EE434
Biomedical Signal Processing
Lecture # 1

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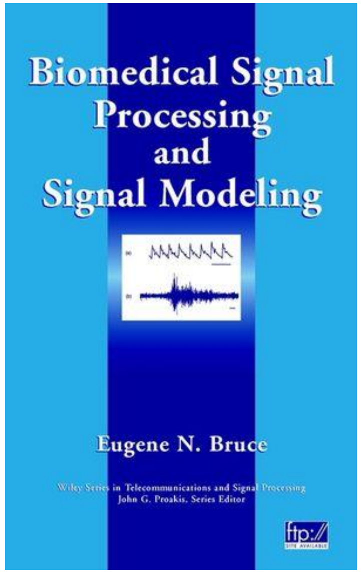
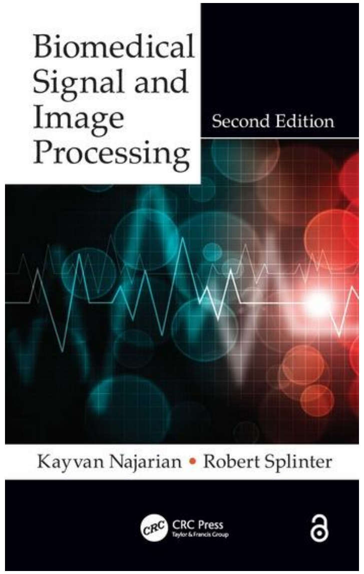
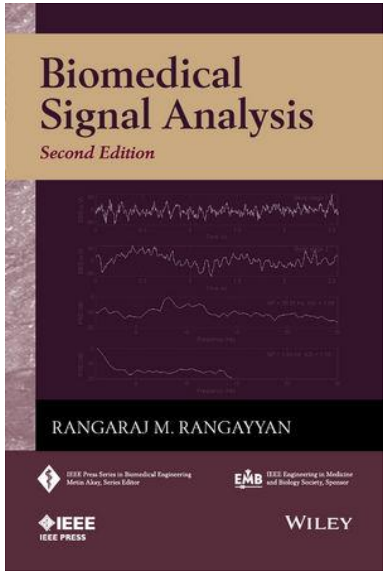
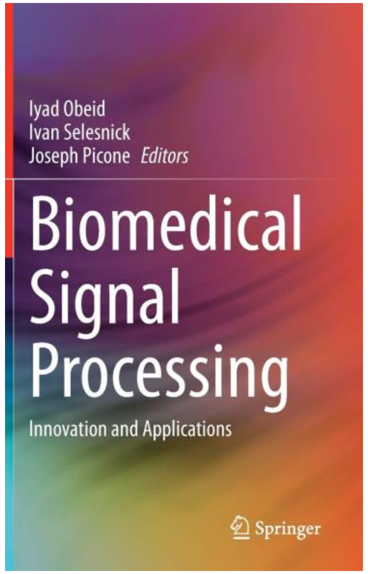
The Books


Biomedical Signal Processing and Signal Modeling
Eugene N. Bruce
Wiley Series in Telecommunications and Signal Processing
John G. Proakis, Series Editor


Biomedical Signal and Image Processing
Second Edition
Kayvan Najarian • Robert Splinter
CRC Press


Biomedical Signal Analysis
Second Edition
RANGARAJ M. RANGAYYAN
IEEE
WILEY


Iyad Obeid
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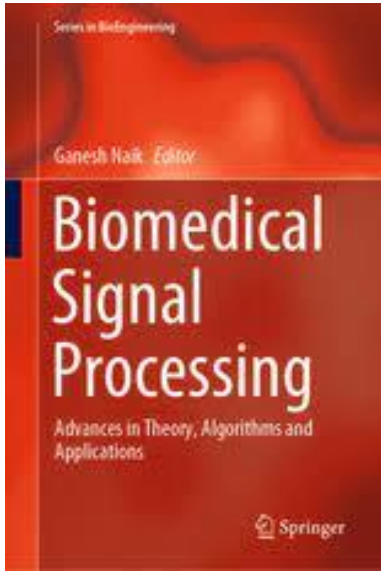
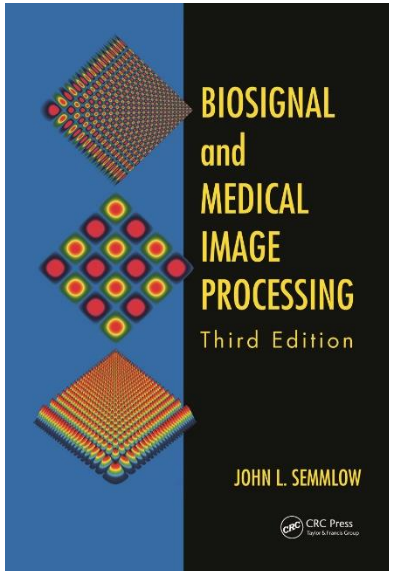
Joseph Picone Editors
Biomedical Signal Processing
Innovation and Applications
Springer


Ganesh Naik Editor
Biomedical Signal Processing
Advances in Theory, Algorithms and Applications
Springer


BIOSIGNAL and MEDICAL IMAGE PROCESSING
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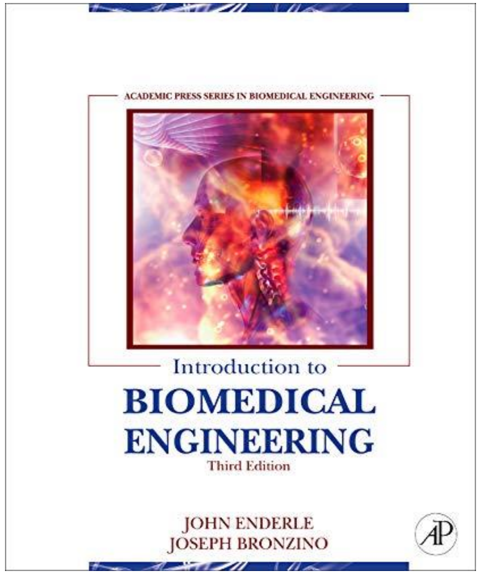
JOHN L. SEMMLOW
CRC Press


ACADEMIC PRESS SERIES IN BIOMEDICAL ENGINEERING
Introduction to BIOMEDICAL ENGINEERING
Third Edition
JOHN ENDERLE
JOSEPH BRONZINO

Tools for Biomedical Signal Processing

Image Processing & Analysis in Java

Download Links:

https://imagej.net/Welcome

https://imagej.nih.gov/ij/

OpenCV (Open Source Computer Vision Library) is an open source computer vision and machine learning software library.

It has C++, Python, Java and MATLAB interfaces and supports Windows, Linux, Android and Mac OS.

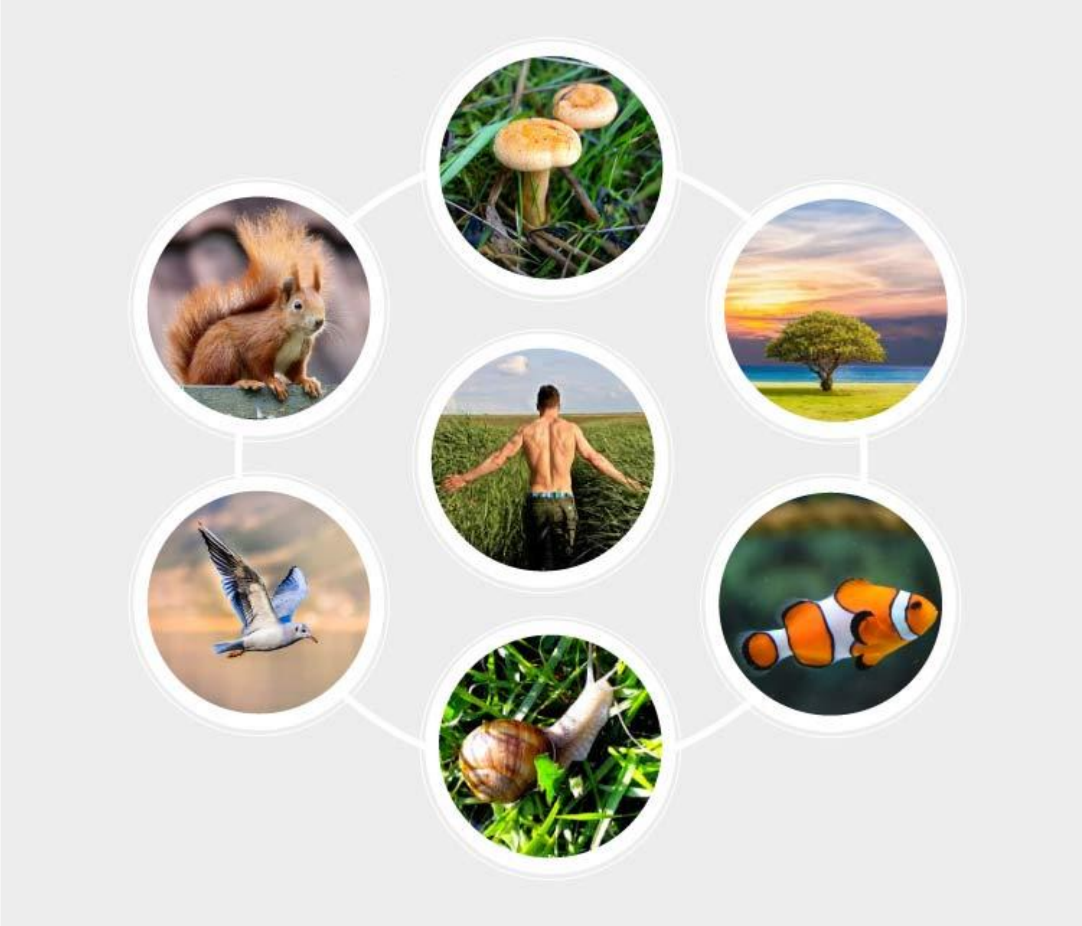
OpenCV is written natively in C++

Characterization of Biomedical Signals

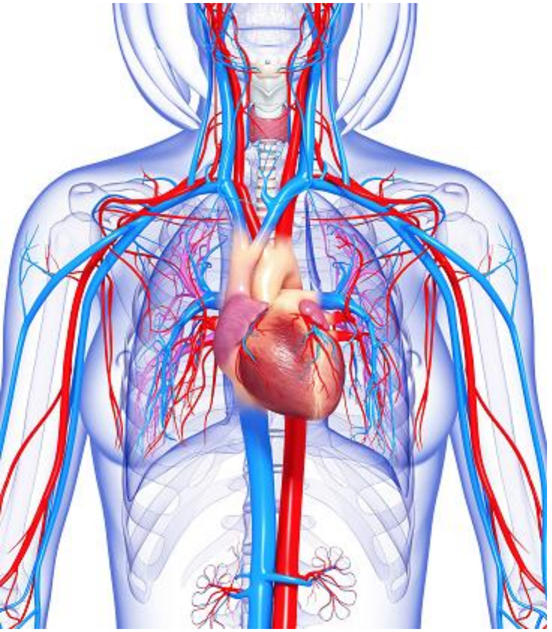
The Nature of Biomedical Signals

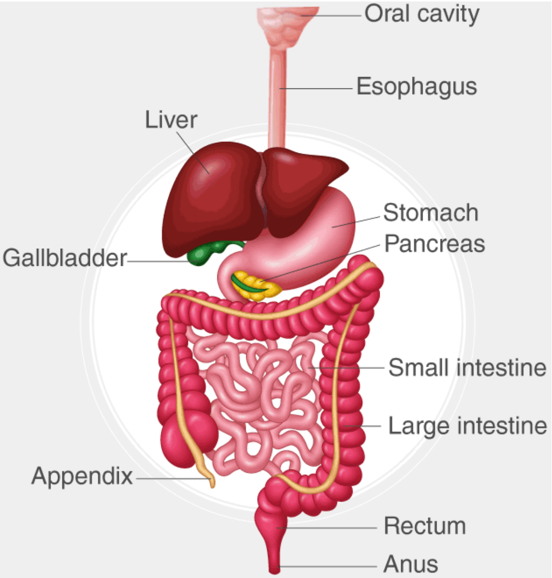
Living organisms are made of many systems – e.g. human body:

- Nervous, cardiovascular, gastrointestinal, endocrine, respiratory, etc.
- Each system is made of subsystems (organs, tissues, etc.) that are responsible for certain **physiological processes**

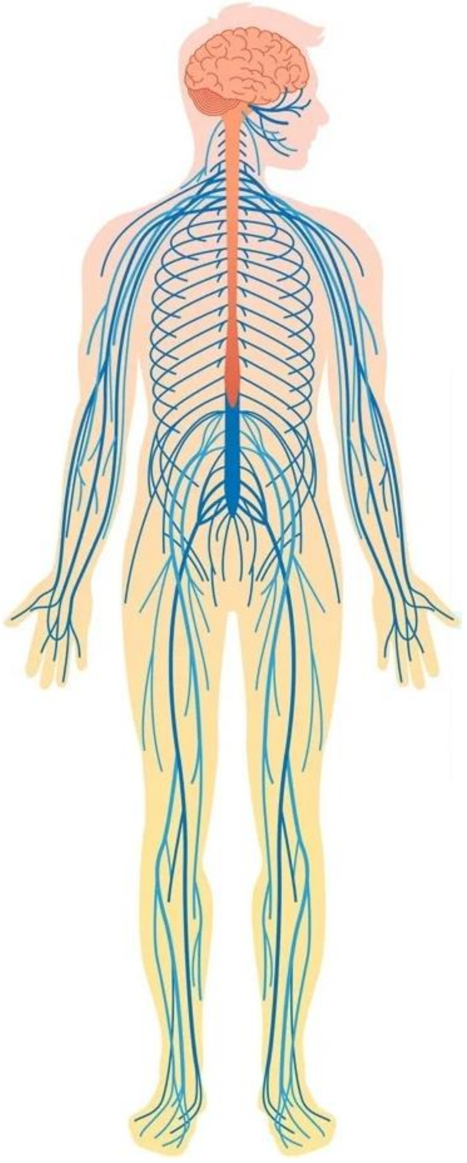


The Nature of Biomedical Signals





- **Cardiovascular system** pumps blood to deliver nutrients to the body
- **Gastrointestinal system** absorbs the food we eat and transforms it into energy and nutrients
- **Nervous system** controls our movements, thoughts and automatic responses to the world around us. It also controls other body systems and processes, such as digestion, breathing and etc.



