Leipzig
- Mind and behavior subject of scientific analysis.
- A new dimension. Pure self-observation was not sufficient; it had to be supplemented by experiments.



Introspection

- Not reliable, not repeatable, inconsistent

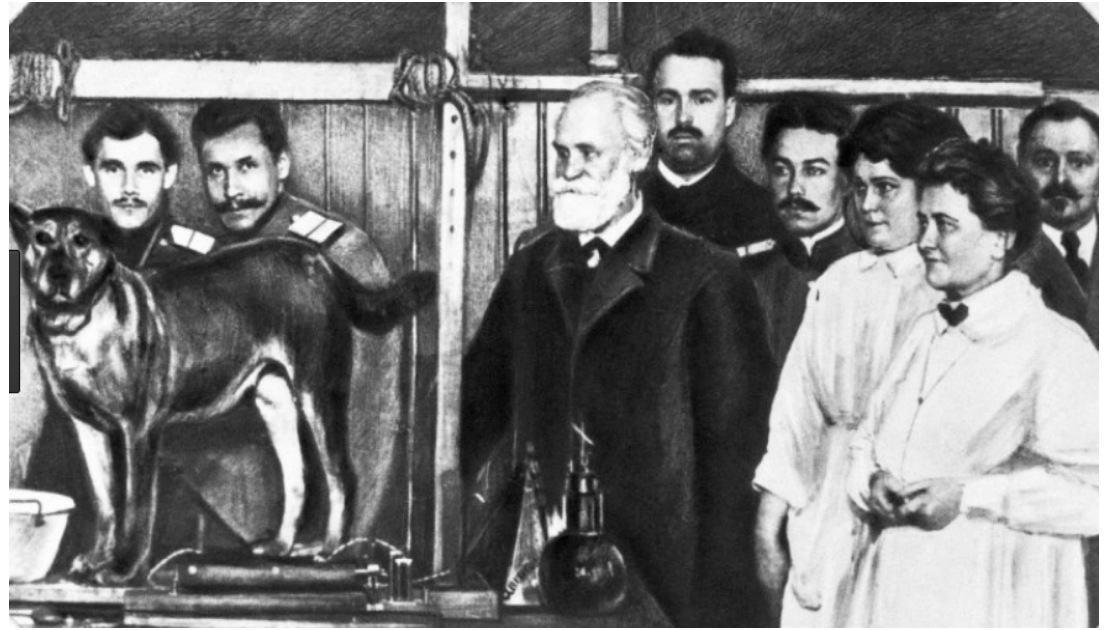


Behaviorists



The Little Albert Experiment (1920)

Source:youtube



Ivan Pavlov's dogs

Source:spiegel.de

- John B. Watson: against the view that conscious experience is the province of psychology
- Data must be open to public inspection
- Behavior is public, consciousness is private
- Almost all behavior is the result of conditioning
- More complicated behaviors can be created from conditioned response units.

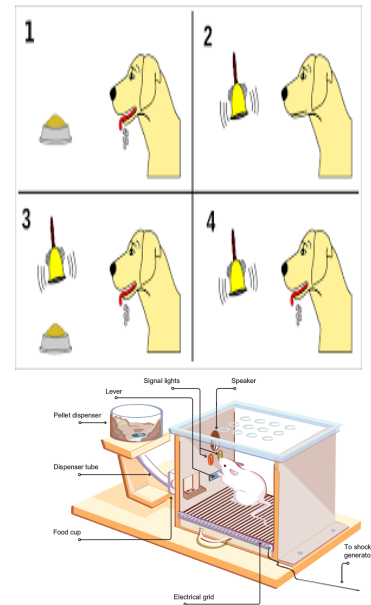
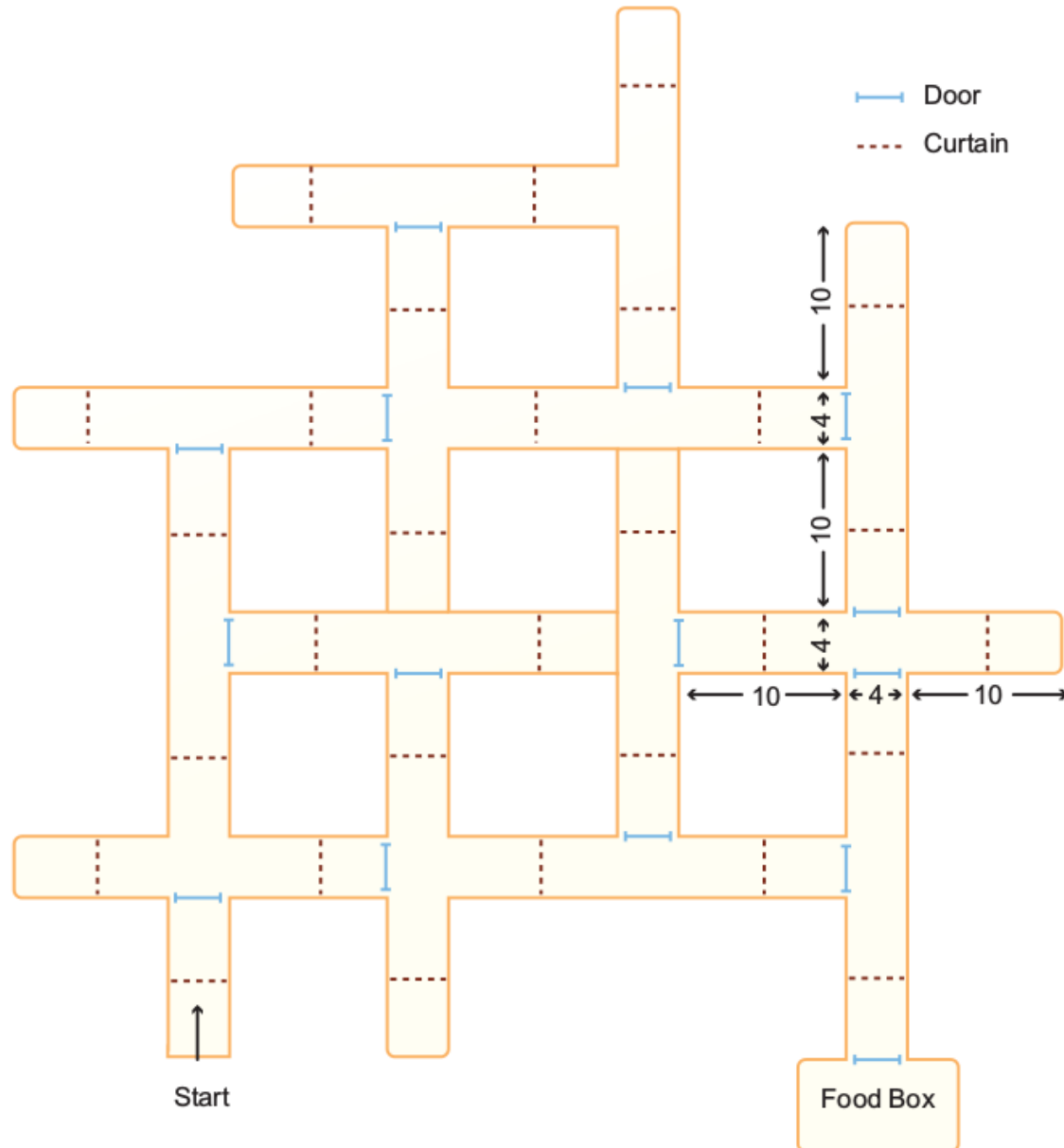
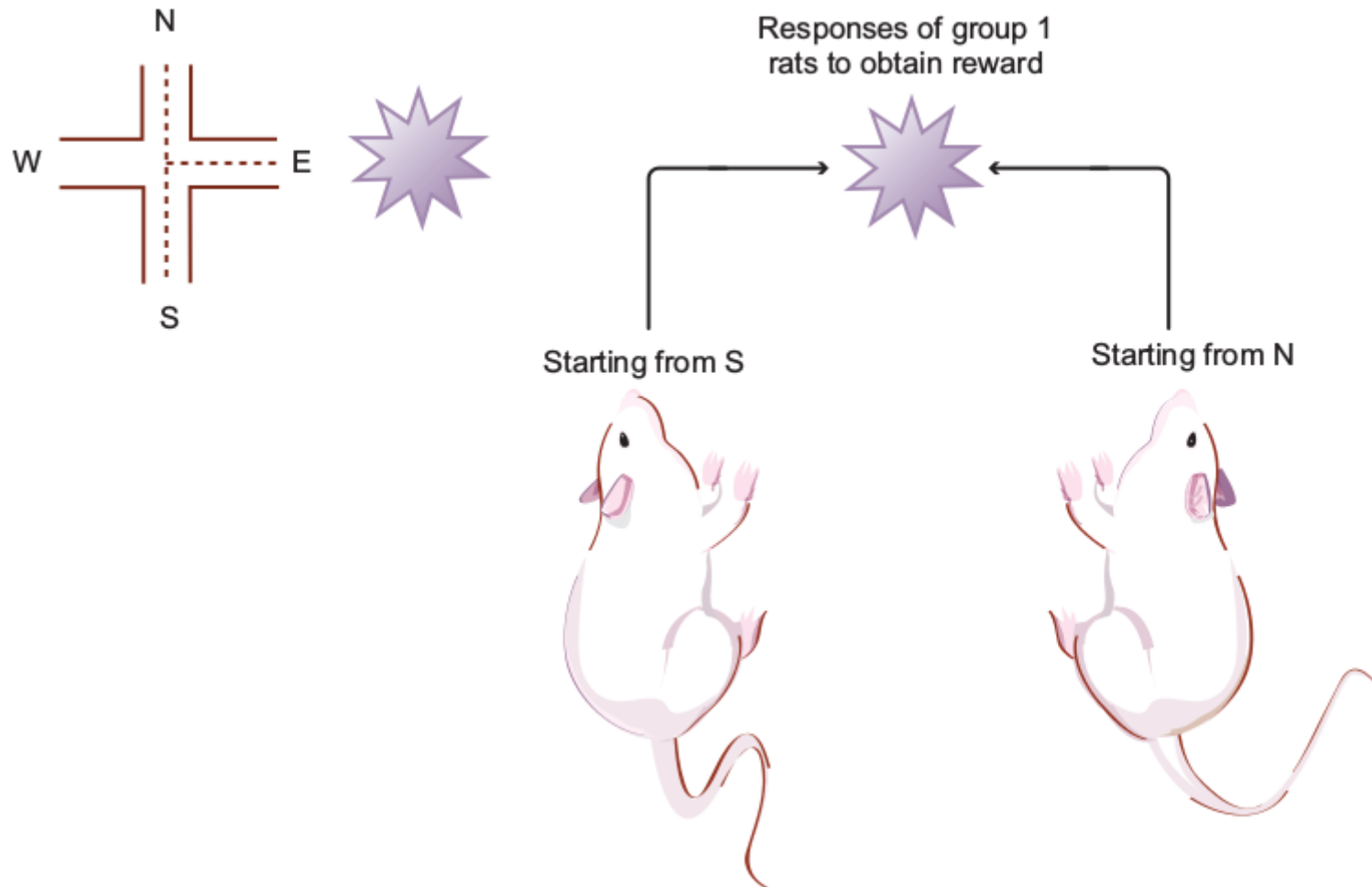


Figure 1.1 A rat in a Skinner box. The rat has a response lever controlling the delivery of food, as well as devices allowing different types of stimuli to be produced. (Adapted from Spivey 2007)

Response by Tolman & Honzik 1930



Cognitive maps



Lashley (1951) – Complex behavior

- Previously: complex behavior is a chain of stimulus-responses.
- Lashley:
 - Organized hierarchically
 - Hypothesis of subconscious information processing
 - Hypothesis of task analysis

Other early schools

- Gestalt psychology
 - Gestalt: “form” or “configuration”
 - Max Wertheimer, Kurt Koffka, Wolfgang Kohler
 - The whole is different from the sum of the parts
- Psychoanalysis
 - At the core: concept of unconscious
 - Thoughts, attitudes, impulses, motivations, emotions
 - Show themselves in dreams, slips of tongue
 - Unconscious wishes involved sex or aggression



20th century

- 1950's: Computers offer a powerful tool for theorizing about psychological processes through simulation
- Many psychological studies: information-processing models
- Check earlier ideas about mind with concrete terms:
 - Memory as analogous computer stores and retrieves information
 - Transfer from temporary storage in its internal memory to hard drive, from working memory to long-term memory
- Development of modern linguistics: theorize about mental structures required to comprehend and speak a language.
- Information processing models, psycholinguistics, neuropsychology → cognitive psychology

Psychological Perspectives – Major approaches



Five perspectives within psychology

Biological perspective

An orientation toward understanding the neurobiological processes that underlie behavior and mental processes.

