Brain Computer Interaction

Class #1

Introduction to Data

<u>COURSE INSTRUCTORS</u>

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User can be anyone

Users

Language illiterate

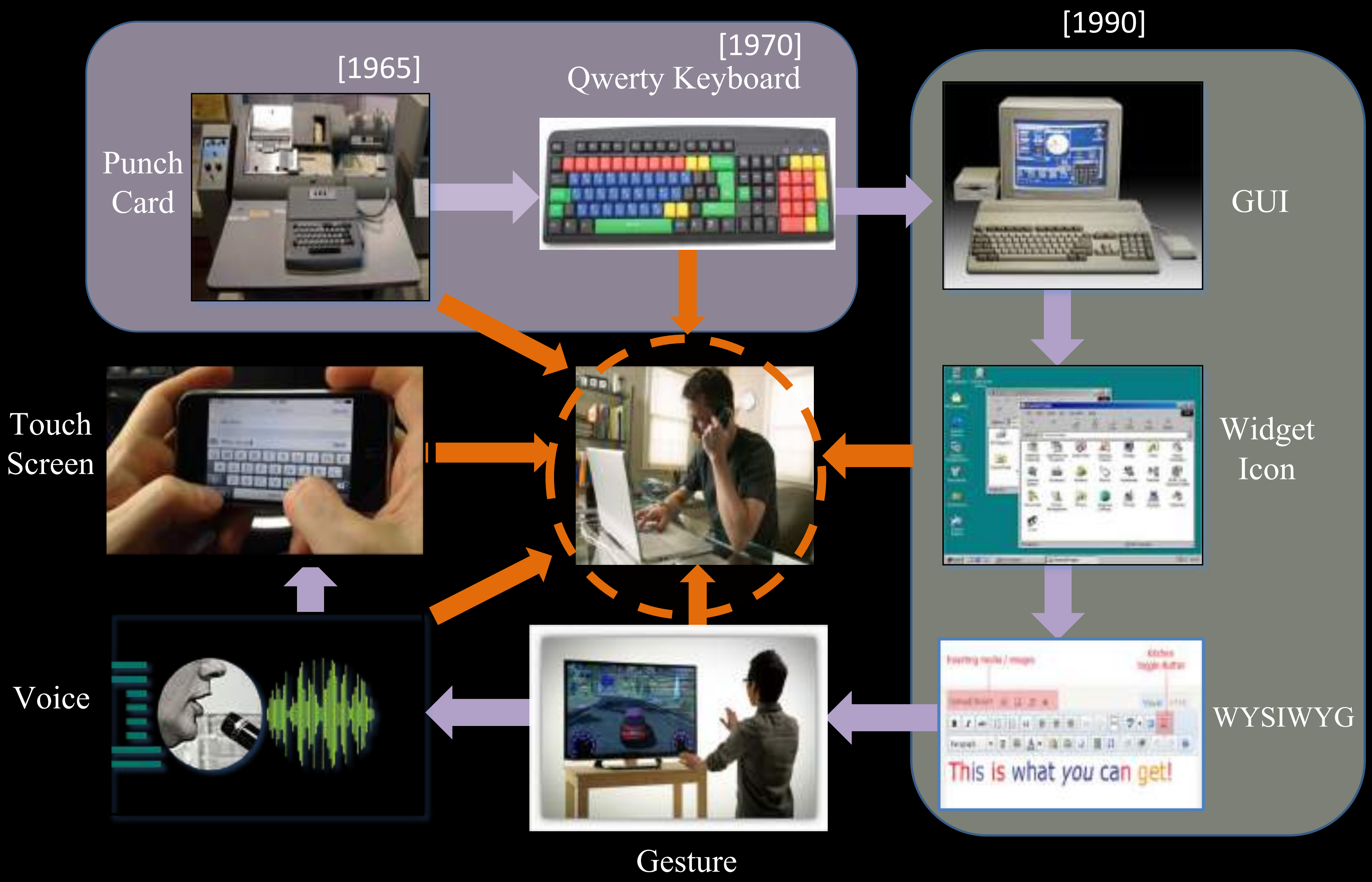
Novice user

Blind user

Old-age people

Disabled user

Evolution of HCI with computer generation



Recent Advancements in HCI

Possibility of next generation HCI

01 Virtual reality

02 Augmented reality

03 3D Holographic projection

04 Brain computer interaction

Virtual Reality

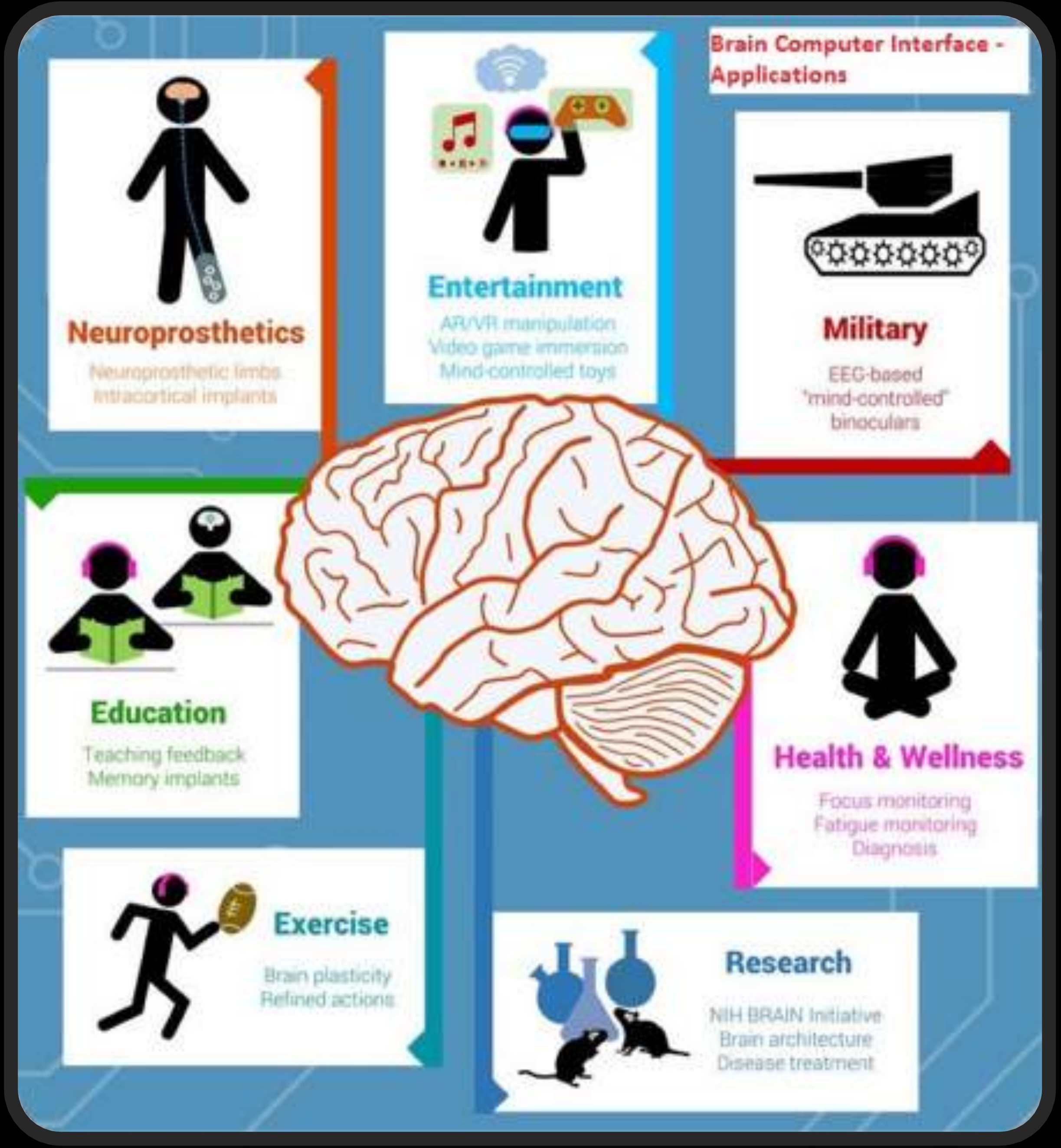
Augmented Reality

Hunting and catching pokemon

Finding suitable wedding rings

3D Holographic projection

Brain Computer Interaction



Some real-time BCI Applications

Communication

Attention Monitoring

Device Control

Automatic Motion Controlling

Games & Entertainment

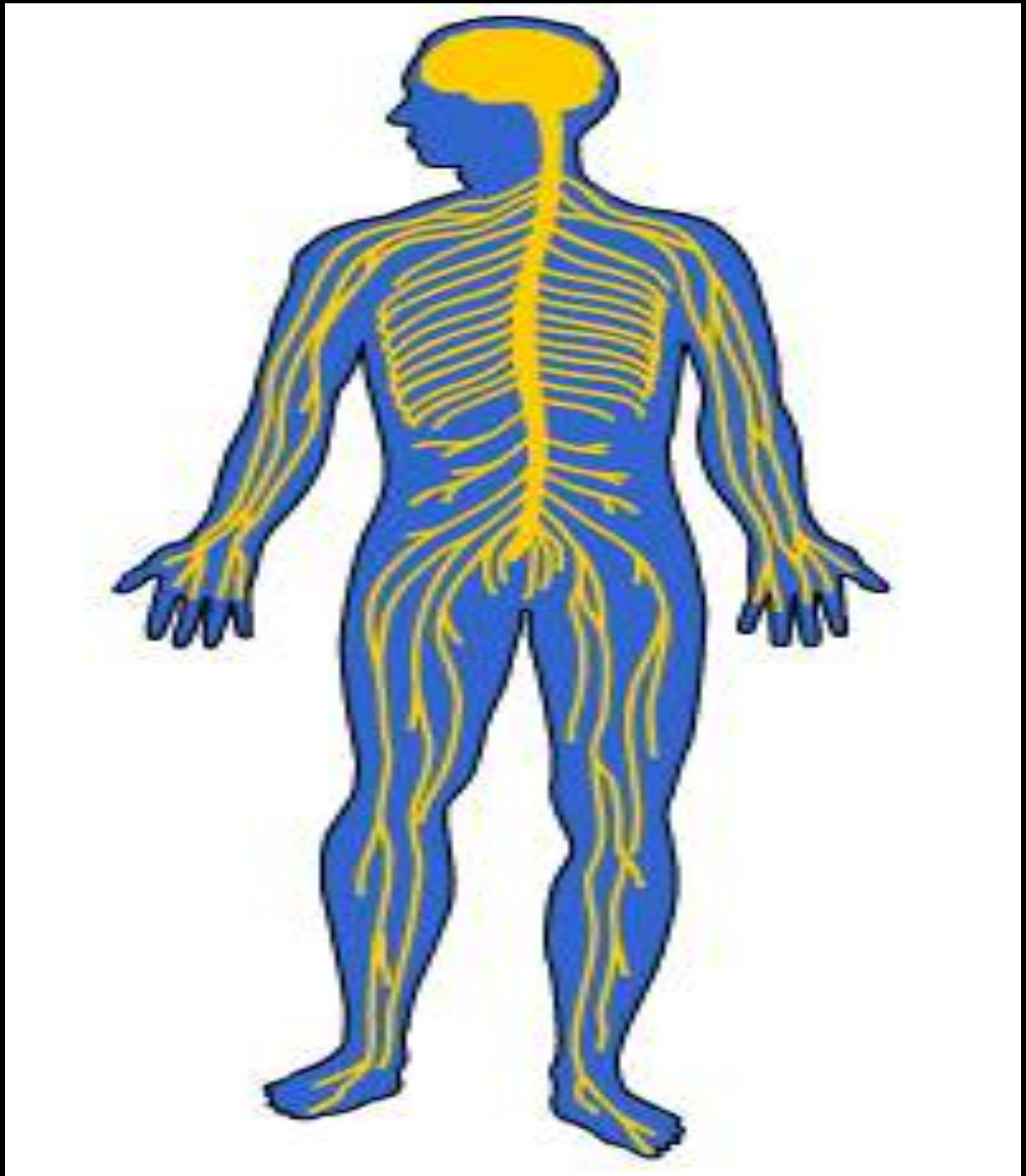
Functions of Human Brain

Neurons and their activity

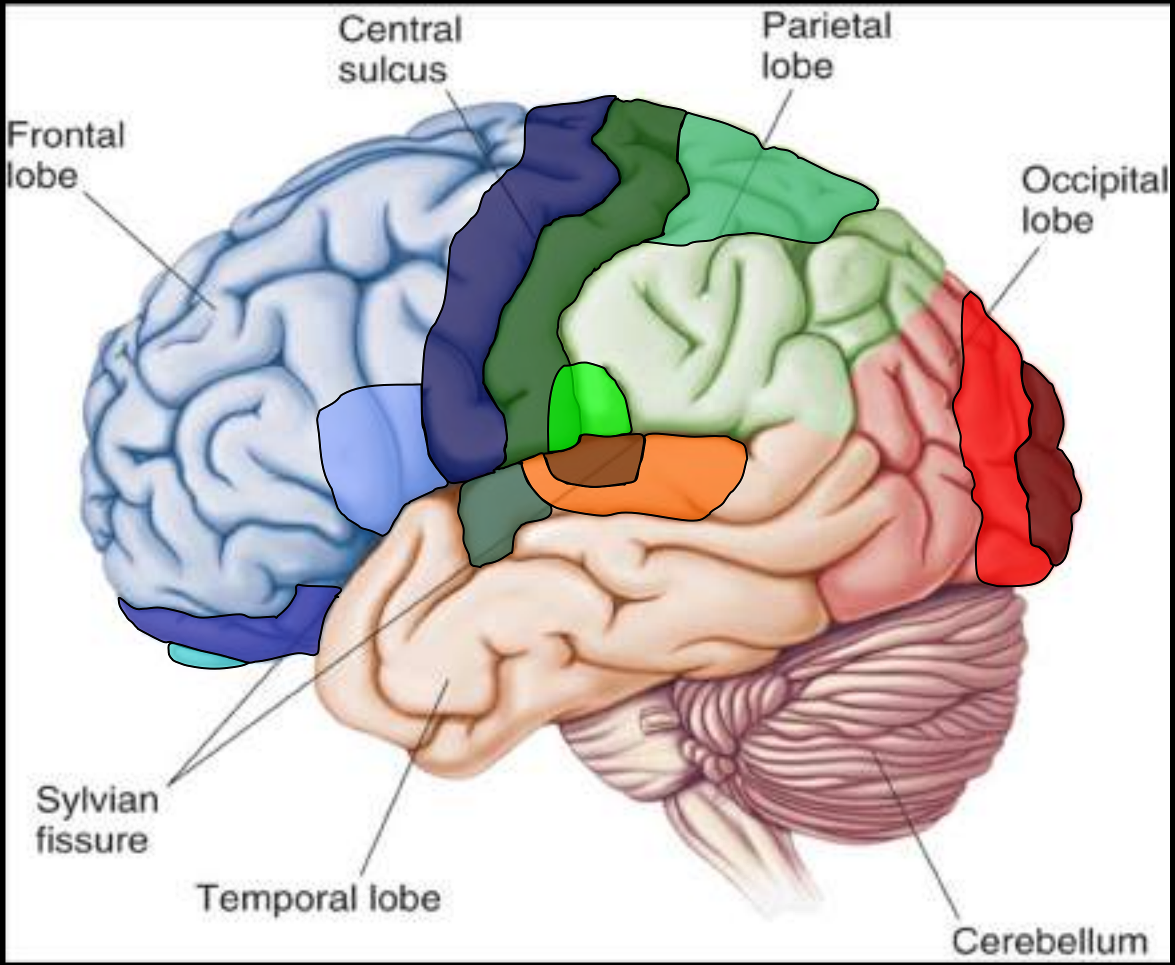
- An average human brain weighs about 1.5 kg and consists of approximately 10^{10} to 10^{11} neurons or cells specialized in information processing.
- Most of the neurons are located in the central nervous system consisting of brain and spinal cord.
- Neurons are highly specialized for electrochemical signaling. They accept input from other cells at their dendrites and send an electrochemical signal along the axon. An average neuron have ten thousands of dendrites.
- Neurons maintain a particular ratio of anions and cations inside the cell as well as outside the cell membrane.
- When this concentration of ions changes, cells are able to produce a transient electric charge and they are termed as *neuron firing*.

Nervous system

- The nervous system controls every part of your daily life, from breathing and blinking to helping you memorize facts for a test.
- Nerves reach from your brain to your face, ears, eyes, nose, and spinal cord and from the spinal cord to the rest of your body.
- Sensory nerves gather information from the environment; send that information to the spinal cord, which then send the message to the brain. The brain then makes sense of that message and fires off a response.
- Motor neurons deliver the instructions from the brain to the rest of your body.
- The spinal cord, made of a bundle of nerves running up and down the spine, is similar to a superhighway, sending messages to and from the brain at every second.



Brain and its Activities



- Sight
- Interprets Information (Image recognition and image perception)

- Processing of tactile information
- Awareness of body in space
- Controlling movements of the body

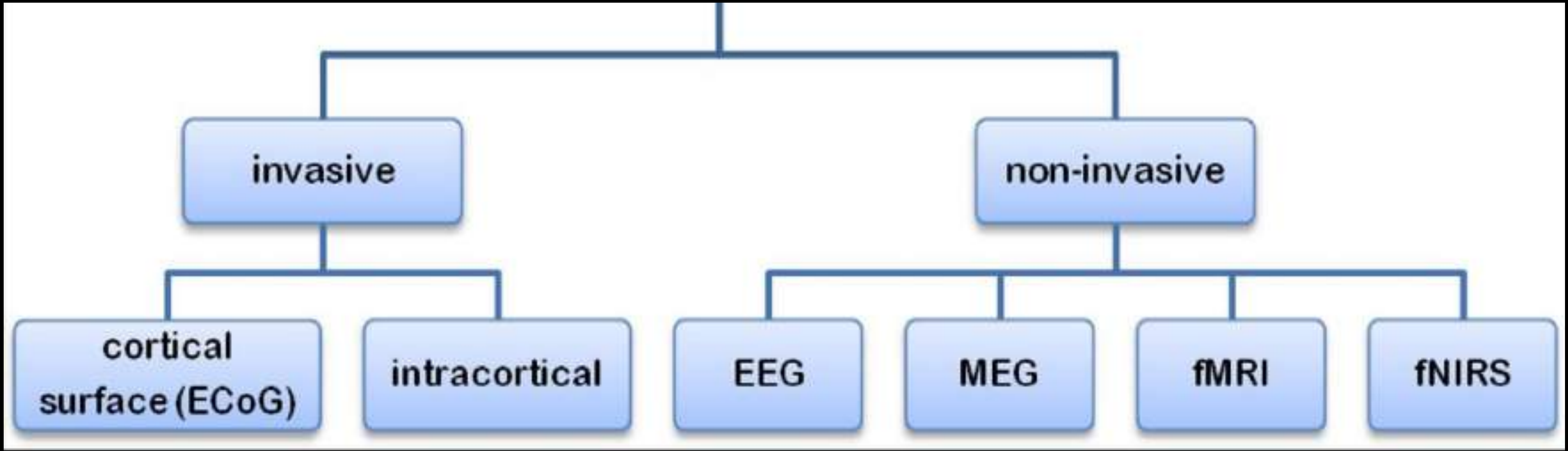
- Responsible for hearing
- Language comprehension

- Sensation of Smell
- Interprets Smell

- Facial neurons and Speech
- Sensation of Taste
- Decision Making

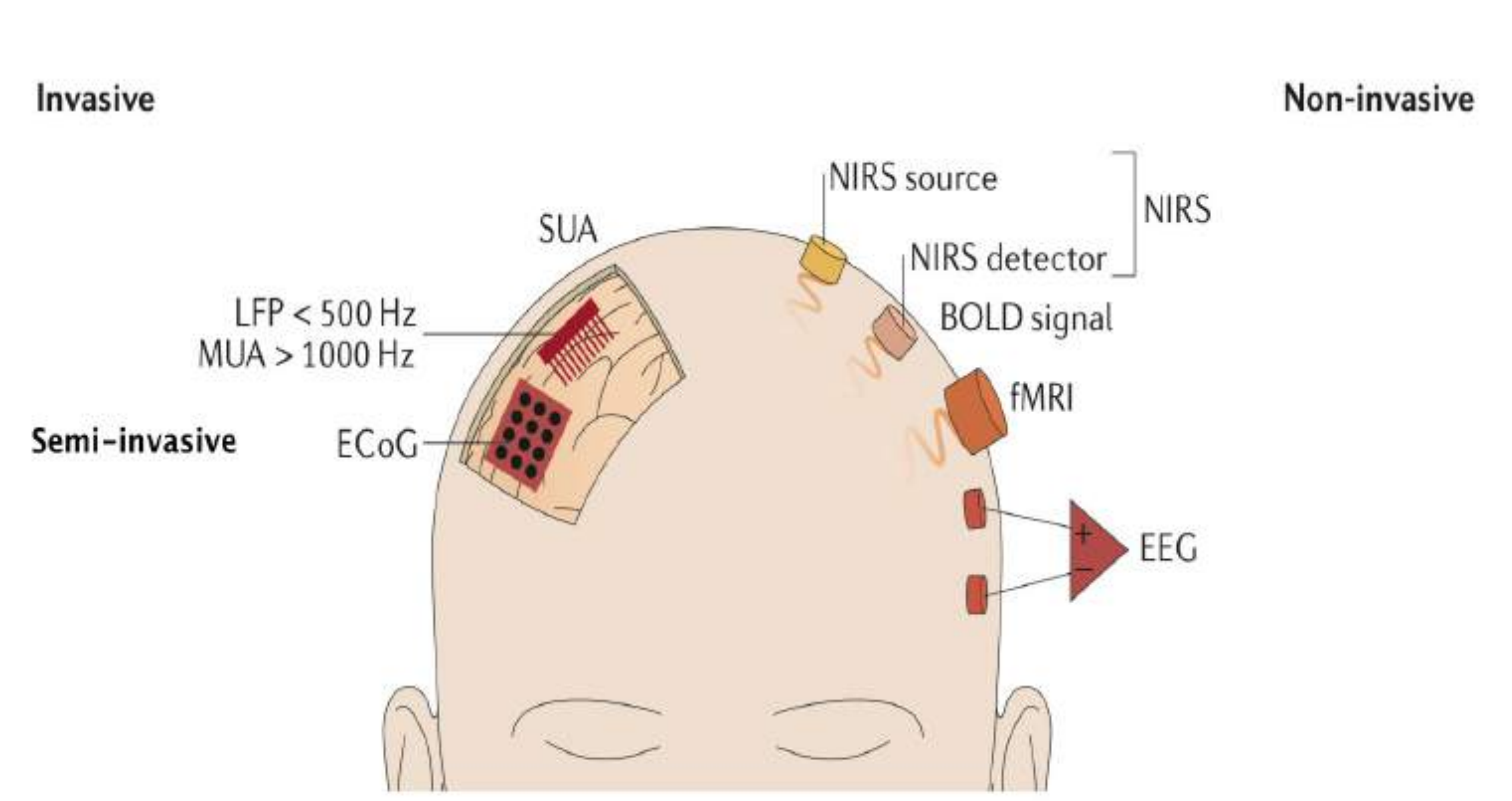
BCI Technologies

BCI devices



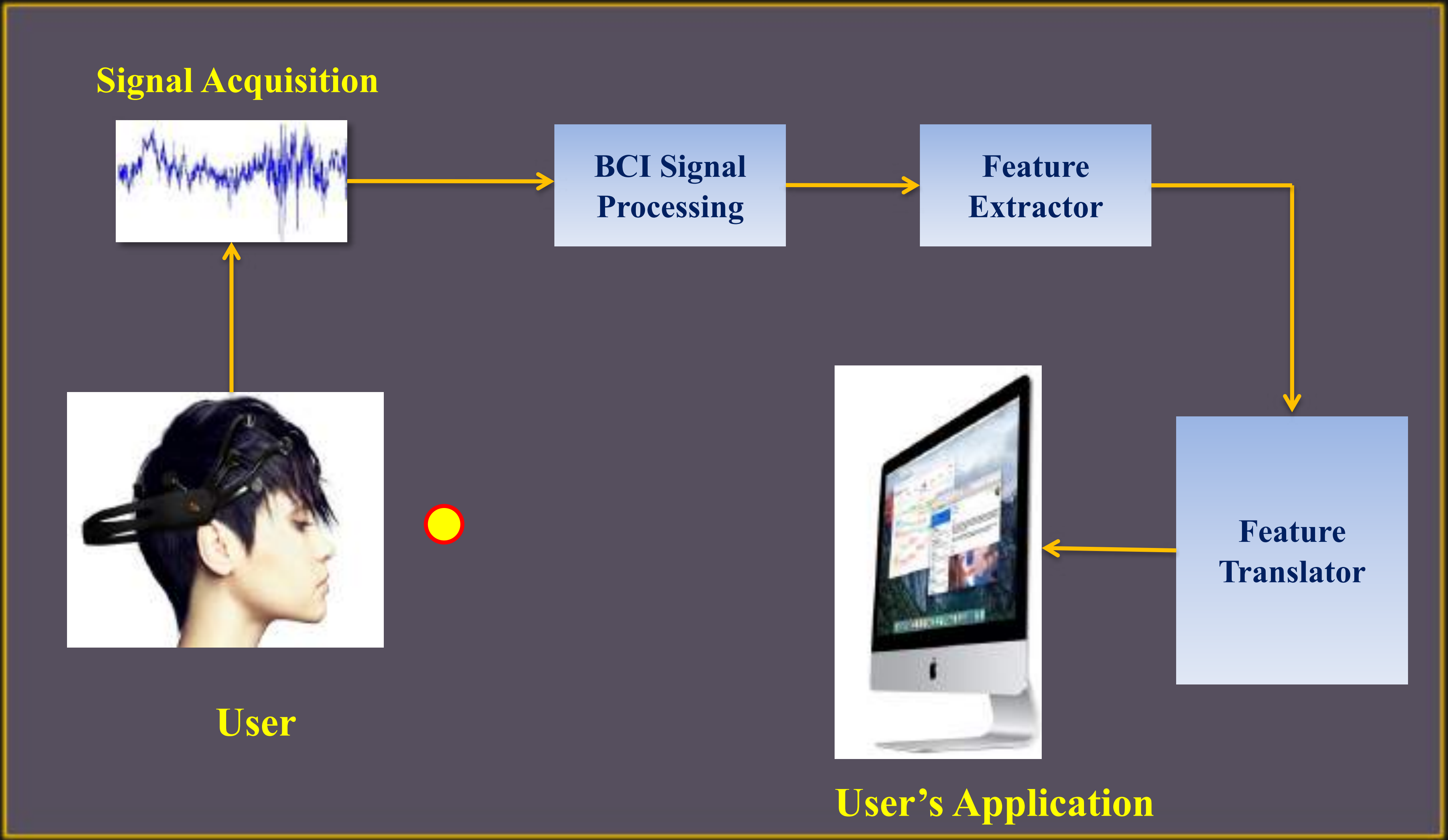
invasive
non-invasive
cortical surface (ECoG)
intracortical
EEG
MEG
fMRI
fNIRS