The Nature of Biomedical Signals

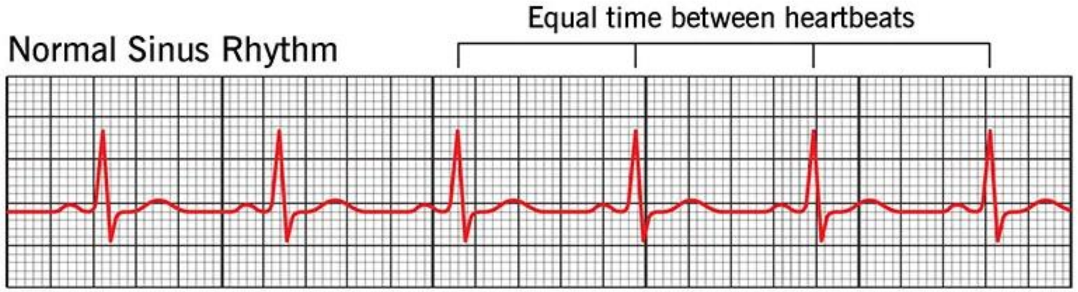
Each **physiological process** is associated with certain types of signals that reflect their nature and activities

Such signals can be of different types:

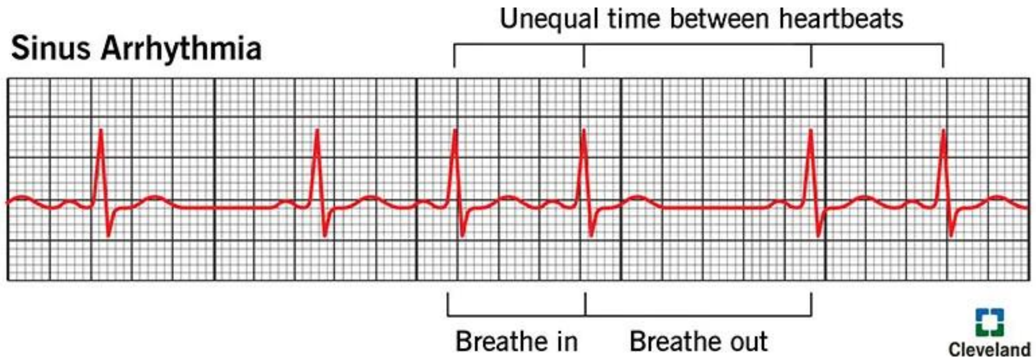
- Biochemical → hormones, neurotransmitters
- Electrical → potentials, currents
- Mechanical → pressure, temperature

The Nature of Biomedical Signals

- Any **deviation** of these signals from their normal parameters typically represents a **disease**/**disorders** → **pathological condition**
- **Observing** these signals and **comparing** them to their known forms, we can often **detect** these pathological conditions



vs.



The Nature of Biomedical Signals

For example:

Most infections

→ an increase in body-core temperature

Cardiovascular disorders

→ arrhythmias in electrocardiogram (ECG), or changes in blood pressure

Certain neurological disorders (such as epilepsy)

→ electroencephalogram (EEG)

The Nature of Biomedical Signals

Each quantity from physiological processes can be measured quantitatively or qualitatively

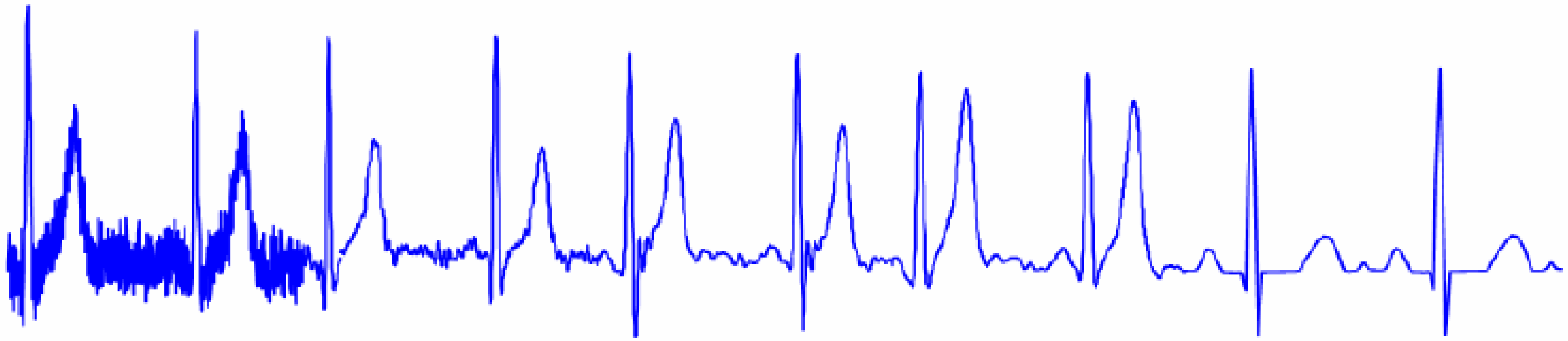
E.g. Increase in body temperature

- Inside of the palm (crude)
- Mercury based thermometer under arm …(better)
- Termistor based thermometer in the artery using a catheter (best)

1-D Signals

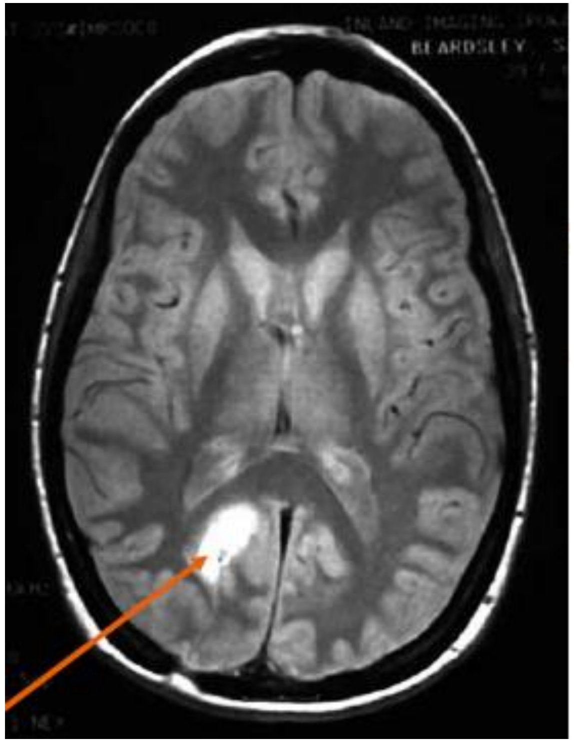
Typical female **core body temperature** variation over one-month

An **ECG** that is progressively been cleaned from noise

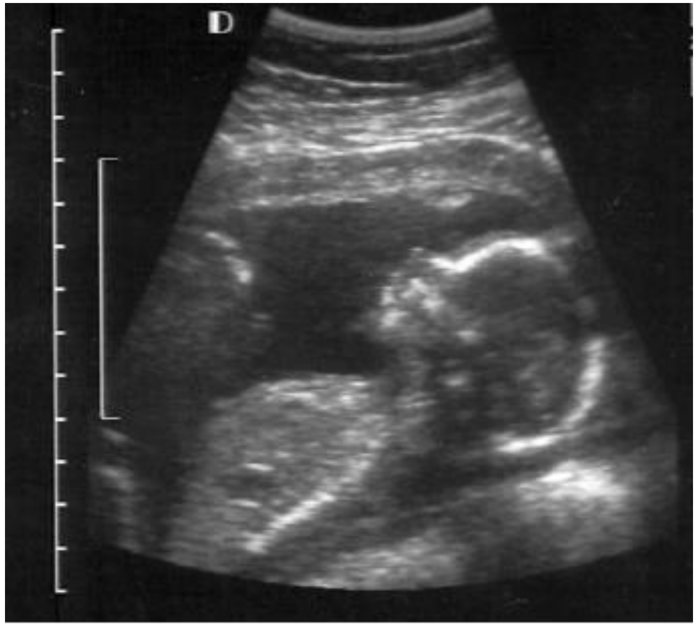


2-D Signals

Images are also used very often in medicine – these are simply two-dimensional signals



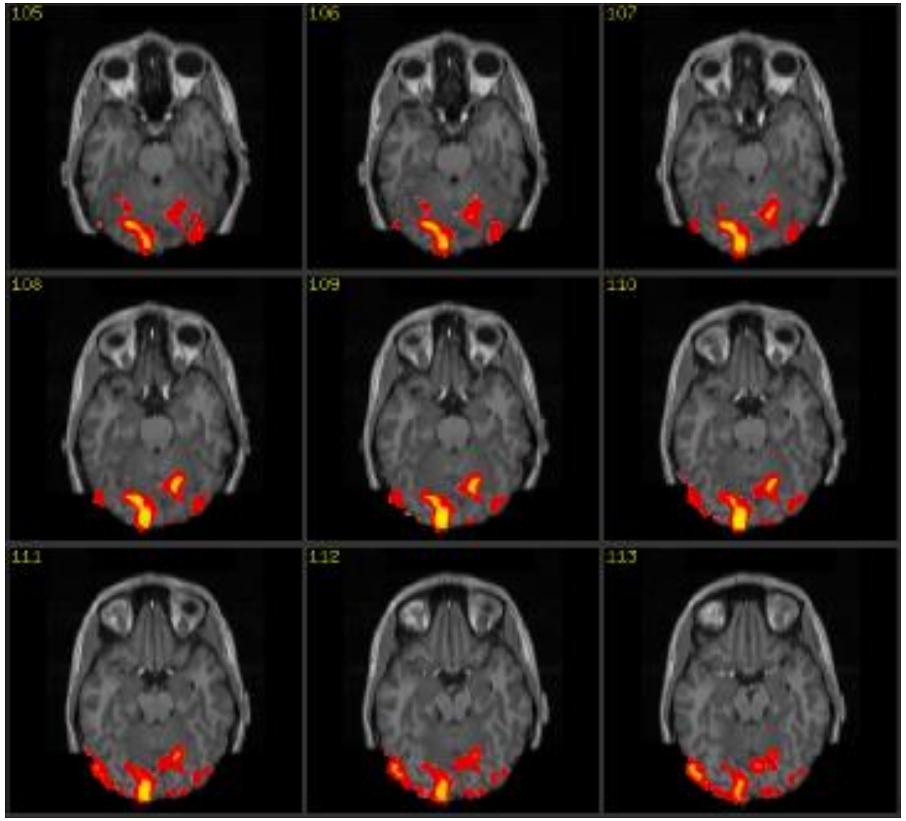
An MR image that shows a tumor

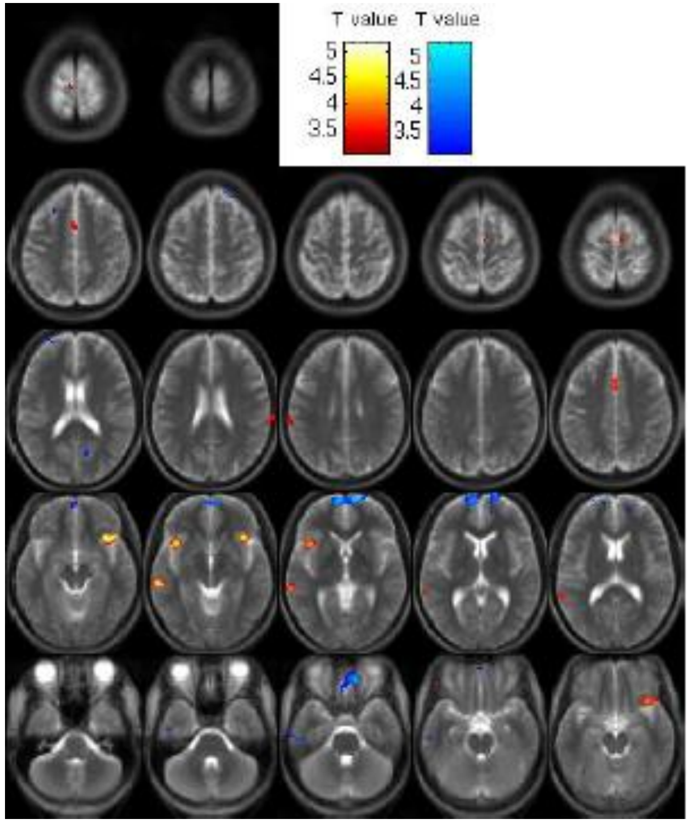


A fetal ultrasound image

3-D Signals

3-D signals, in the form of stacks or series of 2-D images have also common in medical imaging





