

DSP概論: Biomedical Signal Processing

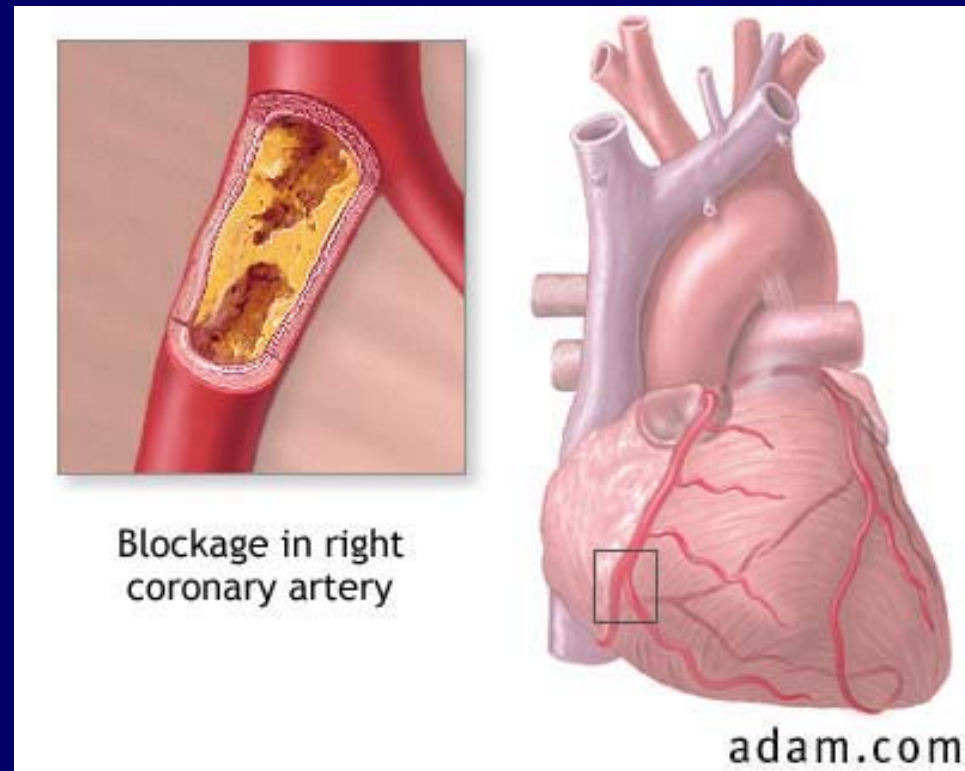
台大電機系李百祺

What is it?

- Biomedical Signal Processing: Application of *signal processing methods*, such as filtering, Fourier transform, spectral estimation and wavelet transform, to *biomedical problems*, such as the analysis of cardiac signals, the breathing cycle,...etc.
- A broader aspect: Biomedical imaging, genomic signal processing,...etc.

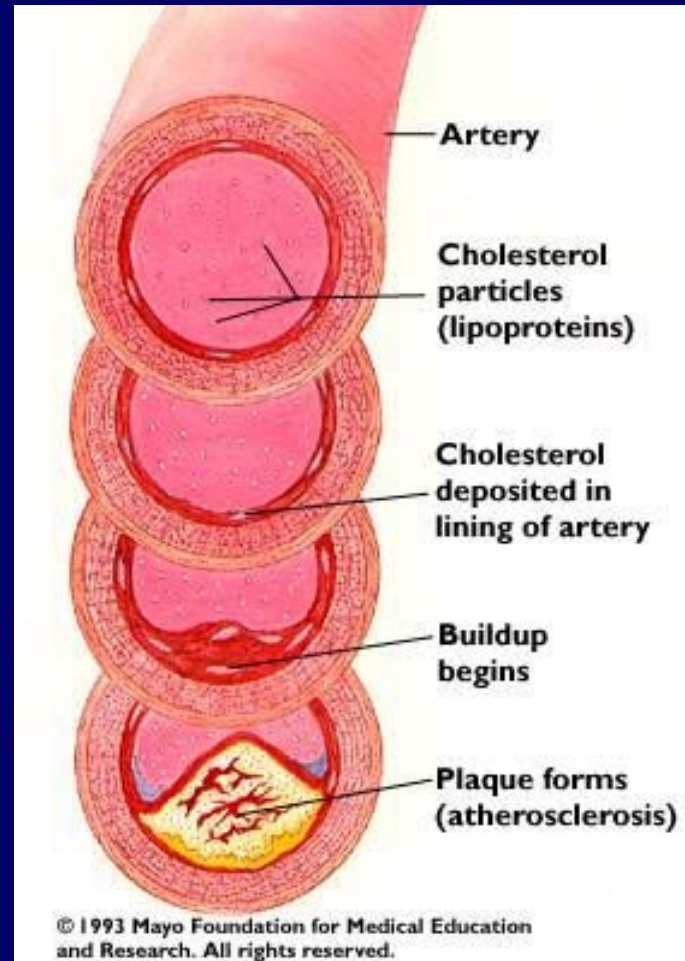
Medical Diagnosis: Heart Attack as an Example

- Heart attack: Coronary artery disease, blockage of blood supply to the myocardium.



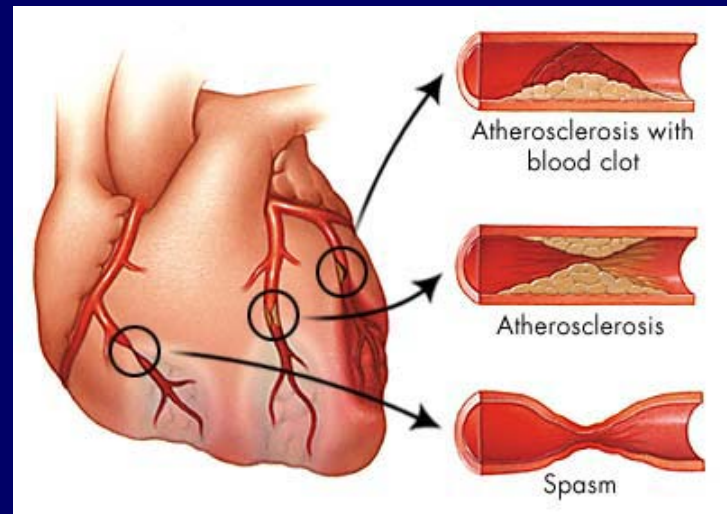
Medical Diagnosis: Heart Attack as an Example

- Plaque: A gradual build-up of fat (cholesterol) within the artery wall.



Medical Diagnosis: Heart Attack as an Example

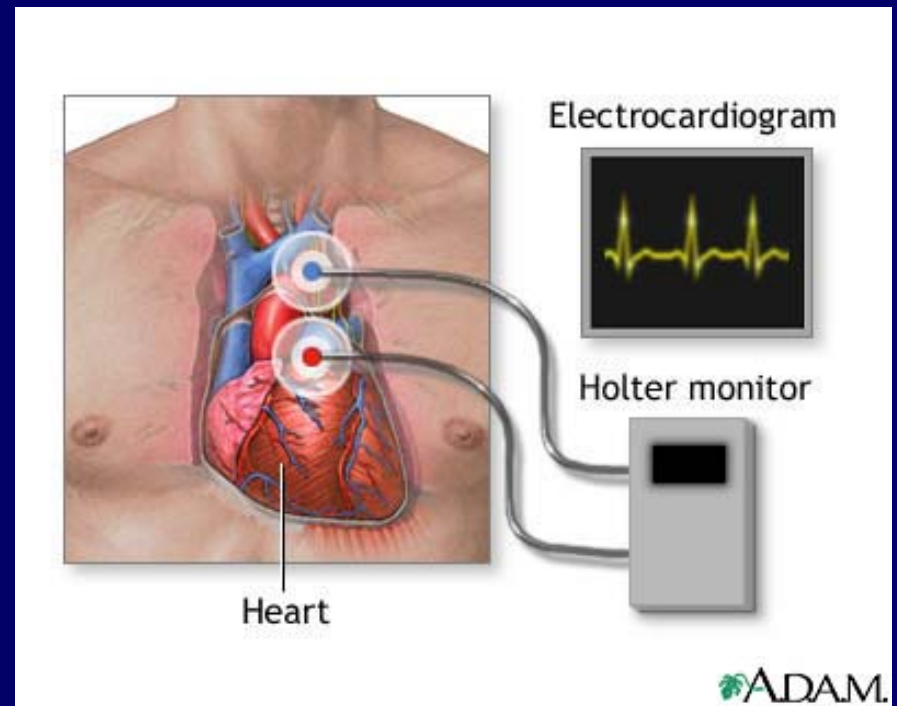
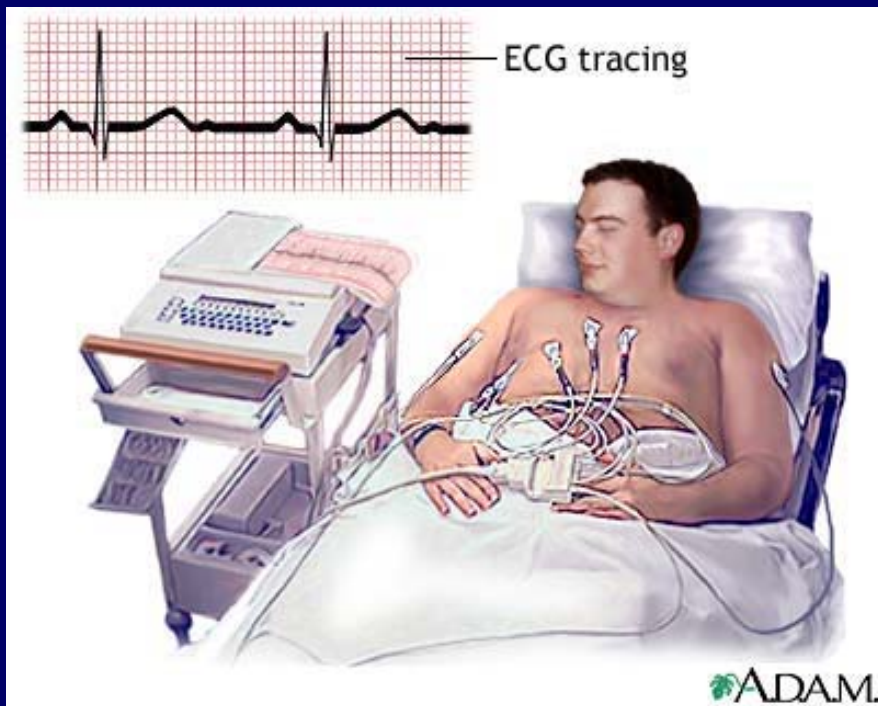
- Symptoms:
 - Chest pressure with stress, heart burn, nausea, vomiting, shortness of breath, heavy sweating.
 - Chest pain, heart attack, arrhythmias.