BCI devices

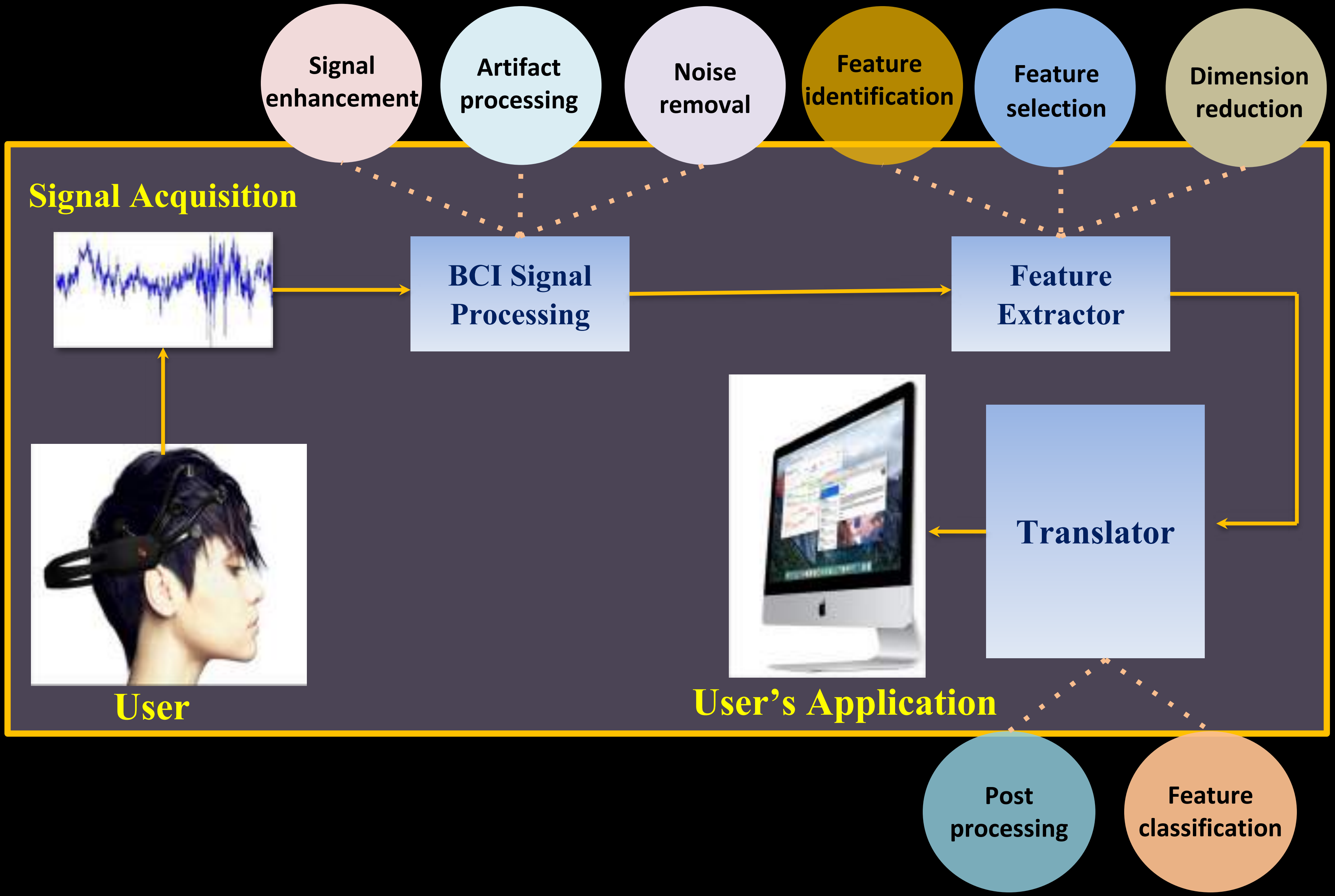


Invasive
Non-invasive
NIRS source
NIRS
SUA
NIRS detector
LFP < 500 Hz
MUA > 1000 Hz
BOLD signal
fMRI
Semi-invasive
ECoG
+
EEG
−

BCI Architecture



BCI Architecture

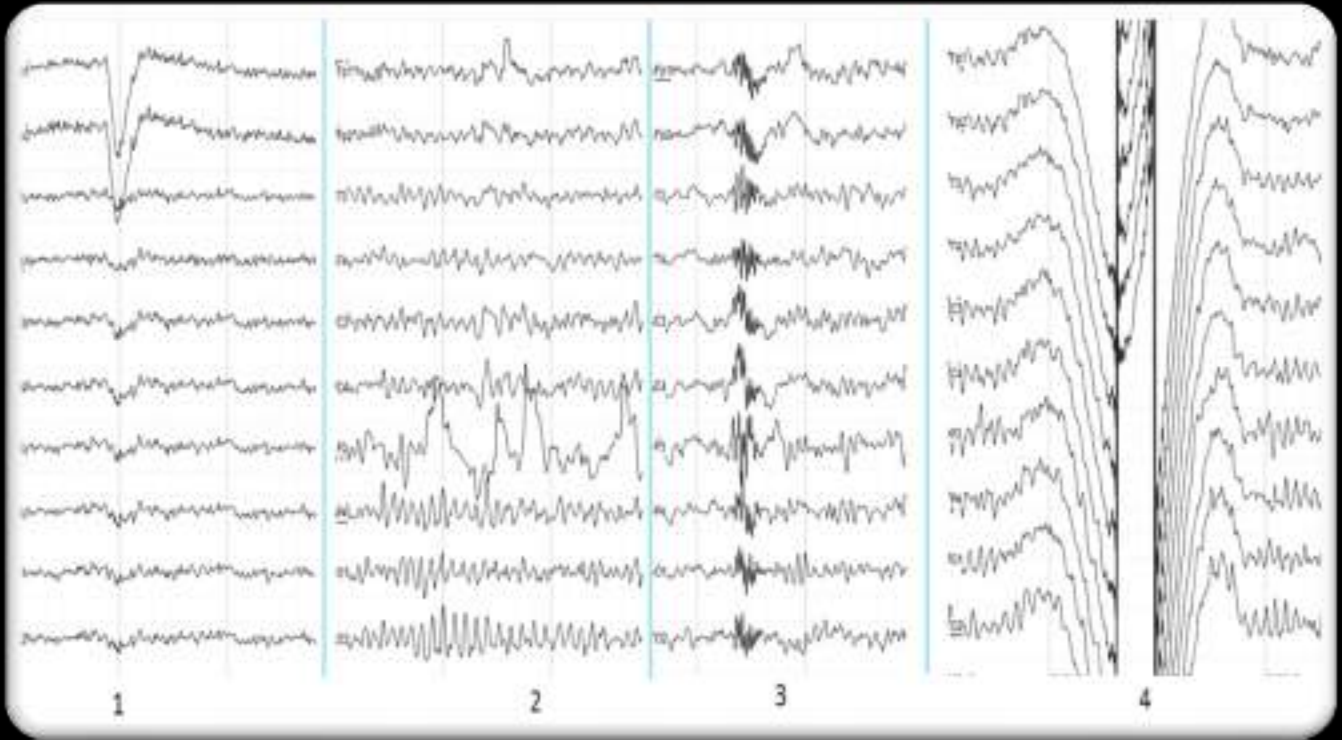


BCI Signal processing

BCI Signal processing

✓ Sensitive to artifacts

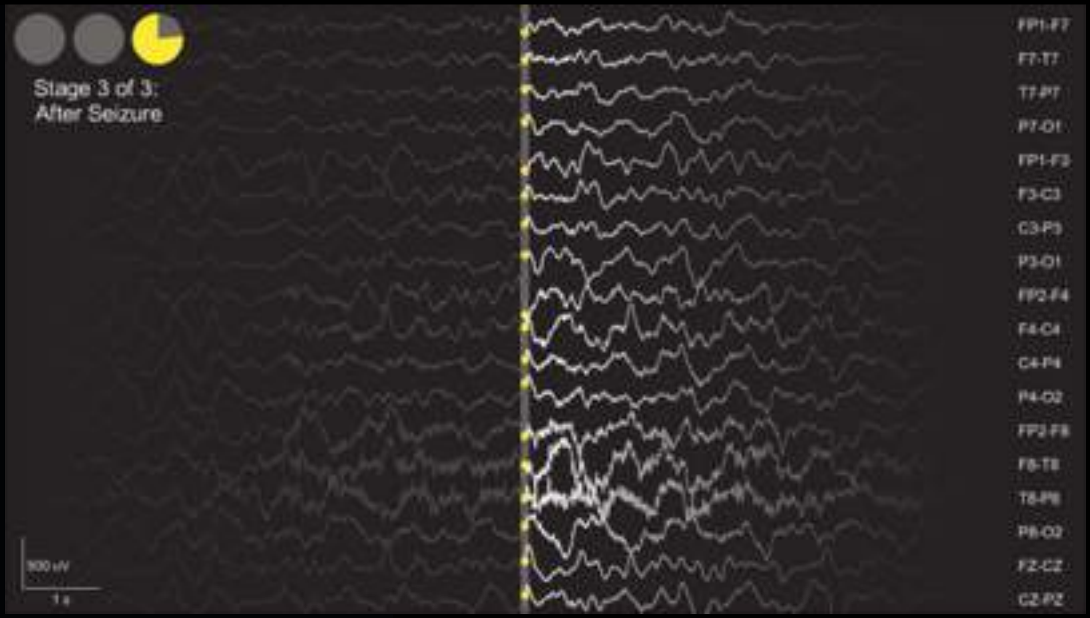
- Eye blinks
- Head and body movements
- Muscle activity
- Speech
- Heart rate
- Environmental noise



EEG Signal with noise (Artifacts)

BCI Signal Processing

- Filtering techniques
  - Band-pass filtering
- Artifact removal techniques
  - Independent component analysis
  - Principal component analysis
  - Sparsity-based methods
  - Wavelet-based methods
- Channel Selection
  - Common spatial pattern
  - Sequential feed forward selection



Feature Extraction

Feature Extraction

Different classes of features:

- Statistical features
- Derivative features
- Time domain features
- Frequency domain features
- Wavelet domain features
- Entropy features
- Cross-correlation features

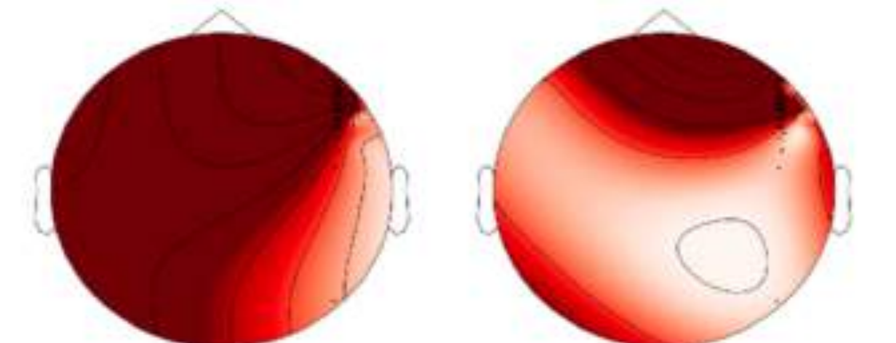
Feature Selection

Why Feature Selection?

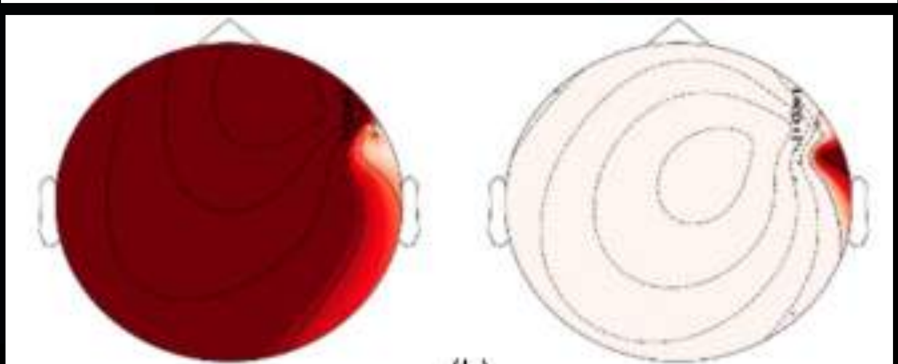
- Simplification of models to make them easier to interpret
- Shorter training times
- To avoid the curse of dimensionality
- Enhanced generalization by reducing overfitting

Feature Classification

- Machine learning algorithms
  - ✓ (e.g. SVM, LDA, kNN, etc.)
- Deep learning architectures
  - ✓ (e.g. RBM, CNN, LSTM, etc.)
- Optimization techniques
  - ✓ (e.g. Sparsity approach)



(a)



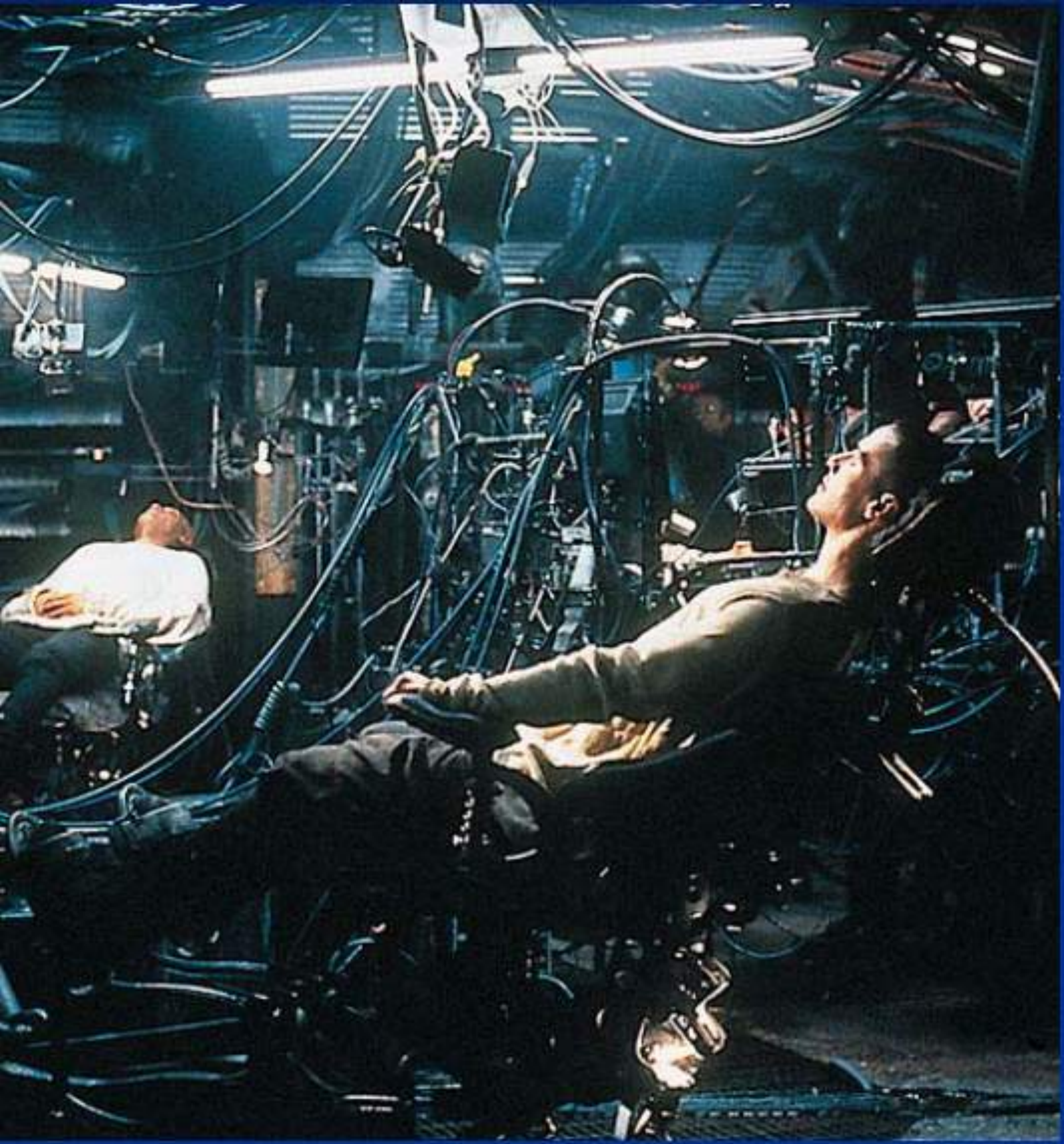
(b)

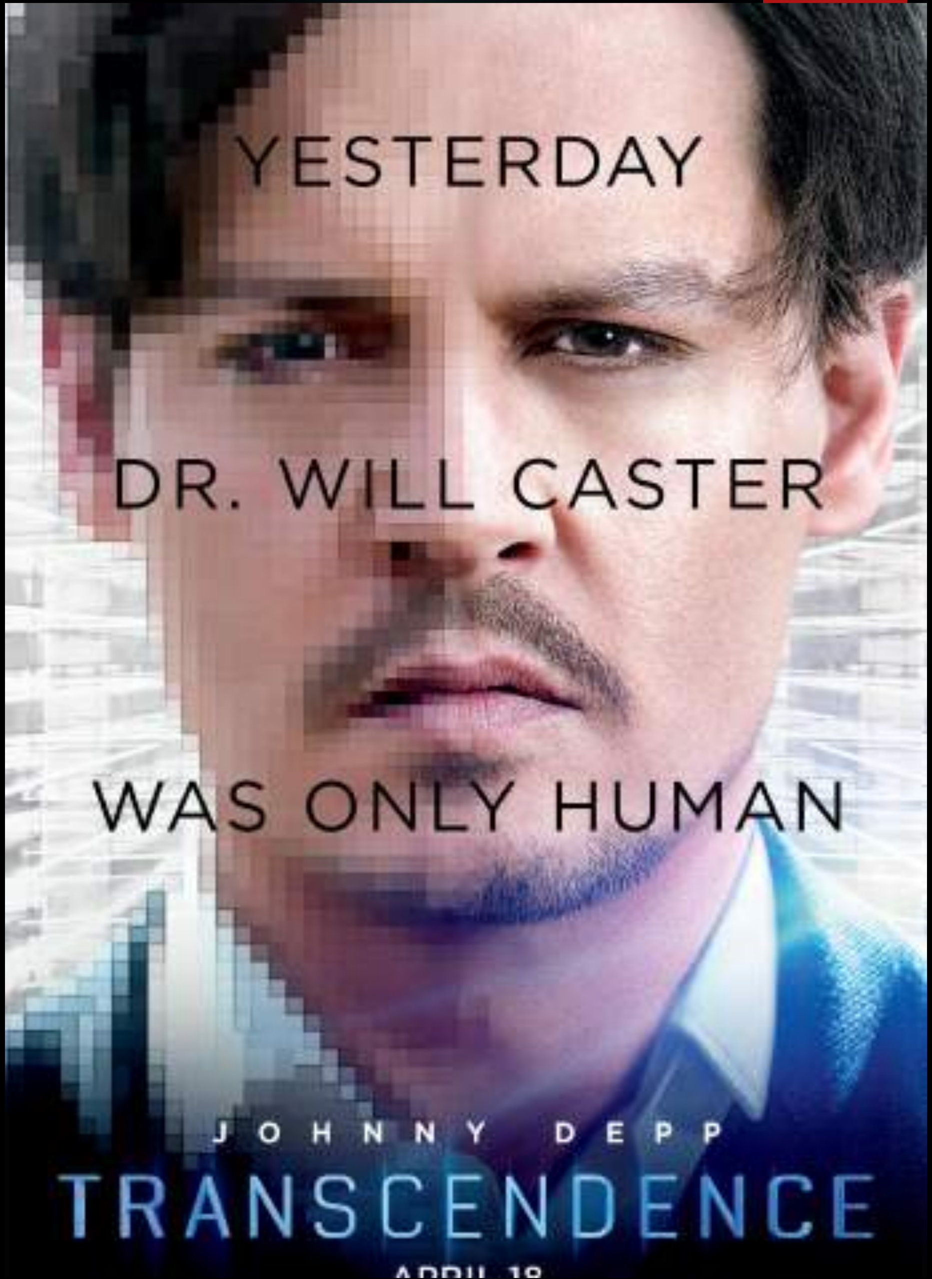
Example of Hand-free Touch-free Interaction:

Thank You!

Brain Computer Interaction

- History of BCI
- Applications of BCI




YESTERDAY
DR. WILL CASTER
WAS ONLY HUMAN
JOHNNY DEPP
TRANSCENDENCE

Is it FICTION or is it POSSIBLE???