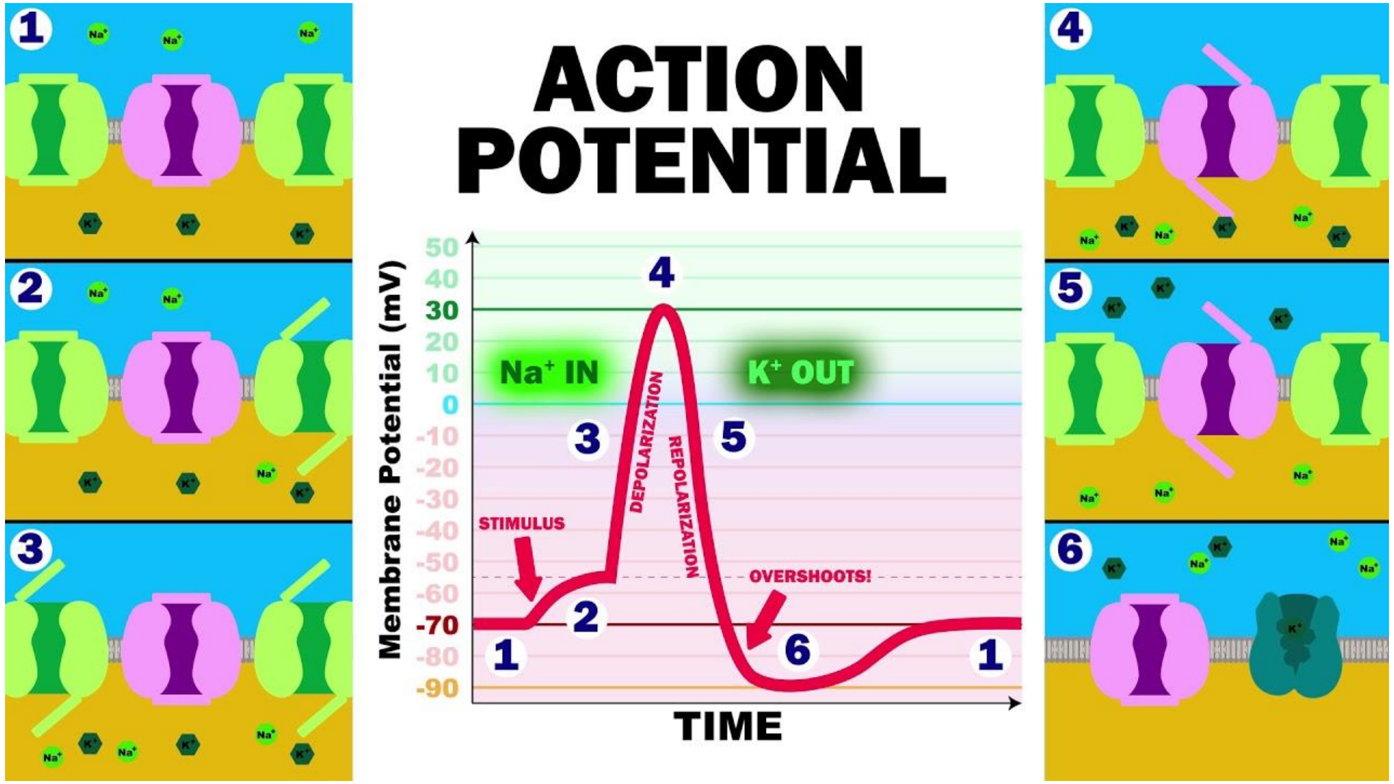
Functional MR images (fMRI)

Some Commonly used Biomedical Signals

- **The action potential** – mother of all biological signals
- **The electroneurogram (ENG)** – propagation of nerve action potential
- **The electromyogram (EMG)** – electrical activity of the muscle cells
- **The electrocardiogram (ECG)** – electrical activity of the heart / cardiac cells
- **The electroencephalogram (EEG)** – electrical activity of the brain
- **The electrogastogram (EGG)** – electrical activity of the stomach
- **The phonocardiogram (PCG)** – audio recording of the heart’s mechanical activity
- **The carotid pulse (CP)** – pressure of the carotid artery
- **The electoretinogram (ERG)** – electrical activity of the retinal cells
- **The electrooculogram (EOG)** – electrical activity of the eye muscles

The **action potential (AP)** is the origin of all biopotentials

- All biological signals of electrical origin are made up from integration of many action potentials



https://i.ytimg.com/vi/8-UBA_Ysgds/maxresdefault.jpg

1. The Action Potential (AP)

The **AP** is the electrical signal that is generated by a single cell when it is mechanically, electrically or chemically stimulated

- It is the primary mechanism through which electrical signals propagate between cells, tissues and organs
- It is due in part, to an electrochemical imbalance across the cell membrane, and in part, due to selective permeability of the membrane to certain ions

Working Mechanism:

- At resting state, the cell membrane is permeable to K^+ and Cl^-, but not to Na^+
- Lots of Na^+ trapped outside make the intracellular region electrically more negative, with a resting membrane potential of -60 ~-80 mV
- When the cell is disturbed, ion channels across the membrane open up and allow an influx of Na^+ : depolarization → inside of the cell becomes more positive: +20mV

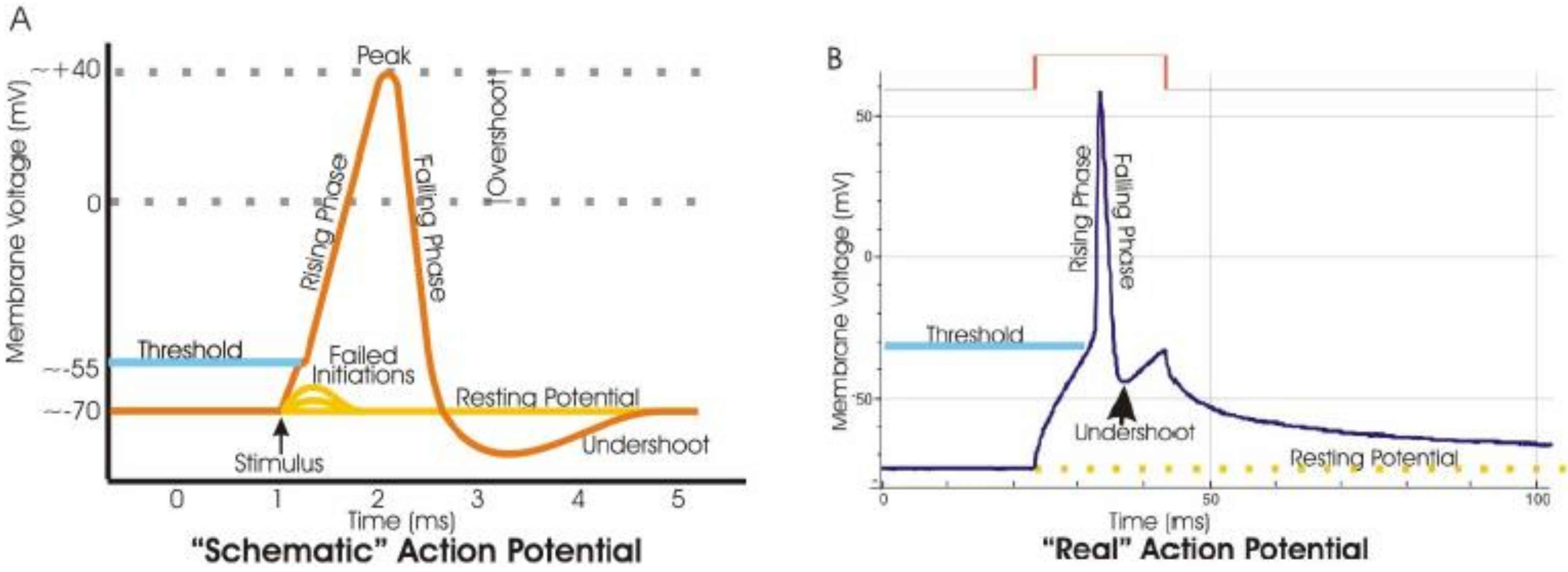
1. The Action Potential (AP)

- However, the channels close soon after, forcing the membrane potential back to its resting stage: repolarization
- The change in membrane potential is the **AP**, which itself then stimulates the neighboring cell, and starts the transmission of the **AP**s

You may look at the animation at [YouTube] to understand this mechanism better.

Recording an **AP** requires the isolation of a single cell

- Microelectrodes (with tips a few μm across) are used to stimulate and record the response. A typical **AP** is 2-4ms long with an amplitude of about 100mV



More on Action Potential

Why it is important?

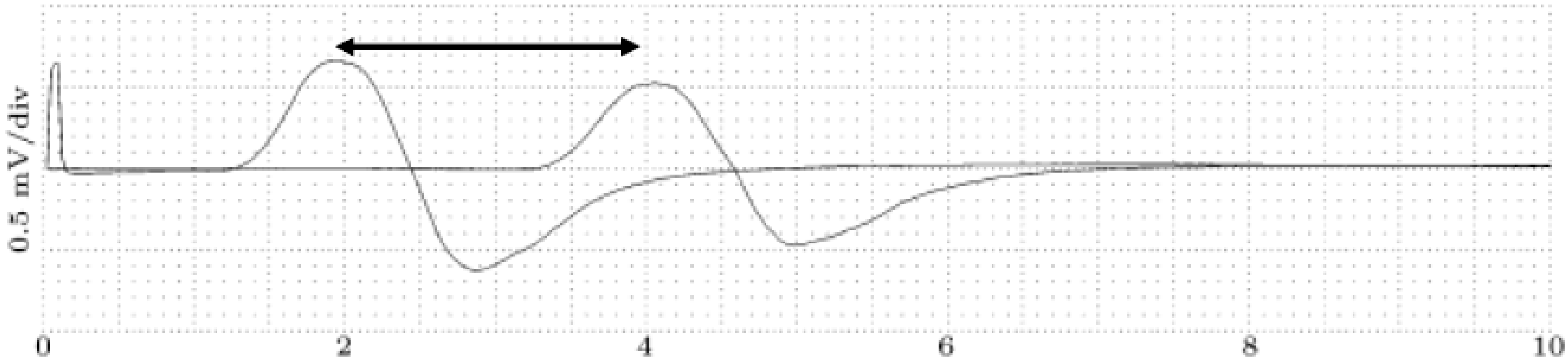
- The **AP** is the basic component of all bioelectric signals – **ECG**, **EEG**, etc. are all integration of many, many **AP**s,
- and understanding the **AP** will therefore be most useful for **characterizing** and **processing** other signals

2. The Electroneurogram (ENG)

ENG is the **response of a (peripheral) nerve cell** when it is stimulated with an electrical shock

- Acquired using needle electrodes
- Used to determine the conduction velocity of the nerve
  - If the **nerve** does not respond quickly enough, or does not respond at all, it signifies a **nerve injury**
  - The conduction velocity is measured by placing two electrodes at close-by locations and recording the **ENG** at both locations. The temporal difference between the two **ENG** can then be used to obtain conduction velocity

2. The Electroneurogram (ENG)



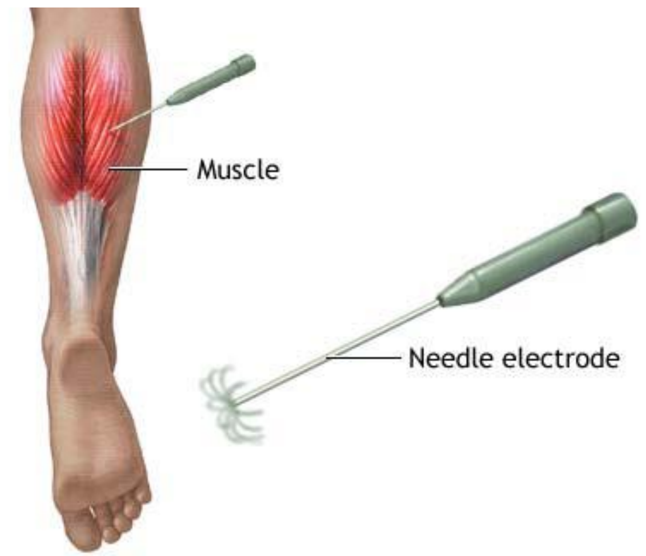
3. The Electromyogram (EMG)

The **EMG** is the graphic representation of the **electrical activity of the skeletal muscles** – either during resting stage, or in response to stimulation

- Unlike **AP** which is measured on the cellular level, the **EMG** is a surface signal obtained through surface and/or needle electrodes
  - It is the collection / integration / amalgamation of millions of muscle **AP**s as measured from the skin surface

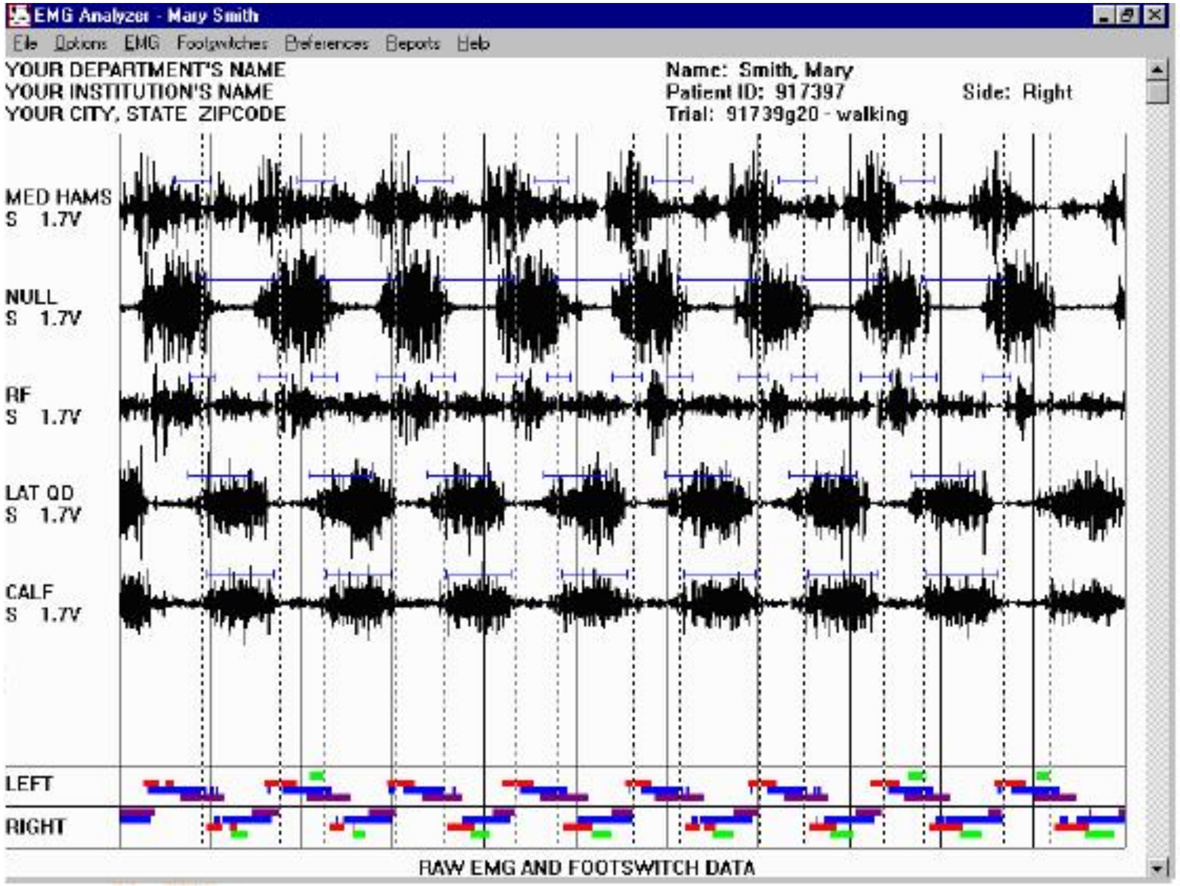
3. The Electromyogram (EMG)