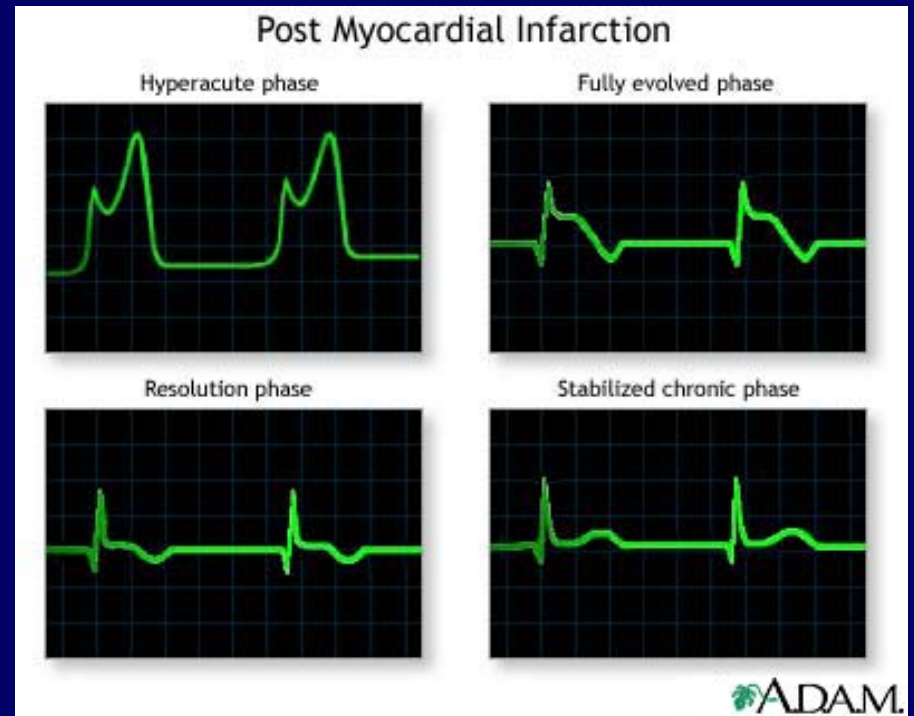
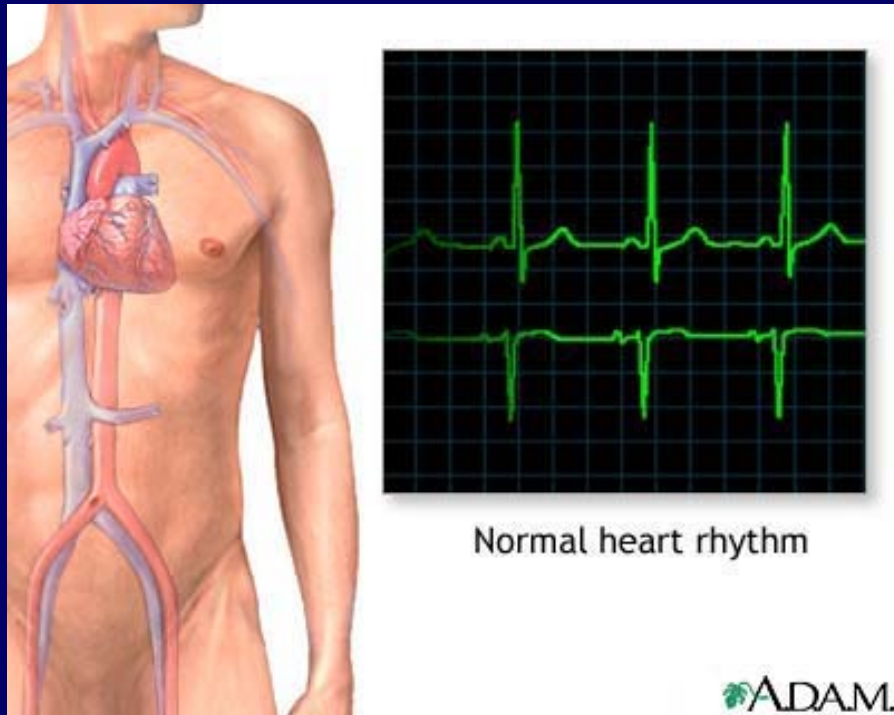
Medical Diagnosis: Heart Attack as an Example

- Diagnosis:
 - Prehospital electrocardiography (ECG).
 - Continuous/serial ECG.
 - Exercise stress ECG.
 - Biochemical tests and biomarkers.
 - Sestamibi myocardial perfusion imaging.
 - Echocardiography.
 - Computer-based decision aids.

Medical Diagnosis: ECG



Medical Diagnosis: ECG



Medical Diagnosis: ECG

Atrioventricular block ECG tracing



ADAM.

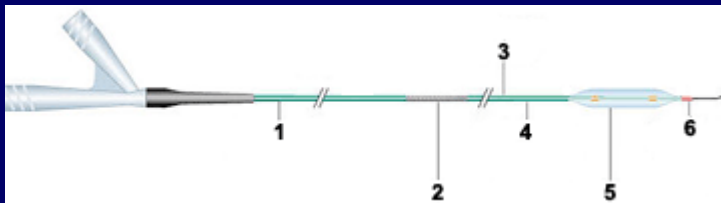
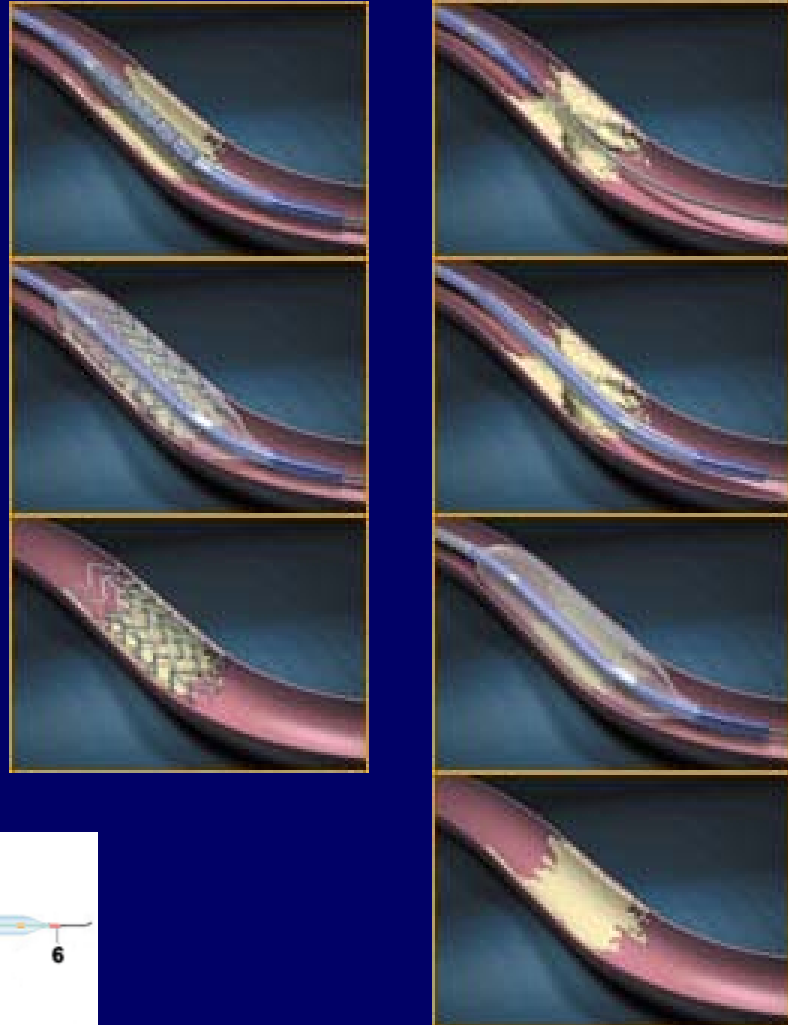
Ventricular tachycardia



ADAM.

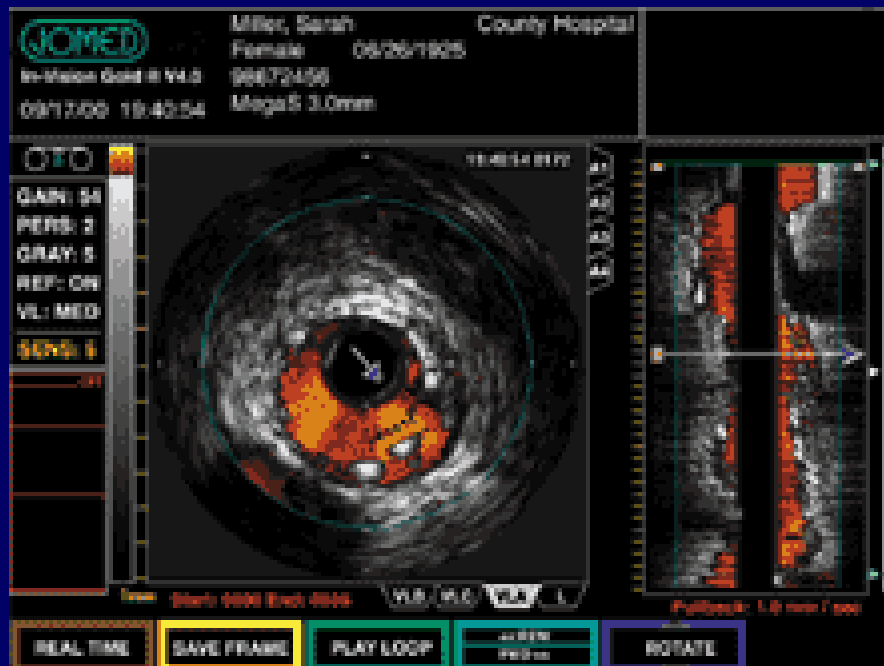
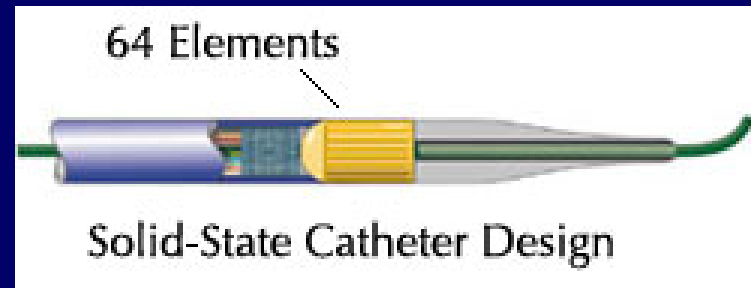
Medical Diagnosis: Heart Attack as an Example

- Treatment:
 - Angioplasty.
 - Stent implantation.
 - Atherectomy.
 - Coronary bypass surgery.
 - Intravascular radiotherapy.
 - Excimer laser.



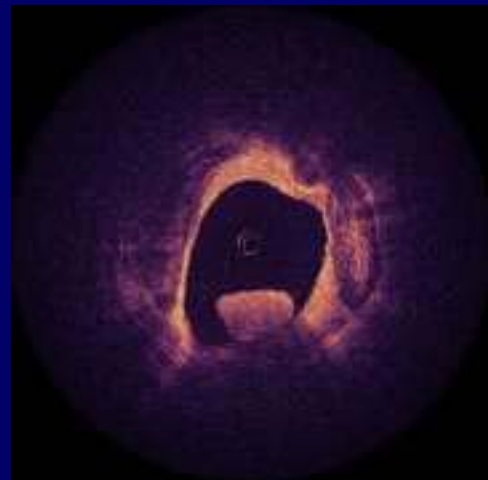
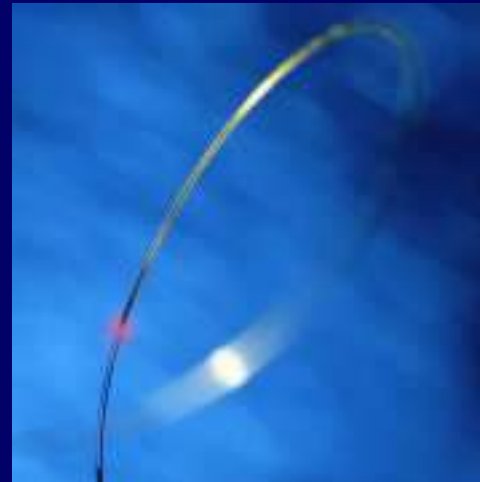
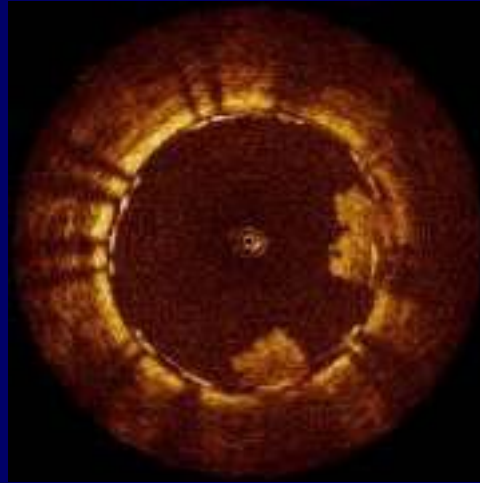
Medical Diagnosis: Heart Attack as an Example

- Imaging:
 - Ultrasound.



Medical Diagnosis: Heart Attack as an Example

- Imaging:
 - Optics.