Behavioral perspective

An orientation toward understanding observable behavior in terms of conditioning and reinforcement.

Cognitive perspective

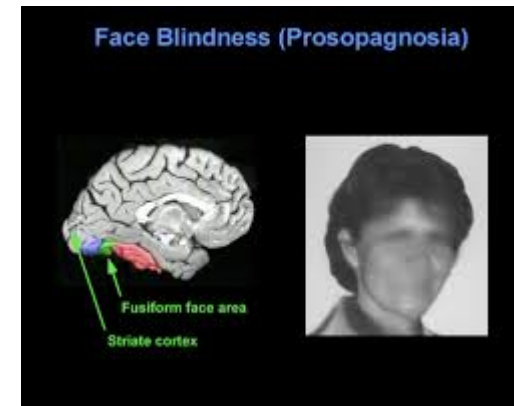
An orientation toward understanding mental processes such as perceiving, remembering, reasoning, deciding, and problem solving and their relationship to behavior.

Psychoanalytic perspective

An orientation toward understanding behavior in terms of unconscious motives stemming from sexual and aggressive impulses.

Subjectivist perspective

An orientation toward understanding behavior and mental processes in terms of the subjective realities people actively construct.



- Following an insult, punch someone in the face
 - Underlying neurobiological processes: Involving brain areas, firing of nerves, activate muscles.
 - Stimulus: insult, response: punch. Not much body reference
 - Mental processes involved: goal is to defend your honor, aggressive behavior is part of achieving such goal.
 - Expression of unconscious aggressive instinct
 - Reaction to interpreting person's utterance as a personal insult

Topics of psychology

- Biological psychology
 - Relationship between biological processes and behavior
- Cognitive psychology
 - Mental processes, problem solving, memory, language, thought
- Developmental psychology
 - Human development, factors (language or period or..)
- Social and personality psychology
 - Perception and interpretation of social world, social relationships
 - Differences between individuals, thoughts/emotions/behaviors
- Clinical and counseling psychology
 - Diagnosis and treatment of emotional and behavioral problems
- School and educational psychology
 - Evaluate learning and emotion problems, teaching. In schools
- Organizational and engineering psychology
 - Job selection, facilitate teamwork, relationship between man and machines

Methods of Psychology

- Experimental method
 - Controlling conditions
 - Measurement
 - Relationships between dependent and independent variables
 - Experimental design
 - Experiment group vs. control group
 - Statistical significance
-

Design and Analysis of an Experiment

- Identify the issue or question of interest
- Review the relevant theories and research
- Develop research hypothesis
- Identify the independent and dependent variables
- Conduct the experiment
- Use descriptive statistics to evaluate the statistical hypotheses
- Draw conclusions regarding the research hypotheses
- Prepare a formal report for publication or presentation

Keppel et al., Intro. to Design and Analysis

Experimental Method

- Hypothesis: Marijuana affects memory
- Variables: marijuana amount(indep); amount of recalled items (dep)
- Experiment:
 - Keep all conditions constant
 - Use enough subjects
 - Provide different sets of subjects different amounts of marijuana. Give same information to memorize
 - One week later, see the recalled items

Analysis of results

- Mean (μ): The average of scores
- Median (m): The middle value when we order the scores (more robust to outliers)
- Variance (S): Average of squared deviations from the mean: $\sum_i (x_i - \mu)^2 / (n-1)$
-

Correlational method

- What if we cannot control the variables under investigation?

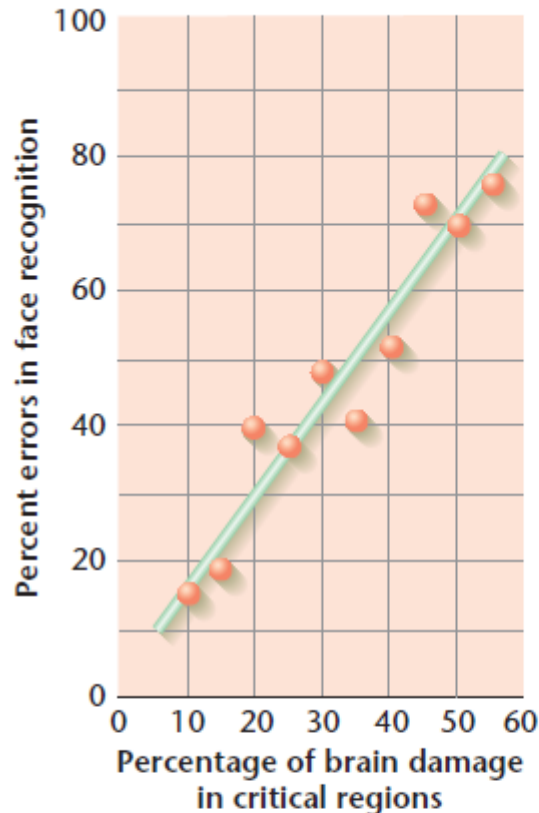
Correlational method

- Correlational method
 - Naturally occurring differences
 - Coefficient of correlation (r)
 - 0: no correlation
 - 1: perfect positive correlation
 - -1: perfect negative correlation
 - Tests
 - Cause-and-effect relations
 - Double dissociation

$$\rho_{X,Y} = \frac{\text{cov}(X, Y)}{\sigma_X \sigma_Y}$$

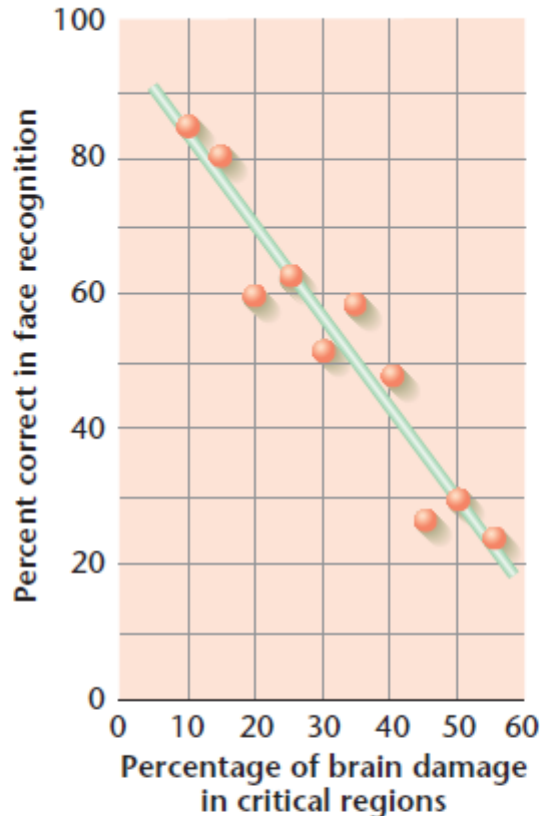
Correlational method

a) Positive correlation



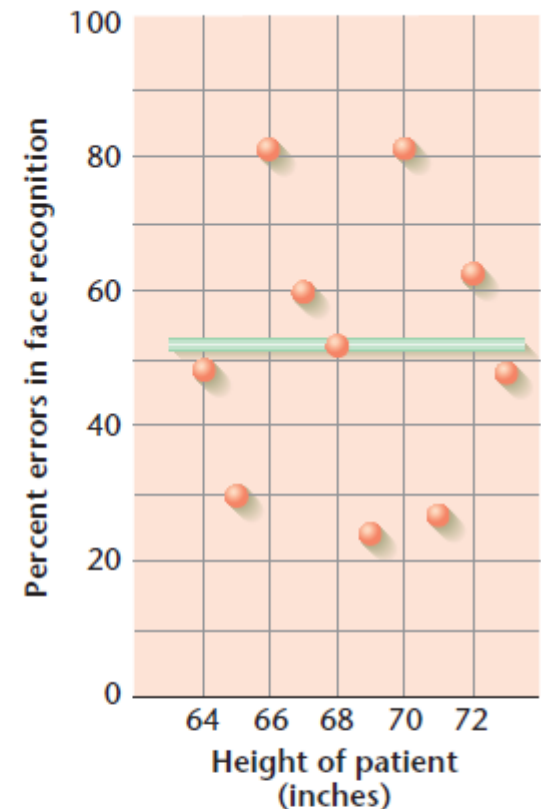
The patients are ordered along the horizontal axis with respect to the amount of brain damage, with the patient represented by the leftmost point having the least brain damage (10%) and the patient represented by the rightmost point having the most brain damage (55%). Each point on the graph represents a single patient's score on a test of face recognition. The correlation is a positive .90.

b) Negative correlation



The same data are depicted, but we now focus on the percentage of correct responses (rather than errors). Now the correlation is a negative .90.

c) Zero correlation



The patients' performance on the face recognition test is graphed as a function of their height. Now the correlation is 0.

Methods of Psychology

- Observational method
 - Direct observation
 - Survey method
 - Case histories



Field studies can often tell us more about social behavior than experimental studies can. Professor Shirley Strum has been observing the same troop of baboons in Kenya for more than 20 years, identifying individual animals, and making daily recordings of their behaviors and social interactions. Her data have provided remarkable information about the mental abilities of baboons and the role of friendships in their social system.