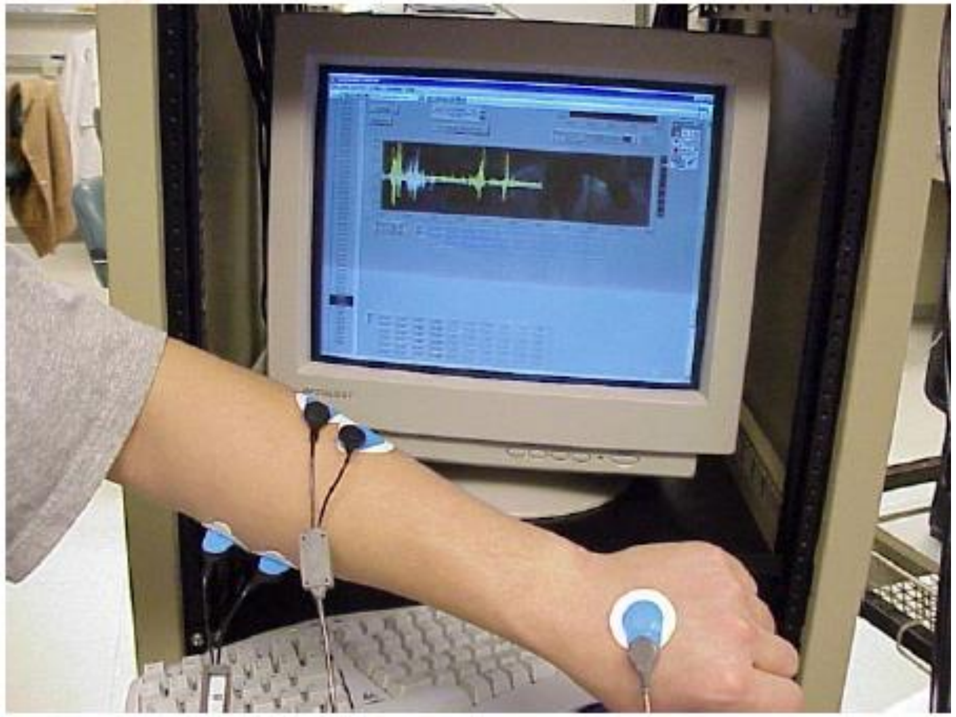
- The **EMG** is used to determine whether a person's perceived muscle weakness is caused by a disease within the muscle or by a problem in a nerve supplying the muscle.



- It is an invasive test. It is performed by inserting needles into muscles and measuring their responsiveness to electrical stimulation. The patient will feel light electrical shocks in the muscles that are tested during the **EMG**.

3. The Electromyogram (EMG)



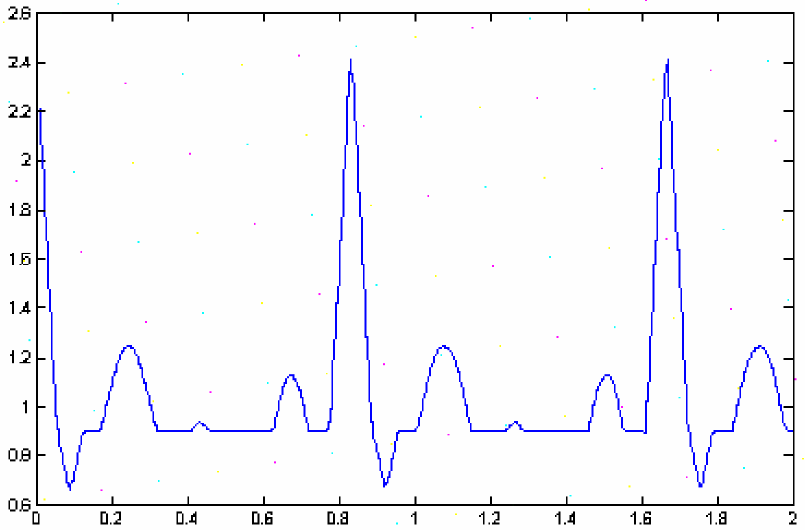


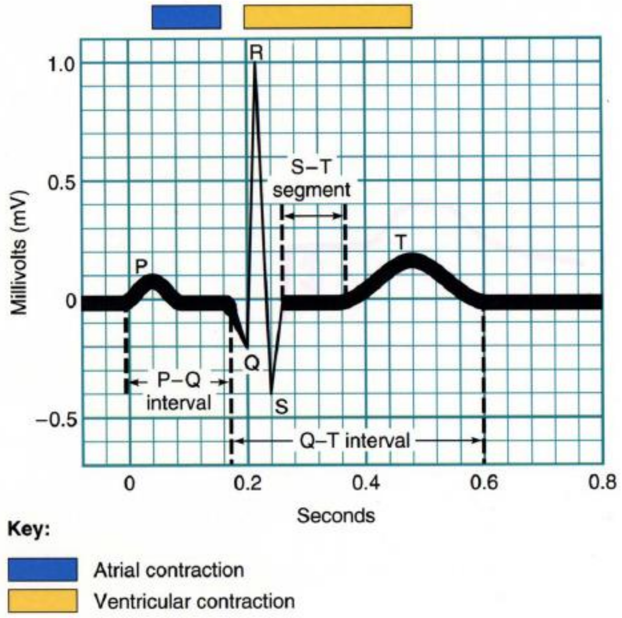
http://www.pitt.edu/~zmli/handlab/image/EMG.JPG

4. The Electrocardiogram (ECG)

ECG is the graphical recording of the **electrical activity of the heart**

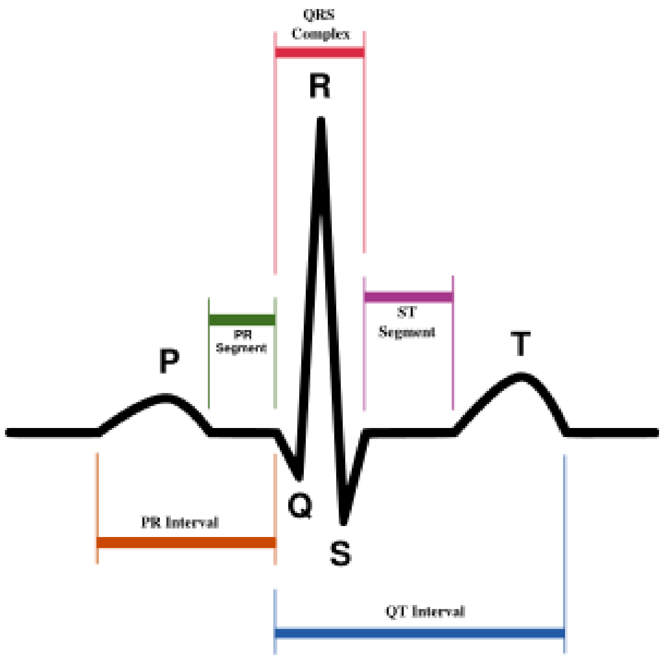
- It is by far the most easily recognized biological signal, and it is also the one that is most commonly used for clinical diagnosis
  - It is routinely used in clinical settings for checking the vital signs of a patient, or the cardiovascular health of a patient
  - The existence of **ECG** (hence the existence of the pulse) single handedly indicates the presence of life