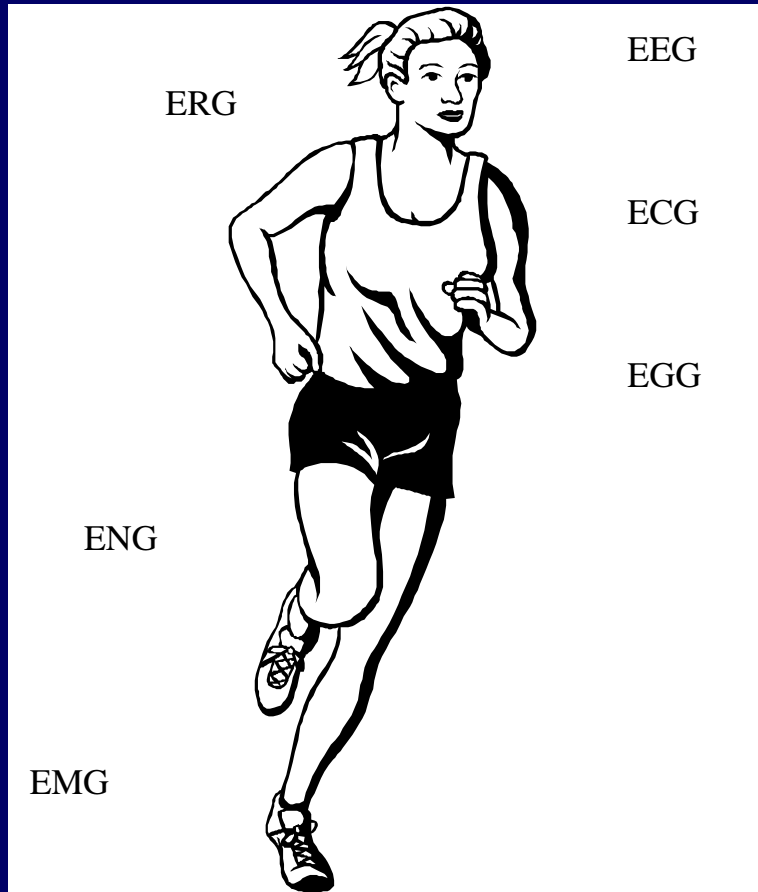
Biomedical Signals: Broader Definition

- Signals as a result of physiological activities in the body:
 - Electrical and Non-electrical
- Invasive/Non-invasive interrogation of an external field with the body
- Diagnosis and therapy
- ➔ *Will focus mostly on bioelectric signal.*

Outline

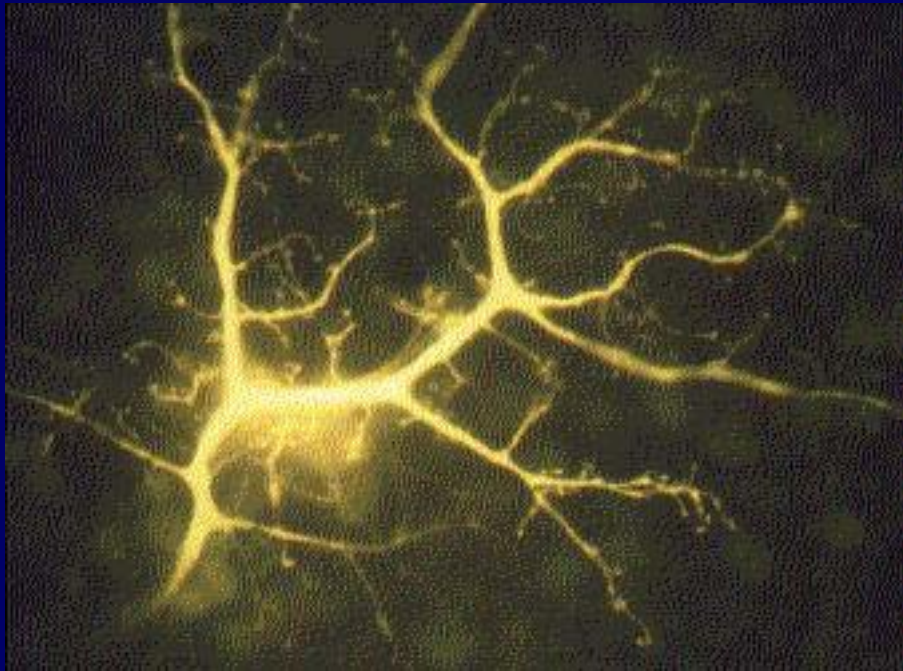
- Bioelectrical signals:
 - Excitable cells
 - Resting/action potential
- ECG, EEG,...etc
- Applications of signal processing techniques
 - Sampling, filtering, data compression,...etc
- Non-stationary nature of biomedical signals

Bioelectrical Signals

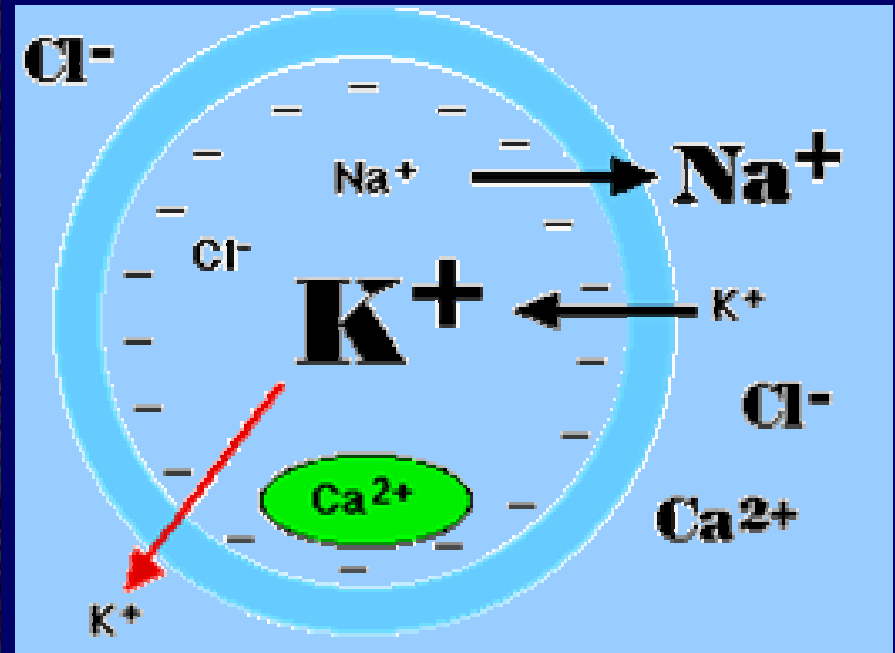


- The bioelectric signals represent many physiological activities.

Excitable Cells

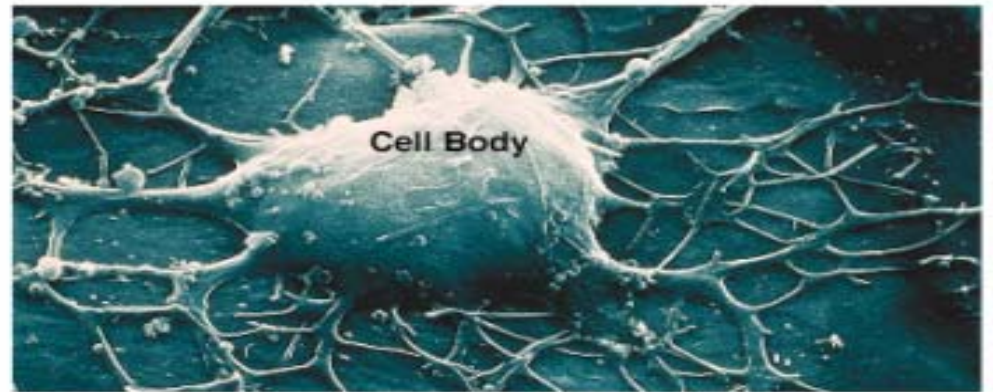
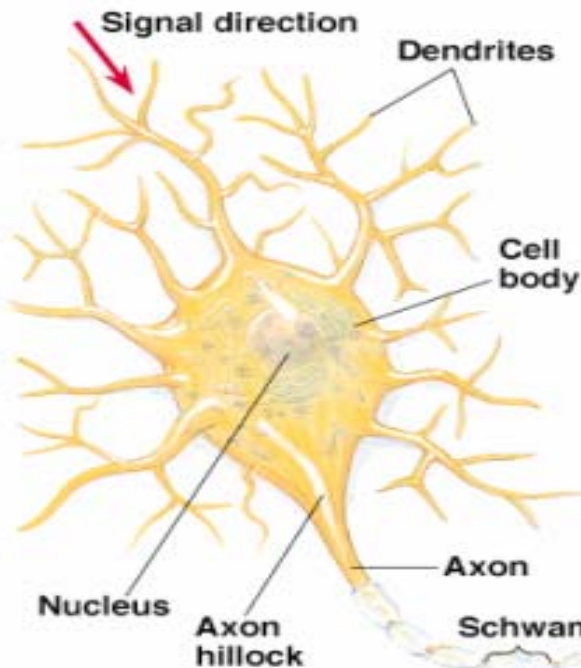


Neuron (Rabbit Retina)

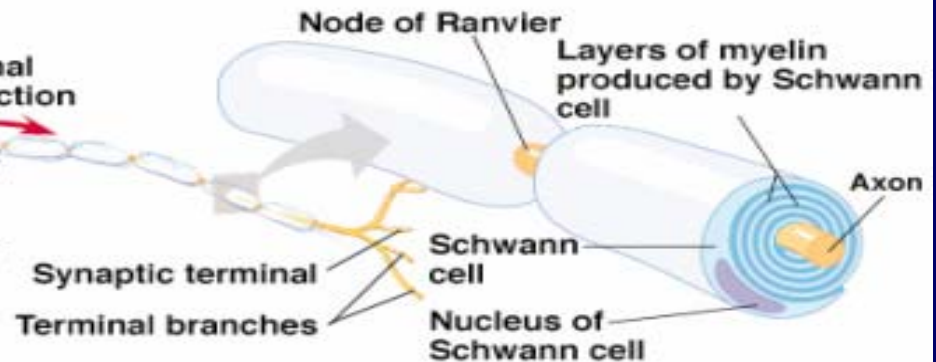


Ionic Relations in the Cell

Structural unit

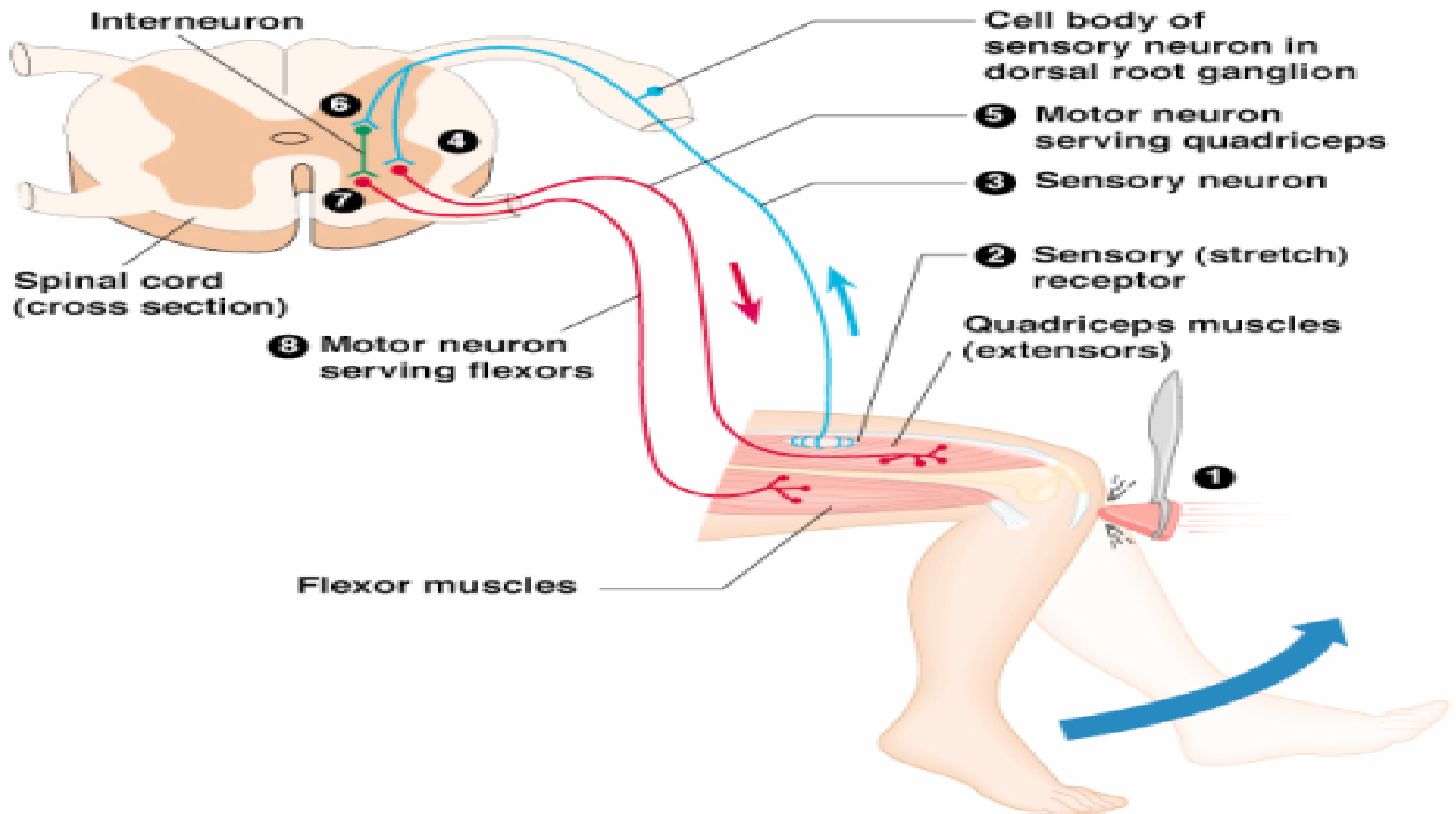


(b)