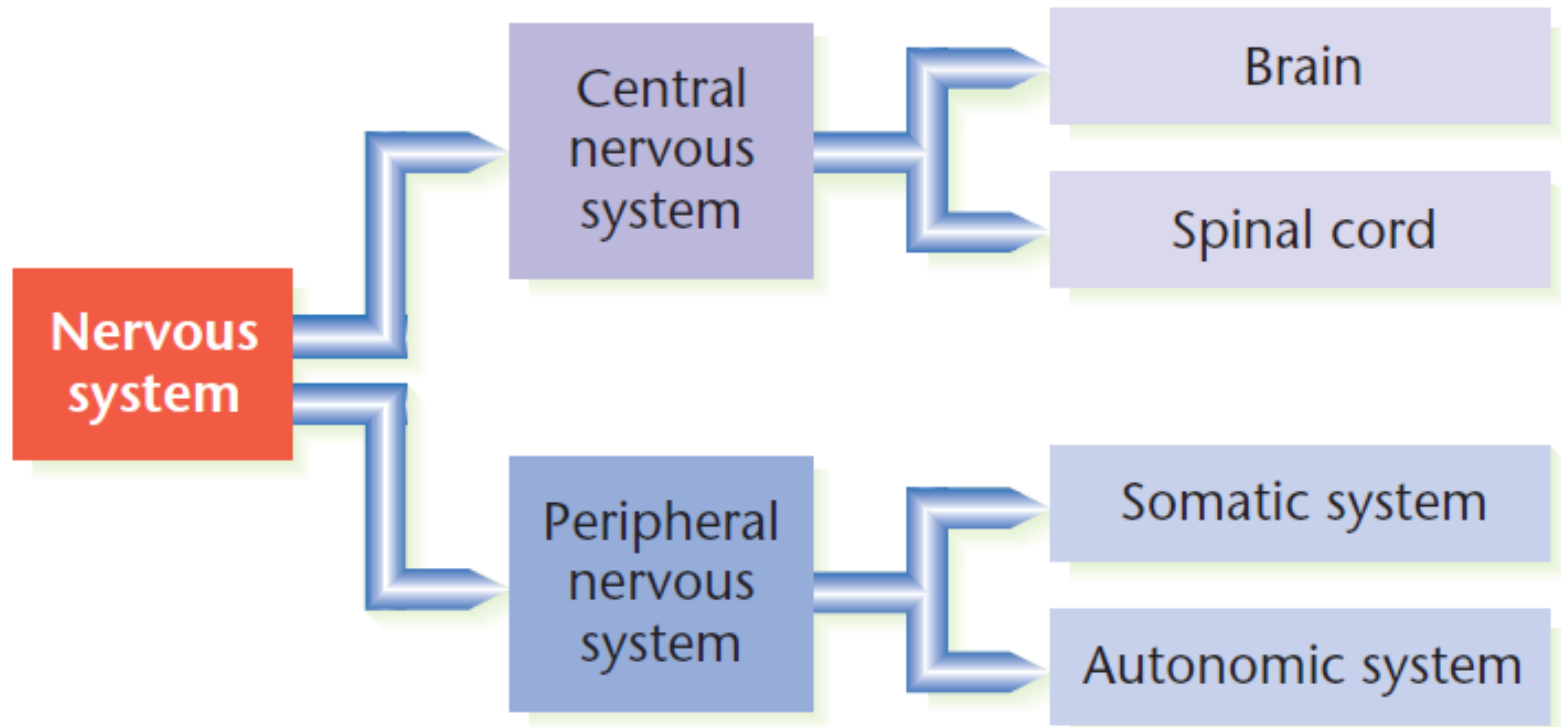
Nervous system and brain

Brain

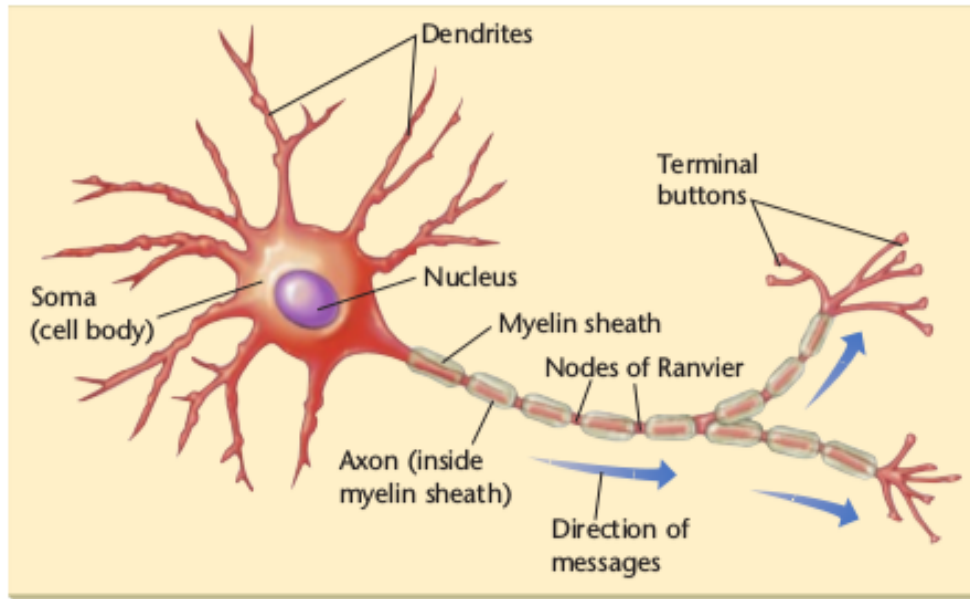


15-30 billion neurons
each thousands of connections

Nervous system



Neurons – basics



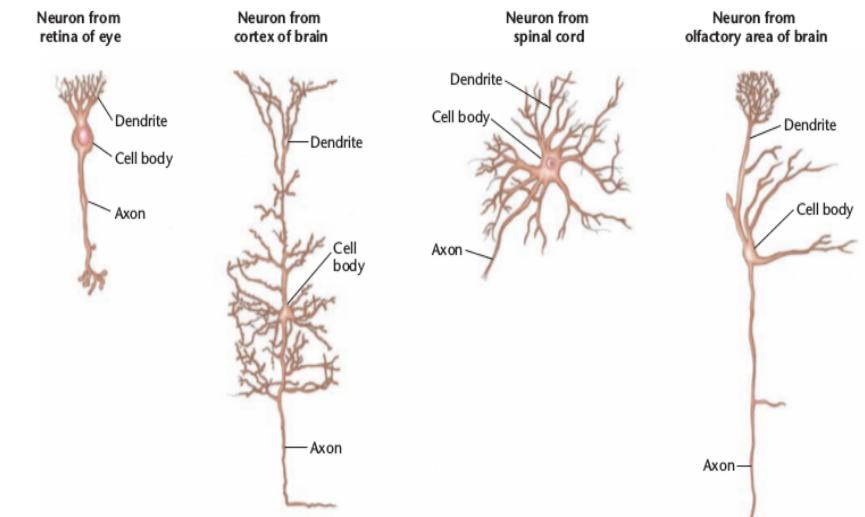
Transmits neural impulses to other neurons, glands, muscles.

Basics known but..

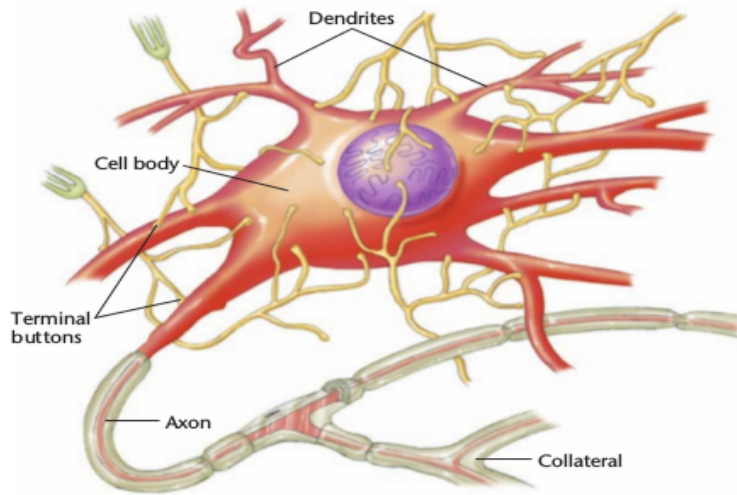
Dendrites, soma, axon, terminals..

Neurotransmitters across gap

Integrate pre-synaptic impulses



Neurons – basic structure



Sensory & motor neurons
Nerve: a bundle. e.g. optic nerve

Glial cells more than half of brain – glue and nutrients

Information moves through electrochemical impulse, movement of ions

Semi-permeable cell membrane

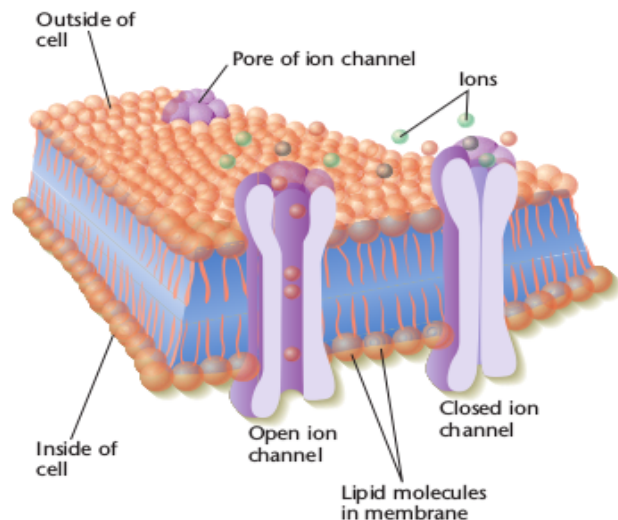


Figure 2.5 Ion Channels. Ions such as sodium (Na^+), potassium (K^+), and chloride (Cl^-) pass through the cell membrane via doughnut-shaped protein molecules called ion channels.

Neurons – resting state

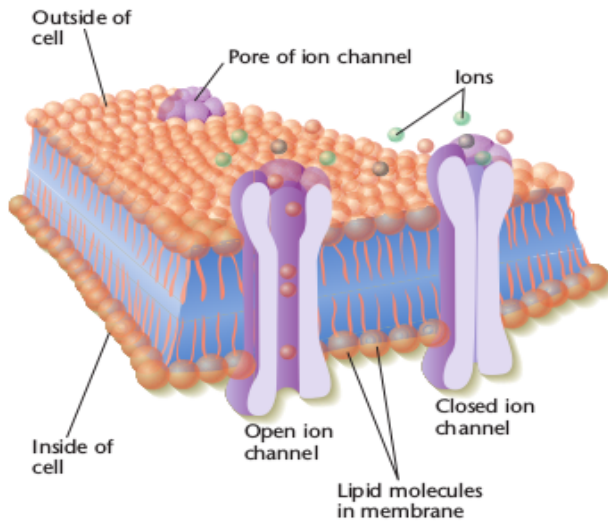
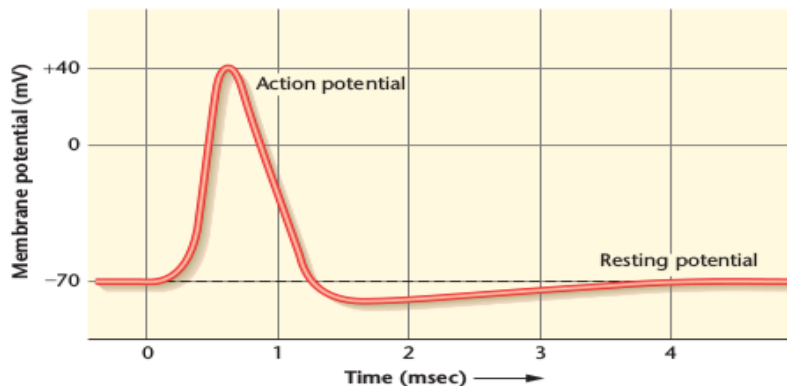


Figure 2.5 Ion Channels. Ions such as sodium (Na^+), potassium (K^+), and chloride (Cl^-) pass through the cell membrane via doughnut-shaped protein molecules called ion channels.