Motivation for BCIs

- Potential for restoring lost sensory and motor function
- To control prosthetic devices such as prosthetic arms or legs for amputees and patients with spinal-cord injuries
- Wheelchairs for paralyzed individuals
- Cursors and word spellers for communication by locked-in patients
- Sensory prosthetic devices such as cochlear implant for the deaf, retinal implant for the blind
- More recently, researchers have begun exploring BCIs for able-bodied individuals for a host of applications such as Game, Entertainment to robotic avatars, biometric identification and Education.

Brain Computer Interface

- A system which translates thoughts and provides an interface used for communication called as Brain Computer Interface (BCI)
- A typical BCI system comprises of signal acquisition system, signal processing (feature extraction and classification) and an output device

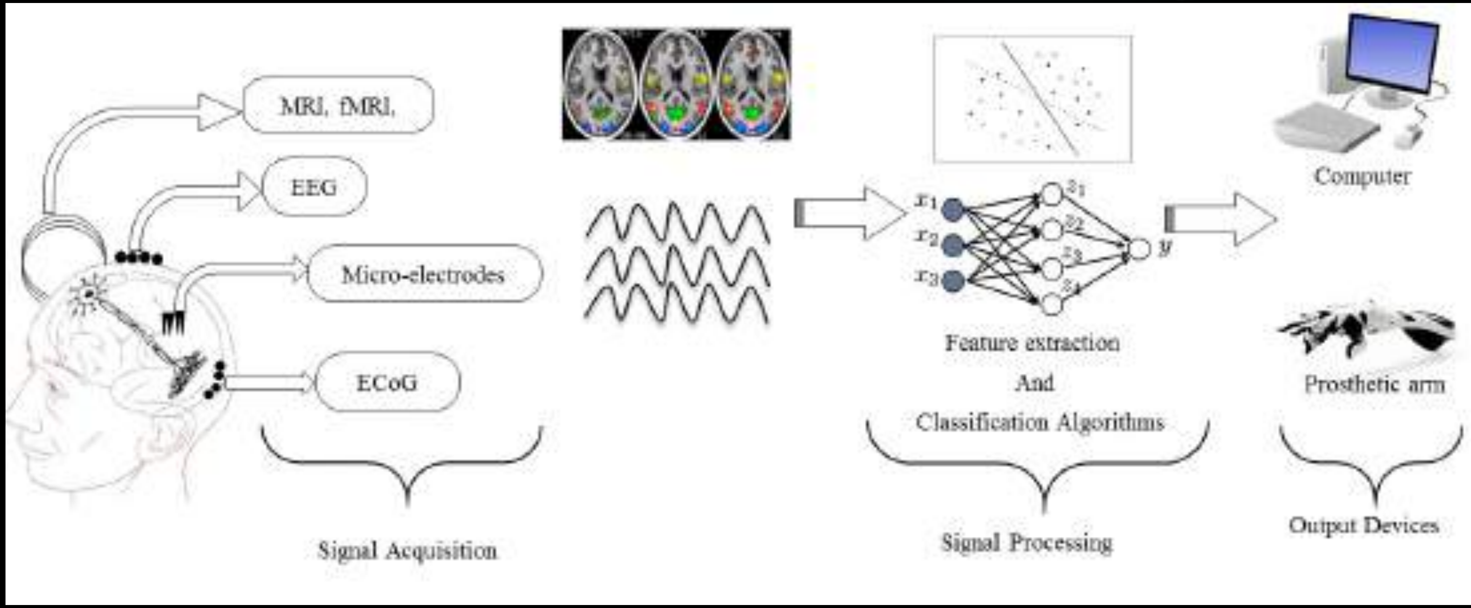


Image Credits: Bablani, Annushree, et al. "Survey on brain-computer interface: An emerging computational intelligence paradigm." ACM Computing Surveys (CSUR) 52.1 (2019): 1-32.

Whether BCIs will eventually become as commonplace as current human accessories for sensory and motor augmentation, such as cellular phones and automobiles.????

That remains to be seen.

There are several moral and ethical challenges that society will need to address

History of Brain Computer Interaction

Timeline of BCI

1875

Electrical impulses from a living brain of a rabbit and monkey were recorded for the first time by Richard Caton

1890

Adolf Beck studied the brain activity of animals in response to sensory simulation

1913

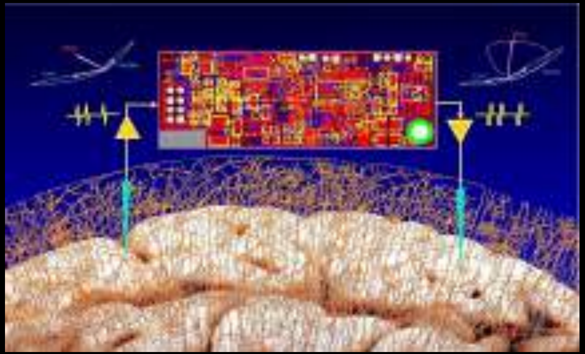
Napoleon Cybulski studied the flow of electric current in muscles using his own capacitor.

1920

Hans Berger recorded EEG signals from the lesion area of the human scalp for the first time using a Siemens double-coil galvanometer and non-polarized electrodes.

1965

Delgado developed an implantable chip (which he called a "stimoceiver") that could be used to both stimulate the brain by radio and send electrical signals of brain activity by telemetry, allowing the subject to move about freely.



1969

Dr. Eberhard Fetz showed that neural activity could be used to drive an external device.

1973

Vidal in 1973 explored the use of scalp-recorded brain signals in humans to implement a simple noninvasive BCI based on "visually evoked potentials"

1990

Philip Kennedy had in 1990 developed "invasive" human brain-computer interface, wires inside the brain attached to a computer.

2001

John Donoghue and his team of Brown University in 2001, commercially design a brain computer interface, the so-called BrainGate.

2004

In 2004, Jonathan Wolpaw and researchers at New York State Department of Health's Wadsworth Center demonstrated the ability to control a computer using a BCI.

June 2014

Phil Kennedy implanted electrodes into his brain in order to establish a connection between his motor cortex and a computer

To Study the Brain, a Doctor Puts Himself Under the Knife

How one of the inventors of brain-computer interfaces ended up getting one himself.

- More recently, researchers have begun exploring BCIs for able-bodied individuals for a host of applications such as
  - Games
  - Entertainment to robotic avatars, biometric identification,
  - and Education.

Our Goal in this course

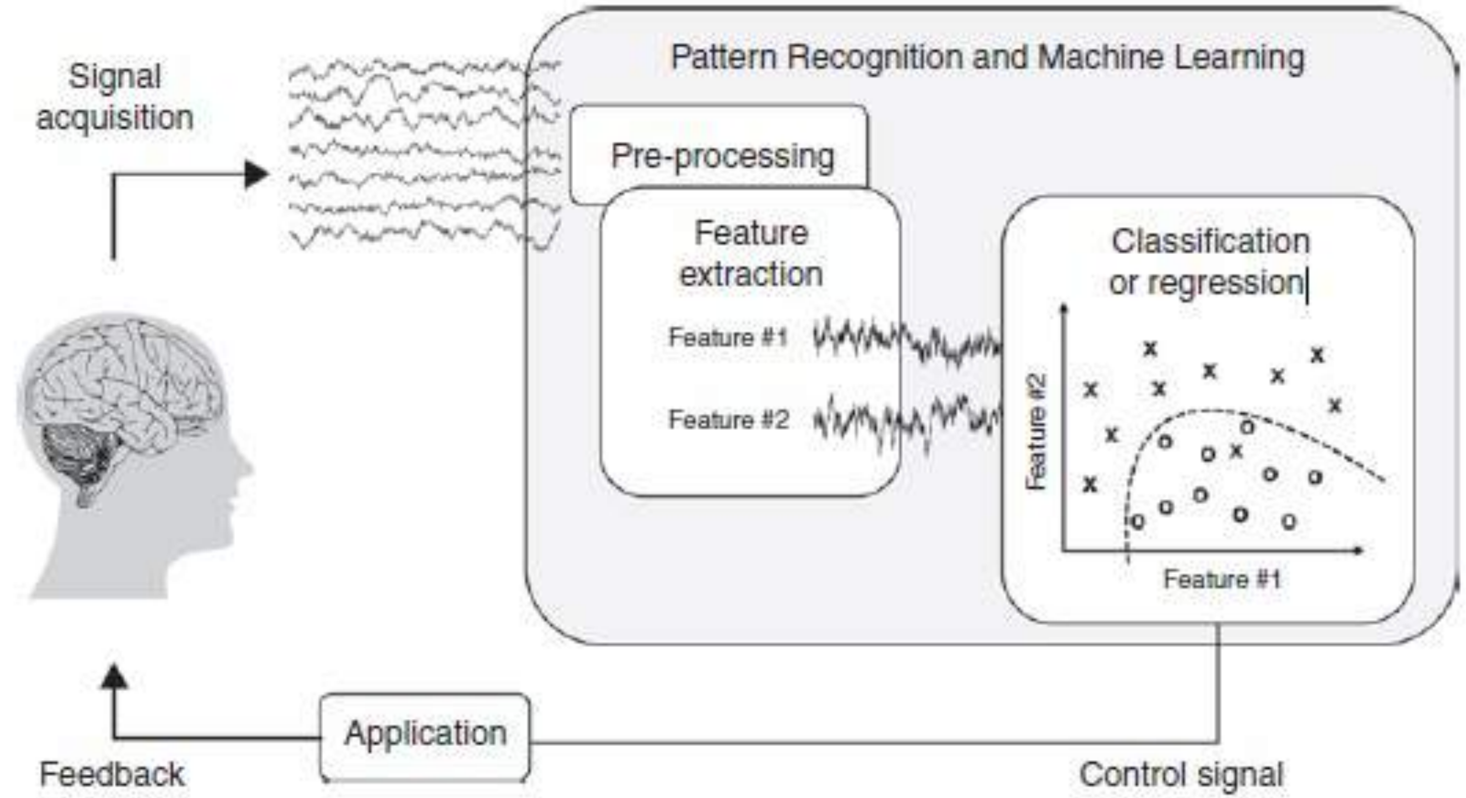
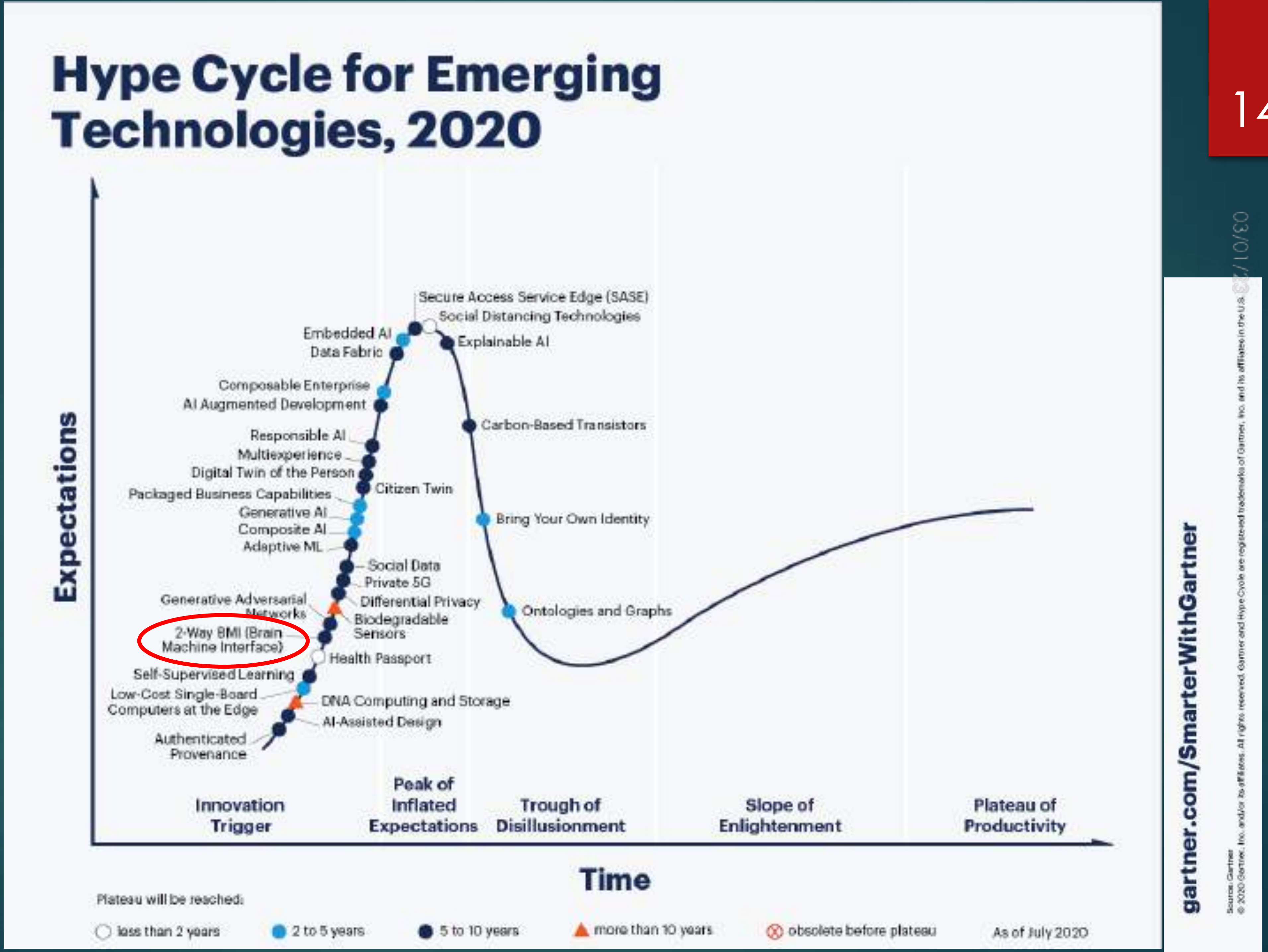


Figure 1.1. **Basic components of a brain-computer interface (BCI).** (Adapted from Rao and Scherer, 2010).

BCI Applications


Hype Cycle for Emerging Technologies, 2020
Expectations
Secure Access Service Edge (SASE)
Social Distancing Technologies
Embedded AI
Data Fabric
Explainable AI
Composable Enterprise
AI Augmented Development
Carbon-Based Transistors
Responsible AI
Multiexperience
Digital Twin of the Person
Citizen Twin
Packaged Business Capabilities
Generative AI
Composite AI
Adaptive ML
Bring Your Own Identity
Social Data
Private 5G
Generative Adversarial Networks
Differential Privacy
Biodegradable Sensors
Ontologies and Graphs
2-Way BMI (Brain Machine Interface)
Health Passport
Self-Supervised Learning
Low-Cost Single-Board Computers at the Edge
DNA Computing and Storage
AI-Assisted Design
Authenticated Provenance
Innovation Trigger
Peak of Inflated Expectations
Trough of Disillusionment
Slope of Enlightenment
Plateau of Productivity
Time
Plateau will be reached:
less than 2 years
2 to 5 years
5 to 10 years
more than 10 years
obsolete before plateau
As of July 2020
gartner.com/SmarterWithGartner

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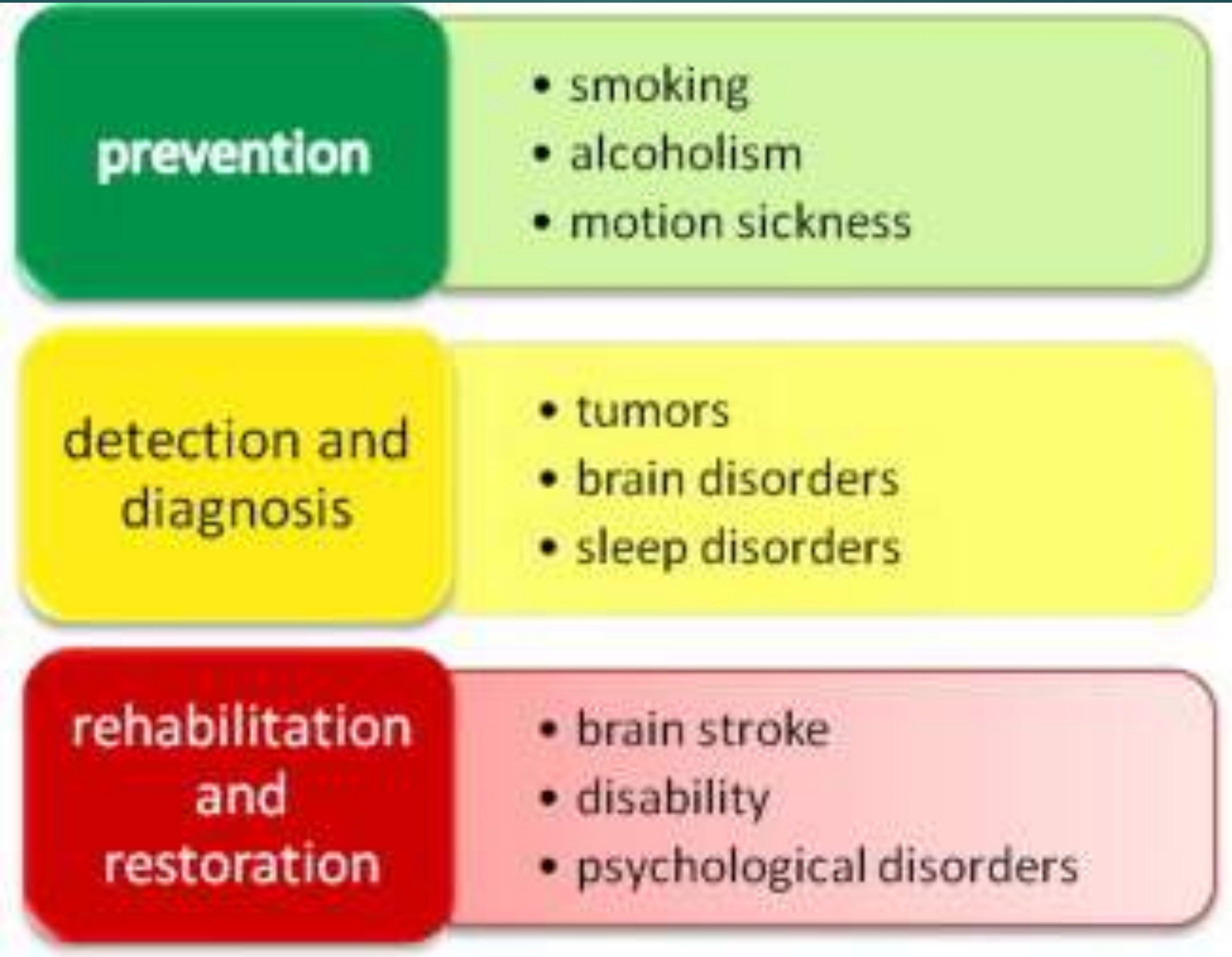
BCI Applications

- Device Control
- User State Monitoring
- Training and Education
- Games and Entertainment.
- Cognitive improvement
- Safety and Security

Medical Applications



Device controls

- For rehabilitation
  - Prosthetic arm
  - Prosthetic legs

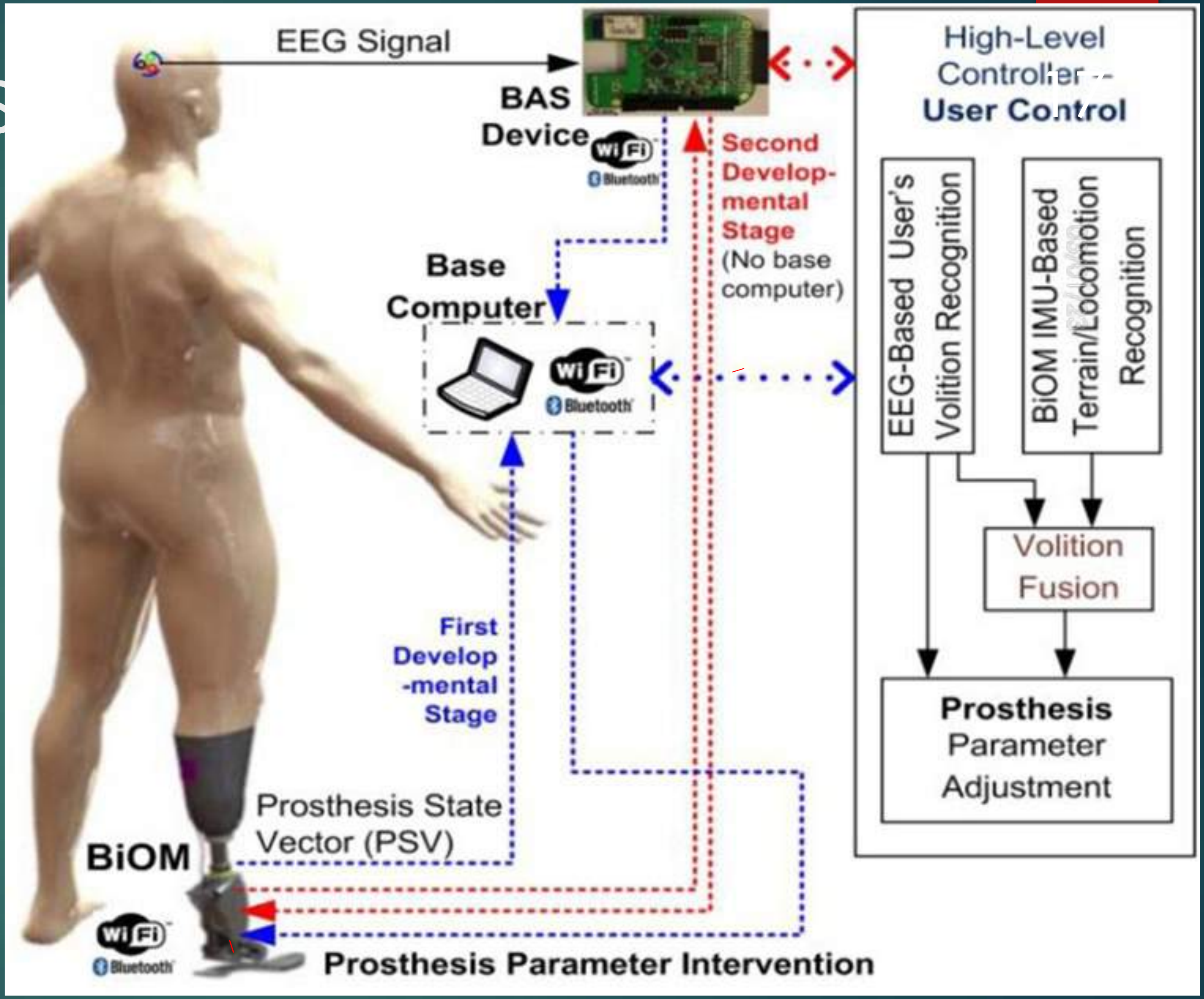
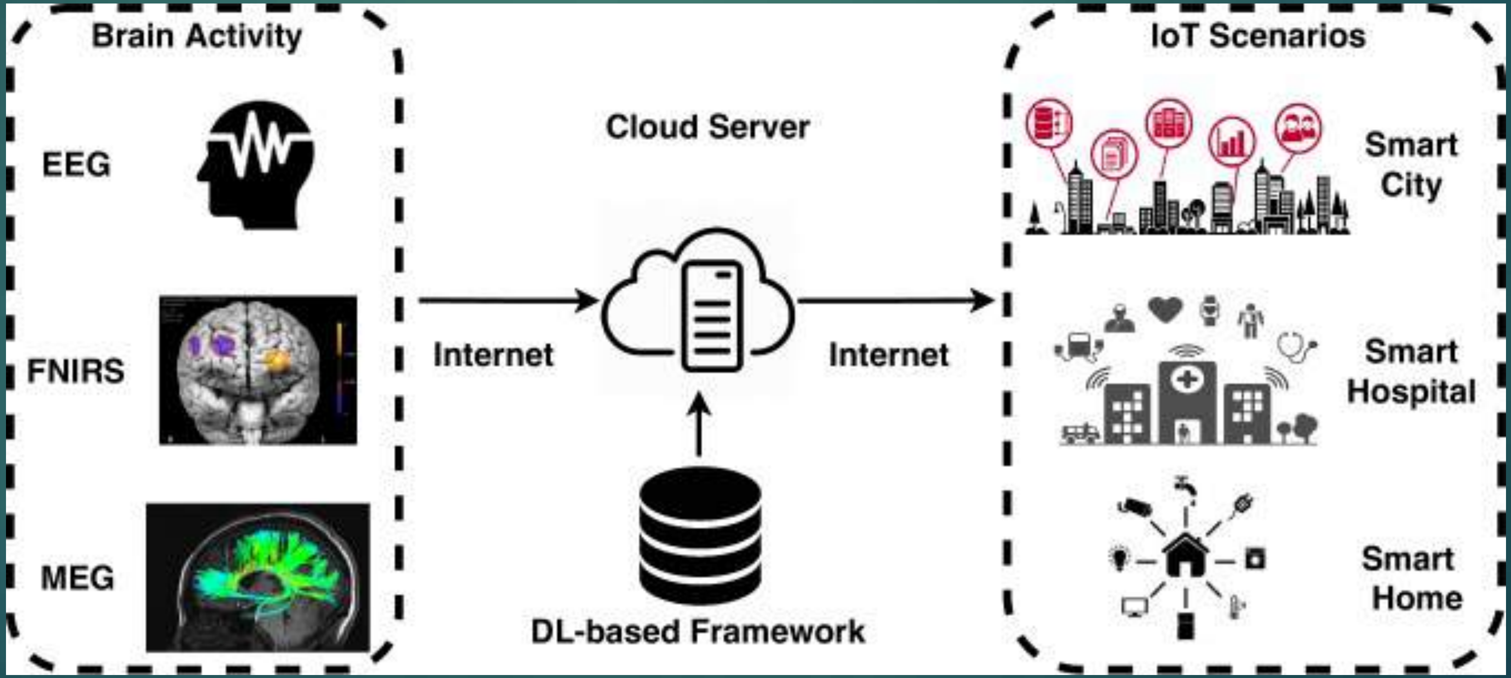