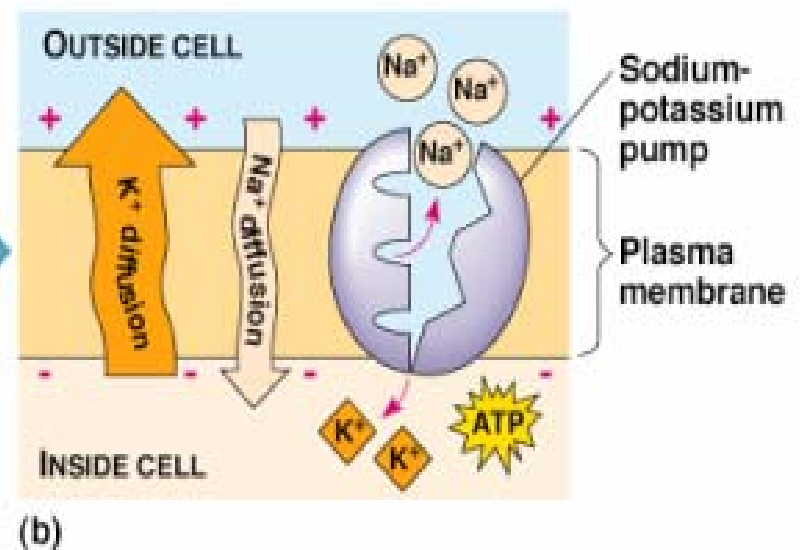
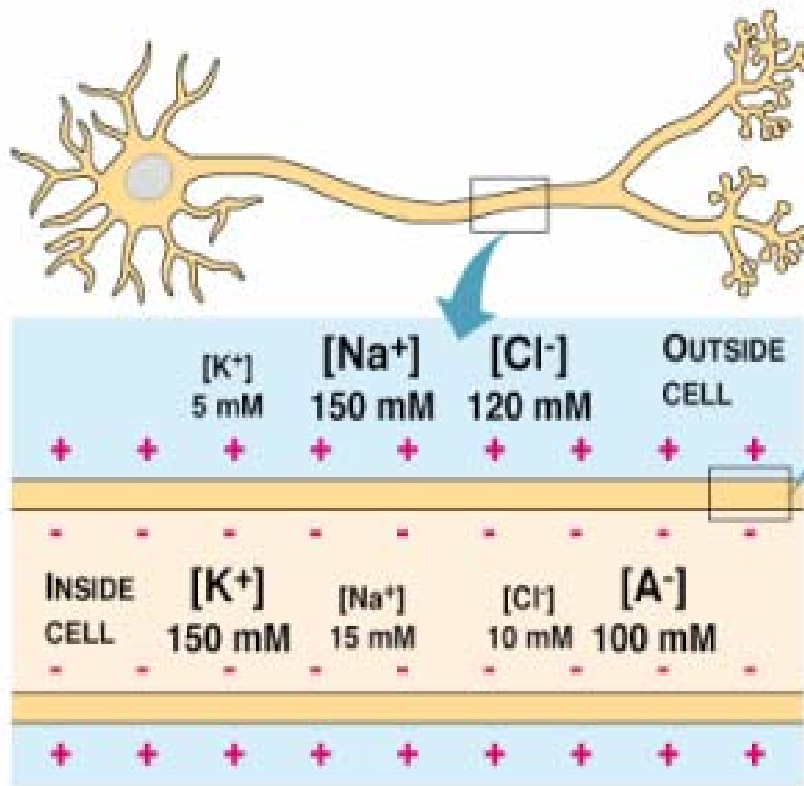


(a)

Functional unit

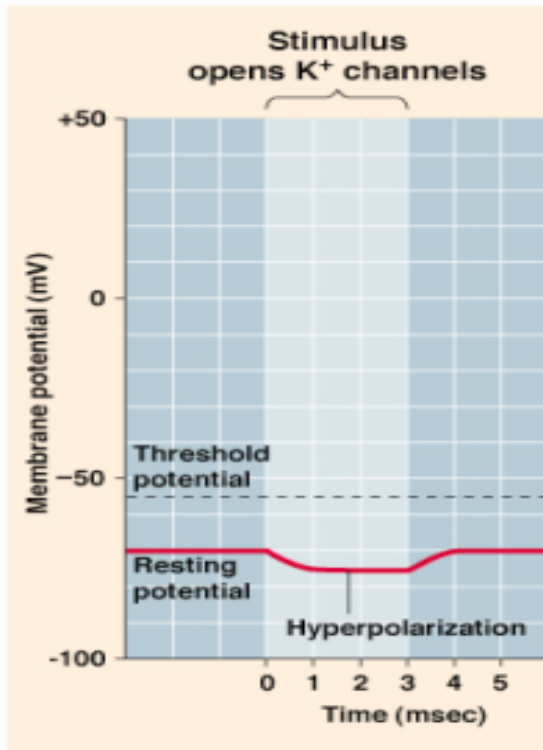


Neural signaling (I)

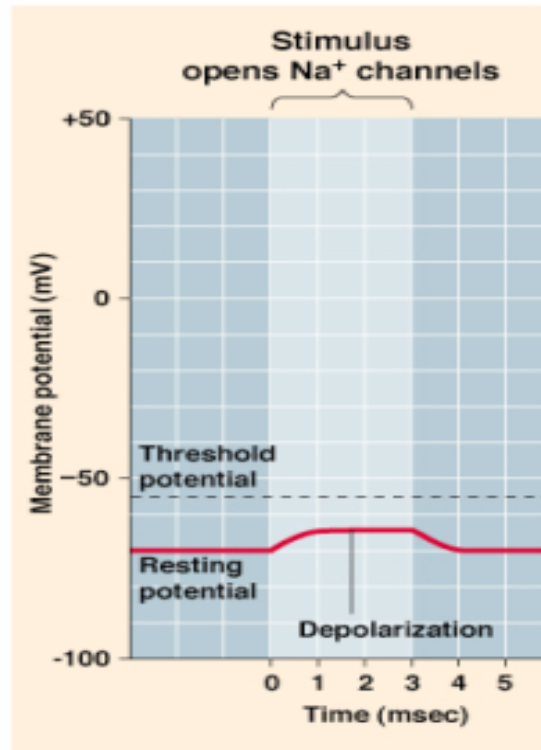


(a)

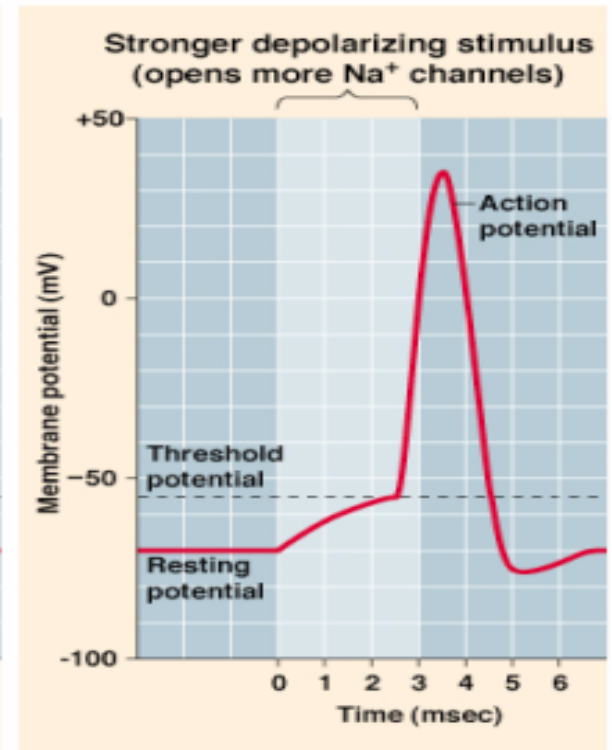
Neural signaling (II)



(a) Graded potential: hyperpolarization

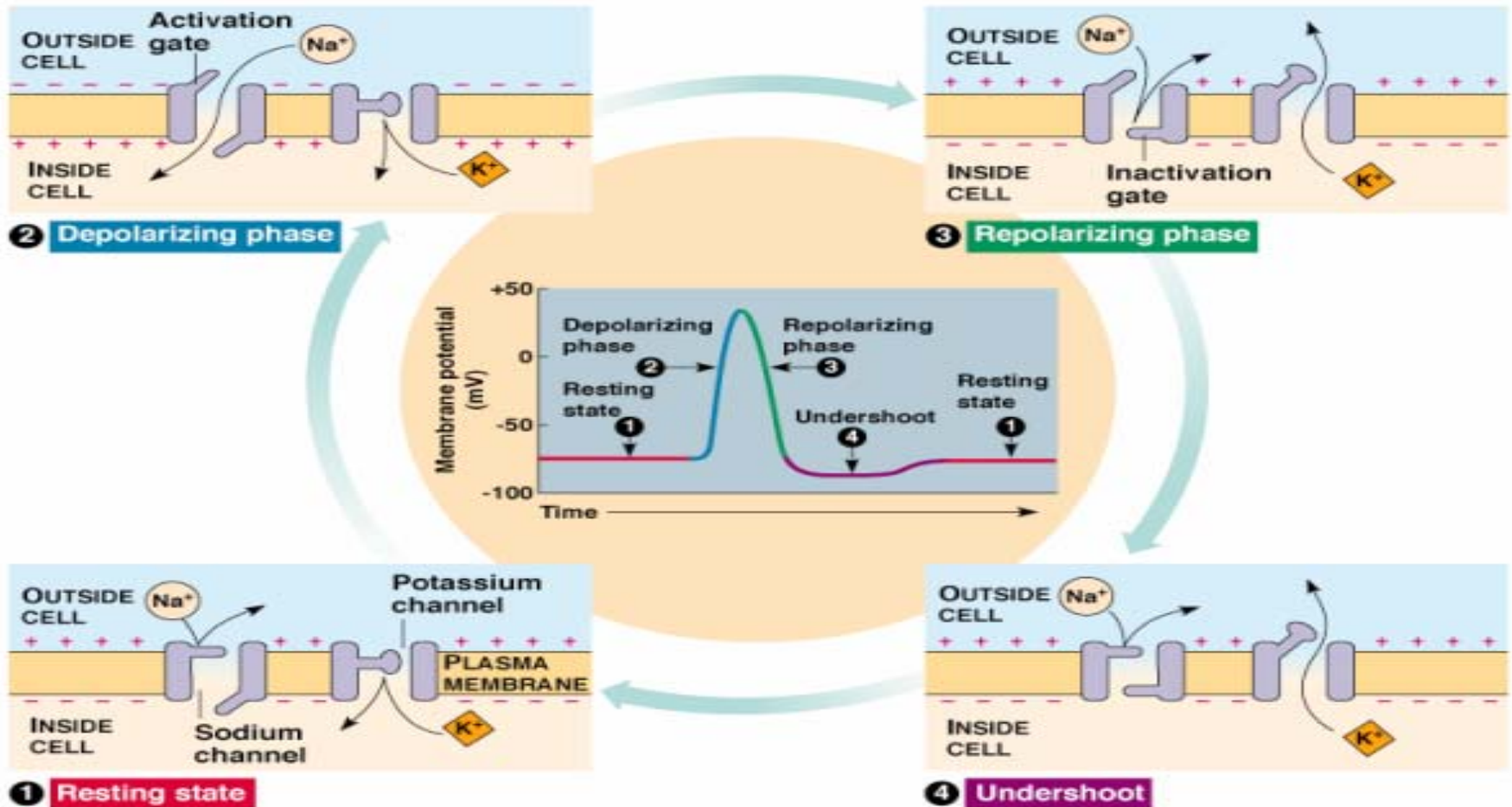


(b) Graded potential: depolarization

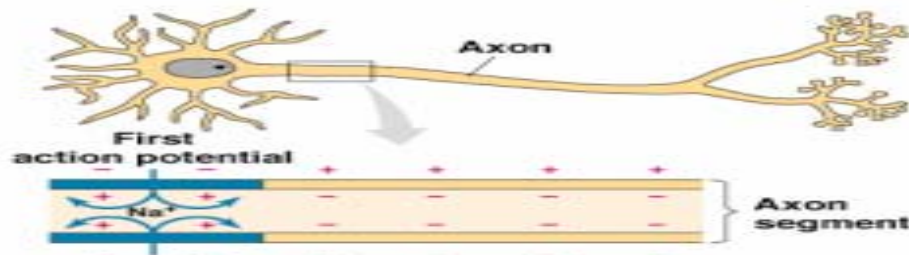


(c) Action potential

Neural signaling (III)