Resting state: membrane not permeable (high Na^+ outside, K^+ inside)

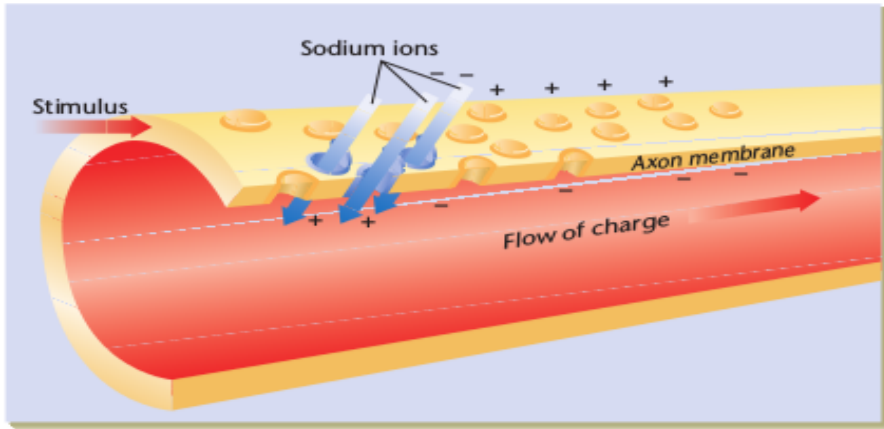
Ion channels and pumps

Action potential from stimulation by other neurons. Caused by neurotransmitters released by pre-synaptic neurons.

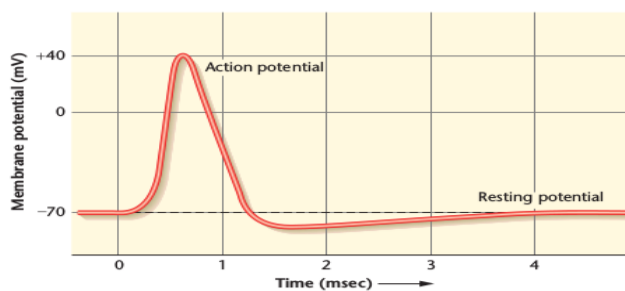
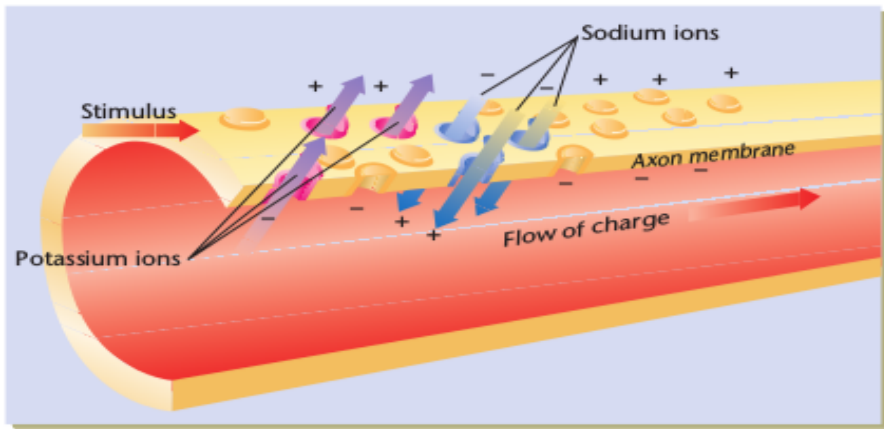
Change small: ion pumps restore

Excitation threshold: -55 mV

Neurons – action potential



a) During an action potential, sodium gates in the neuron membrane open and sodium ions enter the axon, bringing a positive charge with them.



e axon, the sodium
long the axon. When
potassium ions flow

Unstable membrane
Na⁺ ions in
inside +40 mV

Ion pumps restore
“spike” in only
milliseconds

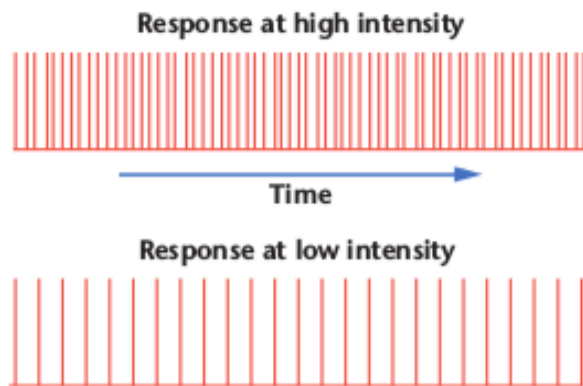
Refractory period. only
in one direction

Neurons - characteristics



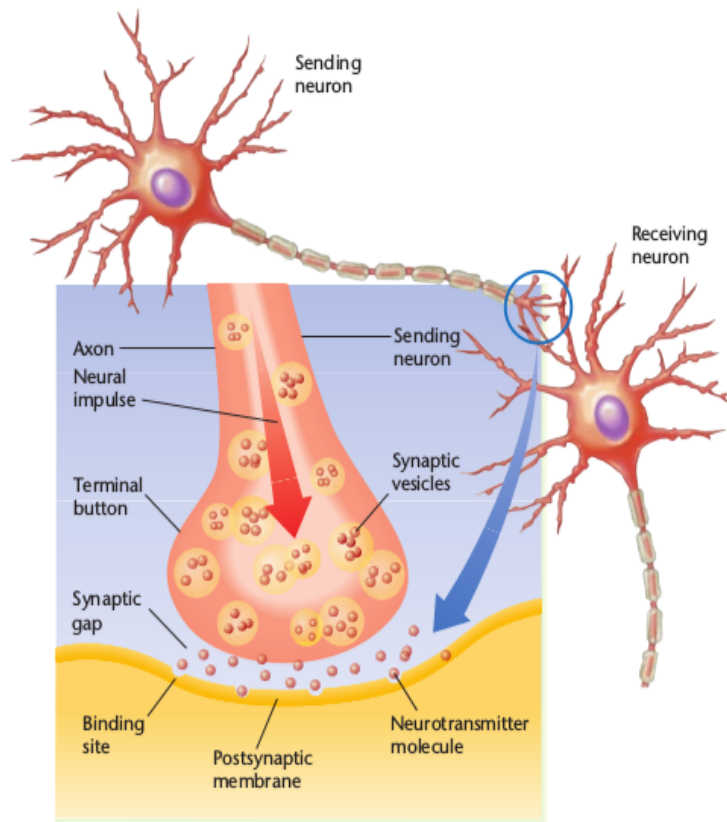
All a neuron can do:
fire!

- Single brief pulse
- Threshold level
- Response size same
- All-or-none law



How to code
complexity? If basic is
so simple.

Neurons - synapse



Not connected

Stimulate synaptic vesicles that contain neurotransmitters

Diffuse from neuron and bind to receptors (proteins) in the dendritic membrane – lock&key

Change permeability of ion channels

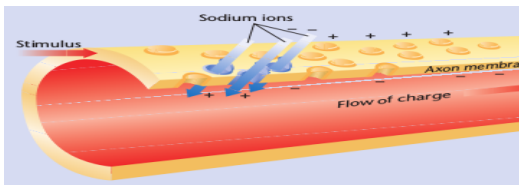
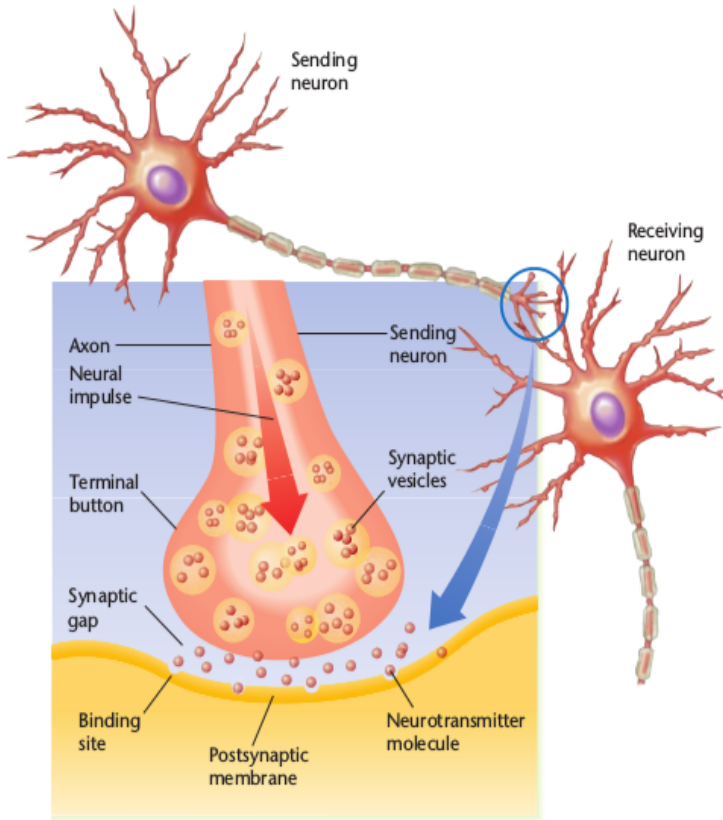
Excitatory or inhibitory

Excitatory: towards reaching excitation threshold

Neurons – input summation

Receive from many.
Summates the input it receives

Excitatory effect >
inhibitory effect
– Depolarization



Neurotransmitters

More than 70.

Different types: Some can bind to more than one type of receptor.

Acetylcholine, Norepinephrine, GABA, Glutamate, Serotonin, Dopamine

Dopamine: release in certain areas produces intense feelings of pleasure.

Serotonin: mood regulation. Low levels: associated with feelings of depression.