Image credits: https://www.frontiersin.org/files/Articles/308916/fneur-08-00696-HTML/image_m/fneur-08-00696-g001.jpg

Neuroergonomics and smart environment

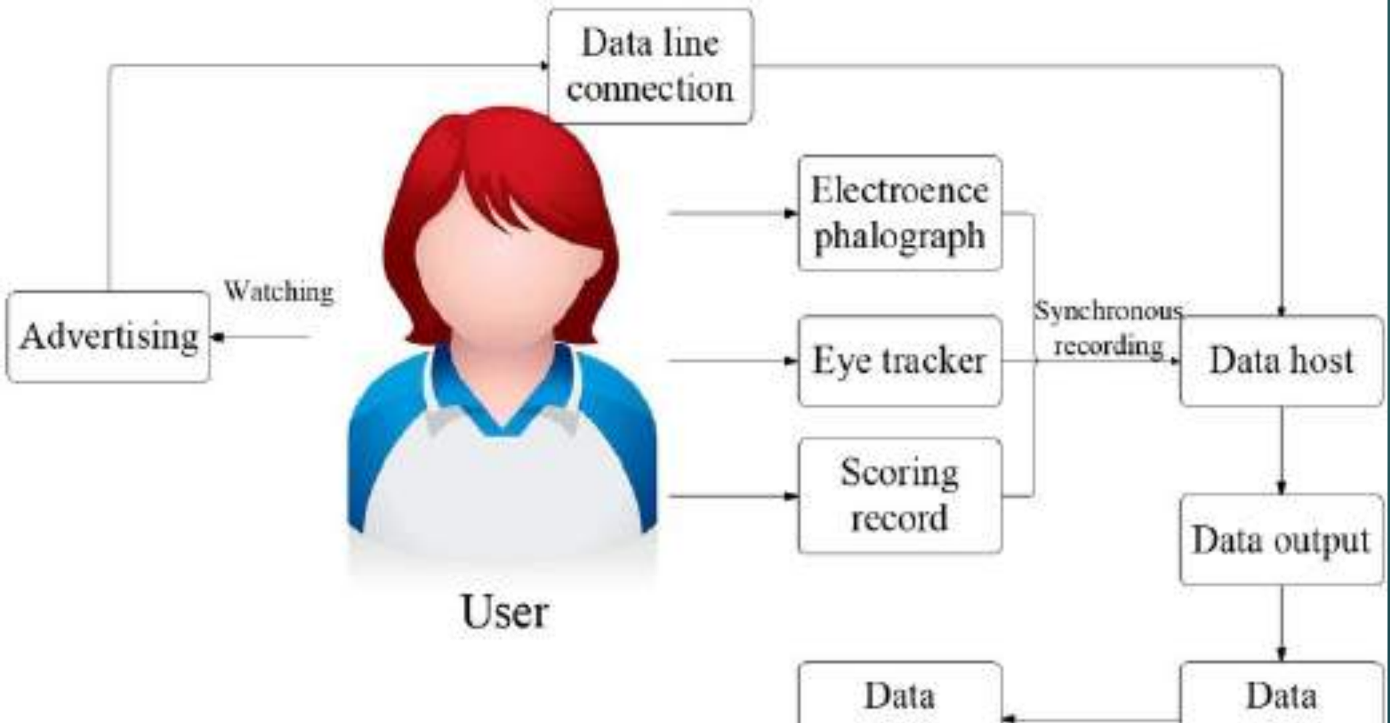
- Cooperation between Internet of Things (IOT) and BCI technologies
- intelligent transportation



by Xiang Zhang, et al. ·

Neuromarketing and advertisement

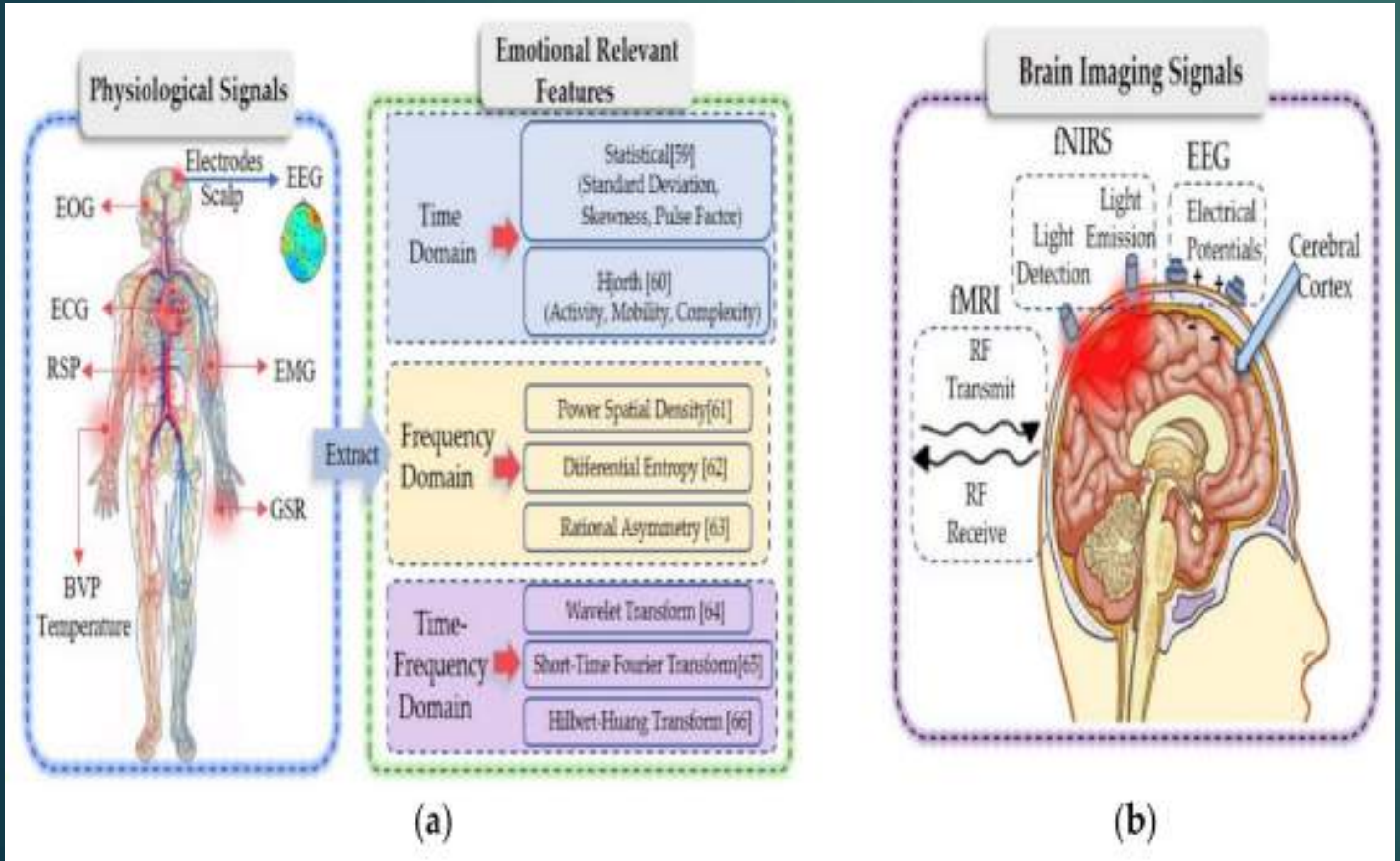
- EEG evaluation for TV advertisements related to both commercial and political fields.
  - The generated attention accompanying watching activity
  - Estimating the memorization of TV advertisements



https://doi.org/10.1515/tnsci-2019-0003

Educational and self-regulation

- Emotional regulation
  - Use of fMRI–EEG BCI to fight the depression feeling as well as other neuropsychiatric disorders



Advances in Multimodal Emotion Recognition Based on Brain–Computer Interfaces
by Zhipeng He

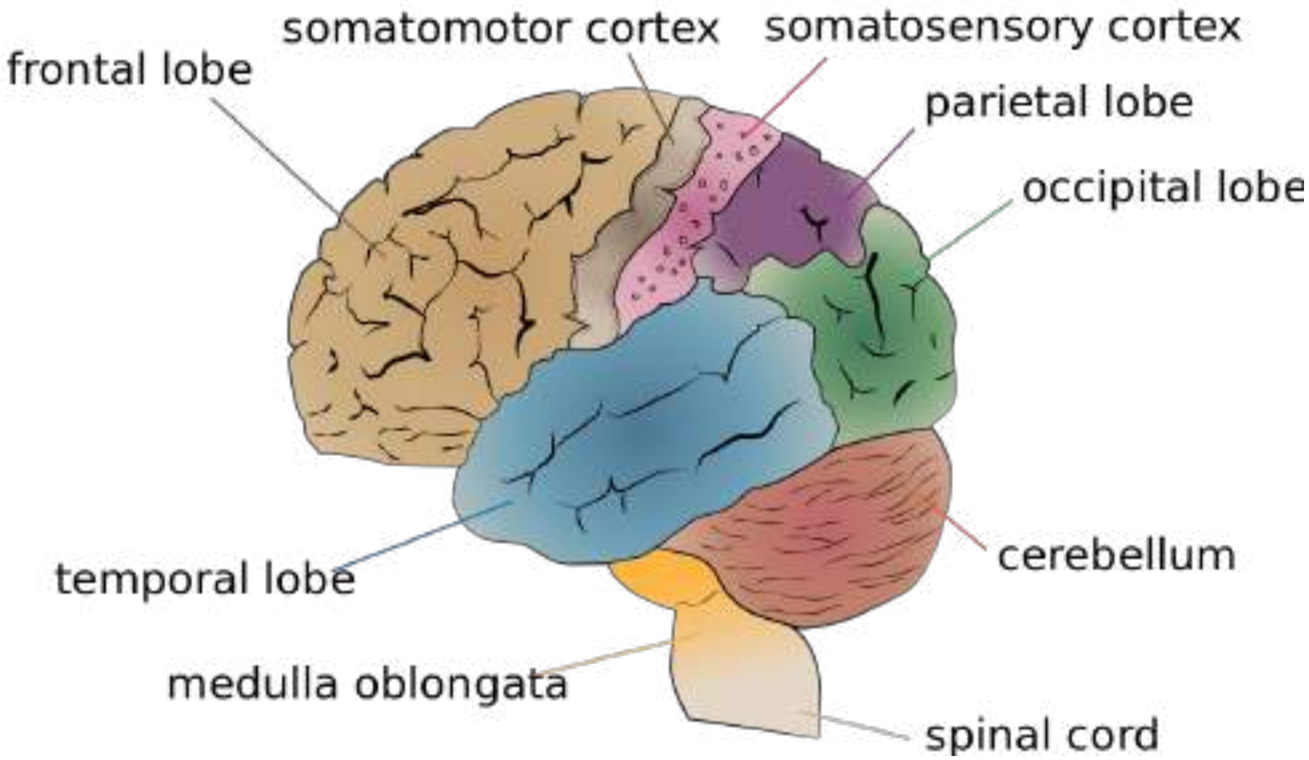
Challenges

- Usability
- Hardware
- Signal processing
- System integration
- Cost

BCI-S2022

Basics of Neuroscience for BCI

The Human Brain



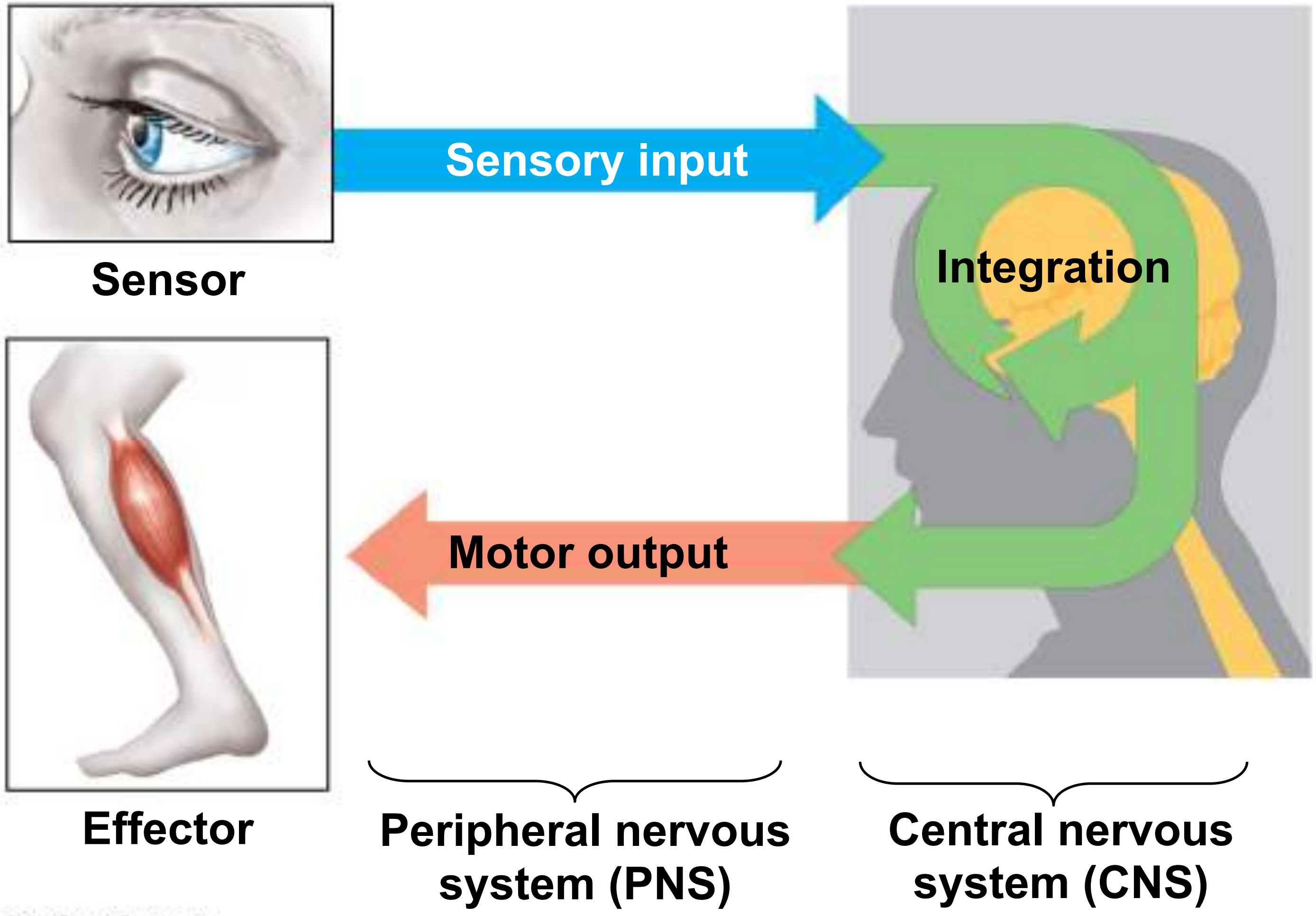
The Neuron

- The brain's unique information processing capabilities arise from its massively parallel and distributed way of computing.
- The workhorse of the brain is a type of cell known as a ***NEURON***.
- Neuron is a complex electrochemical device that receives information from hundreds of other neurons, processes this information, and conveys its output to hundreds of other neurons

The Neuron

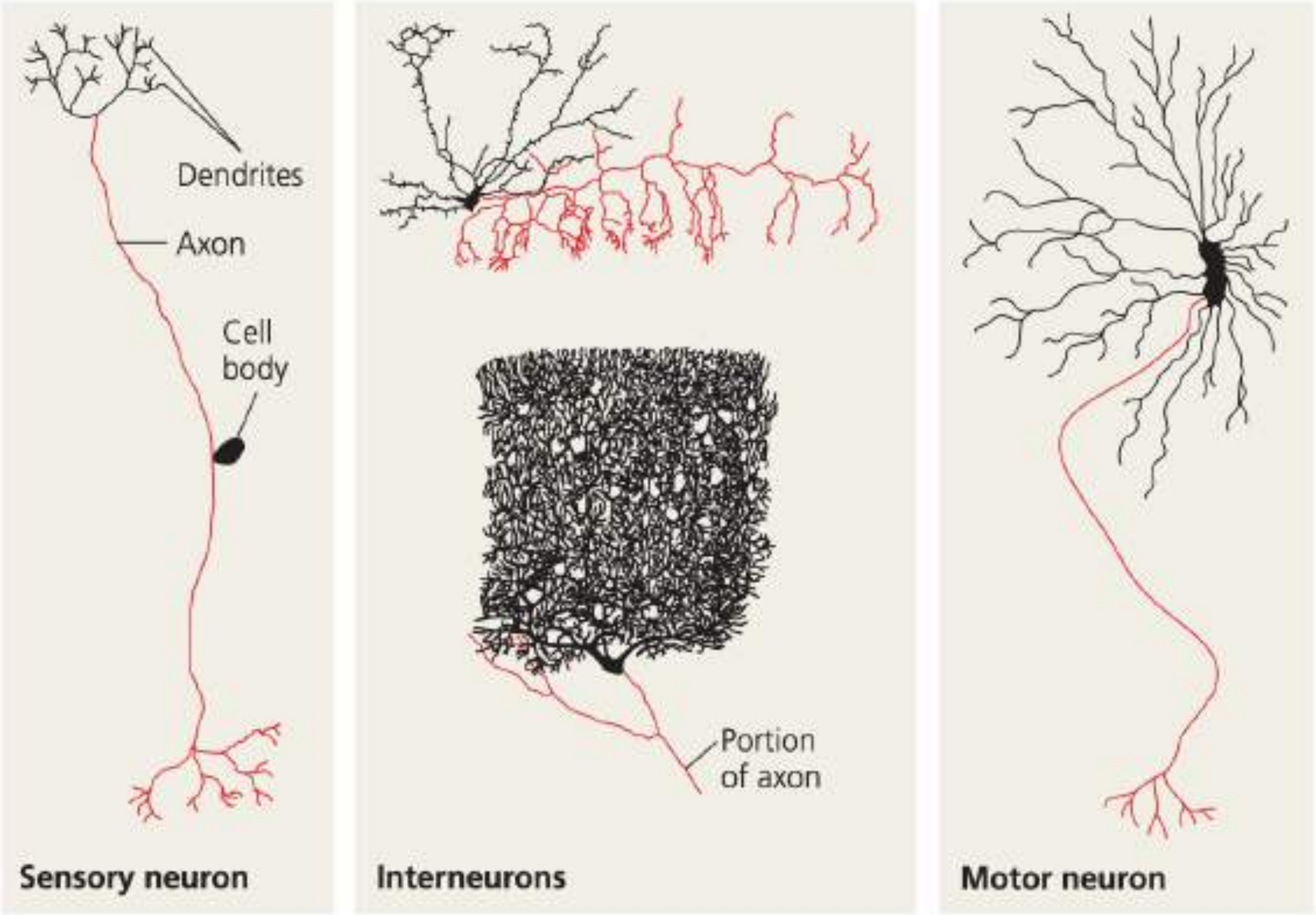
- The neuron can be regarded as a leaky bag of charged liquid.
- The membrane of a neuron is made up of a lipid bi-layer that is impermeable except for openings called ionic channel.
- The ionic channels selectively allow the passage of a few ions

REVISIT : Introduction to Information Processing



Many animals have a complex nervous system that consists of

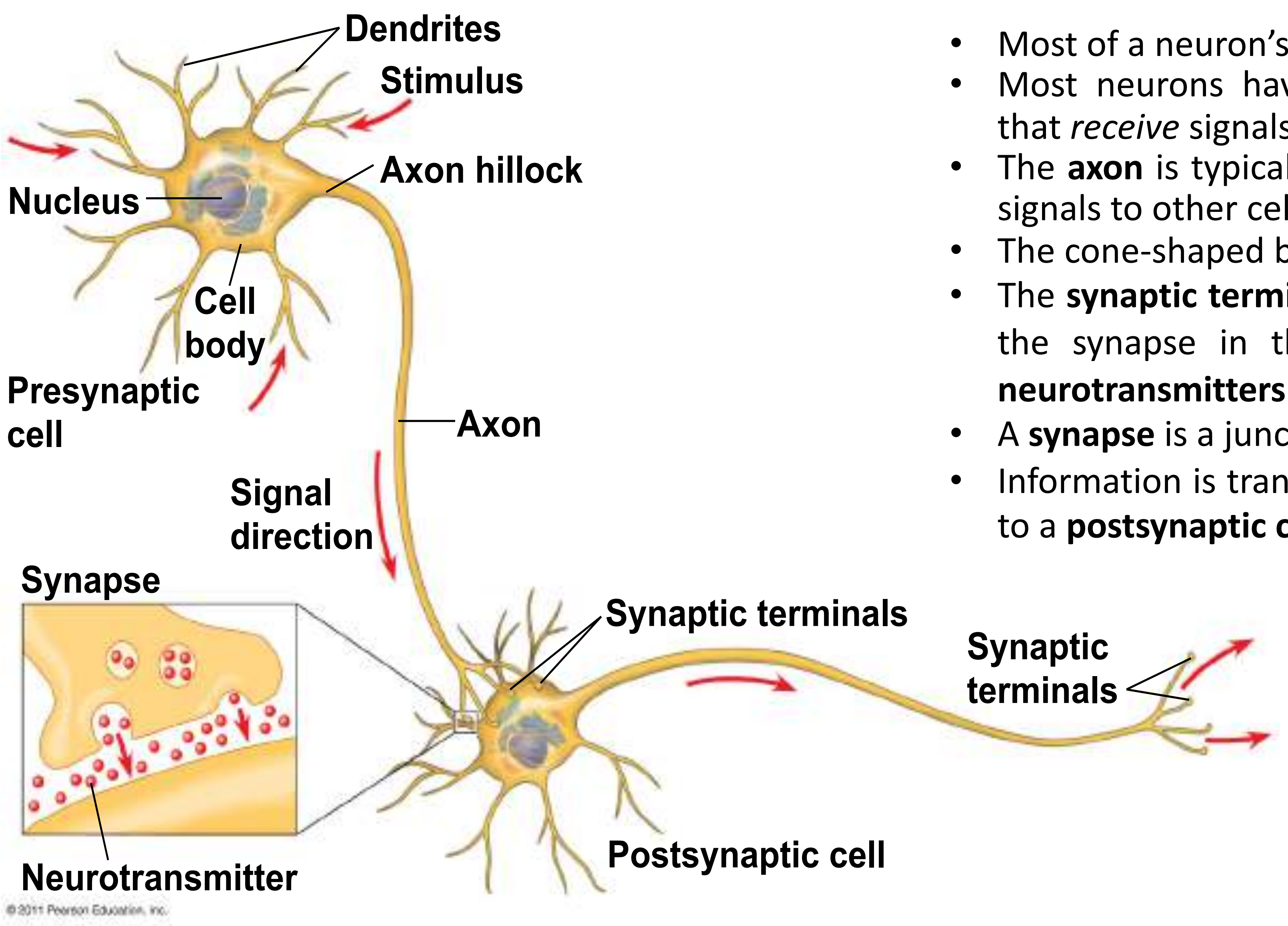
- A **central nervous system (CNS)** where integration takes place; this includes the brain and a nerve cord
- A **peripheral nervous system (PNS)**, which carries information into and out of the CNS
- The neurons of the PNS, when bundled together, form **nerves**