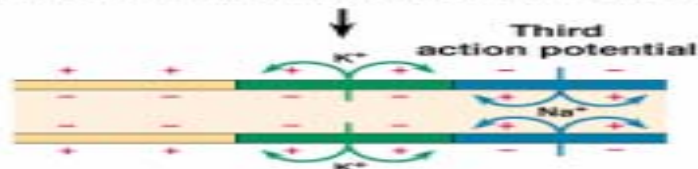
Neural signaling (IV)



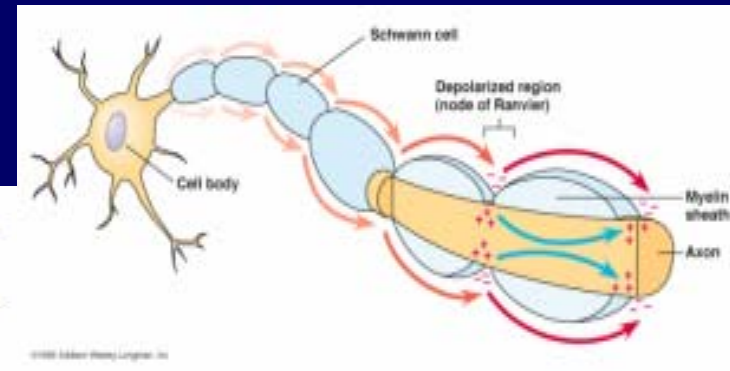
- 1 An action potential is generated as sodium ions flow inward across the membrane at one location.



- 2 The depolarization of the first action potential has spread to the neighboring region of the membrane, depolarizing it and initiating a second action potential. At the site of the first action potential, the membrane is repolarizing as K^+ flows outward.



- 3 A third action potential follows in sequence, with repolarization in its wake. In this way, local currents of ions across the plasma membrane give rise to a nerve impulse that passes along the axon.

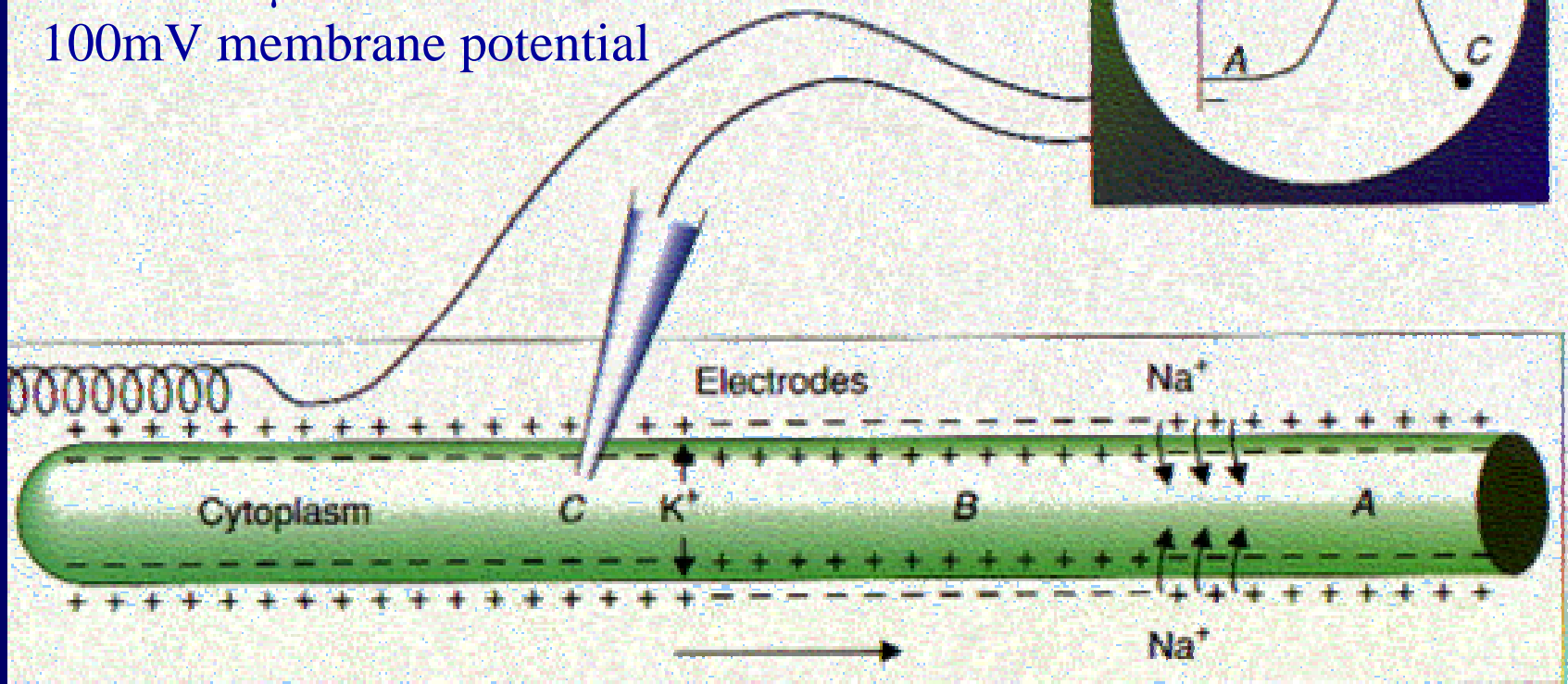
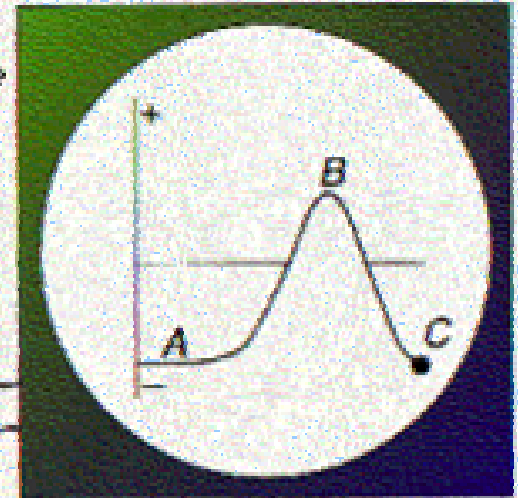


Measurements of Action Potential

$$C = \varepsilon \frac{A}{d}$$

6250 ions/ μm^2 for
100mV membrane potential

Oscilloscope

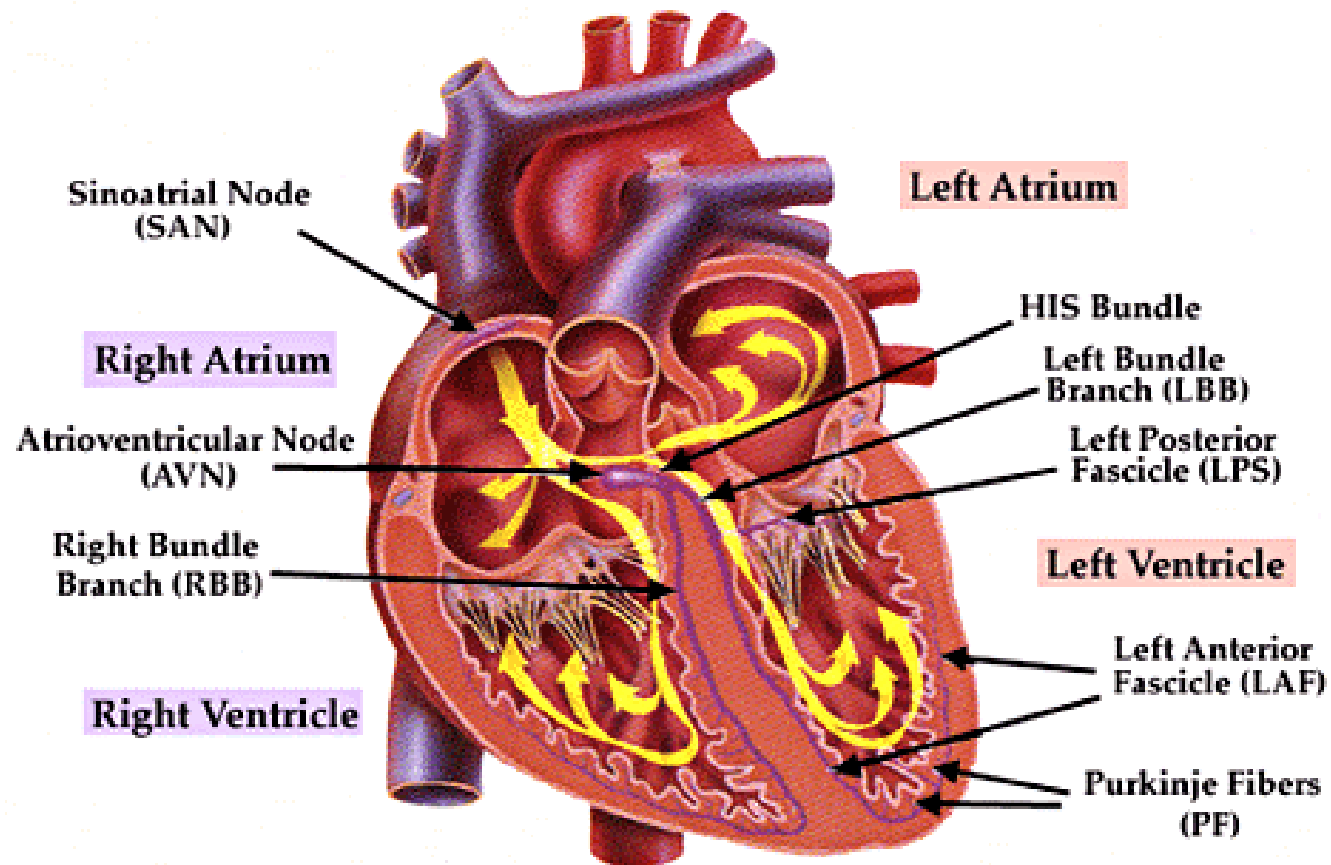


Electrocardiogram (ECG)

ECG

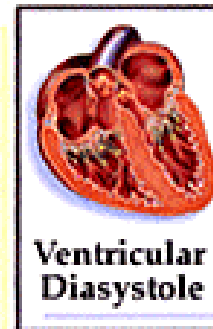
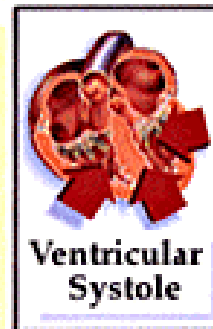
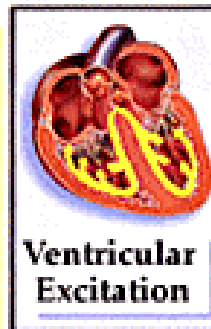
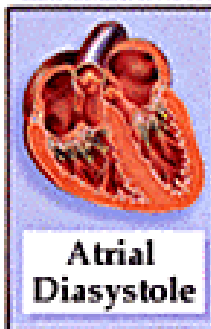
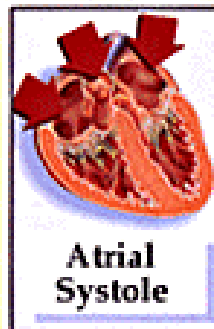
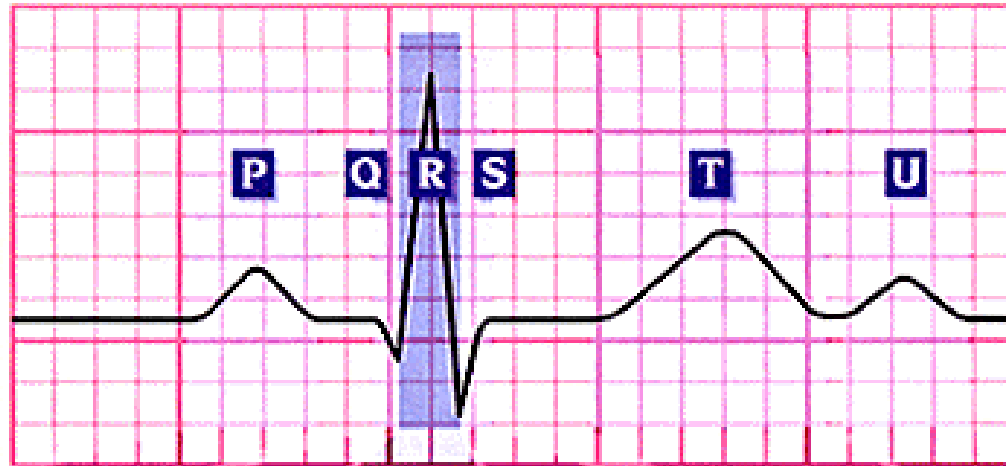
- One of the main methods for assessing heart functions.
- Many cardiac parameters, such as heart rate, myocardial infarction, and enlargement can be determined.
- Five special groups of cell:
 - SA, AV, common bundle, RBB and LBB.