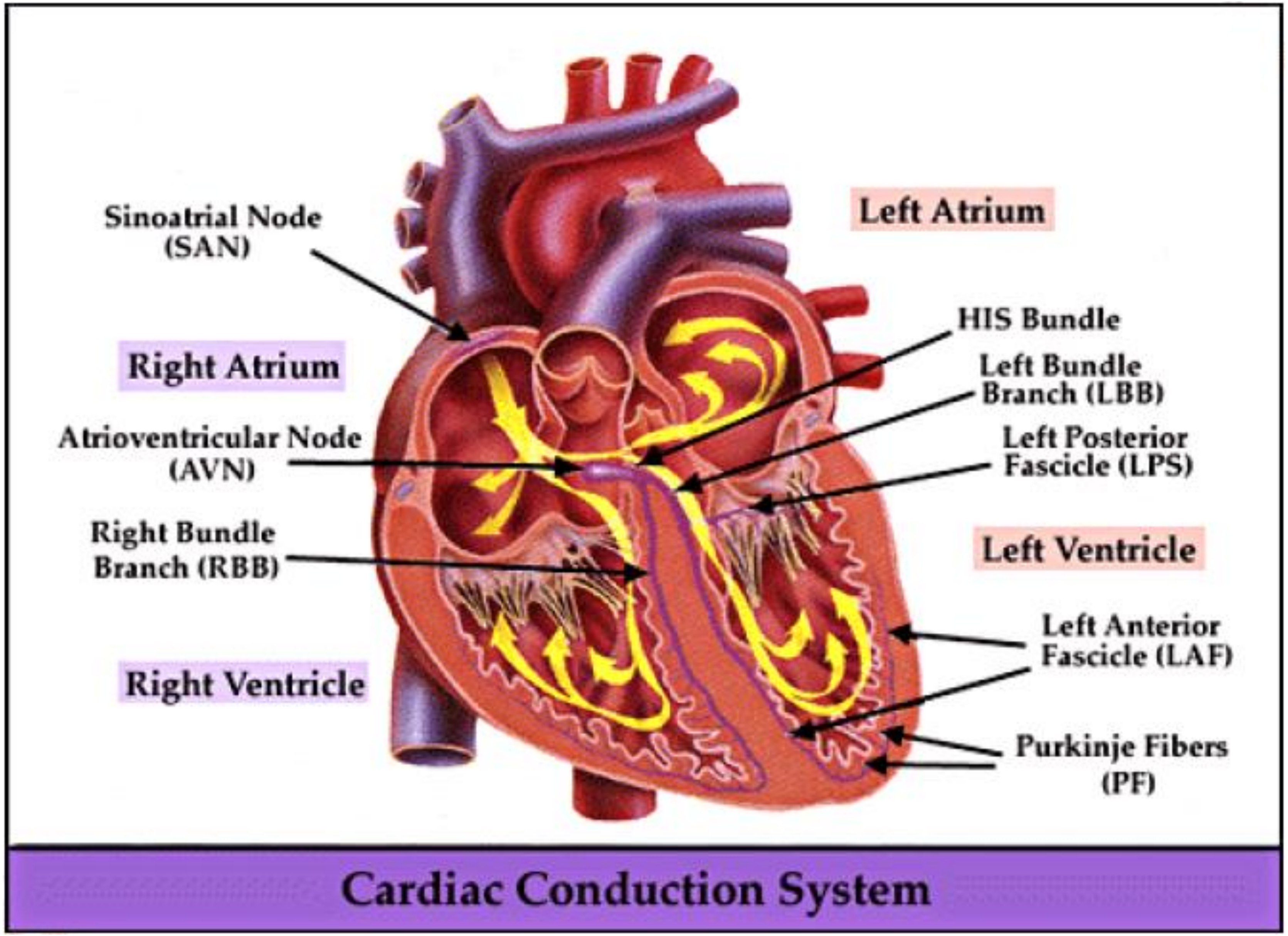


4. The Electrocardiogram (ECG)

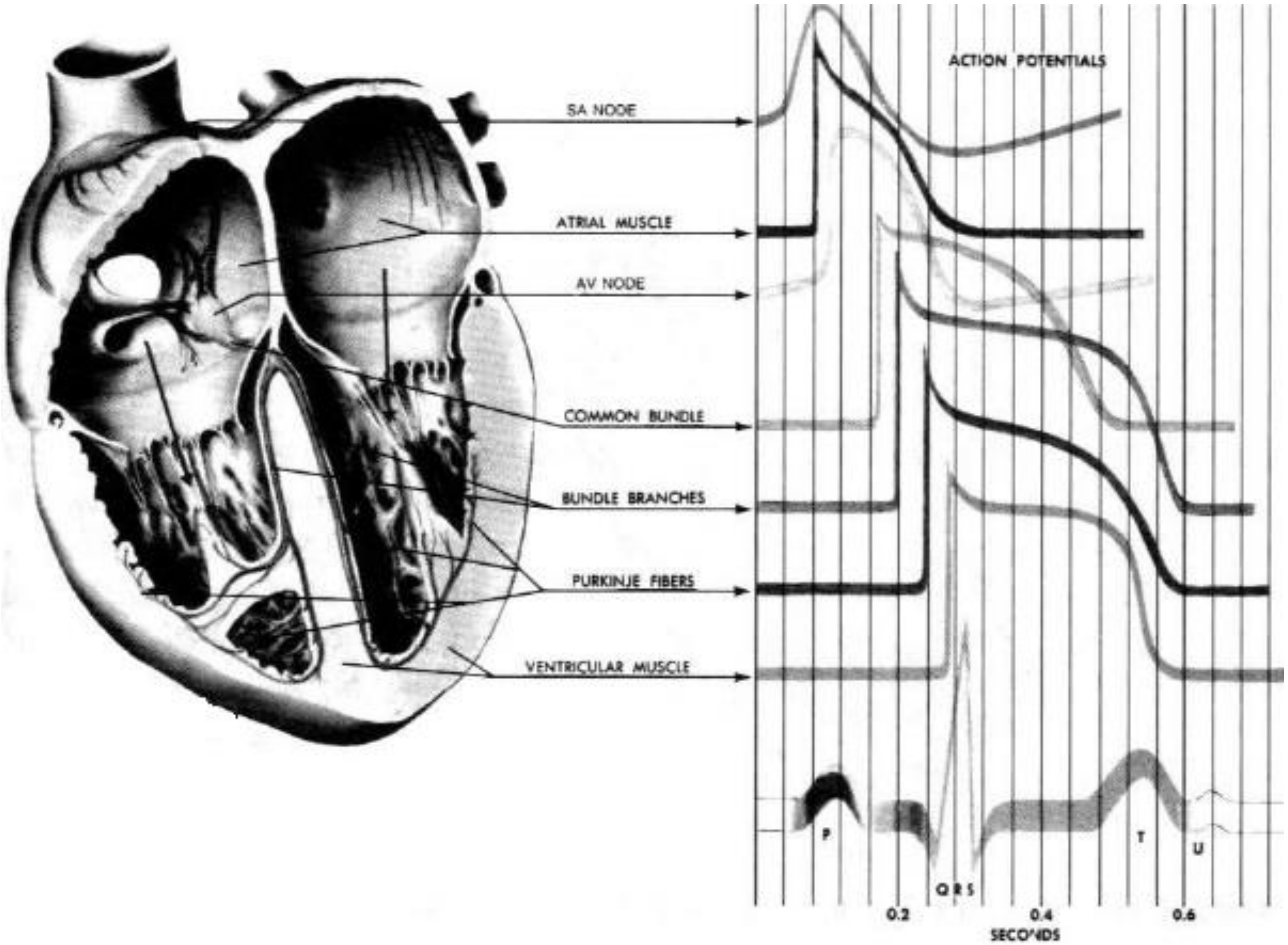
- **ECG** can be obtained easily using surface electrodes
- As with other electrical signals of biological origin, it is the combination of many **AP**s from different regions of the heart that makes up the **ECG**
  - Its characteristic shape is widely recognized
  - It consists of a large peak (QRS) indicating the main contraction of the ventricular muscles, along with several other peaks representing the contraction and relaxation of different cardiac muscle groups



Cardiac Conduction System



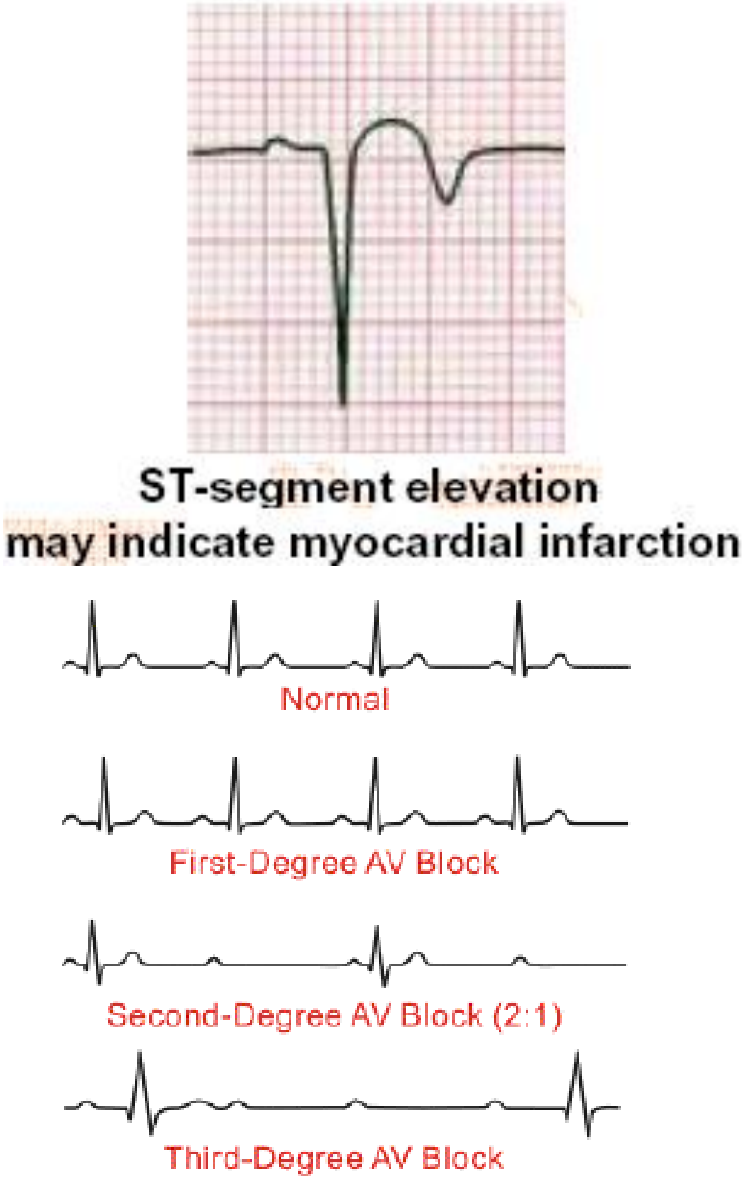
4. The Electrocardiogram (ECG)



Arrhythmias in ECG

Any abnormality in the cardiovascular dynamics manifests itself as an arrhythmia in the **ECG**

- By analyzing the **ECG**s, the cardiologist can typically make a diagnosis.
- Automated diagnosis based on **ECG** analysis using signal processing and pattern recognition techniques have been very popular recently



http://cvpharmacology.com/

5. The Electroencephalogram (EEG)

EEG is the graphical representation of the **electrical activity of the brain**

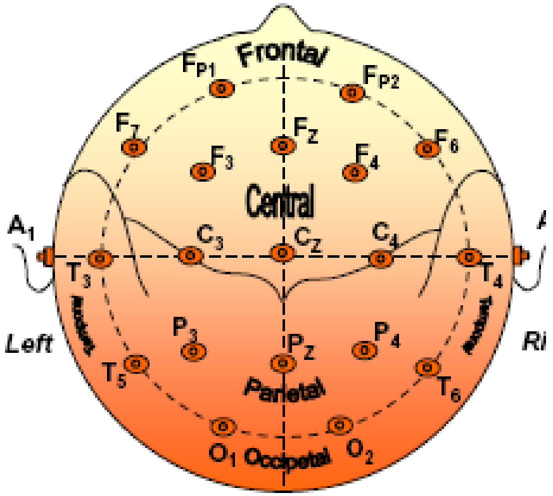
- Very commonly used to diagnose certain neurological disorders, such as epilepsy
- More recently, also investigated whether it can detect various forms of dementia or schizophrenia

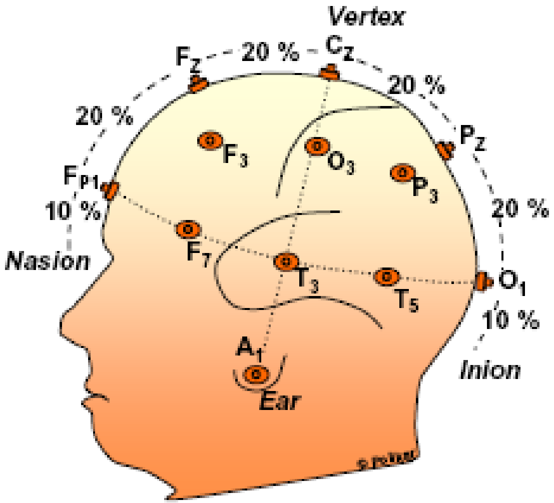
5. The Electroencephalogram (EEG)

- **EEG** is the specific recording obtained using the scalp electrodes from the surface of the skull
  - During surgery, electrodes may also be placed directly on the cortex. The resulting signal is then electrocorticogram (**ECoG**)
  - Just like **ECG**, **EEG** is also obtained using several different electrodes places on different regions of the head / brain

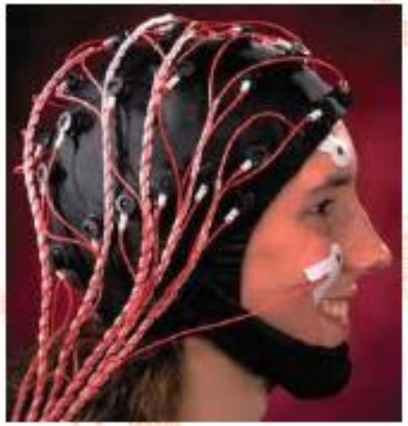
10-20 International Electrode Placement

- Traditionally, electrodes are placed at standard locations





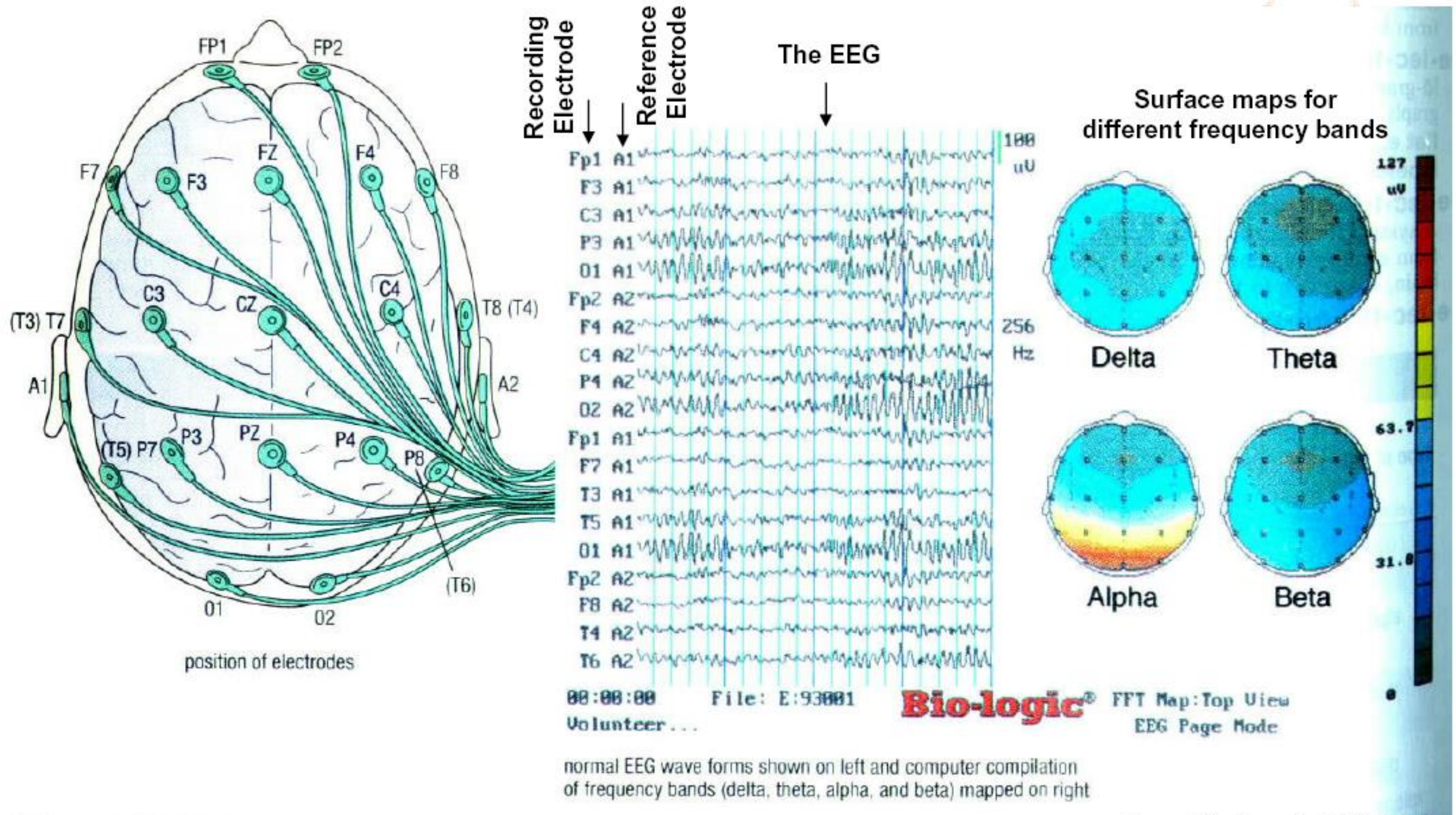
- However, recently electrode-caps allowed additional (64-128) electrodes to be used


http://www.shifz.org/race/eeg2.htm


http://ieng9.ucsd.edu/~phammon/


http://local.wasp.uwa.edu.au/~pbourke/other/eeg/

The EEG Signals



normal EEG wave forms shown on left and computer compilation of frequency bands (delta, theta, alpha, and beta) mapped on right