Structural diversity of neurons. *Cell bodies and dendrites are black in these diagrams; axons are red. In the sensory neuron, unlike the other neurons here, the cell body is located partway along the axon that conveys signals from the dendrites to the axon's terminal branches.*

- Sensors detect external stimuli and internal conditions and transmit information along **sensory neurons**
- Sensory information is sent to the brain, where **interneurons** integrate the information
- Motor output leaves the brain via **motor neurons**, which trigger muscle or gland activity

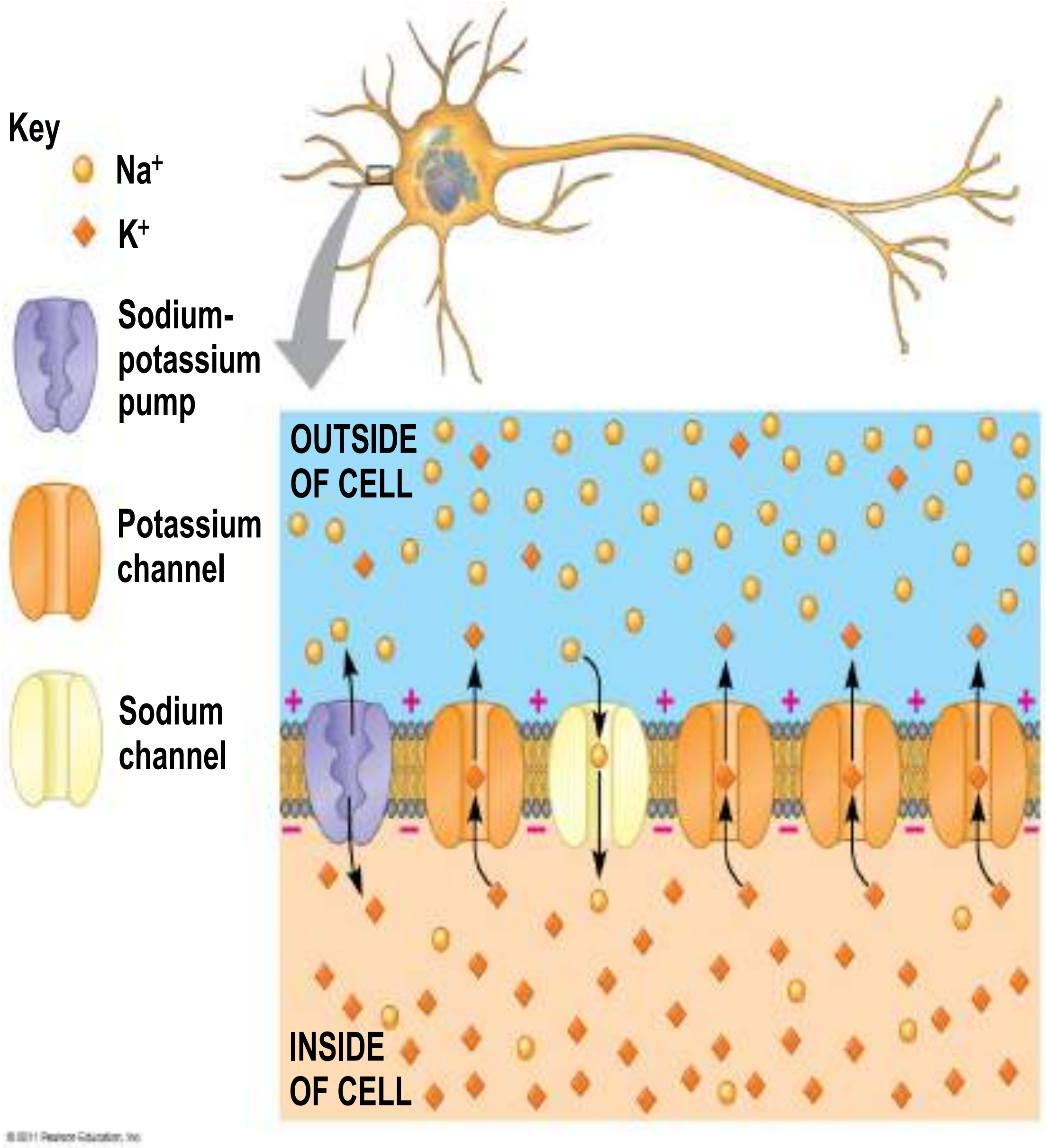
Neuron Structure and Function



- 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 **axon** is typically a much longer extension that transmits signals to other cells at synapses.
- The cone-shaped base of an axon is called the **axon hillock.**
- The **synaptic terminal** of one axon passes information across the synapse in the form of chemical messengers called **neurotransmitters.**
- A **synapse** is a junction between an axon and another cell
- Information is transmitted from a **presynaptic cell** (a neuron) to a **postsynaptic cell** (a neuron, muscle, or gland cell).

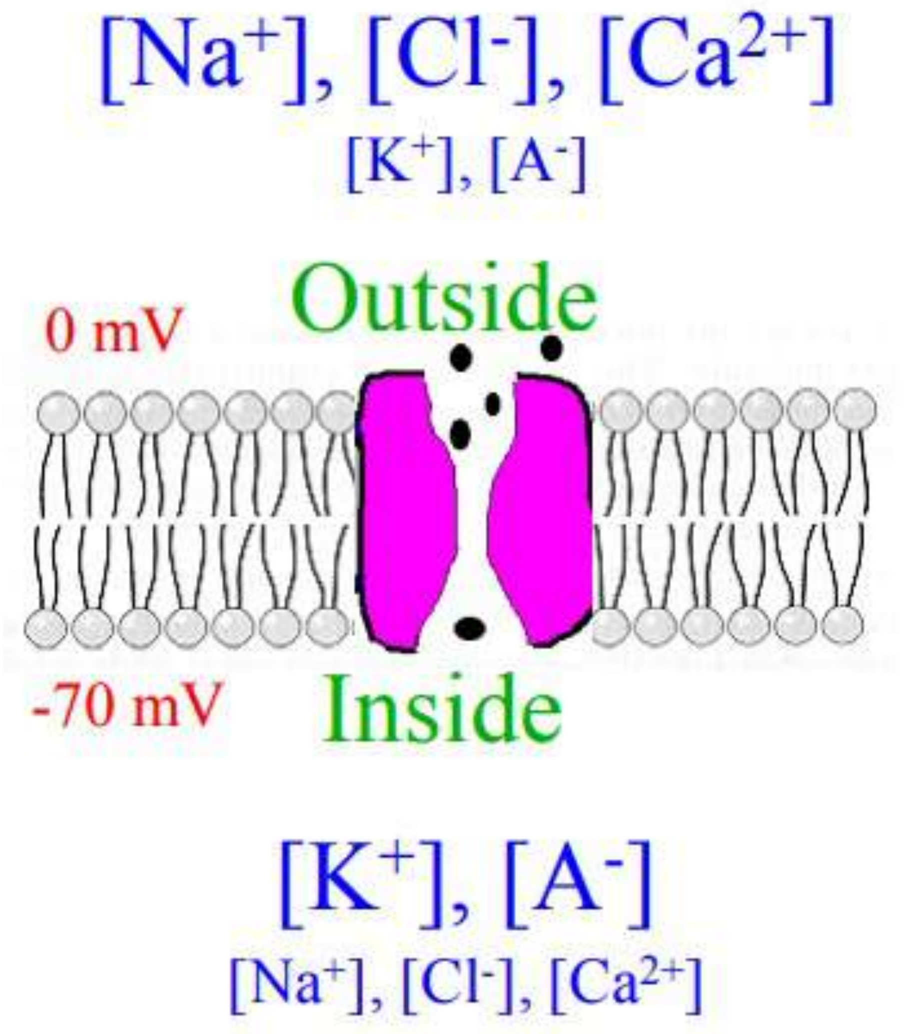
Ion pumps and ion channels establish the resting potential of a neuron

- Every cell has a voltage (difference in electrical charge) across its plasma membrane called a **membrane potential.**
- The **resting potential** is the membrane potential of a neuron not sending signals.
- Changes in membrane potential act as signals, transmitting and processing information.
- In a mammalian neuron at resting potential, the concentration of K^+ is highest inside the cell, while the concentration of Na^+ is highest outside the cell.
- The opening of **ion channels** in the plasma membrane converts chemical potential to electrical potential.
- A neuron at resting potential contains many open K^+ channels and fewer open Na^+ channels; K^+ diffuses out of the cell.
- The resulting buildup of negative charge within the neuron is the major source of membrane potential.



The Electrical Personality of a Neuron

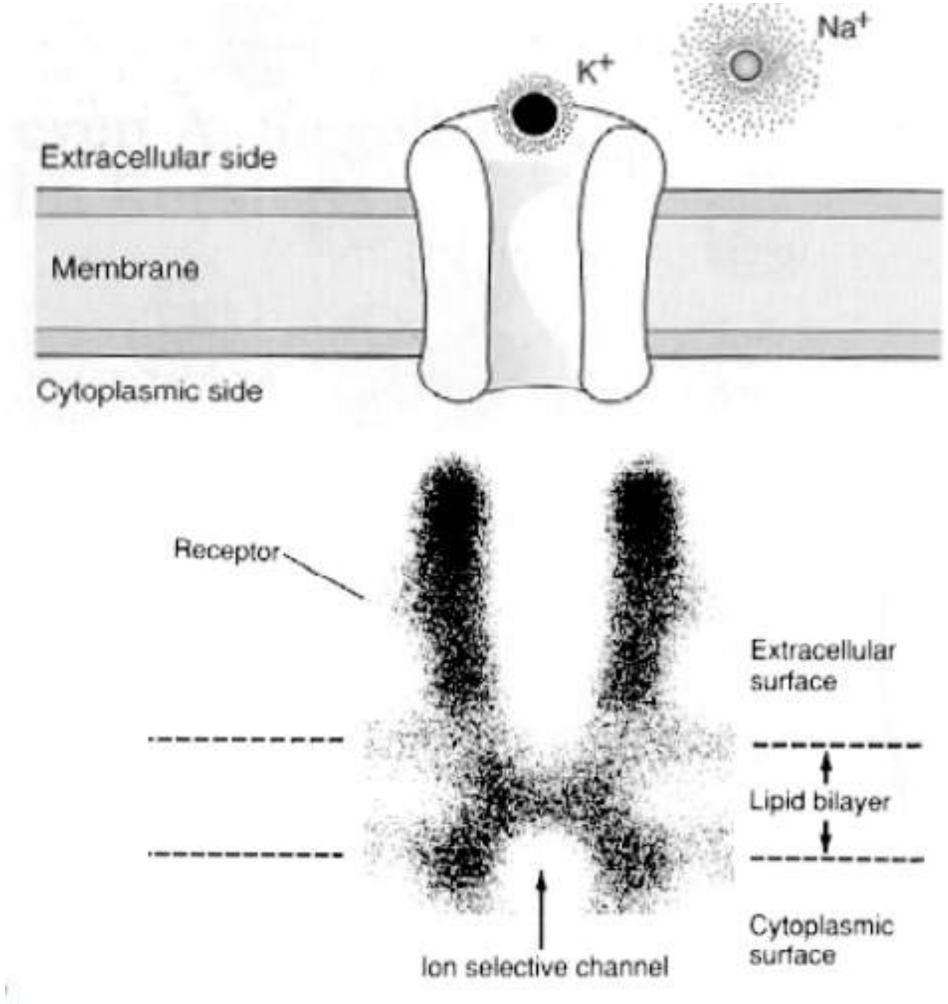
- Each neuron maintains a potential difference across its membrane
- Inside is ±65 to ±70 mV relative to outside
- [Na+], [Cl-] and [Ca2+] higher outside; [K+] and organic anions [A-] higher inside
- Ionic pump maintains -70 mV difference by expelling Na+ out and allowing K+ ions in
- In a resting neuron, the currents of K^+ and Na^+ are equal and opposite, and the resting potential across the membrane remains steady



How can the electrical potential be changed in local regions of a neuron?

Ionic Channels: The Gatekeepers

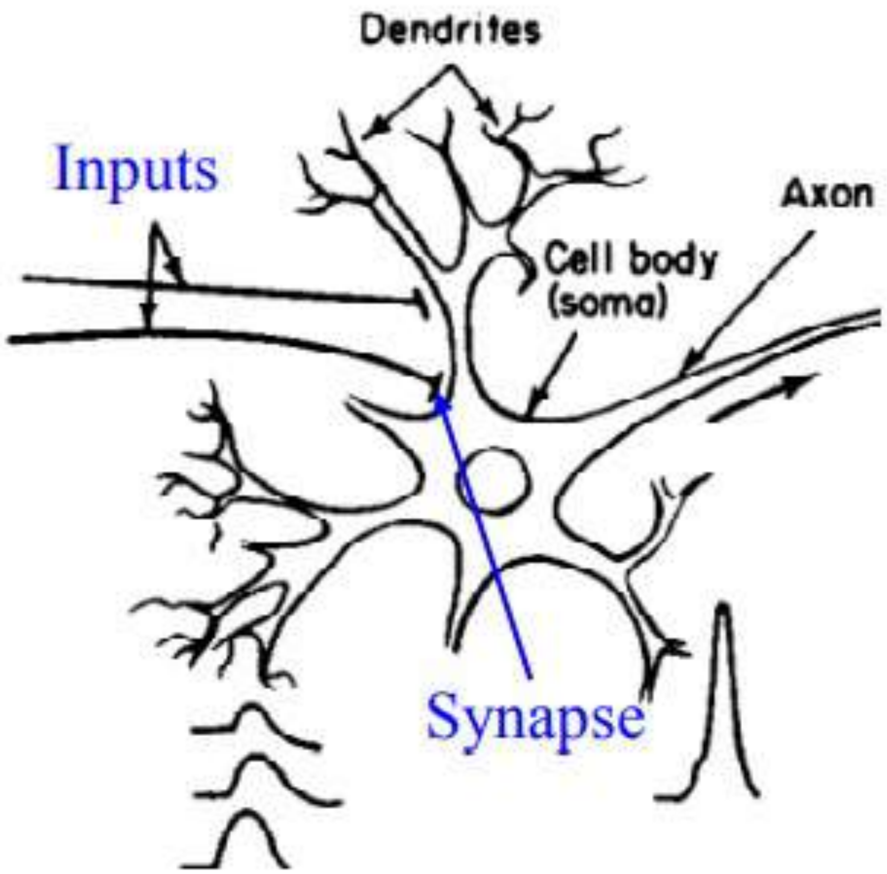
- Changes in membrane potential occur because neurons contain **gated ion channels** that open or close in response to stimuli
- Proteins in membranes act as channels that allow specific ions to pass through.
  - E.g.: Pass K+ but not Cl- or Na+
- These **IONIC CHANNELS** are gated
  - Voltage-gated: Probability of opening depends on membrane voltage
  - Chemically-gated: Binding to a chemical causes channel to open
  - Mechanically-gated: Sensitive to pressure or stretch



From Kandel, Schwartz, Jessel, Principles of Neural Science, 3rd edn., 1991, pgs. 68 & 137

Gated Channels allow Neuronal Signaling

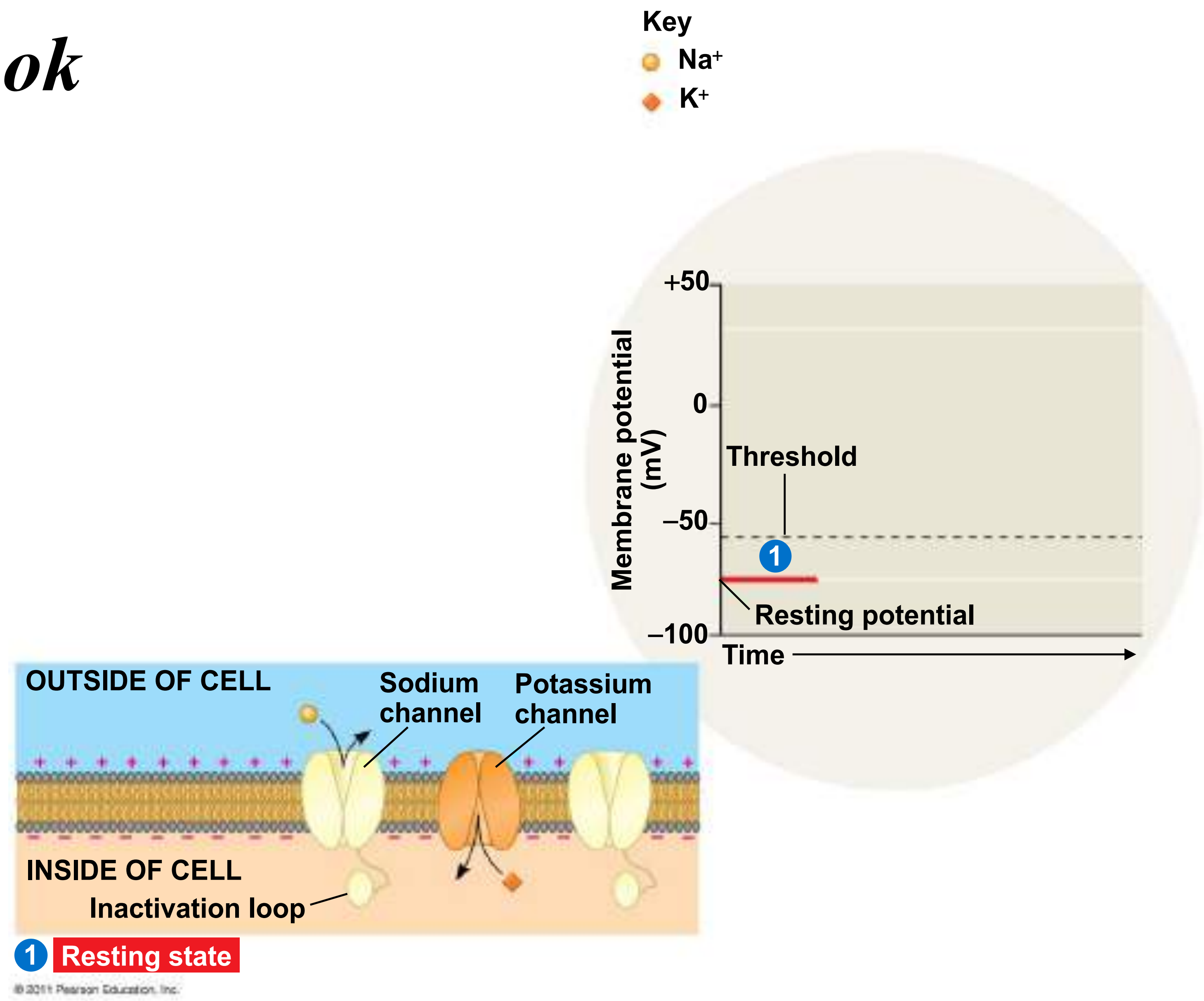
- Inputs from other neurons -> chemically-gated channels (at "synapses") -> Changes in local membrane potential
- This causes opening/closing of voltage-gated channels in dendrites, body, and axon, resulting in depolarization (positive change in voltage) or hyperpolarization (negative change)



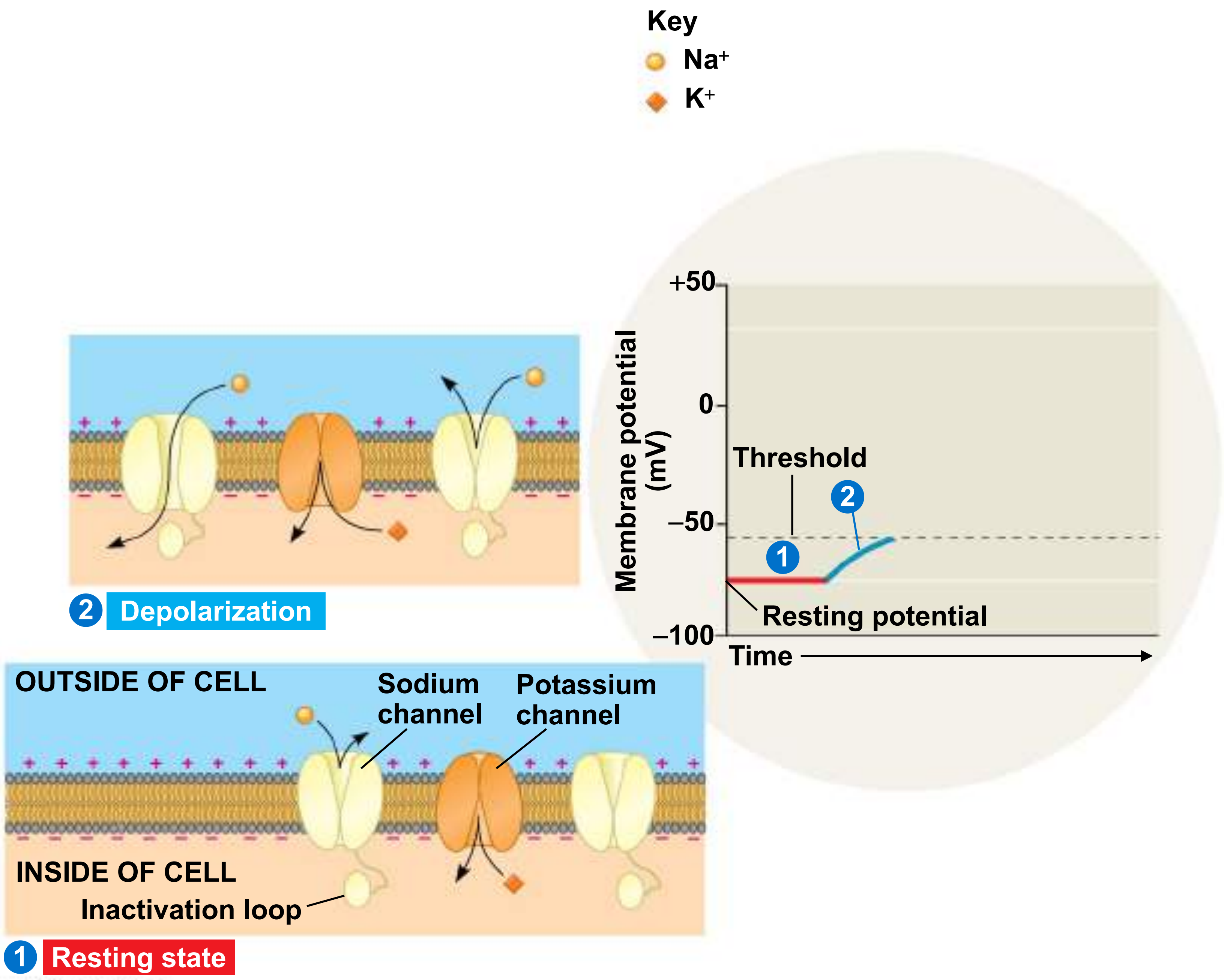
Generation of Action Potentials: *A Closer Look*