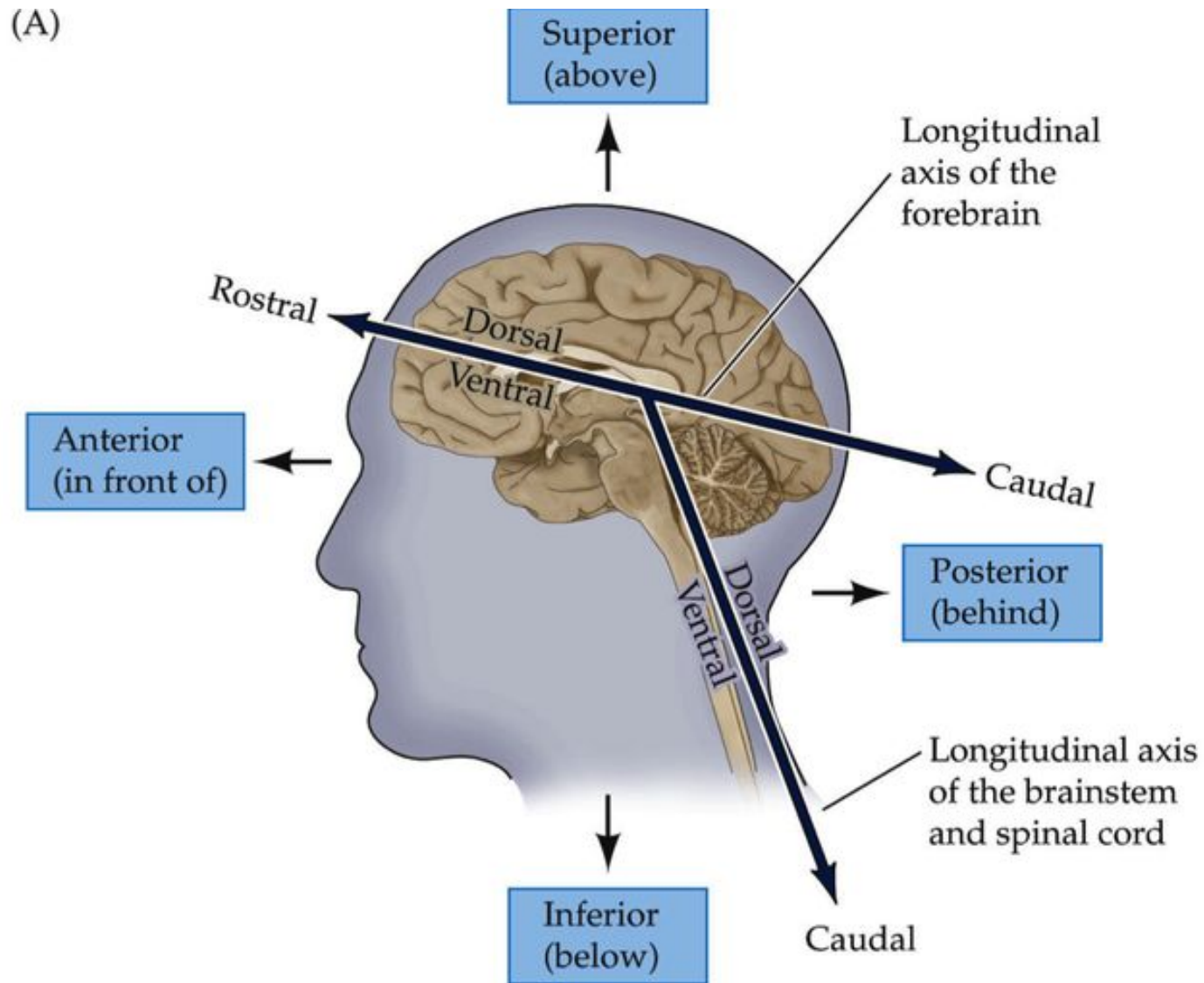
CONCEPT REVIEW TABLE



Neurotransmitters and Their Functions

Neurotransmitter	Function
Acetylcholine	Involved in memory and attention; decreases associated with Alzheimer's disease. Also transmits signals between nerve and muscle.
Norepinephrine	Increased by psycho-stimulants. Low levels contribute to depression.
Dopamine	Mediates the effects of natural rewards (food and sex, for example) and drugs of abuse.
Serotonin	Important in mood and social behavior. Drugs that alleviate depression and anxiety increase serotonin levels in synapse.
Glutamate	Major excitatory neurotransmitter in brain. Involved in learning and memory.
GABA	Major inhibitory neurotransmitter in brain. Drugs that alleviate anxiety enhance activity of GABA.

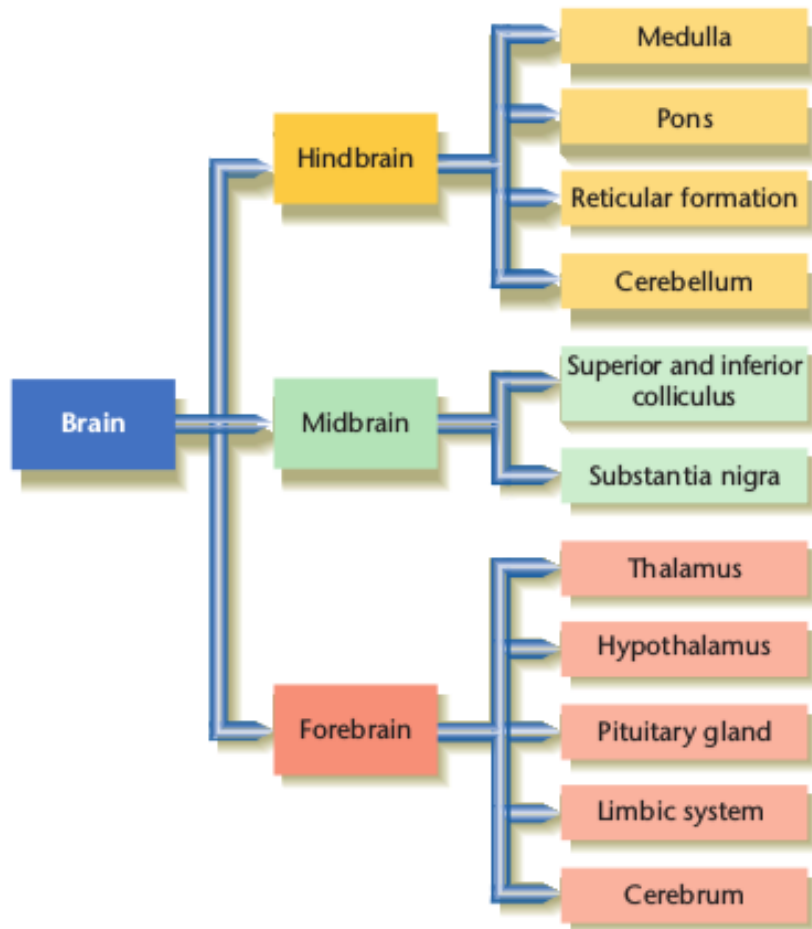
Terminology



NEUROSCIENCE, Fourth Edition, Appendix, Figure A1 (Part 1)

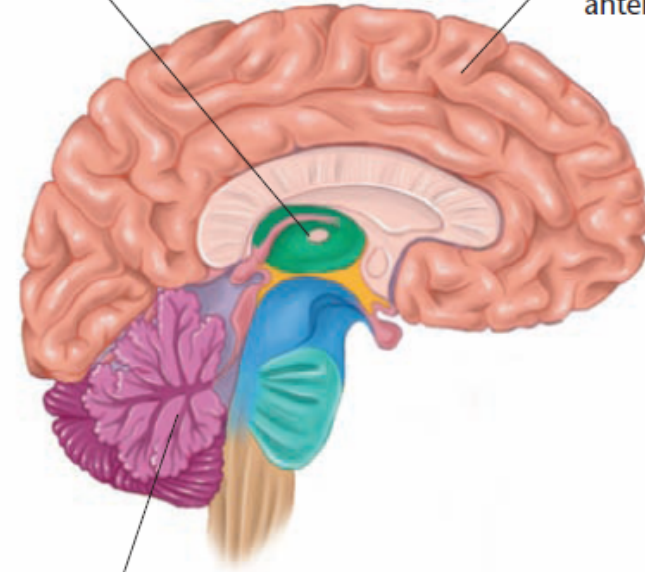
© 2006 Sinauer

The organization of the brain



The midbrain is located in the middle of the brain

The forebrain includes structures located in the anterior part of the brain



The hindbrain includes all structures located in the posterior part of the brain

The organization of the brain

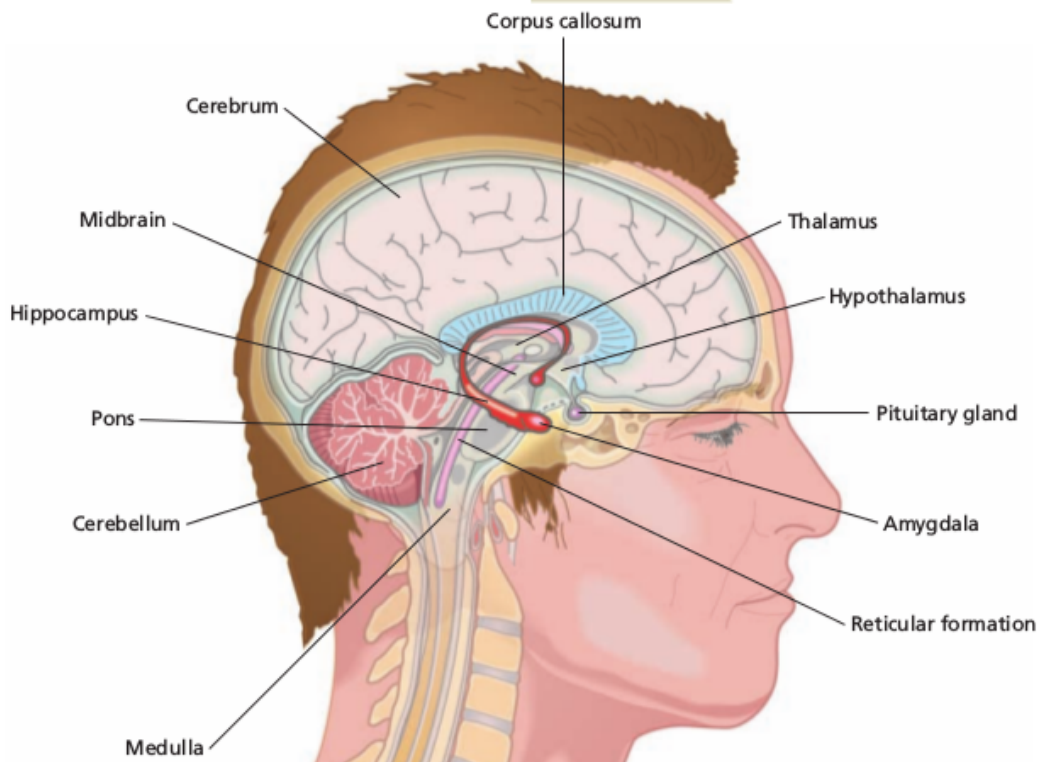
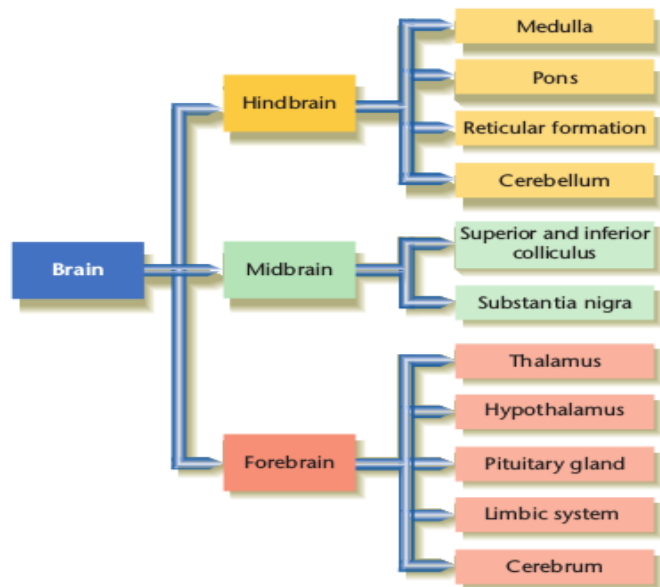
Medulla: reflexes (breathing and posture)

Pons: Attentiveness and sleep

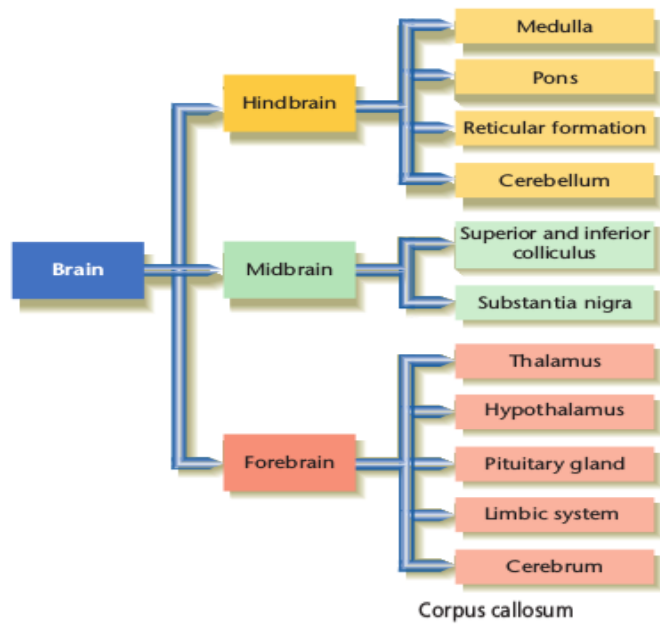
Reticular formation:
Behavioral arousal and consciousness

Cerebellum: coordination of movement. Damage?