electroencephalography

From Stedman's 28th Edition

The EEG Signals

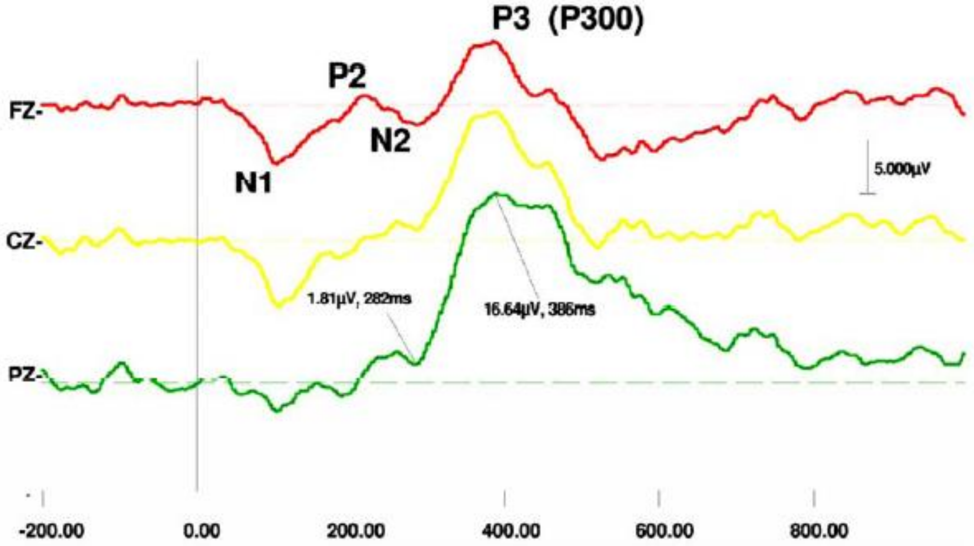
- **EEG** signals are of extremely small amplitude – typically in the μV range
  - Often analyzed in four frequency bands that are associated with certain activities:
    - δ: 0.5 – 4 Hz
    - θ: 4 – 8 Hz
    - α: 8 - 13 Hz
    - β: 13 - 30 Hz

electroencephalogram

type of wave	shape	frequency per sec.	amplitude in µV	physiologic variations of potential: in waking EEG – adult	in waking EEG – child	in sleeping EEG – all ages
beta		14–30	5–50	frontal and precentral prominent, in clusters	seldom prominent	beta-activity ("spindles") sign of light sleep
alpha		8–13	20–120	predominant activity	predominant activity, age 5 and above	not a sign of sleep
theta		4–7	20–100	constant, not prominent	predominant activity, from 18 mos. to 5 yrs.	normal sign of sleep
delta		0.5–3	5–250	not prominent	predominant activity until 18 mos.	concomitant sign of deep sleep
gamma	—	31–60	–10	laws governing predominance and localization not fully known		

ERPs are really **EEG**s obtained under a specific protocol that requires the patient to response to certain stimuli – hence **event related potentials**

- Also called evoked potentials these signals can be used to diagnose certain neurological disorders such as dementia, and they can also be used as a liedetector
  - The oddball paradigm
  - The guilty knowledge test



http://www.bnl.gov/neuropsychology/ERPs_al.asp

6. The Electrogastrogram (EGG)

The **EGG** is the graphical representation of the **electrical activity of the stomach**

- Created by the rhythmic depolarization and repolarization of the underlying smooth muscle cells of the stomach

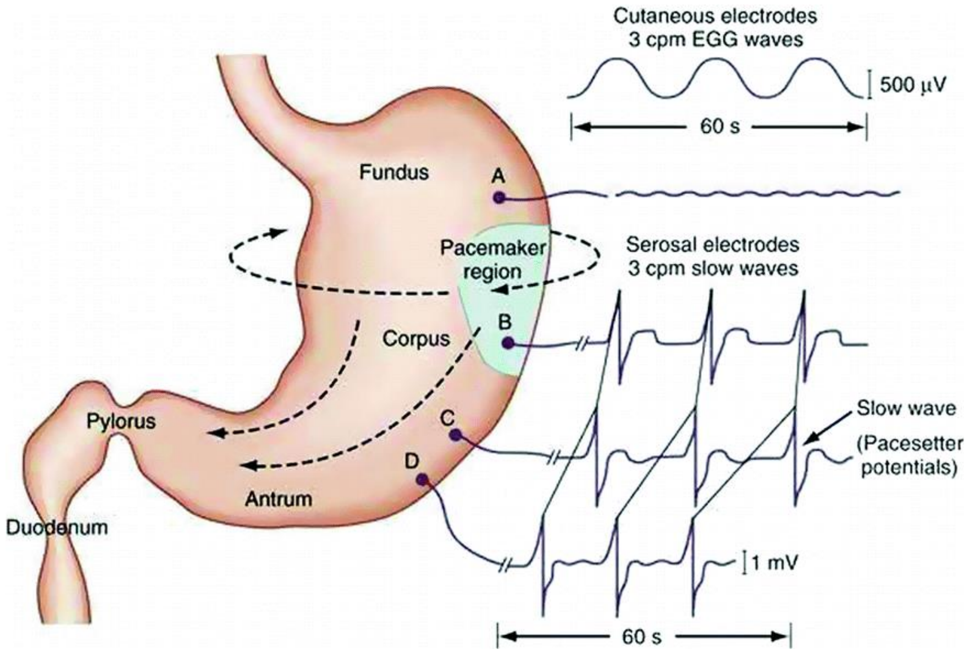
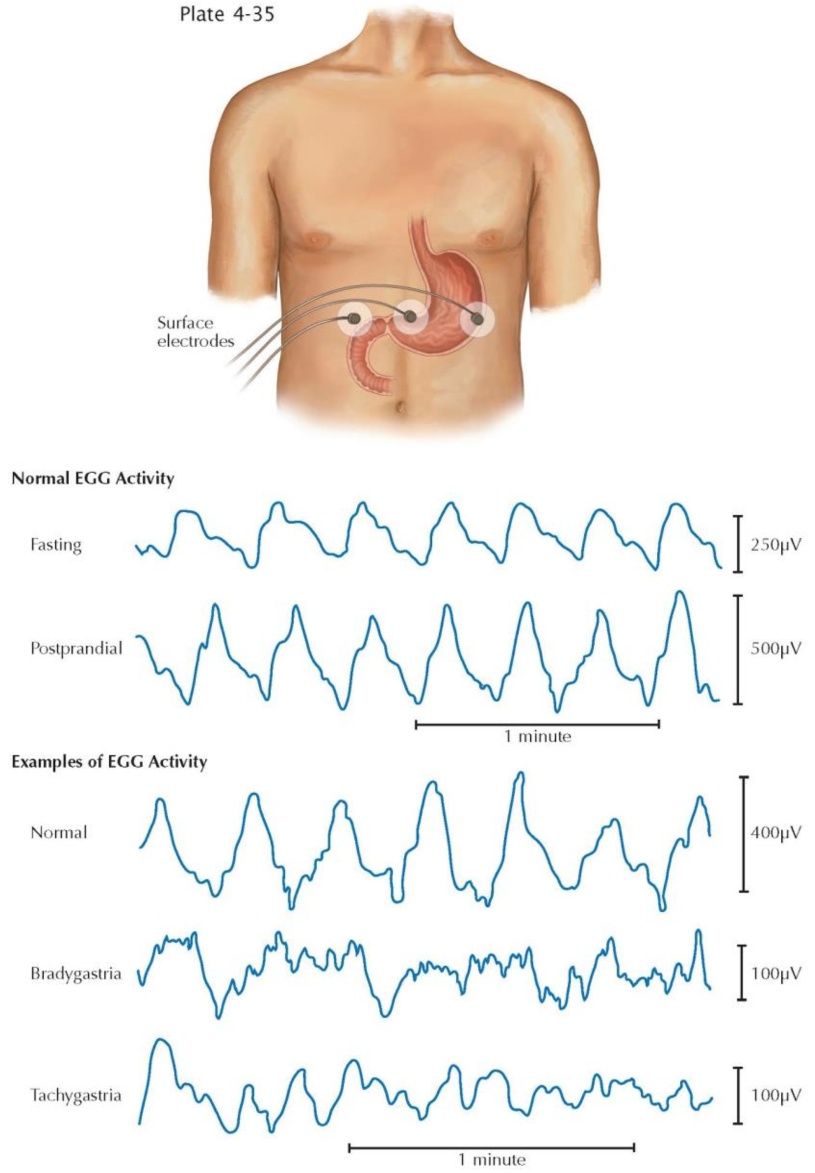


Figure 1. EGG electrode placement.

6. The Electrogastrogram (EGG)

- Just like the **EEG**, the **EGG** activity is always present and it is not in response to specific contractions of the stomach muscle
- **EGG** is also obtained using surface electrodes



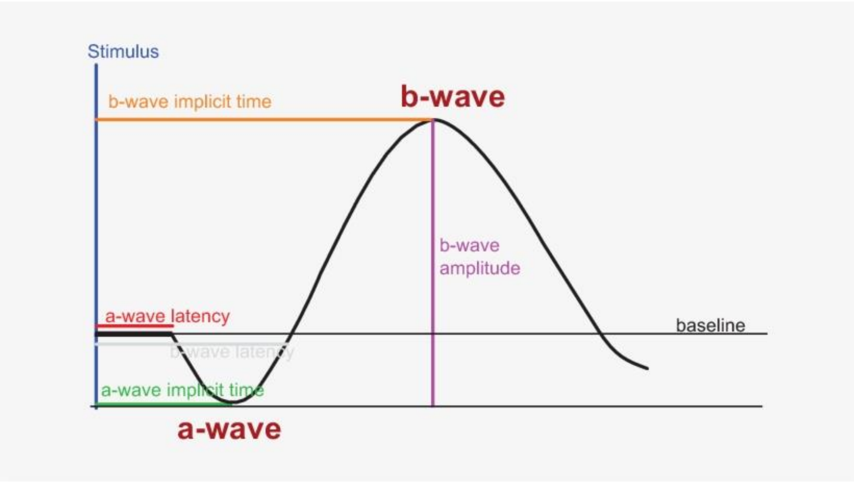
7. The Electroretinogram (ERG)

The **ERG** is the **record of the retinal action currents** produced by the retina in response to a light stimulus

- The **ERG** is recorded using contact lens electrode that the subject wears while watching the stimuli

7. The Electroretinogram (ERG)

- It measures the electrical responses of the light-sensitive cells (such as rods and cones). The stimuli are often a series of light flashes or rotating patterns