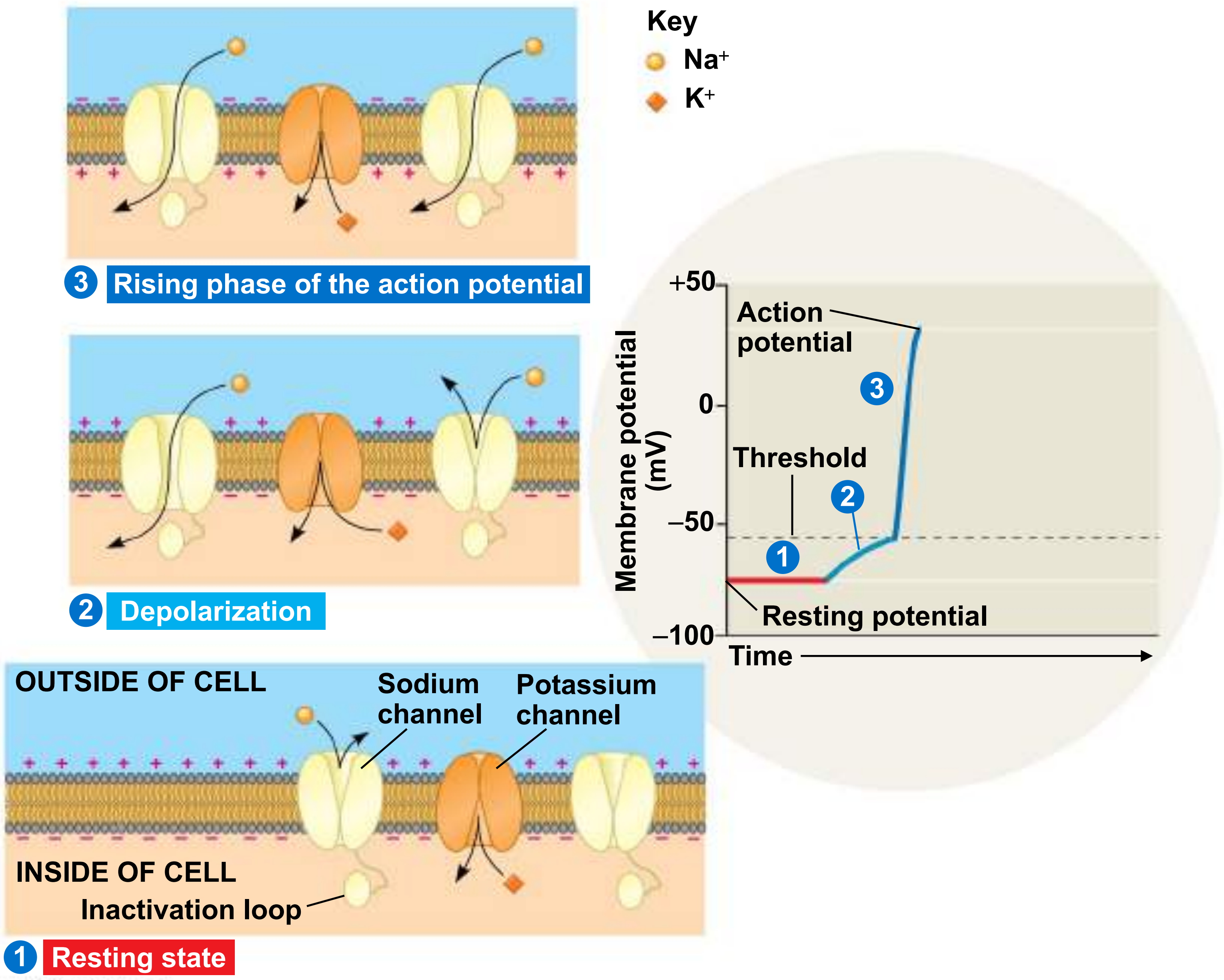
An action potential can be considered as a series of stages

- At resting potential
    1. Most voltage-gated sodium (Na^+) channels are closed; most of the voltage-gated potassium (K^+) channels are also closed

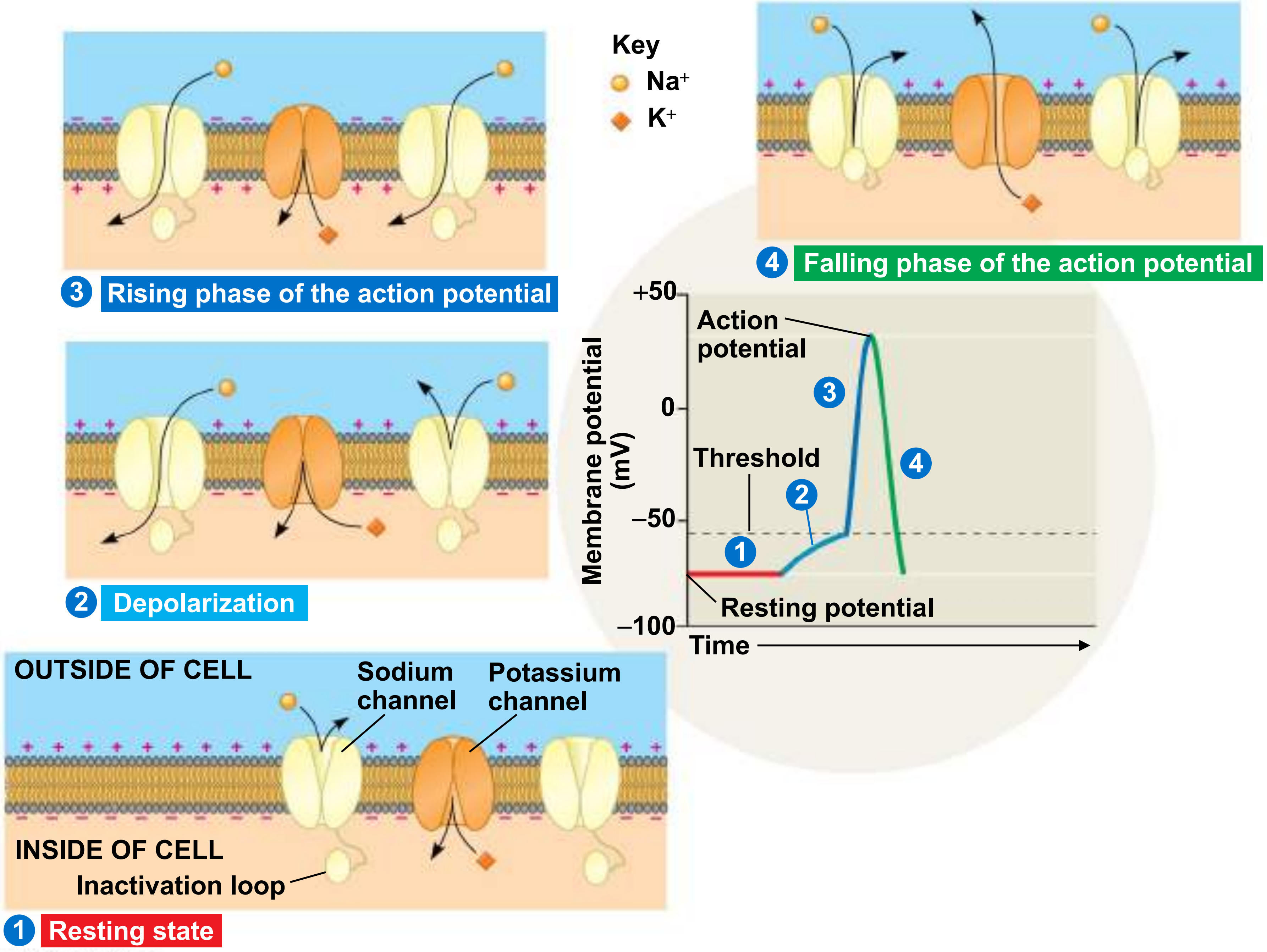


- When an action potential is generated
    2. Voltage-gated Na^+ channels open first and Na^+ flows into the cell
    3. During the *rising phase*, the threshold is crossed, and the membrane potential increases
    4. During the *falling phase*, voltage-gated Na^+ channels become inactivated; voltage-gated K^+ channels open, and K^+ flows out of the cell


Key
Na+
K+
+50
0
−50
−100
Membrane potential (mV)
Threshold
Resting potential
Time
2 Depolarization
OUTSIDE OF CELL
Sodium channel
Potassium channel
INSIDE OF CELL
Inactivation loop
1 Resting state

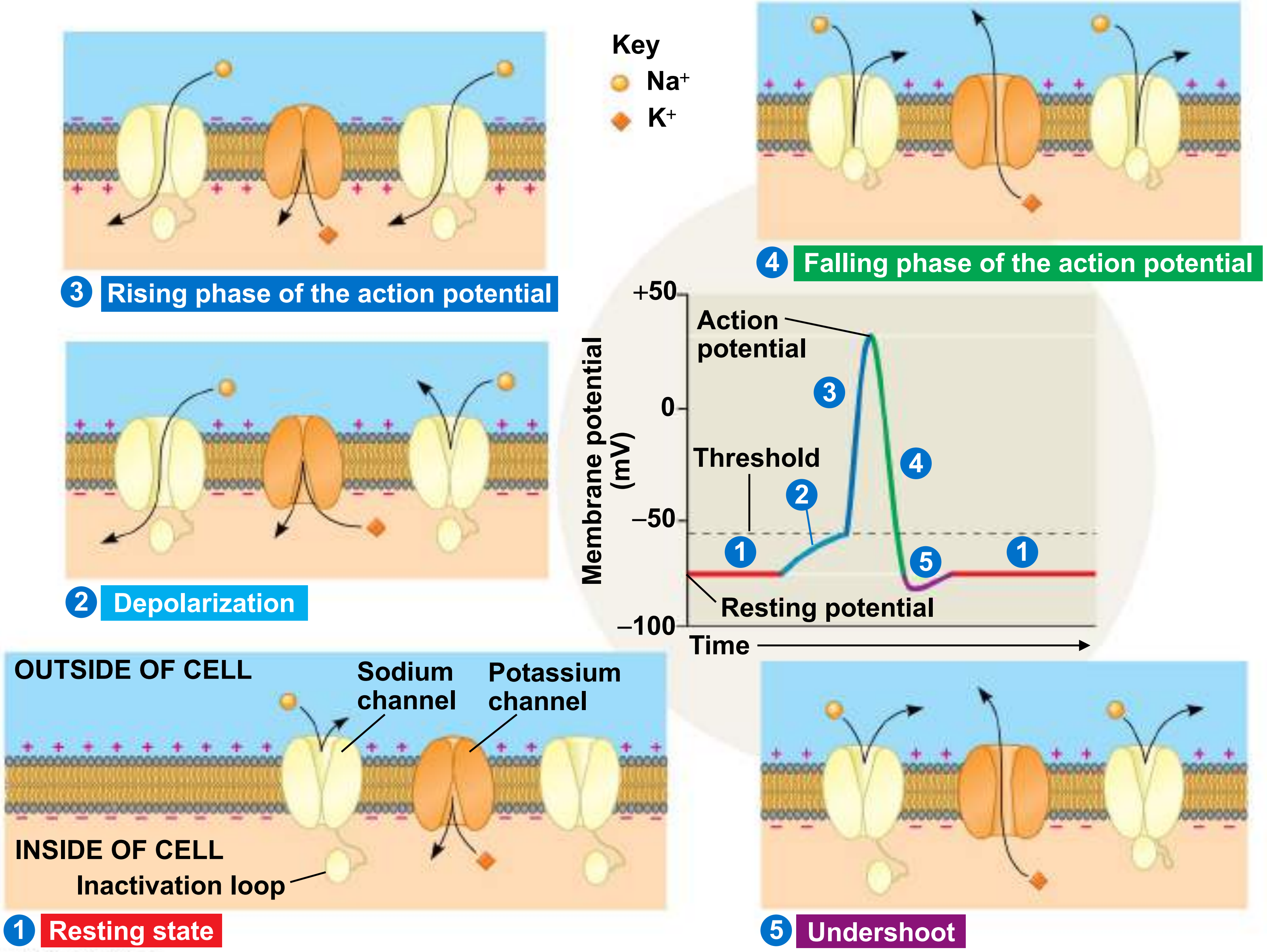


Key
Na+
K+
Rising phase of the action potential
Depolarization
OUTSIDE OF CELL
Sodium channel
Potassium channel
INSIDE OF CELL
Inactivation loop
Resting state
+50
0
–50
–100
Membrane potential (mV)
Action potential
Threshold
Resting potential
Time

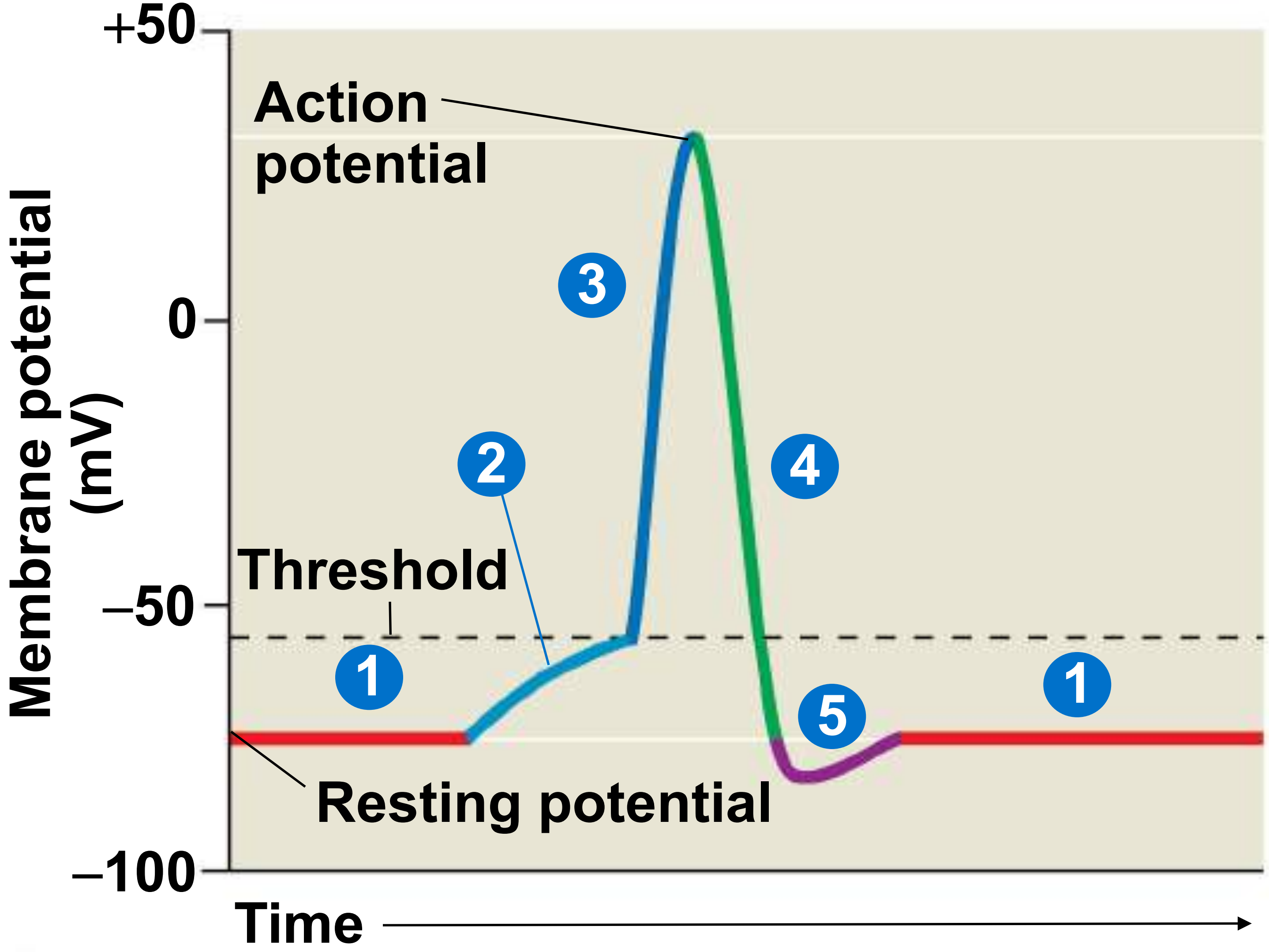


Key
Na+
K+
Rising phase of the action potential
Falling phase of the action potential
Depolarization
Resting state
OUTSIDE OF CELL
INSIDE OF CELL
Sodium channel
Potassium channel
Inactivation loop
Action potential
Threshold
Resting potential
Membrane potential (mV)
+50
0
–50
–100
Time
1
2
3
4

5. During the *undershoot*, membrane permeability to K^+ is at first higher than at rest, then voltage-gated K^+ channels close and resting potential is restored



Key
Na+
K+
Rising phase of the action potential
Falling phase of the action potential
Depolarization
Membrane potential (mV)
+50
0
–50
–100
Action potential
Threshold
Resting potential
Time
OUTSIDE OF CELL
Sodium channel
Potassium channel
INSIDE OF CELL
Inactivation loop
Resting state
Undershoot



+50
0
–50
–100
Membrane potential (mV)
Action potential
Threshold
Resting potential
Time
1
2
3
4
5
1

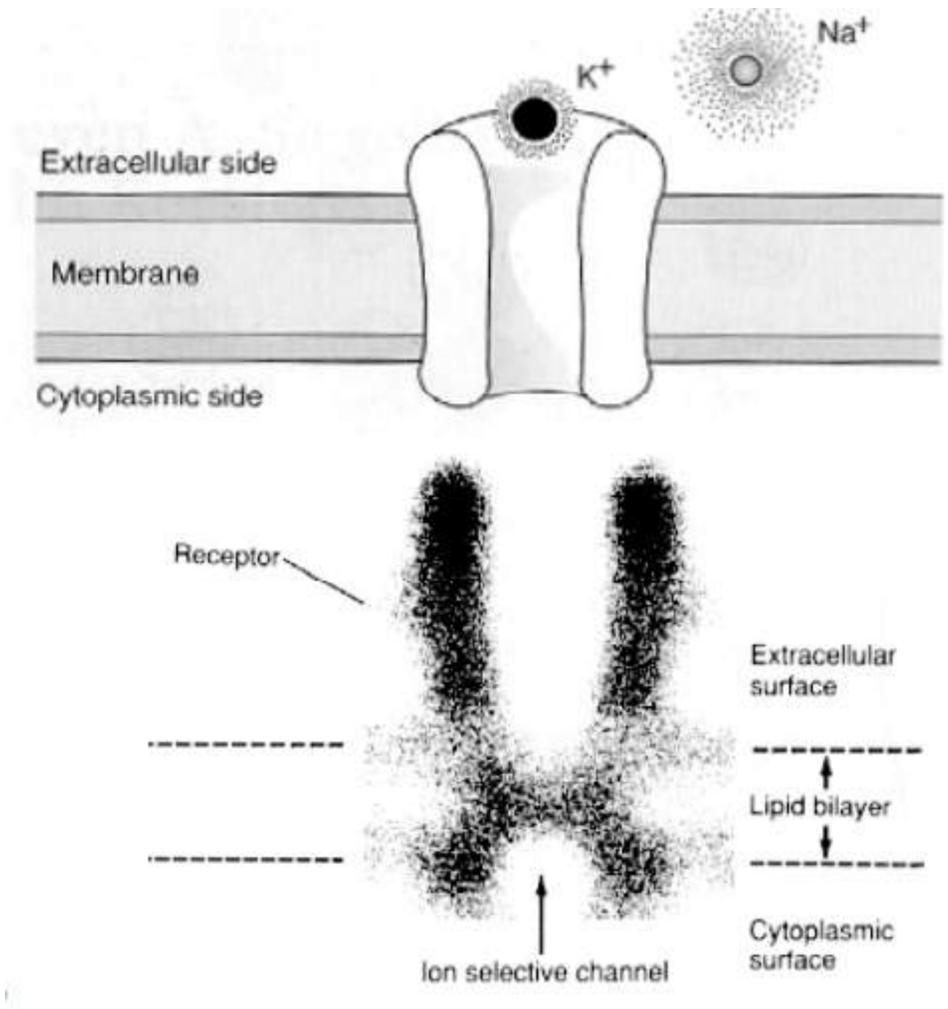
- During the **refractory period** after an action potential, a second action potential cannot be initiated
- The refractory period is a result of a temporary inactivation of the Na^+ channels

BCI-S2022

Basics of Neuroscience for BCI

Ionic Channels: The Gatekeepers

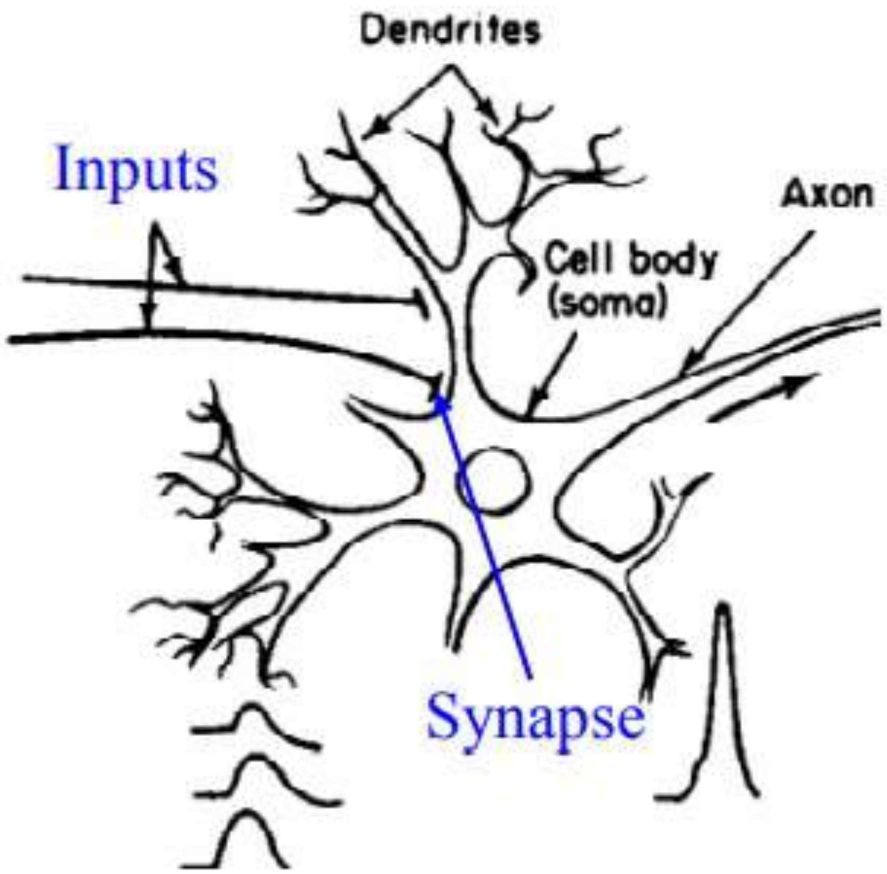
- Changes in membrane potential occur because neurons contain **gated ion channels** that open or close in response to stimuli
- Proteins in membranes act as channels that allow specific ions to pass through.
  - E.g.: Pass K+ but not Cl- or Na+
- These **IONIC CHANNELS** are gated
  - Voltage-gated: Probability of opening depends on membrane voltage
  - Chemically-gated: Binding to a chemical causes channel to open
  - Mechanically-gated: Sensitive to pressure or stretch



From Kandel, Schwartz, Jessel, Principles of Neural Science, 3rd edn., 1991, pgs. 68 & 137