- Learning new movements
- Direct connections to frontal

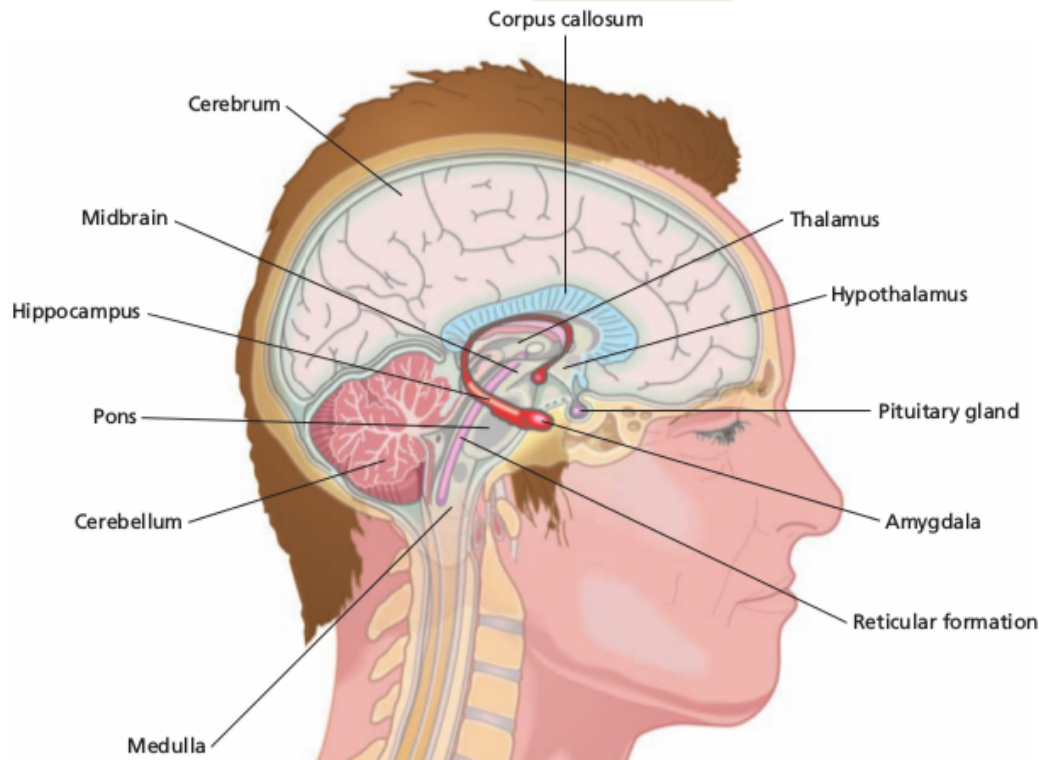


Midbrain

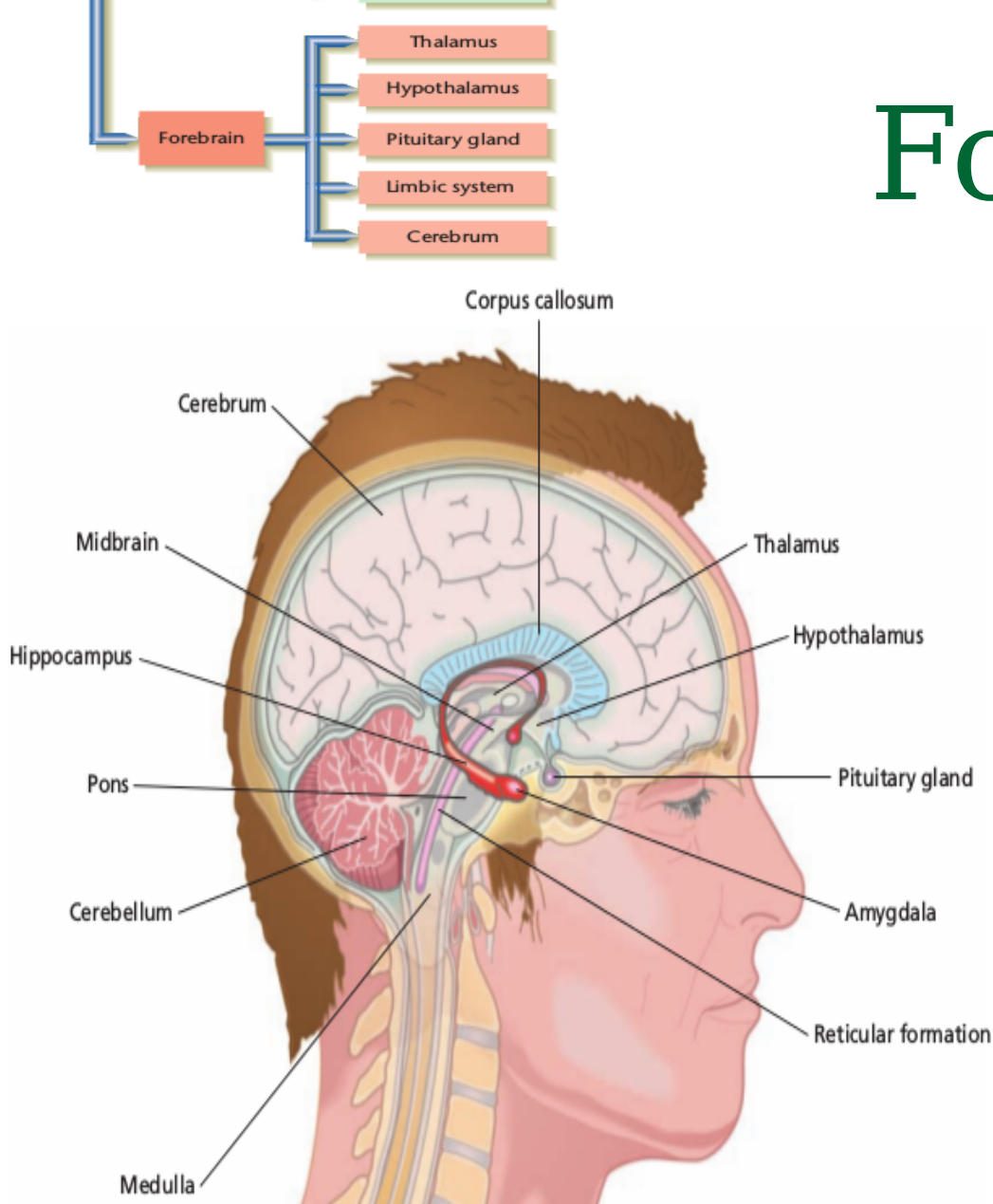


Relaying sensory information to the brain and for movement control (including eye)

Important part of dopamine-containing pathway (reward pathway).



Forebrain



Large cerebrum.

- Upper part: cerebral cortex
- Subcortical: hippocampus, basal ganglia, olfactory bulb

Thalamus: sensory relay station.

Hypothalamus: eating, drinking, and sexual behavior.

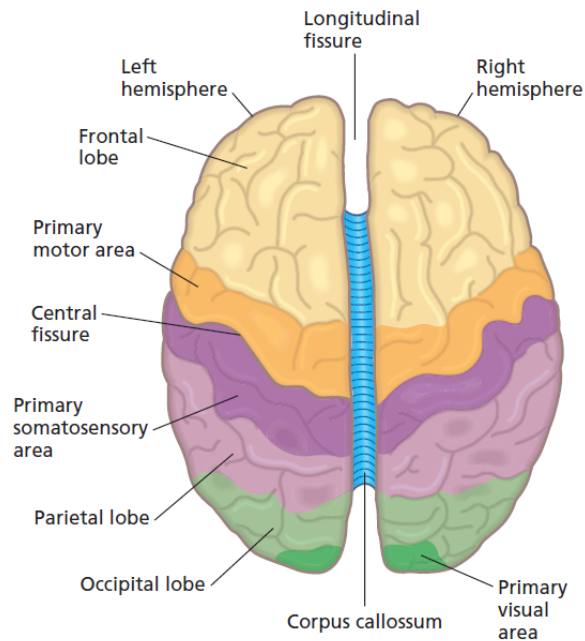
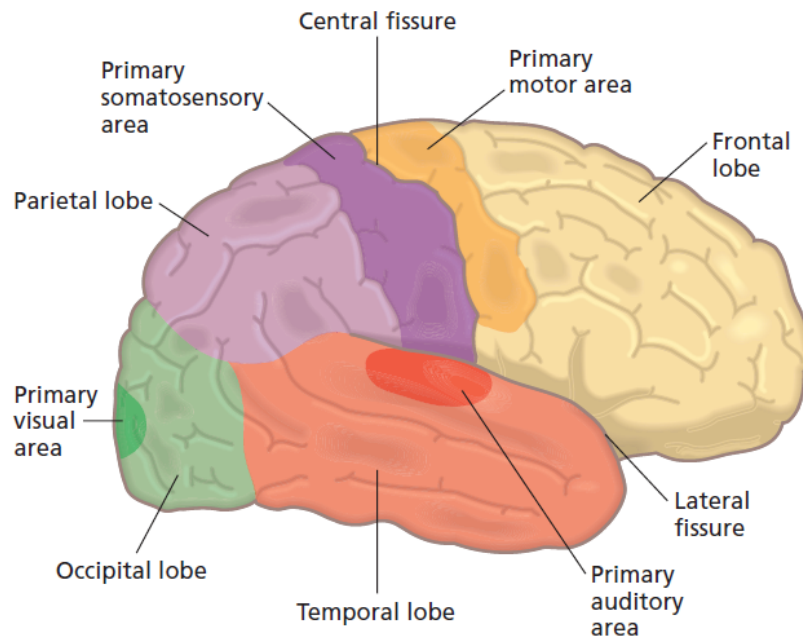
Pituitary gland: part of endocrine sys.

Limbic system: instinctive behaviors regulated by central core.

Hippocampus (part of limbic) role in memory.

Amygdala: critical in emotions such as fear. Damage in amygdala?

Cerebral Cortex



Each sensory system sends info to specific areas. Motor responses or movements are controlled by specific areas.