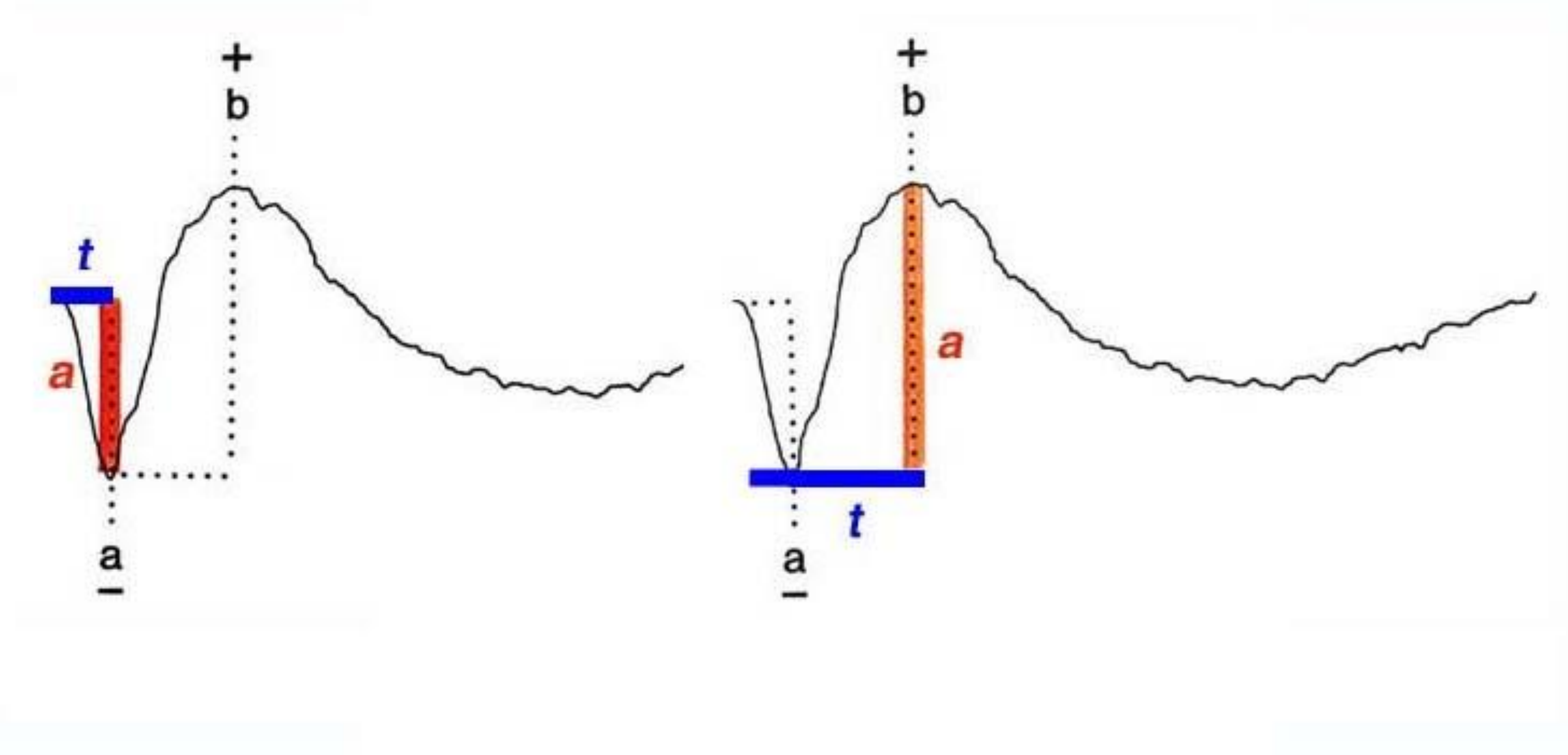


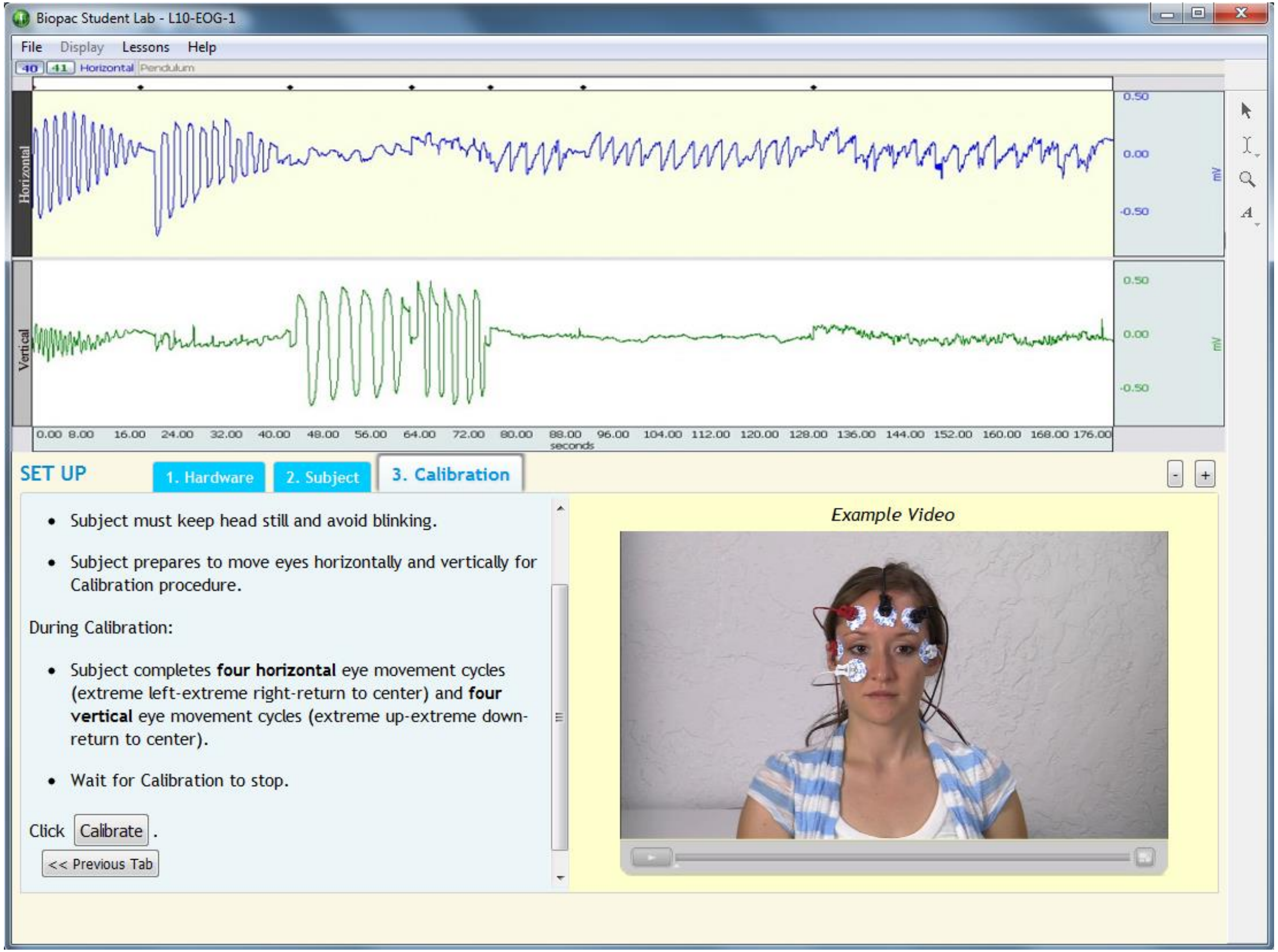
Fig.2 Amplitude and implicit time measurements of the ERG waveform.

8. The Electrooculogram (EOG)

The **EOG** measures the **resting potential of the re**tina. Unlike **ERG** it is not recorded in response to a stimulus

- The **EOG** is often used in recording the eye-movements (such as in VR applications, or as a reference in **EEG** applications to remove eye-blink artifacts)
- **EOG** is also used in diagnosing certain sleep disorders, where the active REM can easily be recorded using the **EOG**

8. The Electrooculogram (EOG)



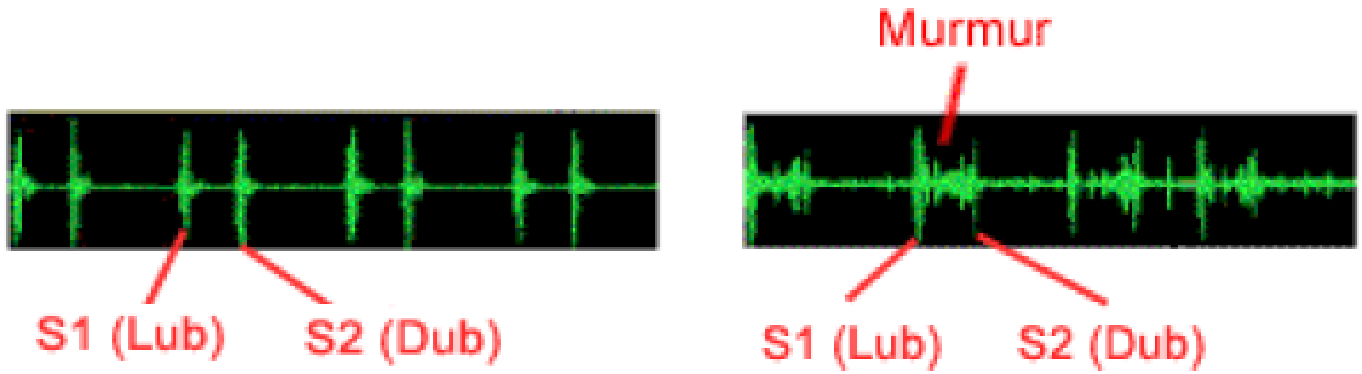
9. Phonocardiogram (PCG)

The PCG is the **graphic record of the heart sounds and murmurs**. It is thus a mechanical / audio signal, rather than an electrical signal

- Can be easily heard using a stethoscope
- Or can be converted into an electrical signal using a transducer
- Typically used to determine the disorders related to the heart valve, since their routine opening and closing create the well-known sounds.

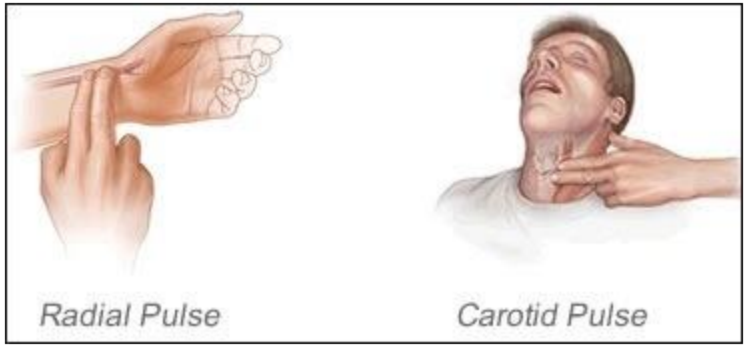
9. Phonocardiogram (PCG)

- S1 sounds: First heart sounds – ventricular contractions move blood into atria closing of the AV (mitral and tricuspid) valves, then semilunar valves open and blood ejected out of ventricles – immediately follows the QRS complex
- S2 sounds: Second heart sounds – Closure of semilunar (aortic and pulmonary) valves
- Any unexpected sound may indicate a malfunctioning valve that causes the blood flow into / out of a chamber when it should not. Also called heart murmurs



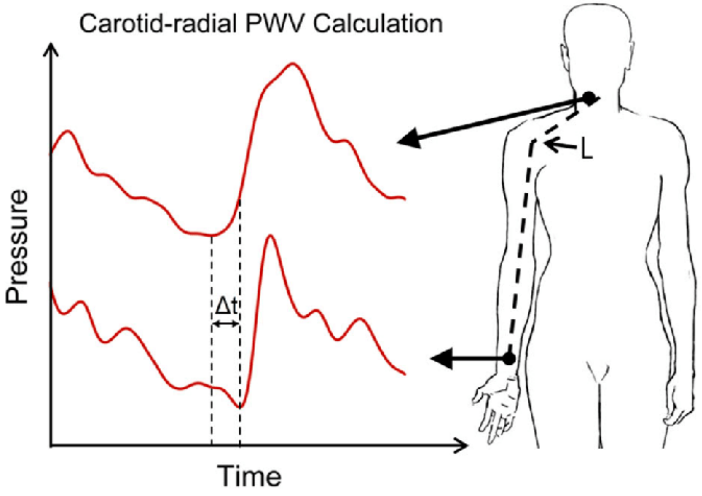
10. The Carotid Pulse (CP)

CP is a **mechanical signal measured using pressure transducer over the carotid artery**



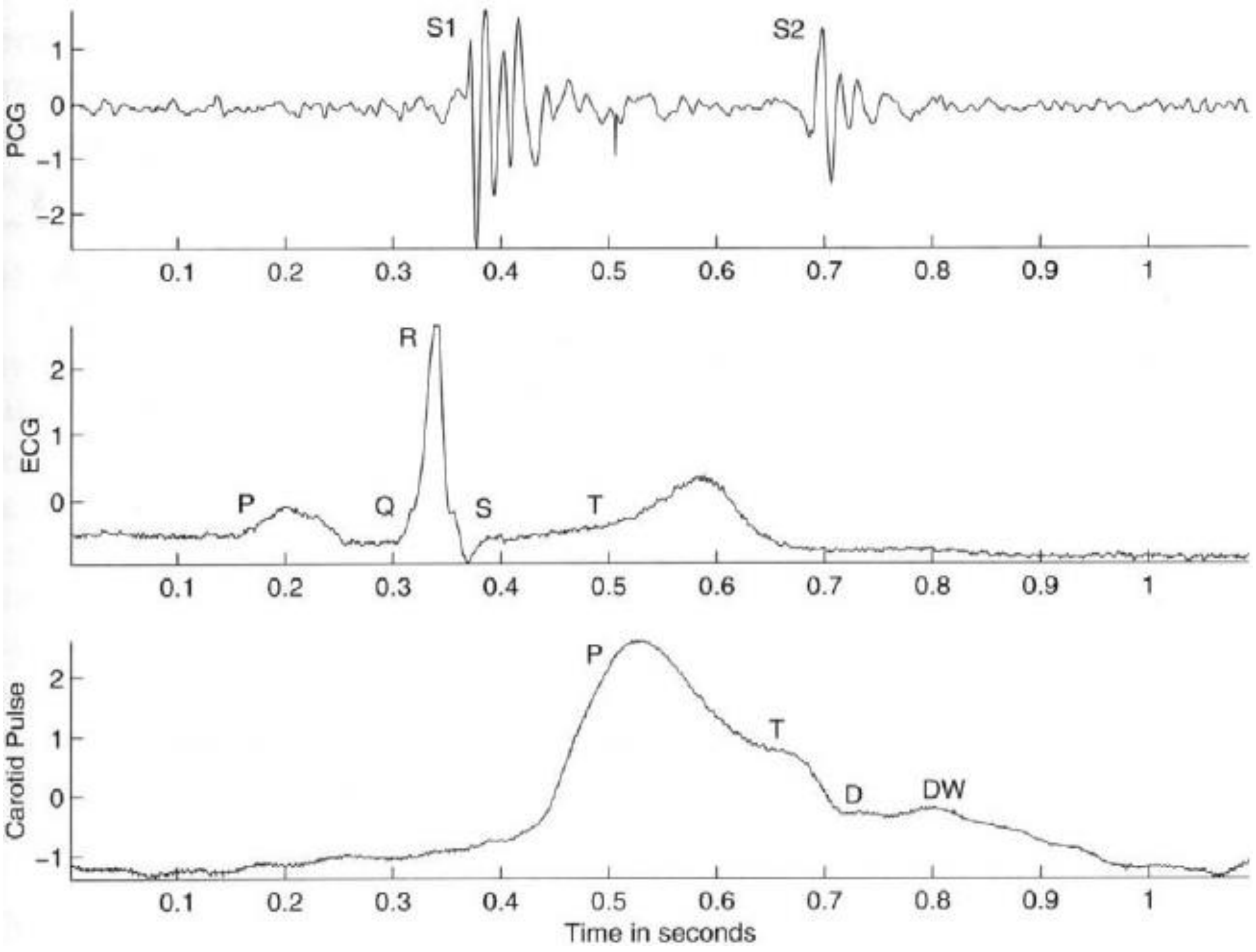
- Provides the pulse signal indicating the changes in arterial blood pressure / volume with each heart beat – usually measured together with **PCG** and **ECG**.

- While it closely resembles the actual pressure, it does not measure the pressure itself directly.