ECG



Cardiac Conduction System

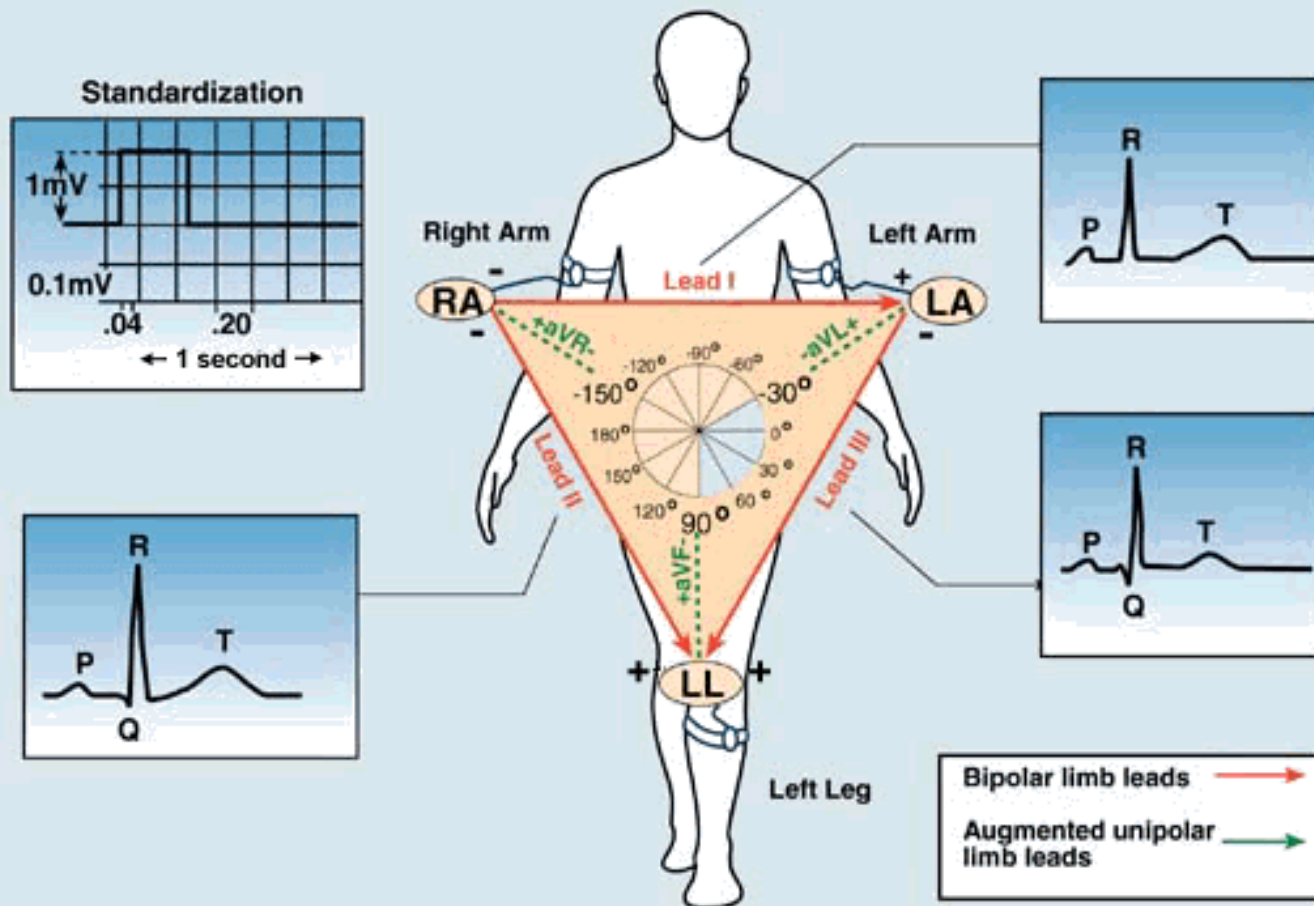
ECG



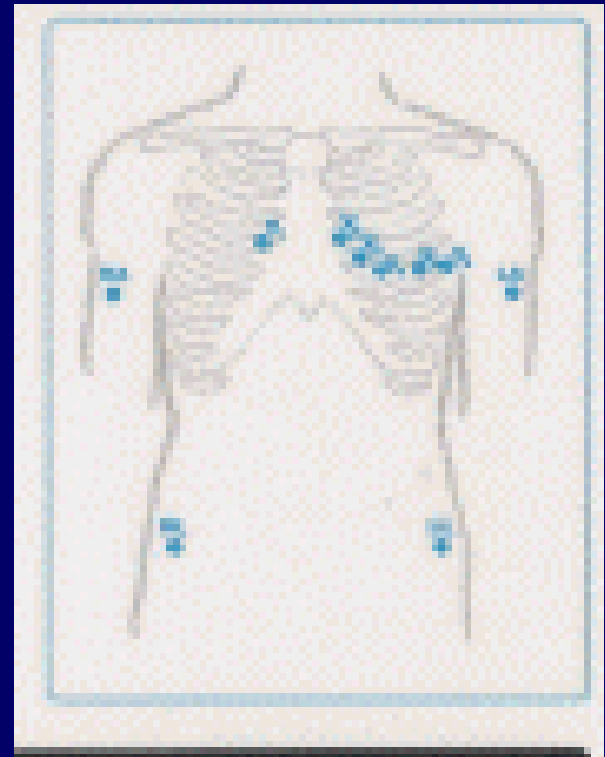
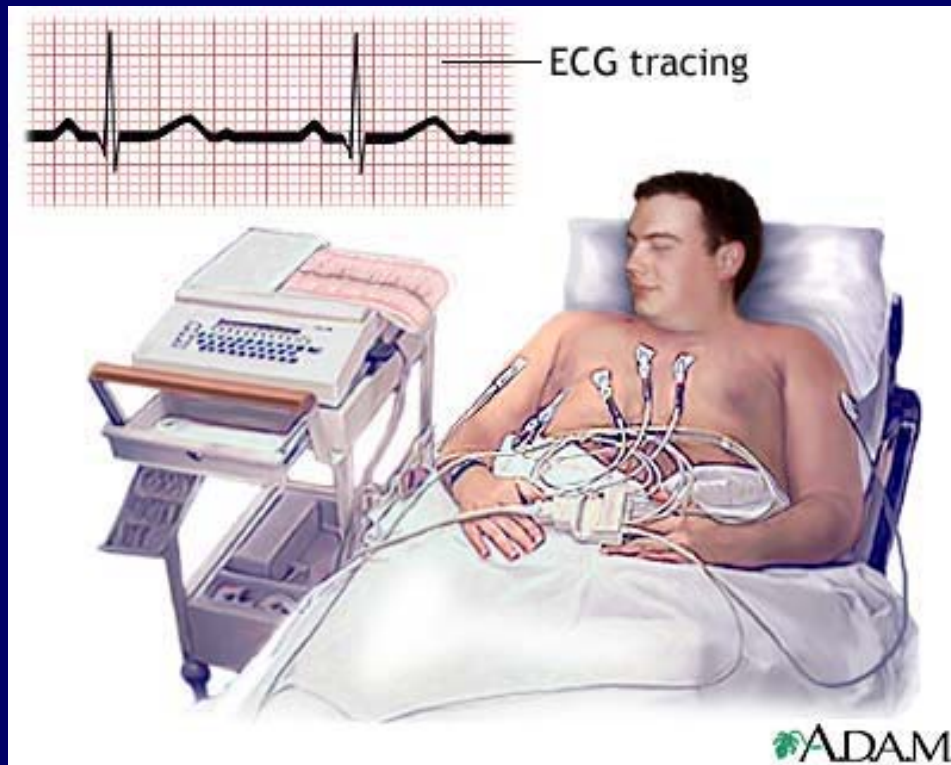
Electrical and Mechanical Events