Appears gray because nerve cell bodies and unmyelinated fibers – gray matter. Inside, myelinated axons, therefore white matter.

Left and right sides are connected by corpus callosum. Symmetrical.

Each hemisphere is divided into 4 with diverse functionalities.

Frontal/parietal : central fissure

Lateral fissure: sets off the temporal



A lateral view of the human brain, color-coded to show major lobes and functional areas. The labels and their corresponding regions are:

- Central fissure**: The deep groove separating the frontal and parietal lobes.
- Primary motor area**: A yellow region in the frontal lobe, anterior to the central fissure.
- Frontal lobe**: The anterior portion of the brain, colored yellow.
- Parietal lobe**: The lateral portion of the brain, colored purple.
- Primary somatosensory area**: A purple region in the parietal lobe, posterior to the primary motor area.
- Primary visual area**: A green region in the occipital lobe.
- Occipital lobe**: The posterior portion of the brain, colored green.
- Temporal lobe**: The inferior lateral portion of the brain, colored orange.
- Primary auditory area**: A red region in the temporal lobe.
- Lateral fissure**: The deep groove separating the temporal lobe from the other lobes.

Body is represented upside down.

Sensory experiences: primary somatosensory area. Stimulation

Amount of somatosensory area associated with a part's sensitivity and use.

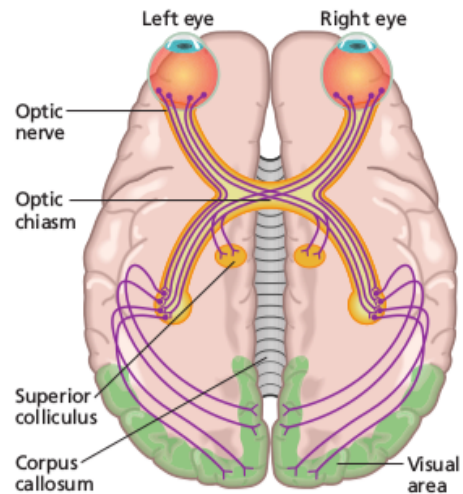
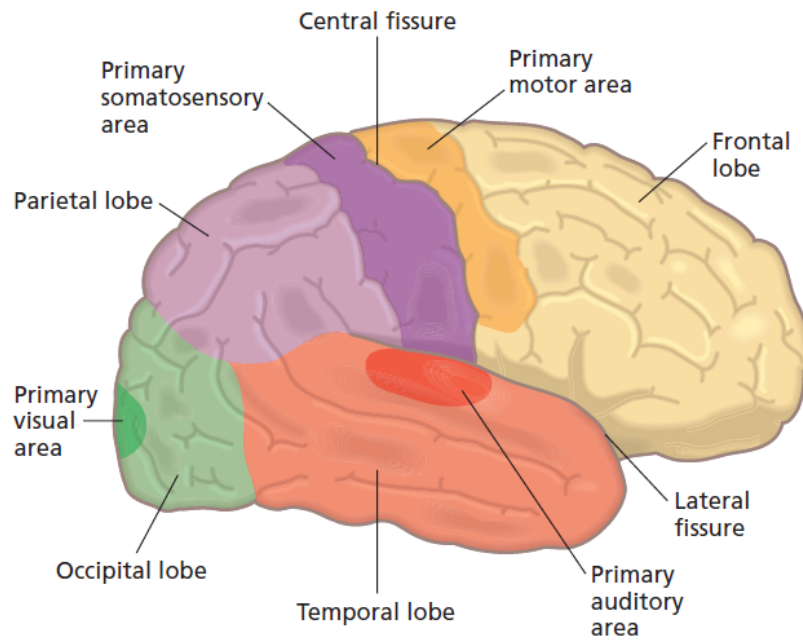


Cerebral Cortex

Visual/auditory

Primary visual area.

Primary auditory area:



Studying the brain: methods of inquiry

Studying the brain: methods of inquiry

<i>Name of method</i>	<i>Procedure</i>	<i>Notes</i>
Selective lesioning	Studying the behavioral consequences of planned and selective lesioning (surgically removing or damaging a structure in the brain)	Only used in animal studies
Single-cell recordings	Studying the activity of single neurons, by probing them with small microelectrodes to discover what stimulus or behavior triggers the cell's activity	Only used in animal studies
Post mortem dissection	Examining patient's brain for lesions (damaged areas) after death	Behavioral consequences must have been studied prior to the death of the patient
Exploratory neurosurgery	Examining patient's brain by electrically stimulating certain areas of the exposed brain	
Event-related potentials (ERPs)	Recording the electrical activity of the brain at the scalp, using electroencephalograms (EEGs), as it occurs in response to a stimulus or preceding a motor response ('event-related')	Gives precise information on the timing of the brain activity, but less precise information on the location (since the recording occurs at the scalp only)
Computerized axial tomography (CAT or CT)	Mapping the brain using X-ray technique	Used to scan the brain for large structural abnormalities
Positron emission tomography (PET)	Measuring brain activity using a radioactive tracer mixed with glucose; active neurons require the most glucose and will be most radioactive	Gives precise information on the location of the brain activity, but less precise information on the timing (since glucose consumption is a relatively slow process)
Functional magnetic resonance imaging (fMRI)	Measuring brain activity by recording magnetic changes resulting from oxygen consumption	Gives precise temporal and spatial information; is relatively expensive
Transcranial magnetic stimulation (TMS)	Examining the consequences of (temporary) disruptions of normal brain functioning caused by magnetic stimulation of small areas	Used to study cognitive functioning
Magnetoencephalography (MEG)	Localizing brain activity by measuring magnetic changes	Precise method used in surgical applications, alongside electrical stimulation of the exposed brain

Studying the brain: methods of inquiry

Selective lesioning

Studying the behavioral consequences of planned and selective lesioning (surgically removing or damaging a structure in the brain)

Only used in animal studies

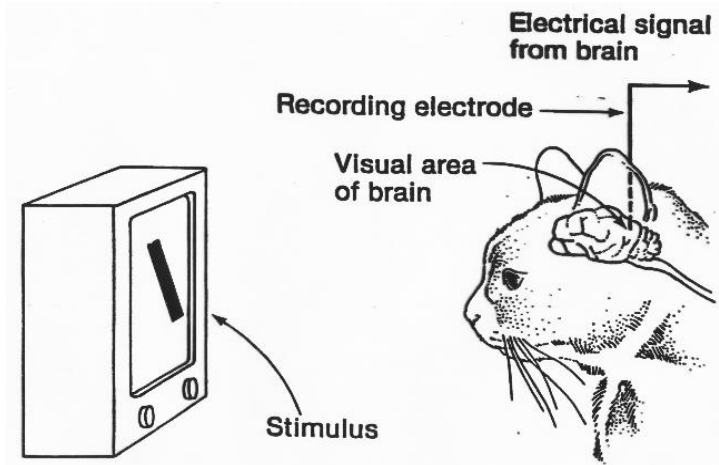


Studying the brain: methods of inquiry

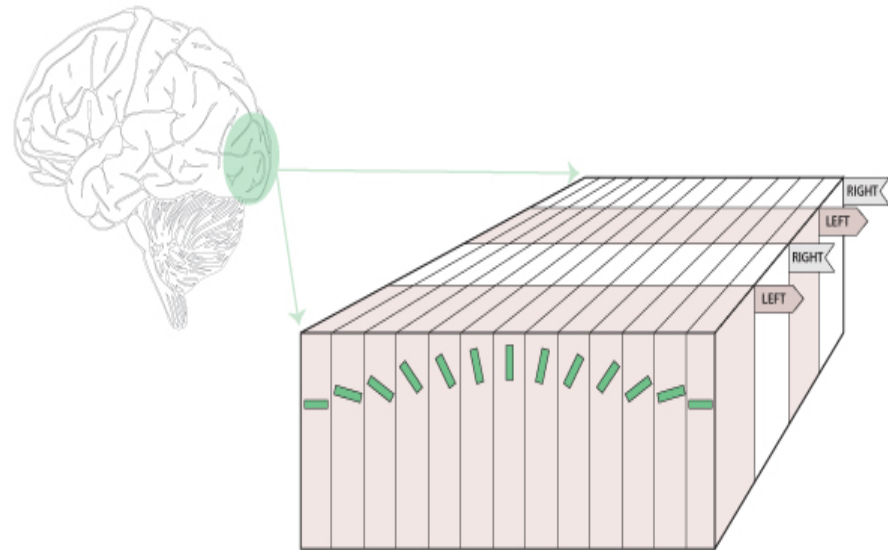
Single-cell recordings

Studying the activity of single neurons, by probing them with small microelectrodes to discover what stimulus or behavior triggers the cell's activity

Only used in animal studies



Hubel and Wiesel (1950)



Studying the brain: methods of inquiry

Exploratory neurosurgery

Examining patient's brain by electrically stimulating certain areas of the exposed brain

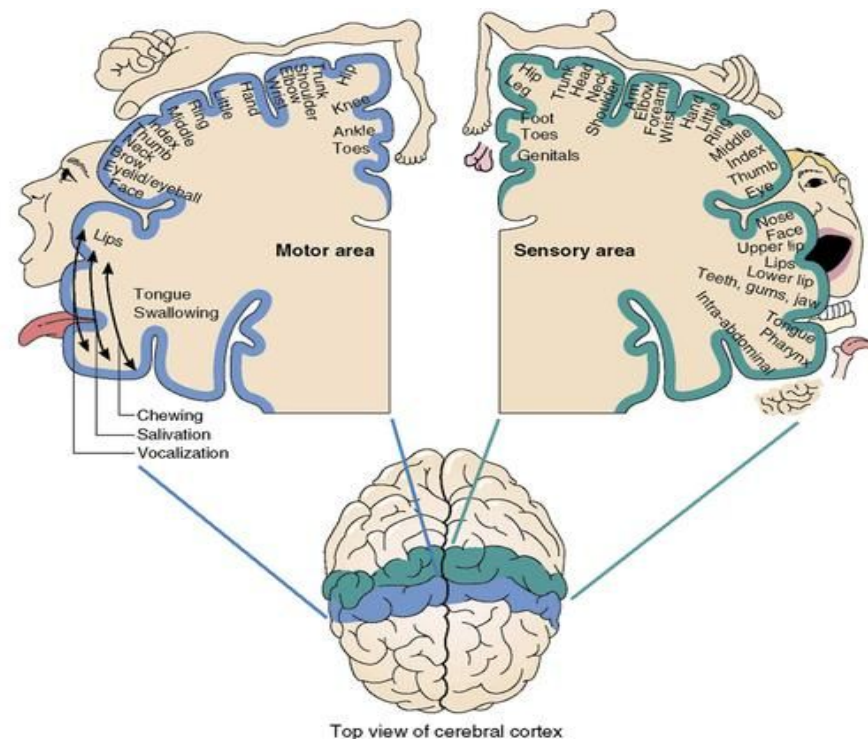
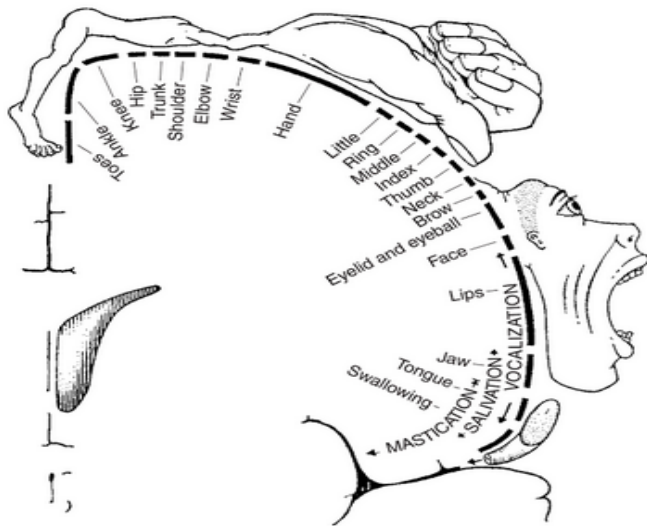