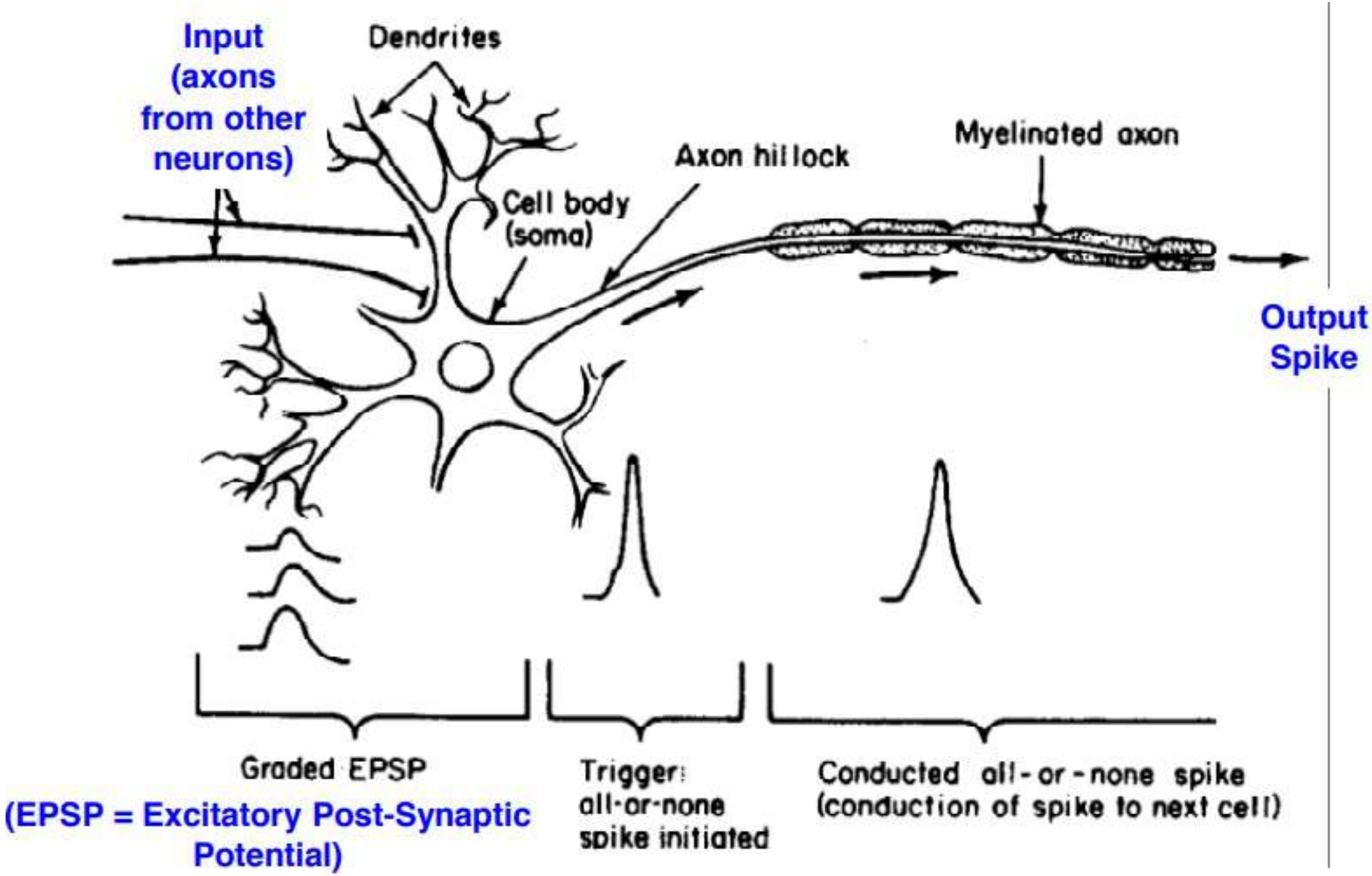
Gated Channels allow Neuronal Signaling

- Inputs from other neurons -> chemically-gated channels (at "synapses") -> Changes in local membrane potential
- This causes opening/closing of voltage-gated channels in dendrites, body, and axon, resulting in depolarization (positive change in voltage) or hyperpolarization (negative change)



Regions of Neurons

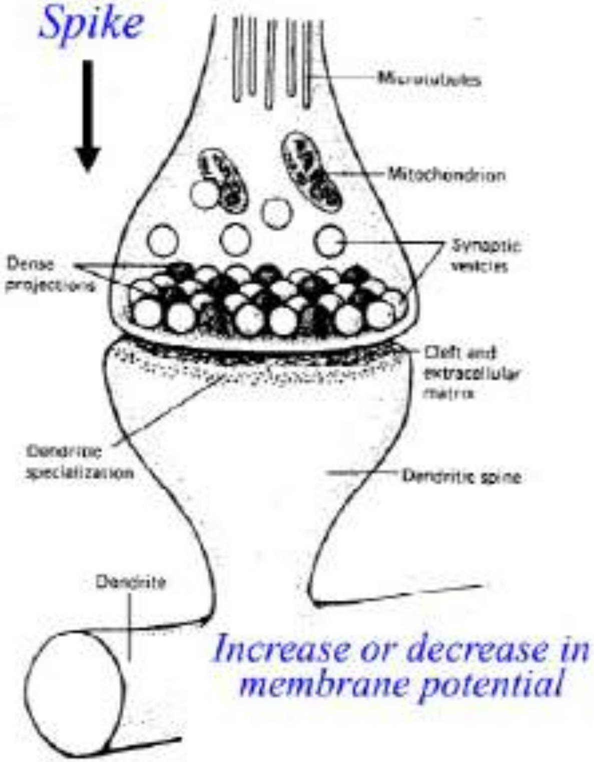
- Neurons in different regions of the brain have different morphological structures
- The typical structure includes a cell body (called the soma) connected to a tree-like structure with branches called dendrites
- A single branch called the axon that emanates from the soma and conveys the output spike to other neurons.
- The spike is typically initiated near the junction of the soma and axon and propagates down the length of the axon.
- Many axons are covered by myelin, a white sheath that significantly boosts the speed of propagation of the spike over long distances.



Input (axons from other neurons)
Dendrites
Cell body (soma)
Axon hillock
Myelinated axon
Output Spike
Graded EPSP
(EPSP = Excitatory Post-Synaptic Potential)
Trigger: all-or-none spike initiated
Conducted all-or-none spike (conduction of spike to next cell)

Synapse

- Neurons communicate with each other through connections known as synapses.
- Synapses can be electrical but are more typically chemical.
- A synapse is essentially a gap or cleft between the axon of one neuron (called the presynaptic neuron) and a dendrite (or soma) of another neuron (called the postsynaptic neuron)



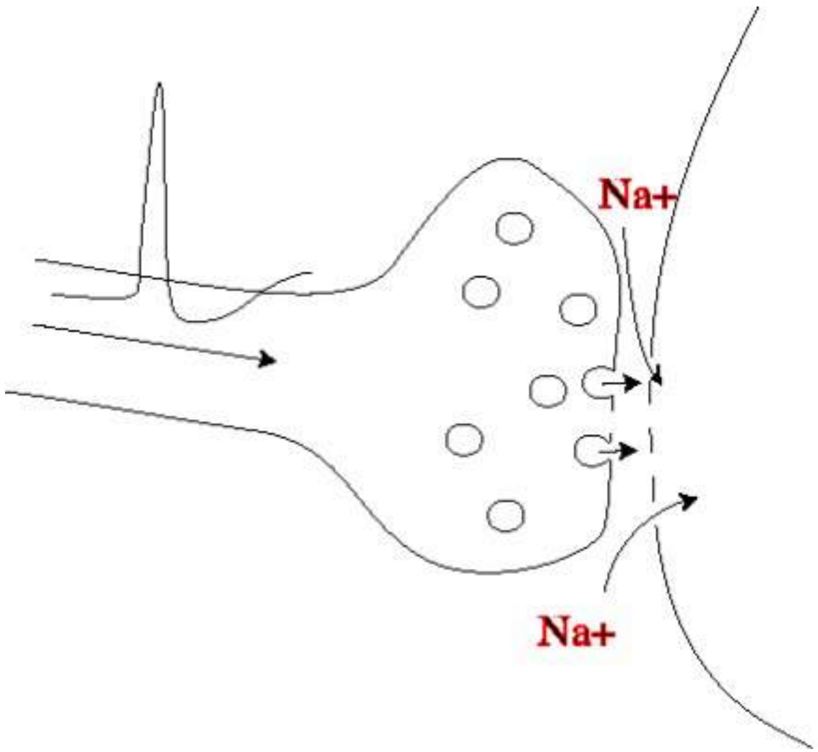
Synapse

- When an action potential arrives from a presynaptic neuron, it causes the release of chemicals known as neurotransmitters into the synaptic cleft.
- These chemicals in turn bind to the ionic channels (or receptors) on the postsynaptic neuron, causing these *channels to open*, thereby influencing the local membrane potential of the postsynaptic cell.

Synapse

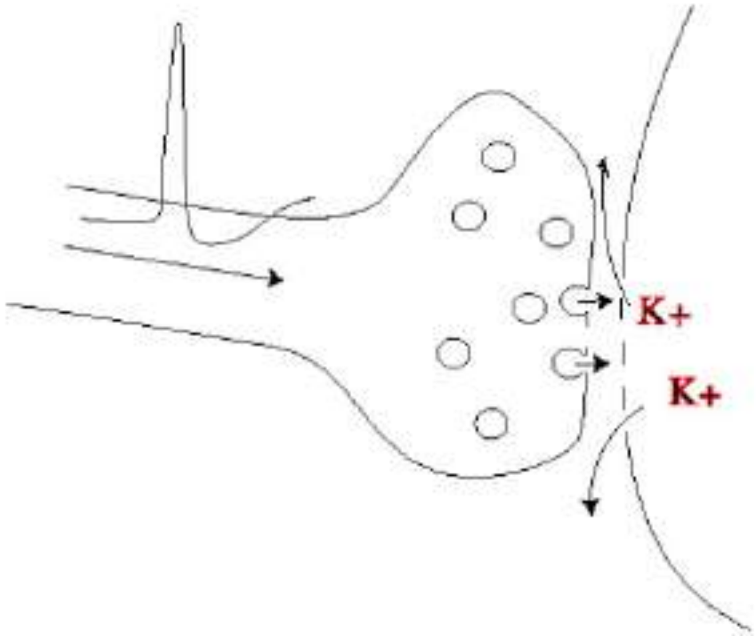
- Synapses can be excitatory or inhibitory.
- Excitatory synapses cause a momentary increase in the local membrane potential of the postsynaptic cell.
  - This increase is called an excitatory postsynaptic potential (EPSP).
  - EPSPs contribute to a higher probability of firing a spike by the postsynaptic cell.
- Inhibitory synapses do the opposite, temporarily decrease the local membrane potential of the postsynaptic cell
  - They cause inhibitory postsynaptic potentials (IPSPs)
- A neuron is called excitatory or inhibitory based on the kind of synapse it forms with *postsynaptic neurons*

An Excitatory Synapse



Input spike →
Neurotransmitter
release →
Binds to Na
channels (which
open) →
Na+ influx →
Depolarization due
to EPSP (excitatory
postsynaptic
potential)

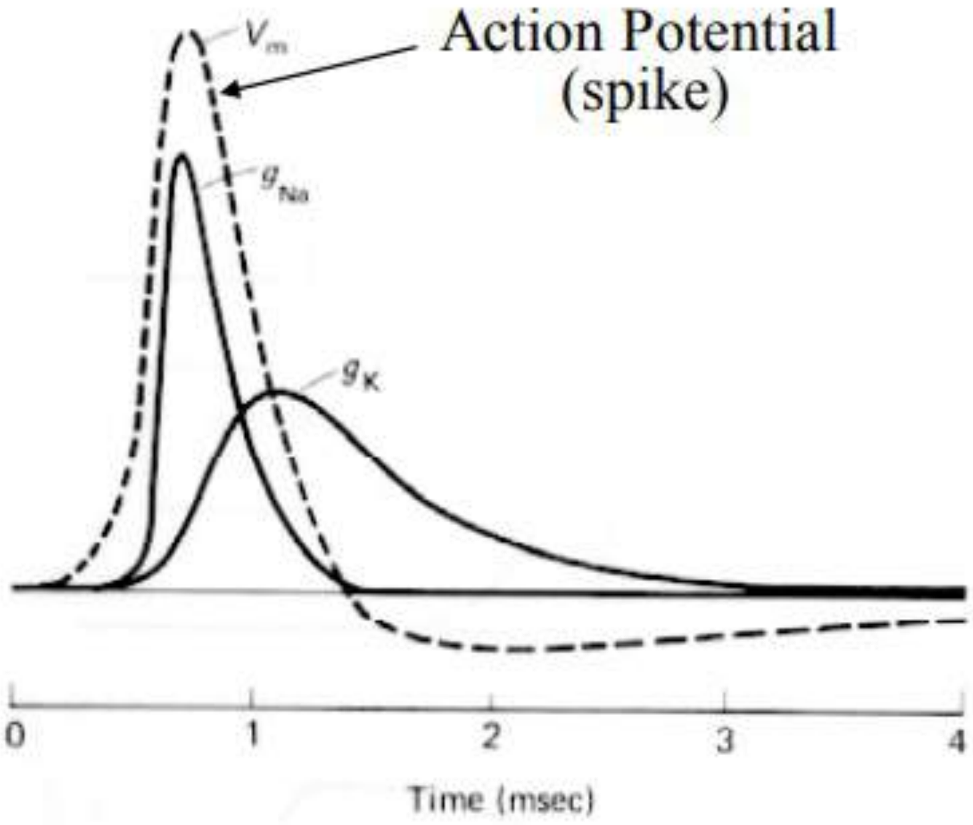
An Inhibitory Synapse



Input spike →
Neurotransmitter release →
Binds to K channels →
K+ leaves cell →
Hyperpolarization due to IPSP (inhibitory postsynaptic potential)

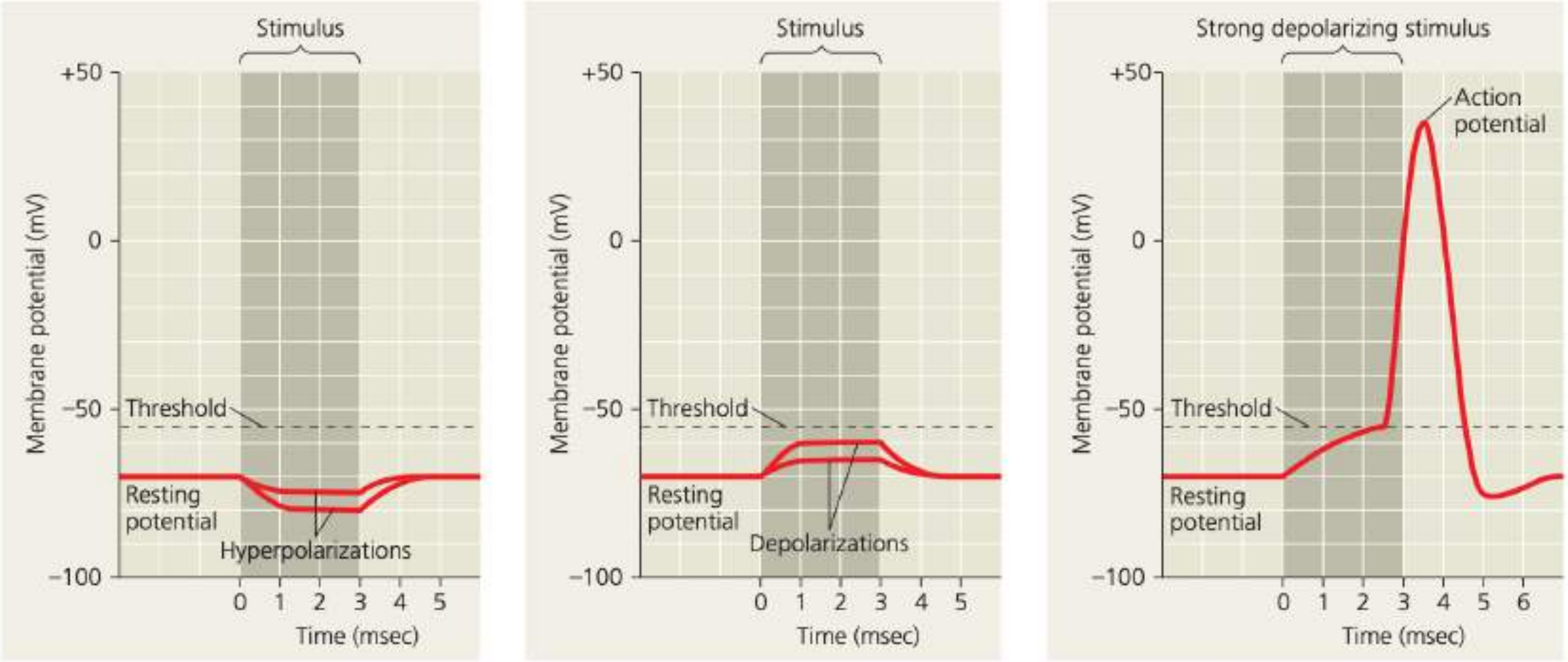
Action Potential or Spikes

- When the neuron receives sufficiently strong inputs from other neurons a cascade of events is triggered
- Rapid influx of Na+ ions into the cell
  - *Causing the membrane potential to rise rapidly.*
- The opening of K+ channels triggers the outflux of K+ ions
  - *Causing a drop in the membrane potential.*
- This rapid rise and fall of the membrane potential is called an ***action potential*** or **spike** and represents the dominant mode of communication between one neuron and another.



From Kandel, Schwartz, Jessel, Principles of Neural Science, 3rd edn., 1991, pg. 110

Graded potentials and an action potential in a neuron.



(a) Graded hyperpolarizations produced by two stimuli that increase membrane permeability to K^+. The larger stimulus produces a larger hyperpolarization.

(b) Graded depolarizations produced by two stimuli that increase membrane permeability to Na^+. The larger stimulus produces a larger depolarization.

(c) Action potential triggered by a depolarization that reaches the threshold.

Spike Generation

- The generation of a spike by a neuron involves a complex cascade of events involving sodium and potassium channels
- This process can be simplified into a simple threshold model of spike generation.
  - *When the neuron receives sufficiently strong inputs from its synapses for its membrane potential to cross a neuron-specific threshold, a spike is emitted.*

Synaptic plasticity: Adapting the connections

- **Long Term Potentiation (LTP):** Increase in synaptic strength of a synaptic connection between two neurons caused by correlated firing of the two neurons
  - lasts for several hours or more.
- Measured as an increase in the excitatory postsynaptic potential (EPSP) caused by presynaptic spikes
- LTP has been found in several brain areas including the hippocampus and the neocortex.
- Note: *LTP is regarded as a biological implementation of Donald Hebb's famous postulate (also called Hebbian learning or Hebbian plasticity) that if a neuron A is consistently involved in causing another neuron B to fire, then the strength of the connection from A to B should be increased.*

Synaptic plasticity: Adapting the connections

- **Long-term depression or LTD:** Decrease in the strength of a synaptic connection caused
  - by uncorrelated firing between the two neurons involved.
  - Reduction in synaptic strength that lasts for several hours or more
- LTD has been observed most prominently in the cerebellum, although it also coexists with LTP in the hippocampus, neocortex, and other brain areas

Synaptic plasticity: Adapting the connections

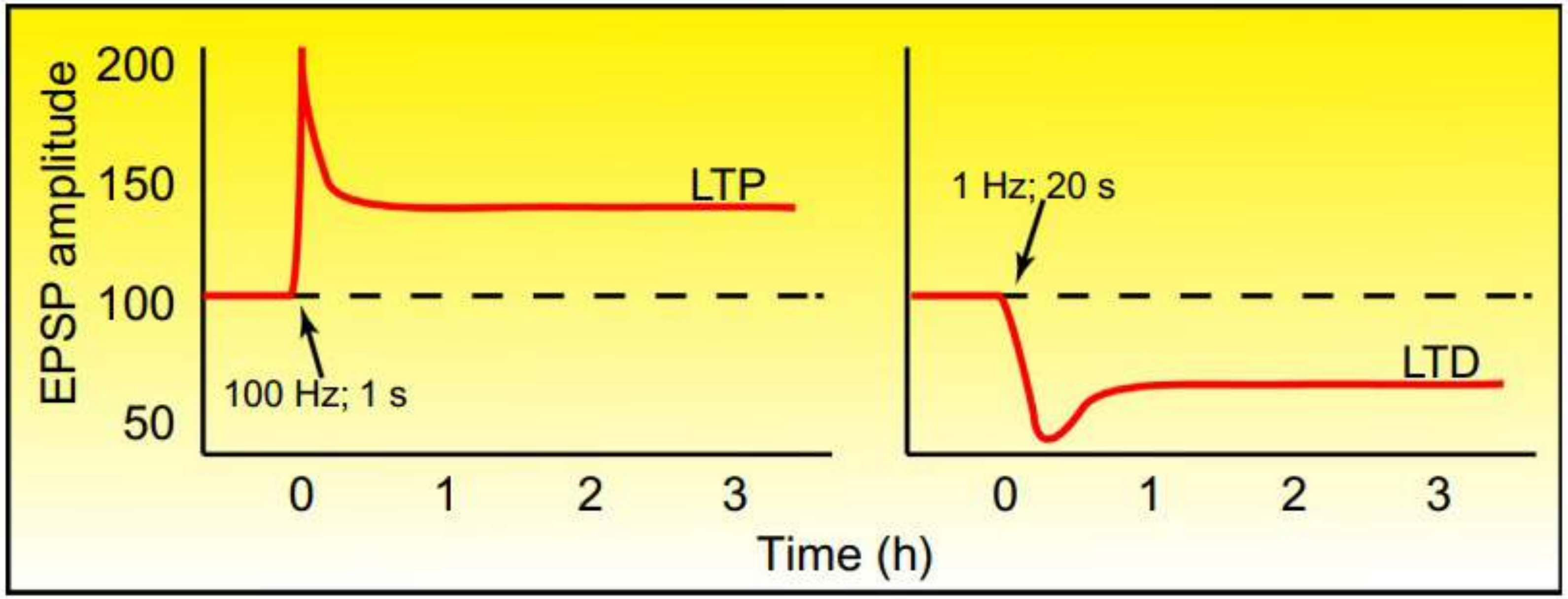


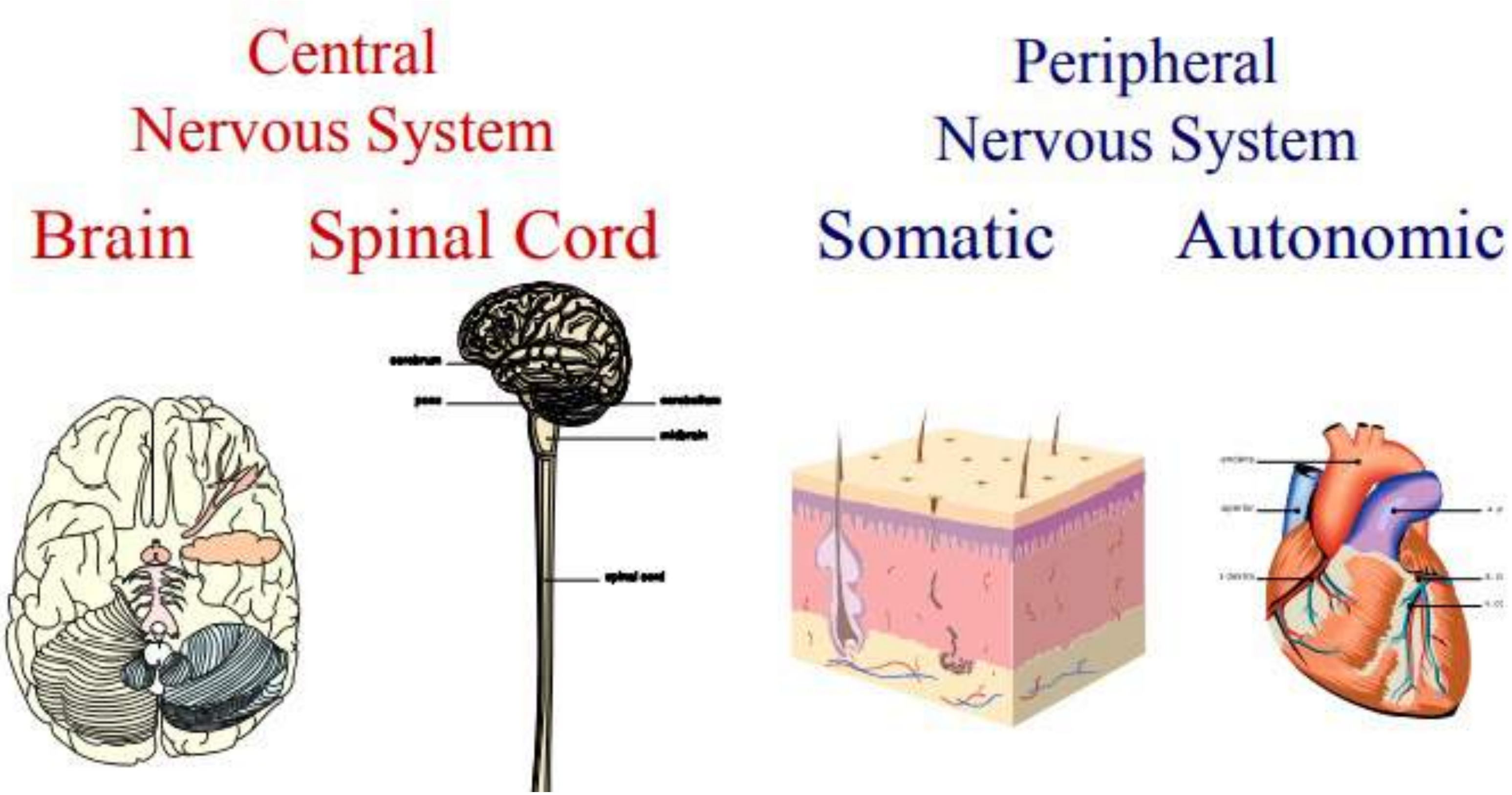
Figure: Long-term potentiation (LTP) and long-term depression (LTD).
Plots of excitatory postsynaptic potential amplitude at a hippocampal synapse over time during two different stimulus patterns. (Left panel) Following a long burst of high-frequency stimulation (100 Hz for 1 s), synapses strengthen, leading to a larger EPSP amplitude, and this is maintained for hours (LTP). The transient spike in strengthening that occurs immediately after the 100 Hz stimulus train results from post-tetanic potentiation. (Right panel) Following a low-frequency train of activity (1 Hz for 20 s), synapses weaken persistently, leading to a smaller EPSP amplitude (LTD).