ECG Leads

The Standard Limb Leads

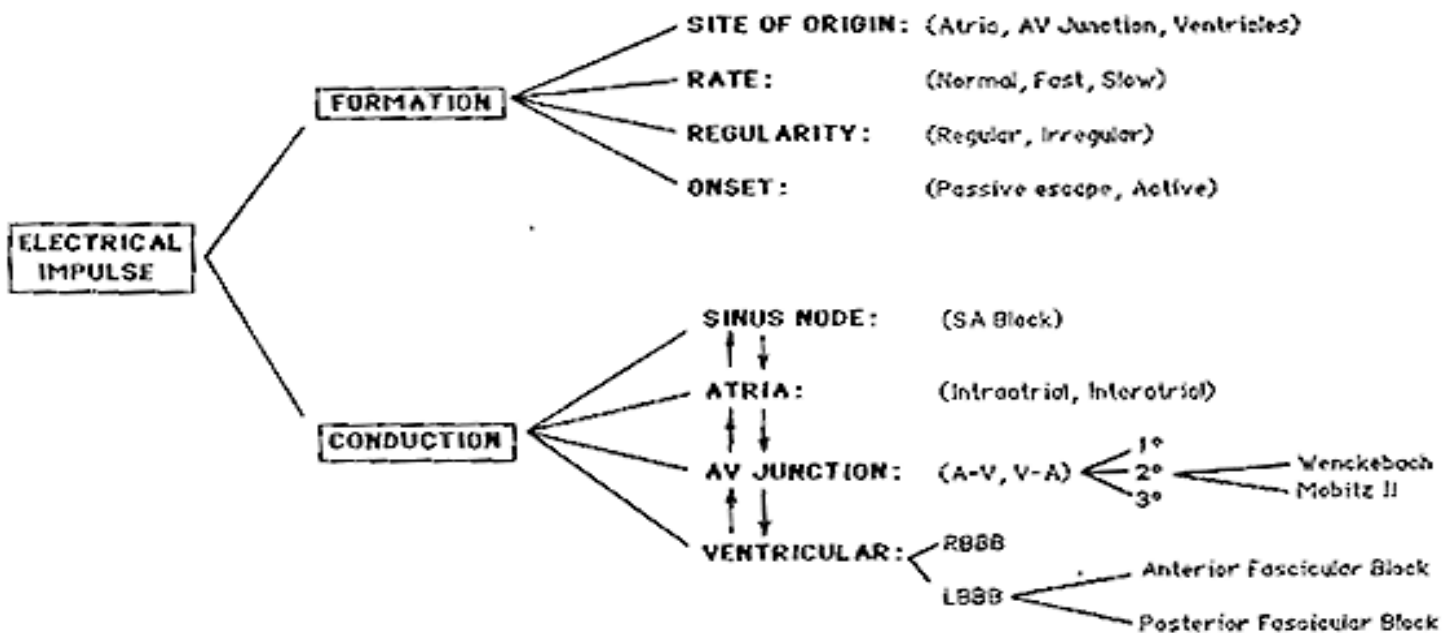


ECG Leads

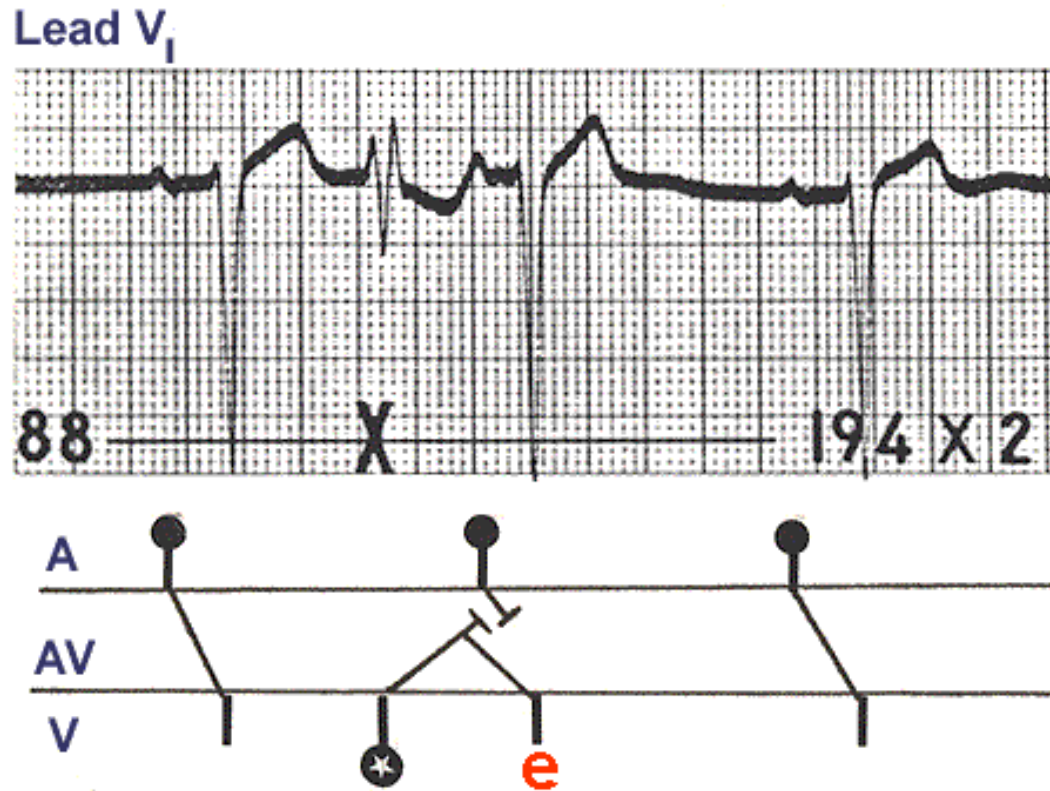


ECG Diagnosis

HOW TO THINK ABOUT ARRHYTHMIAS AND CONDUCTION DISTURBANCES



ECG Diagnosis

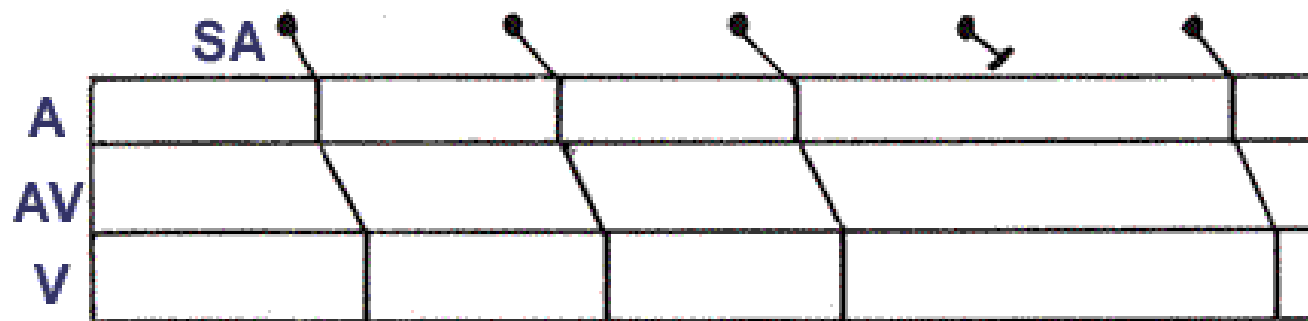
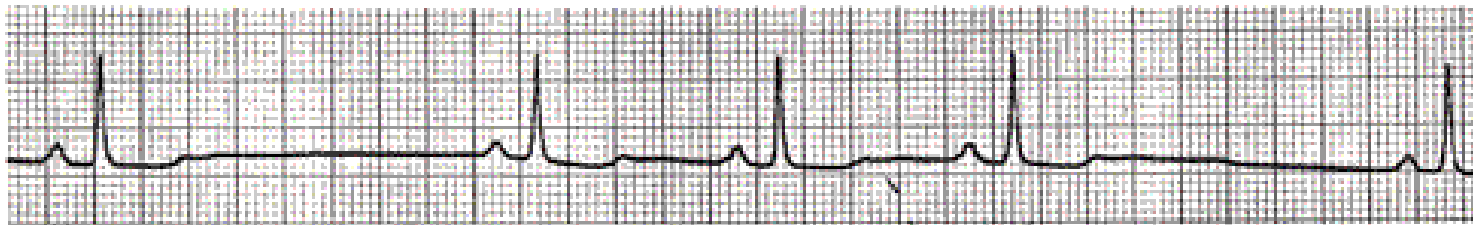


Interpolated PVC with ventricular echo (e)

PVC with echo

ECG Diagnosis

Lead II



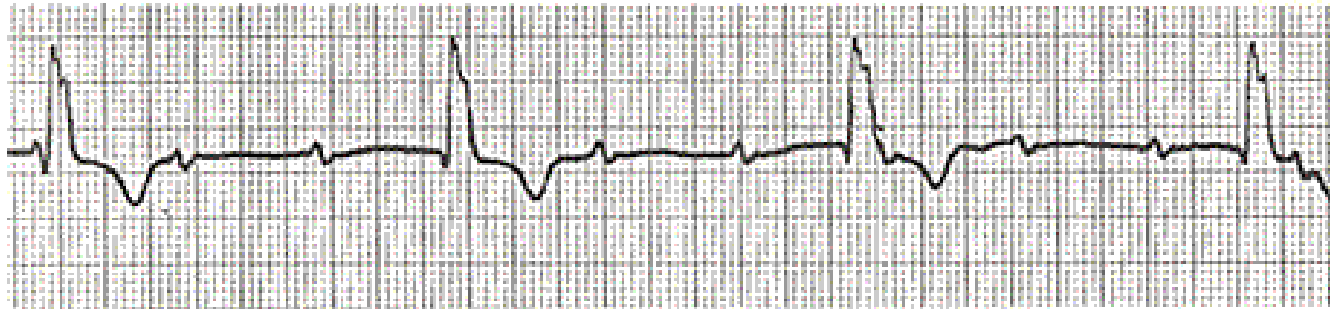
Sino-Atrial Exit Block (type I)

Conduction: SA Block (Type I)

ECG Diagnosis

Lead V_I

A



B



Conduction: Complete AV Block

ECG Diagnosis

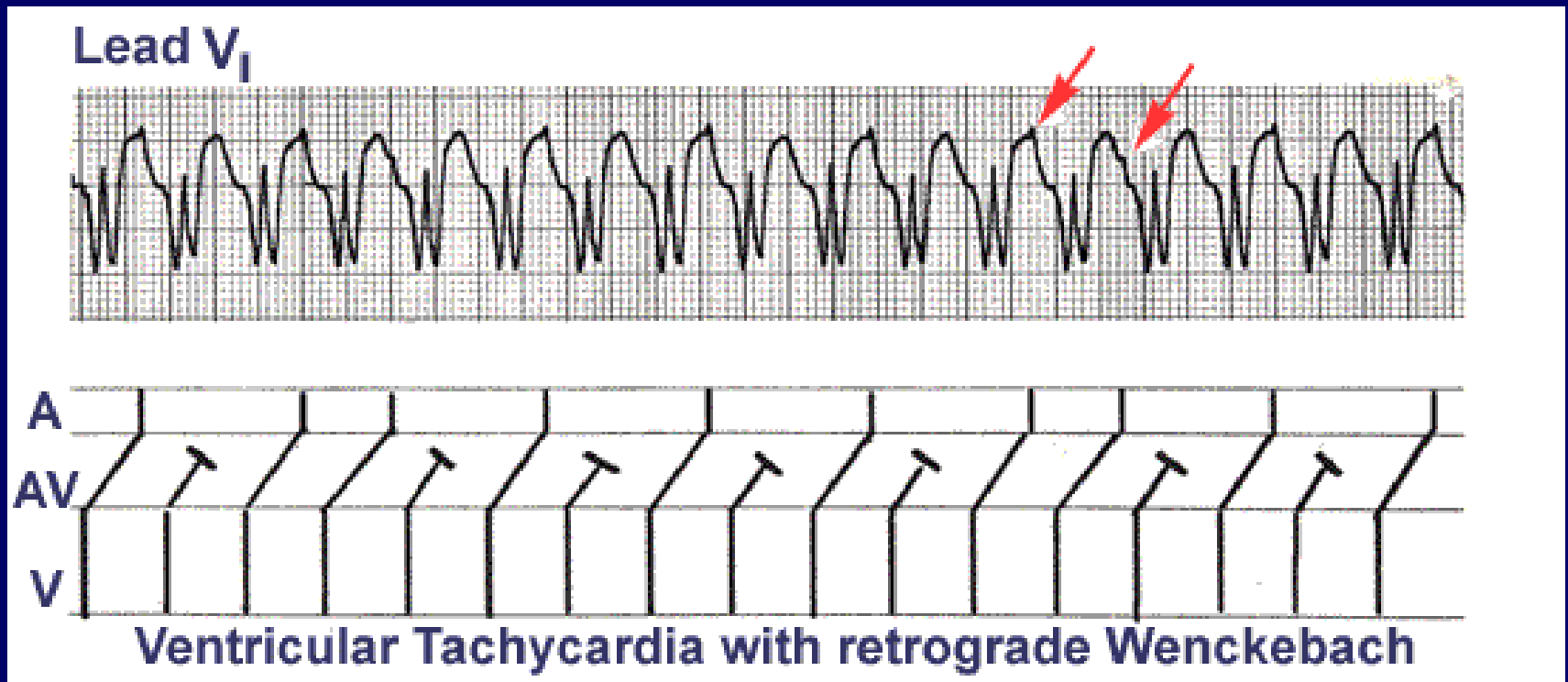
Lead V₁



Atrial tachycardia with variable AV block

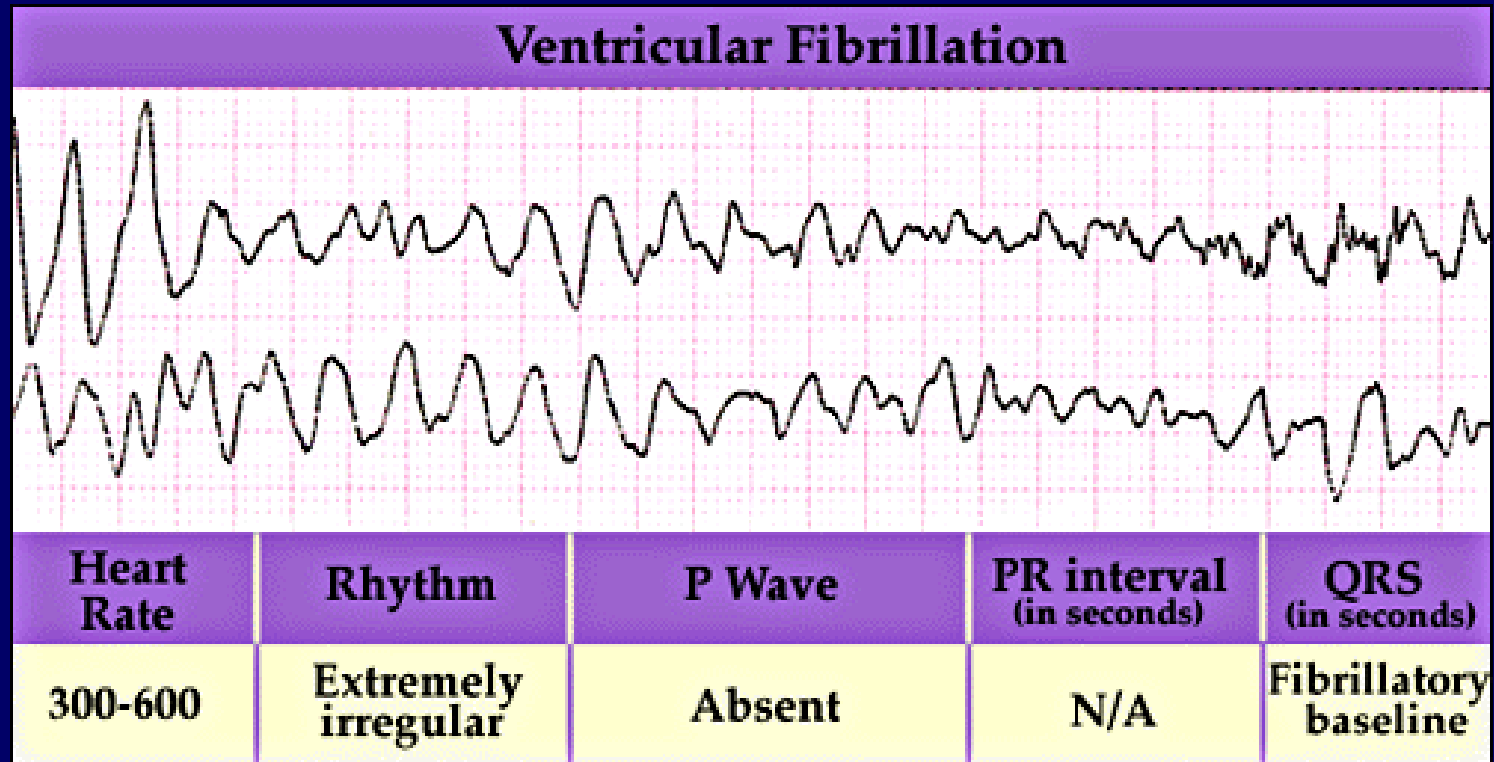
Rate: Atrial Tachycardia (160 bpm)