10. The Carotid Pulse (CP)

- Its components:
  - P: Percussion wave - Ejection of blood from the left ventricle
  - T: Tidal wave - Pulse returning from upper body
  - D: Dicrotic notch - Closure of the aortic valve
  - DW: Dicrotic wave - Pulse reflected from lower body

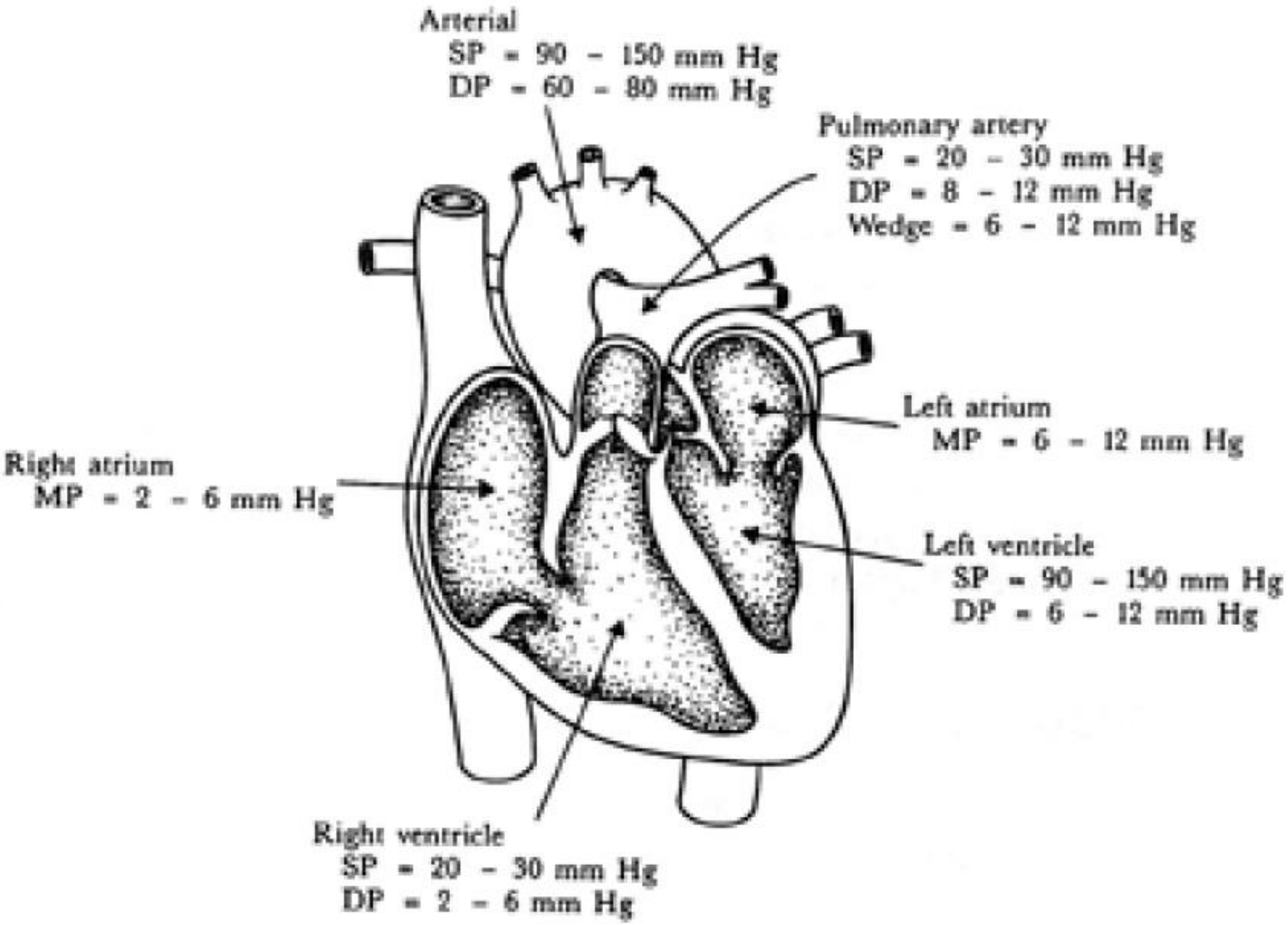


11. The Blood Pressure

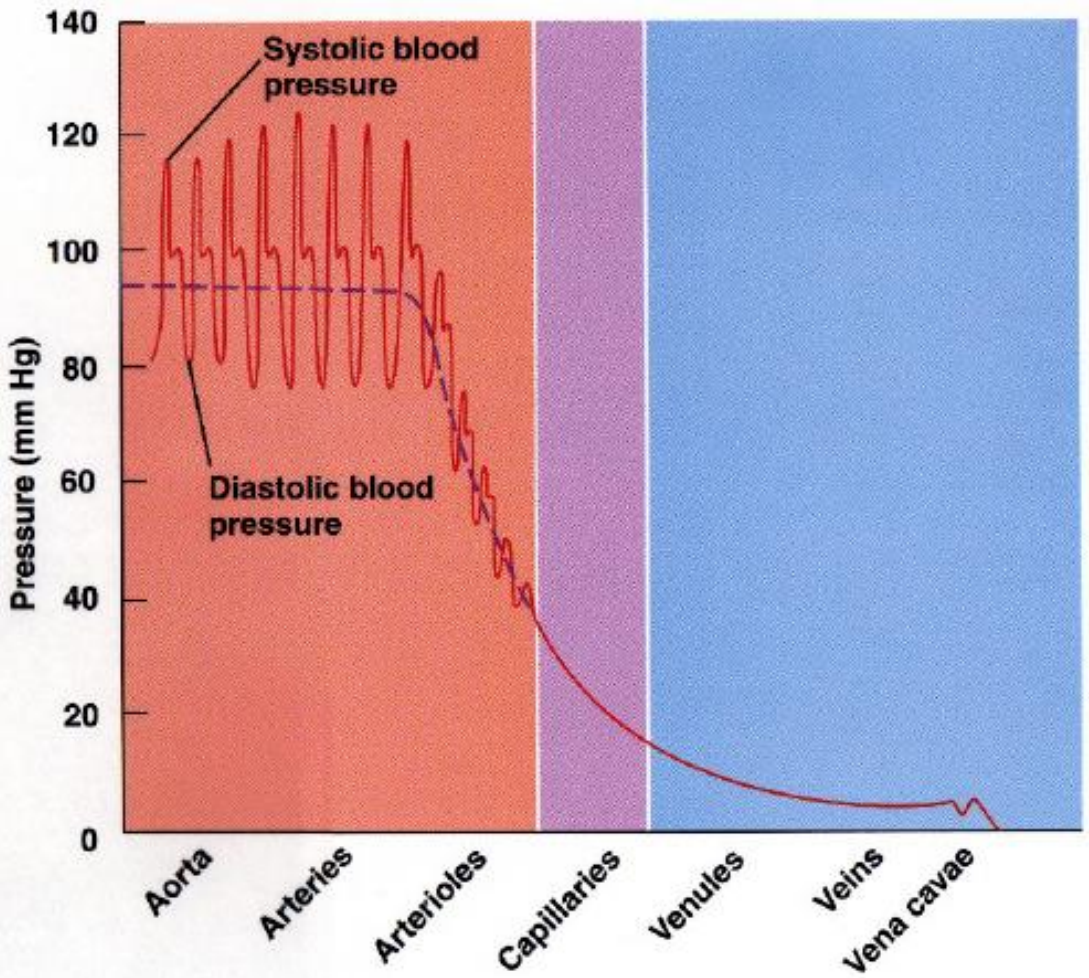
- What does the actual **blood pressure signal** looks like…?
  - First need to understand the pressure gradient and how blood moves around
- Blood transports O_2 and nutrients to tissues, and carry metabolic waste away from the cells
  - The transportation is made possible by a "pressurized vessel" system, the arteries, veins, arterioles, venules and capillaries, 100,000 km in all…
  - The pressure is provided by a mechanical pump, the heart.
  - Measuring this pressure at various locations of this transportation network carries significant clinical information. These measurements can be made directly or indirectly
  - The blood always travels down its pressure gradient

11. The Blood Pressure

- Highest points:
  - Aorta
    - SP: 90-150 mmHg
    - DP: 60-80 mmHg
  - Right atrium
    - MP: 2 –6 mmHg



11. The Blood Pressure



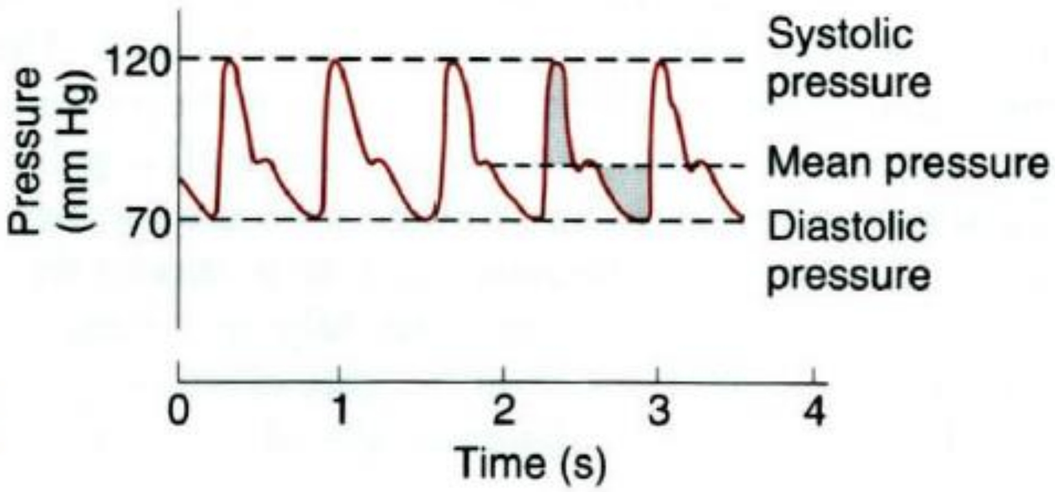


Figure 30–16. Brachial artery pressure curve of a normal young human, showing the relation of systolic and diastolic pressure to mean pressure. The shaded area above the mean pressure line is equal to the shaded area below it.

Properties of Biological Signals

Biological signals, in general, are extremely difficult to process:

- First, they are **difficult to acquire**
- The signal **amplitudes are very small**, which require large amplification, which in turn increases the amount of noise
- They are **very prone to noise**
    - In part due to large amplification
    - In part due their small original amplitude (and hence masked by external, stronger signals)
    - In part due to the presence of so many other biological signals in the near vicinity, e.g. one often sees **EMG** noise on **ECH**, **EOG** noise on **EEG**, etc.

Properties of Biological Signals

- They are **non-stationary**:

  their frequency content changes with time → Fourier based techniques are often not adequate

- The **noise spectrum often coincides with that of the signal spectrum**

  standard filtering approaches fail → need more advances adaptive filtering techniques

Characterization of Biological Signals

Measurement	Range	Frequency, Hz	Method
Blood flow	1 to 300 mL/s	0 to 20	Electromagnetic or ultrasonic
Blood pressure	0 to 400 mmHg	0 to 50	Cuff or strain gage
Cardiac output	4 to 25 L/min	0 to 20	Fick, dye dilution
Electrocardiography	0.5 to 4 mV	0.05 to 150	Skin electrodes
Electroencephalography	5 to 300 μ V	0.5 to 150	Scalp electrodes
Electromyography	0.1 to 5 mV	0 to 10000	Needle electrodes
Electroretinography	0 to 900 μ V	0 to 50	Contact lens electrodes
pH	3 to 13 pH units	0 to 1	pH electrode
pCO_2	40 to 100 mmHg	0 to 2	pCO_2 electrode
pO_2	30 to 100 mmHg	0 to 2	pO_2 electrode
Pneumotachography	0 to 600 L/min	0 to 40	Pneumotachometer
Respiratory rate	2 to 50 breaths/min	0.1 to 10	Impedance
Temperature	32 to 40 °C	0 to 0.1	Thermistor

Why signals are processed?

Signal processing can be defined as the manipulation of a signal for the purpose of either

- Extracting information from the signal
- Extracting information about the relationships of two (or more) signals
- Producing an alternative representation of the signal
- Removing unwanted signal components that are corrupting the signal of interest (filtering, noise removal)
- Predicting future values of the signal in order to anticipate the behavior of its source

Why signals are processed?

Example for extracting information from a signal:

- The objective is to discriminate abnormal from normal signals and on this basis diagnose the presence of disease
- For example, in several cardiorespiratory diseases, such as congestive heart failure, blood pressure oscillates with a period of a few of several tens of seconds. To detect this oscillation one examine the power spectrum (which is proportional to the squared magnitude of the Fourier transform) of blood pressure. Then filter the undesired part from the spectrum

Why signals are processed?

Examples for predicting future values of the signal:

- There are two different situations:
  - Controlling behavior (e.g., regulating the blood glucose level by periodic injections of insulin)
  - Early detection of the onset of a disease process (e.g., to correlate indices of fractal behavior of heart rate with the presence or absence of disease)

Types of Signals

1. Deterministic signals:

- A deterministic signal is one whose values in the future can be predicted exactly with absolute confidence if enough information about its past is available
- Encountered commonly in textbook examples but less frequently in the real world
- Impulses, steps, and exponential functions are deterministic
- In fact, any signal which can be expressed exactly in closed mathematical form as a function of time or other variable is deterministic

Types of Signals

2. Stochastic (Random) signals:

- Stochastic signals are signals for which it is impossible to predict an exact future value even if one knows its entire past history
- Also the name "random signal" is often used for this signals
- Some random signals are completely unpredictable (uncorrelated), some others can be predicted with greater (but not absolute) confidence
- Random signals are abundant in physical processes
- Example: Noise generated by electronic components in instrumentation is a common type of random signal that is present in much biomedical data

Types of Signals

3. Fractal signals:

- Fractal signals have the interesting property that they look very similar at all levels of magnification - a property referred to as scale-invariance
- It can be expected that random signals would exhibit this property also, but there are important quantitative differences between the scaling properties of fractal signals and of random signals
- Example: A part of the beat-to-beat heart rate signal is fractal as well as the signal representing current through a single ionic channel of a cell membrane

4. Chaotic signals:

- Chaotic signals are deterministic signals that cannot be predicted exactly in the future
- Sensitive dependence on initial conditions: For some deterministic signals their trajectories in the future are so sensitive to their past values that it is impossible to specify those past values with sufficient accuracy that we can predict ahead in time with certainty
- In theory, these signals are deterministic, beyond a short time into the future the error of the prediction becomes very large
- It has also some characteristics of a RS but RS are not chaotic and CS are not RS
- Example: Some immunological and biochemical regulatory processes can exhibit chaotic behavior, and **EEG** activity and breathing may have chaotic series