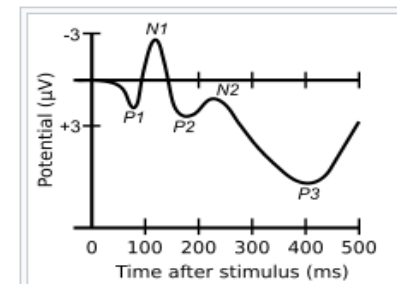
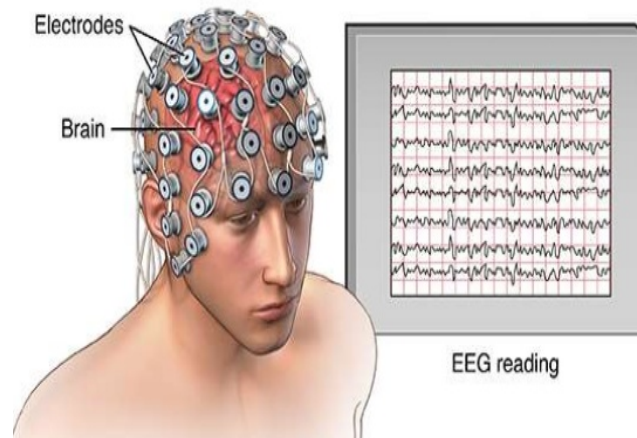
FIGURE 11.18 In the motor homunculus (BA5), muscular control of the mouth, jaw, tongue, vocal cords, as well as actions like chewing and swallowing reside next to Broca's area for the control of speaking (BA 6, 44 and 45). The 'motor homunculus', first discovered by Wilder Penfield using electrical stimulation of motor cortex in awake patients during **exploratory neurosurgery** (Penfield and Roberts, 1959). Notice that mastication, vocalization and swallowing are marked next to the mouth region of the homunculus. *Source:* Standring, 2005.

Studying the brain: methods of inquiry

Event-related potentials (ERPs)

Recording the electrical activity of the brain at the scalp, using electroencephalograms (EEGs), as it occurs in response to a stimulus or preceding a motor response ('event-related')

Gives precise information on the timing of the brain activity, but less precise information on the location (since the recording occurs at the scalp only)



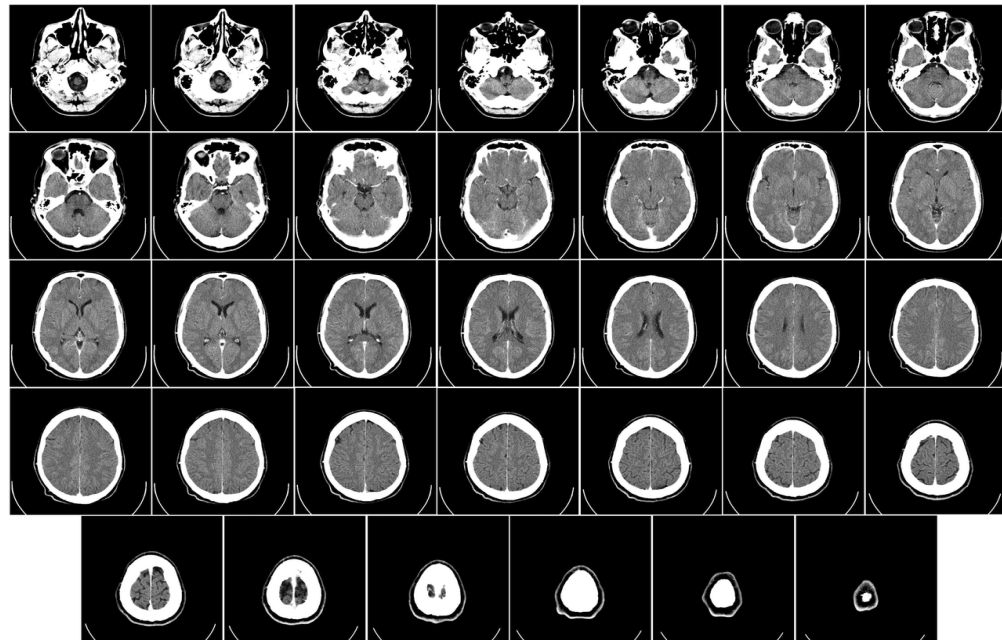
A waveform showing several ERP components, including the **N100** and **P300**. Note that the ERP is plotted with negative voltages upward, a common, but not universal, practice in ERP research

Studying the brain: methods of inquiry

Computerized axial tomography
(CAT or CT)

Mapping the brain using X-ray technique

Used to scan the brain for large structural abnormalities

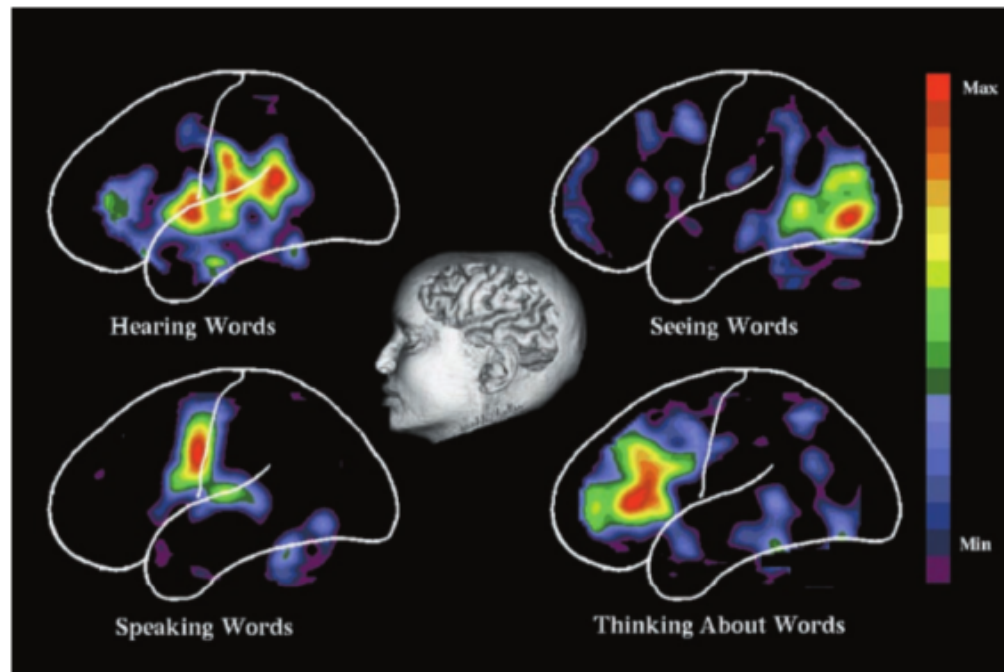


Studying the brain: methods of inquiry

Positron emission tomography (PET)

Measuring brain activity using a radioactive tracer mixed with glucose; active neurons require the most glucose and will be most radioactive

Gives precise information on the location of the brain activity, but less precise information on the timing (since glucose consumption is a relatively slow process)



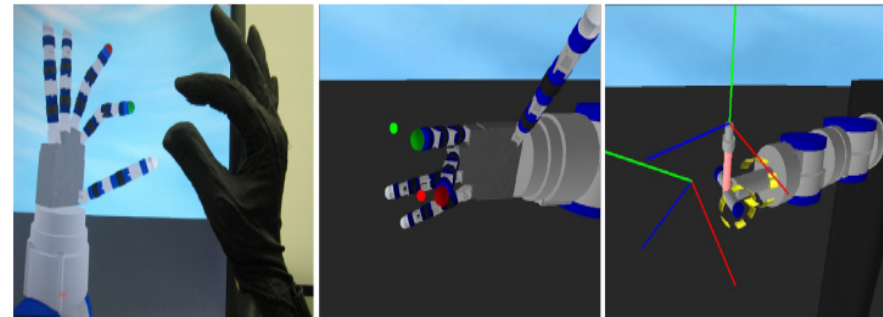
PET scans in a human subject illustrating that different areas of the brain are involved in different modes of word processing.

Studying the brain: methods of inquiry

Functional magnetic resonance imaging (fMRI)

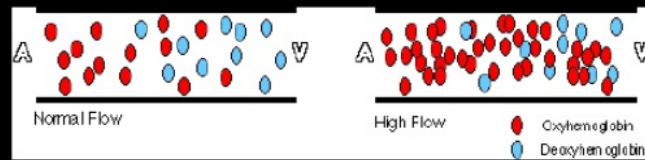
Measuring brain activity by recording magnetic changes resulting from oxygen consumption

Gives precise temporal and spatial information; is relatively expensive



BOLD

- Blood Oxygenation Level Dependent (BOLD) signal
 - indirect measure of neural activity
 - Commonly used method



- $\uparrow$ neural activity $\rightarrow$ $\uparrow$ blood flow $\rightarrow$ $\uparrow$ oxyhemoglobin $\rightarrow$ $\uparrow$ T_2^* $\rightarrow$ $\uparrow$ MR signal

<https://www.slideshare.net/ricksw78/fmri-presentation>

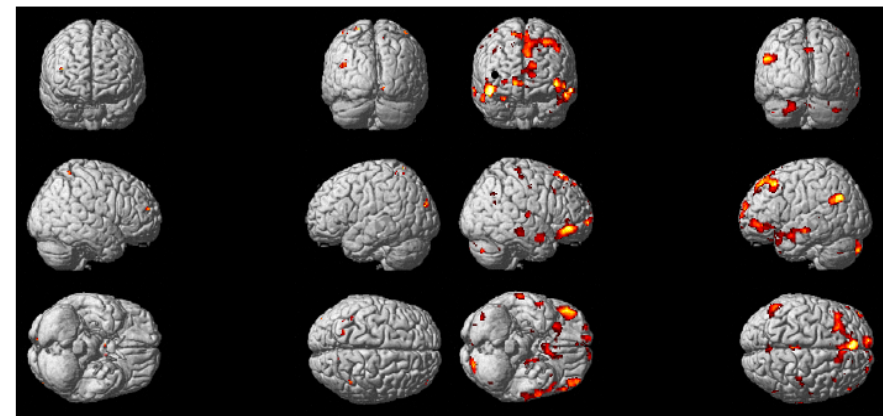


Figure 6. AN-NAN (left) and NAN-AN (right) contrasts for a single subject ($p < 0.005$)

Humanoid Brain Science Erhan Oztop, Emre Ugur, Yu Shimizu, Hiroshi Imamizu, Humanoid Robotics and Neuroscience: Science, Engineering and Society, 29