Image from: *Meriney, Stephen D. (2019). Synaptic Transmission || Synaptic Plasticity. , (), 287–329.*

Brain Organization, Anatomy, and Function

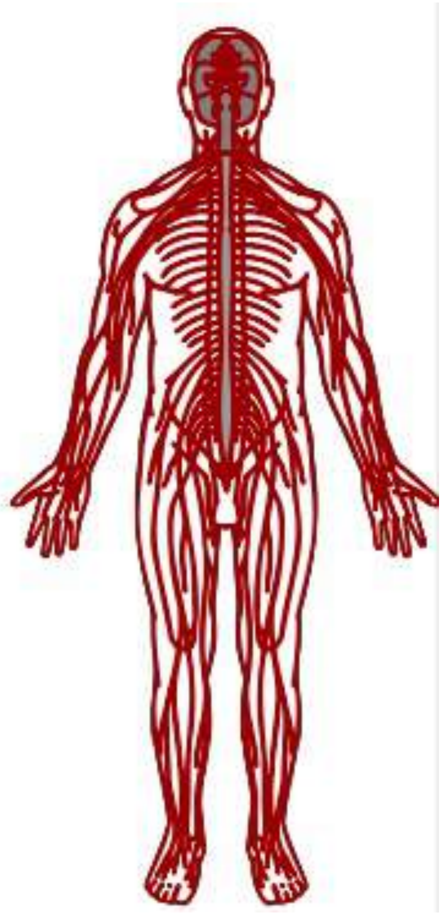
- The design of a brain-computer interface typically involves choices regarding which brain areas to record from and, in some cases, which brain areas to stimulate.
- The human nervous system can be broadly divided into
  - The central nervous system (CNS).
    - The CNS consists of the brain and the spinal cord.
  - The peripheral nervous system (PNS).
    - The PNS consists of the somatic nervous system (neurons connected to skeletal muscles, skin, and sense organs) and the autonomic nervous system (neurons that control visceral functions such as the pumping of the heart, breathing, etc.).

Brain Organization, Anatomy, and Function



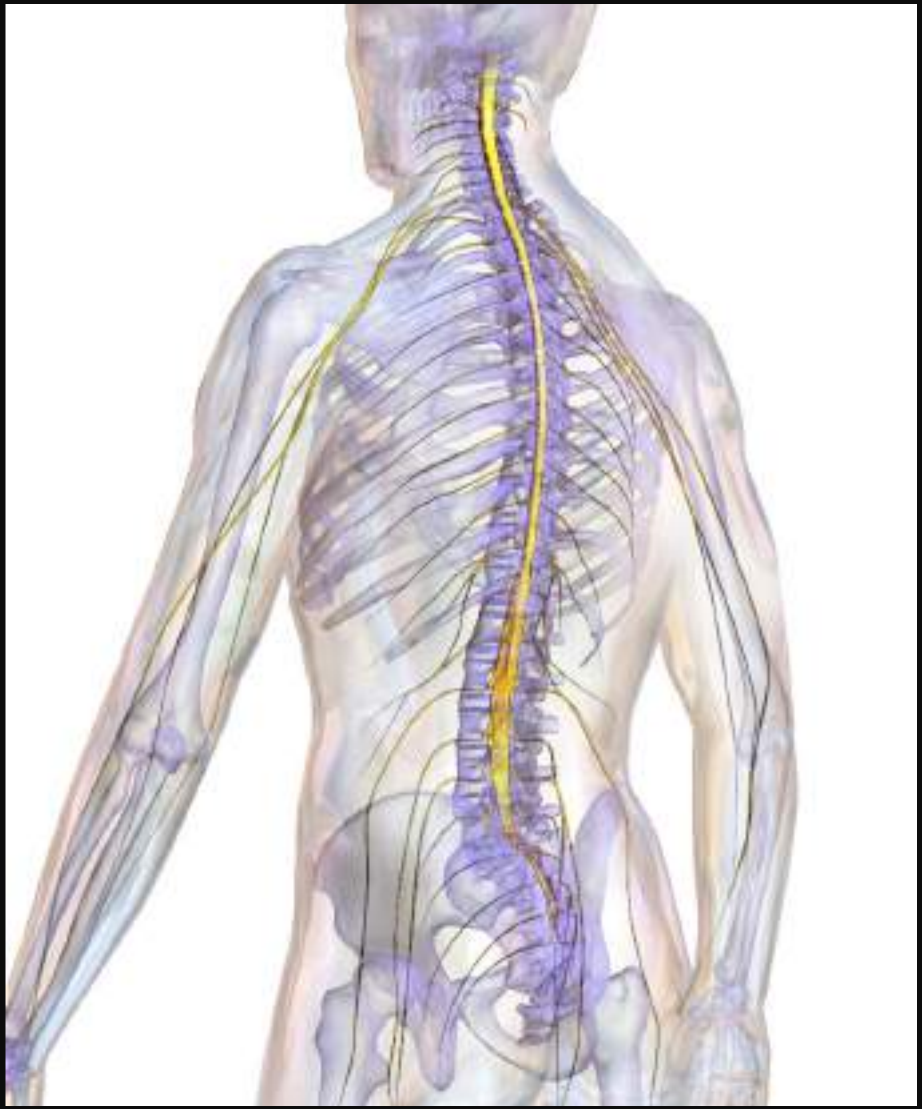
Skeletal/Somatic Nervous System

- Nerves that connect to voluntary skeletal muscles and to sensory receptors
- Afferent Nerve Fibers (incoming)
  - Axons that carry info away from the periphery to the CNS
- Efferent Nerve Fibers (outgoing)
  - Axons that carry info from the CNS outward to the periphery



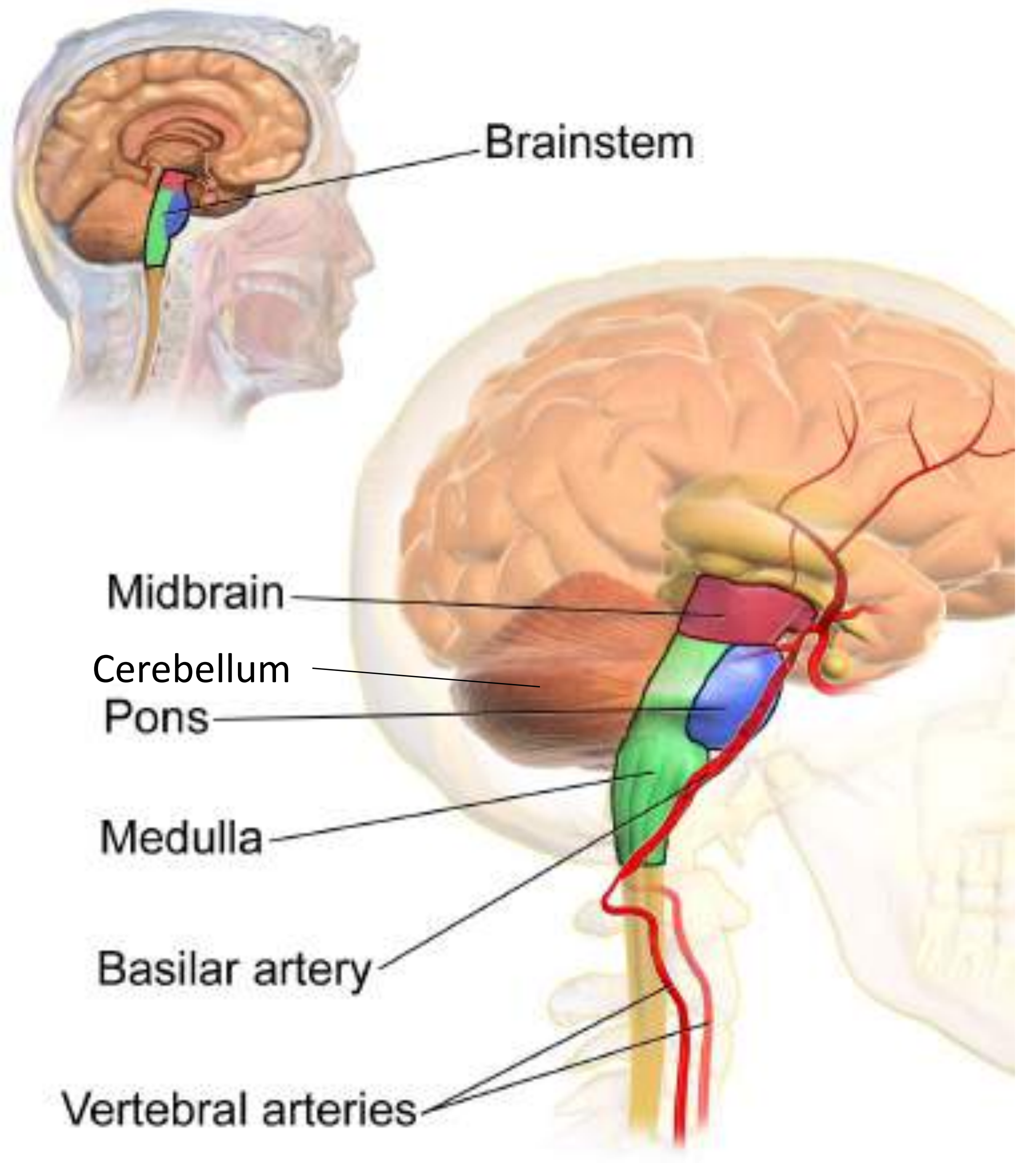
Autonomic and Central Nervous System

- Autonomic: Nerves that connect to the heart, blood vessels, smooth muscles, and glands
- CNS = Brain + Spinal Cord
- Spinal Cord
    - Local feedback loops control reflexes
    - Descending motor control signals from the brain activate spinal motor neurons
    - Ascending sensory axons transmit sensory feedback information from muscles and skin back to brain



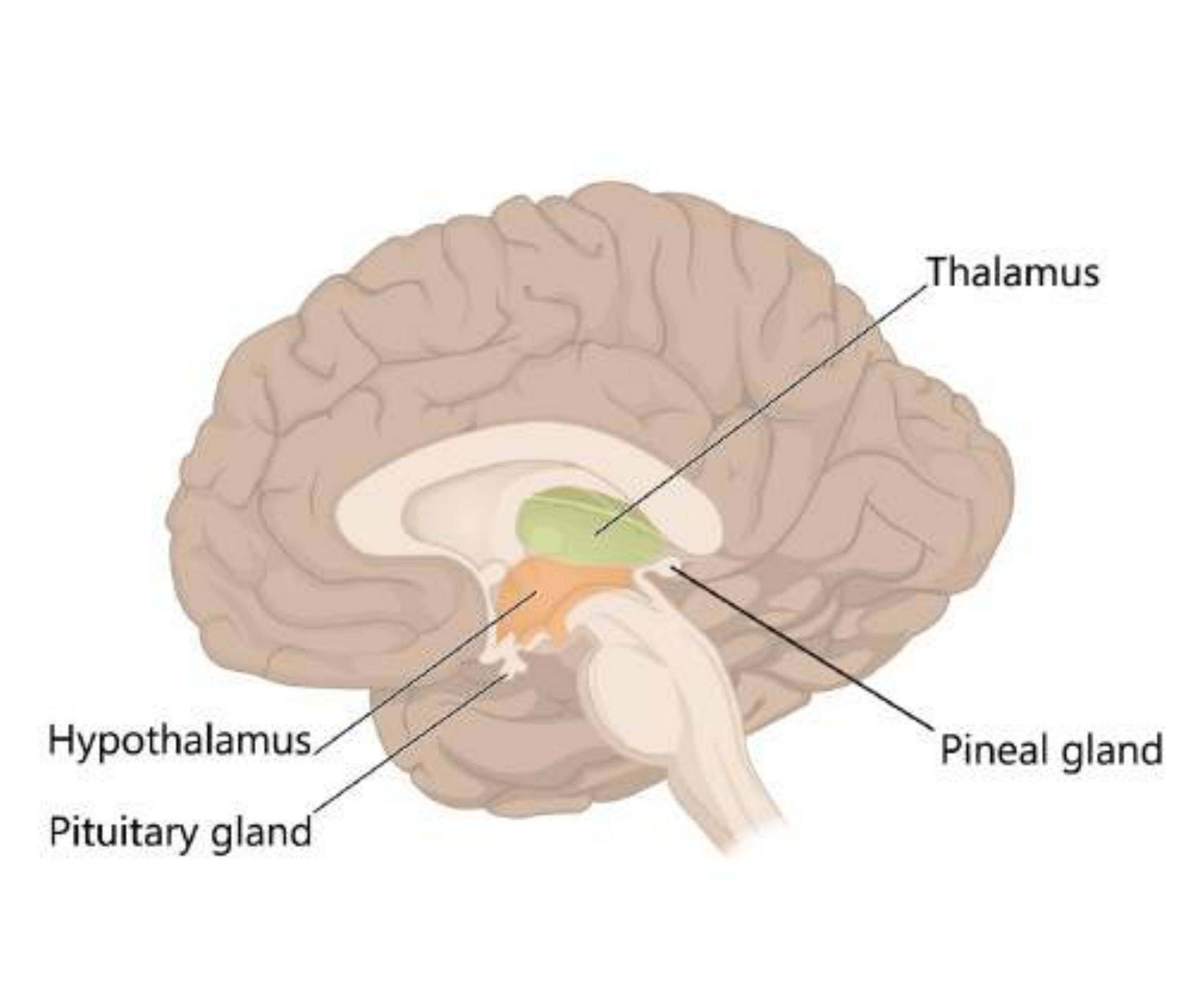
Major Brain Regions: Brain Stem

- Medulla: Breathing, muscle tone and blood pressure
- Pons: Connects brainstem with cerebellum & involved in sleep and arousal
- Cerebellum: Coordination of voluntary movements and sense of equilibrium
- Midbrain: Eye movements, visual and auditory reflexes



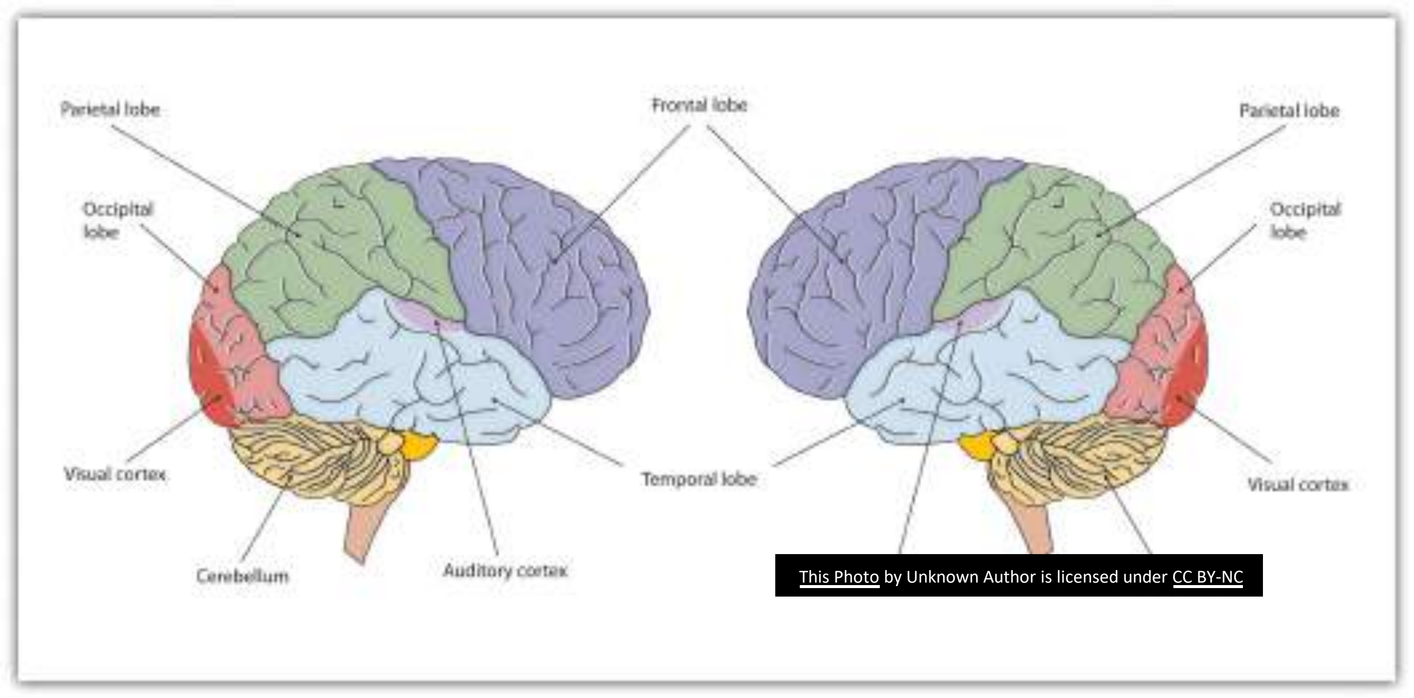
Major Brain Regions: Diencephalon

- Thalamus: Relay station for all sensory info (except smell) to the cortex
- Hypothalamus Regulates basic needs fighting, fleeing, feeding, and mating



Major Brain Regions: Cerebral Hemispheres

- Consists of Cerebral cortex, basal ganglia, hippocampus, and amygdala
- Involved in perception and motor control, cognitive functions, emotion, memory, and learning



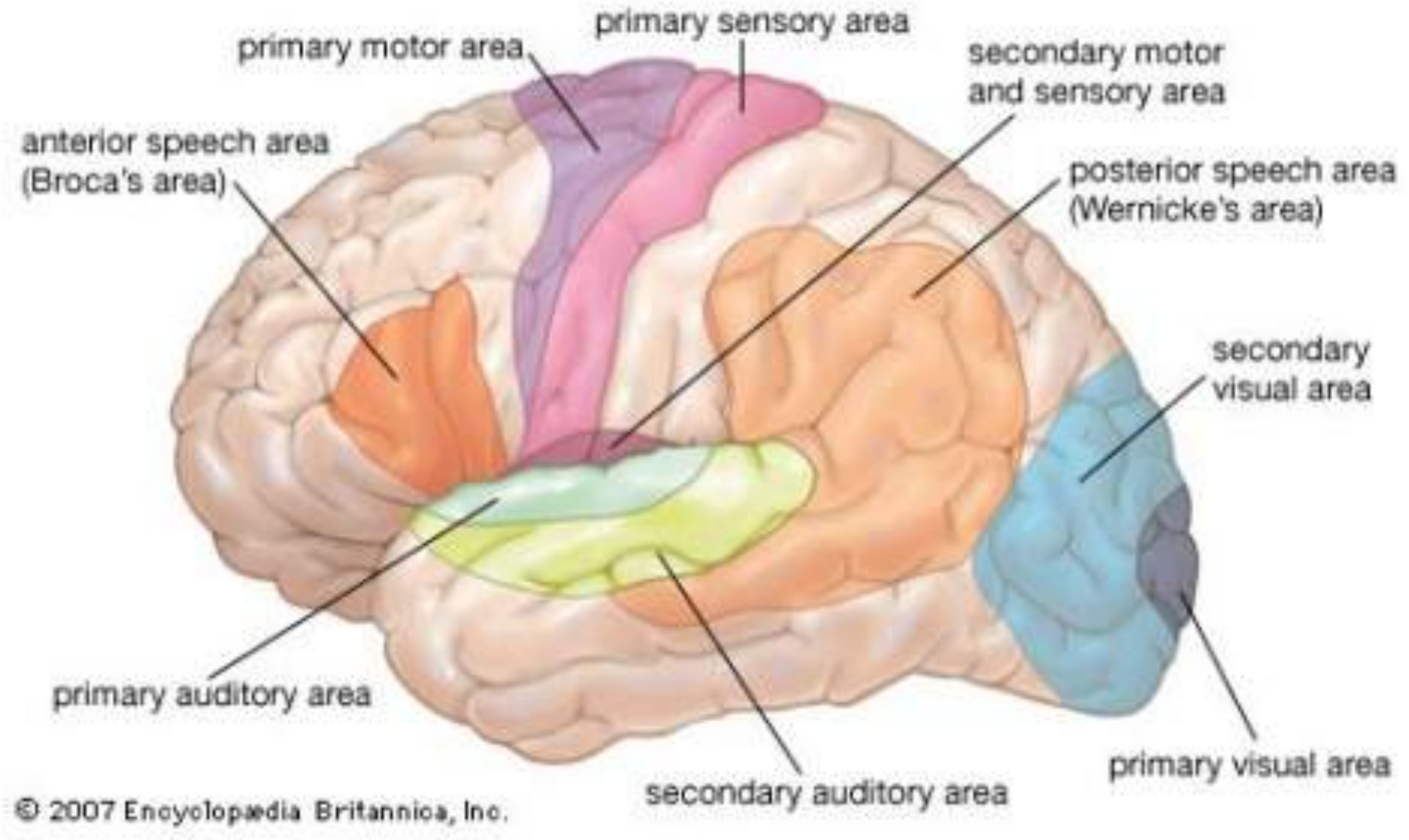


Figure 2.2: Regions of the cerebral cortex [Goldberg, 2002]

Cortical area	Function
Auditory association area	Complex processing of auditory information
Auditory cortex	Detection of sound quality (loudness, tone)
Broca's area (speech center)	Speech production and articulation
Prefrontal cortex	Problem solving, emotion, complex thought
Premotor cortex	Coordination of complex movement
Primary Motor cortex	Initiation of voluntary movement
Primary somatosensory cortex	Receives tactile information from the body
Sensory association area	Processing of multisensory information
Gustatory area	Processing of taste information
Wernicke's area	Language comprehension
Primary Visual Cortex	Complex processing of visual information