ECG Diagnosis



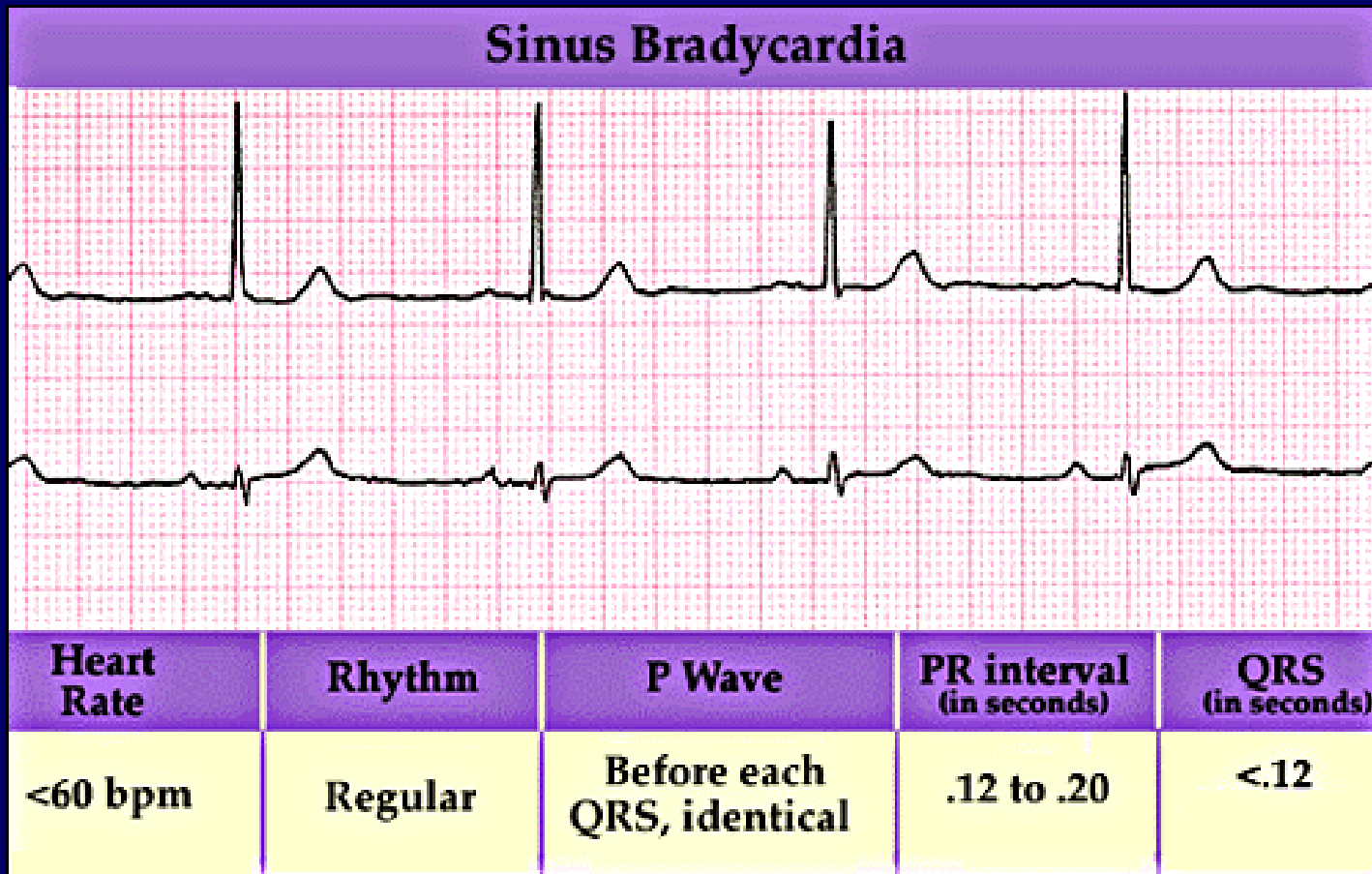
Rate: Ventricular Tachycardia

ECG Diagnosis



Rate: Ventricular Fibrillation

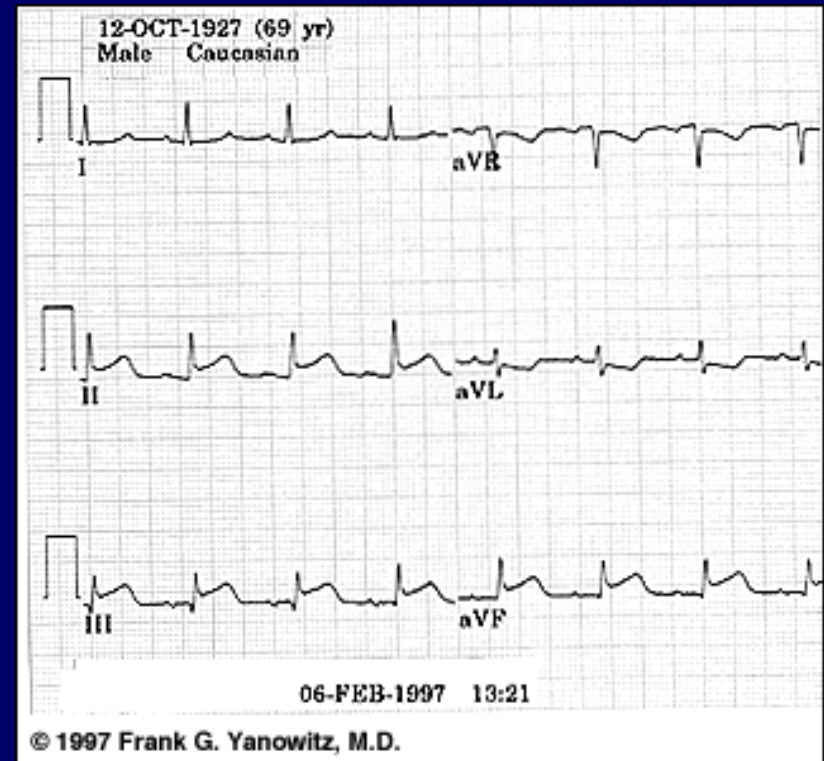
ECG Diagnosis



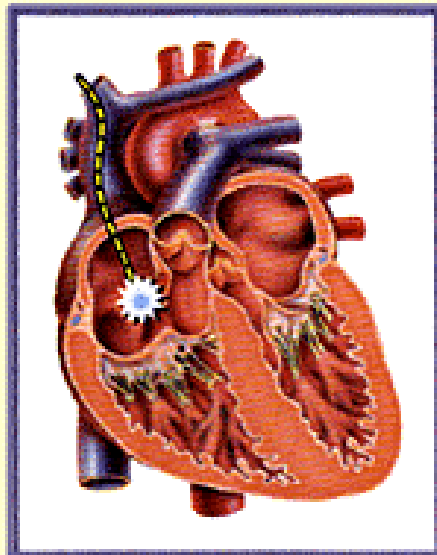
Rate: Sinus Bradycardia

ECG Diagnosis

- Other abnormalities:
 - Myocardial infarction
 - Atrial/Ventricular enlargement
 - ST segment elevation
 -

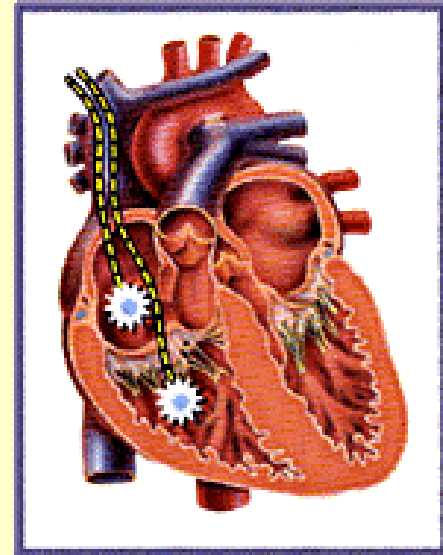
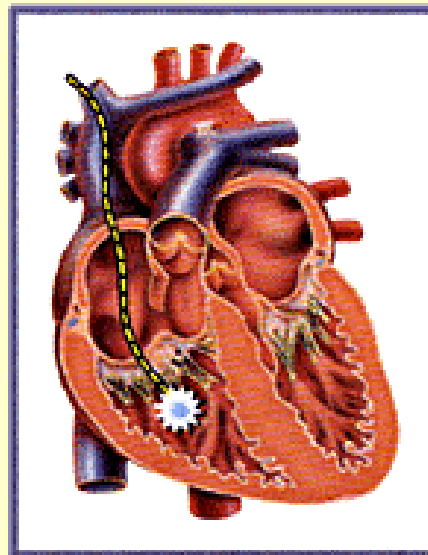


Pace Makers



Atrial Pacing
The pacing lead is inserted into the atrium to cause atrial depolarization.

Ventricular Pacing
The pacing lead is inserted into the ventricle to cause ventricular depolarization



A-V Sequential Pacing
The pacing leads are inserted into both the atrium and ventricle stimulating at set intervals.

Pacemaker Lead Wire Replacement

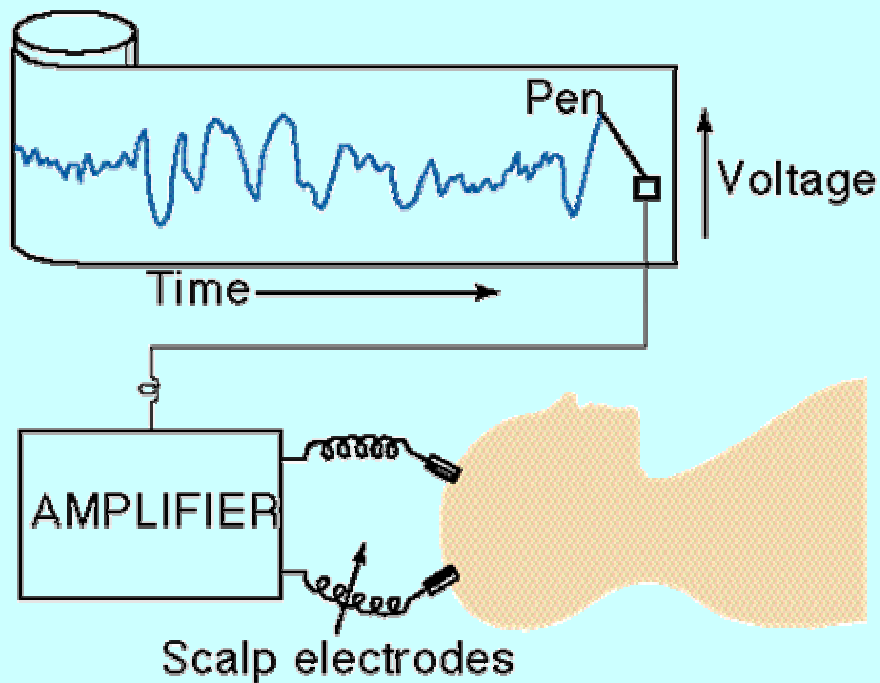
Electroencephalogram (EEG)

EEG

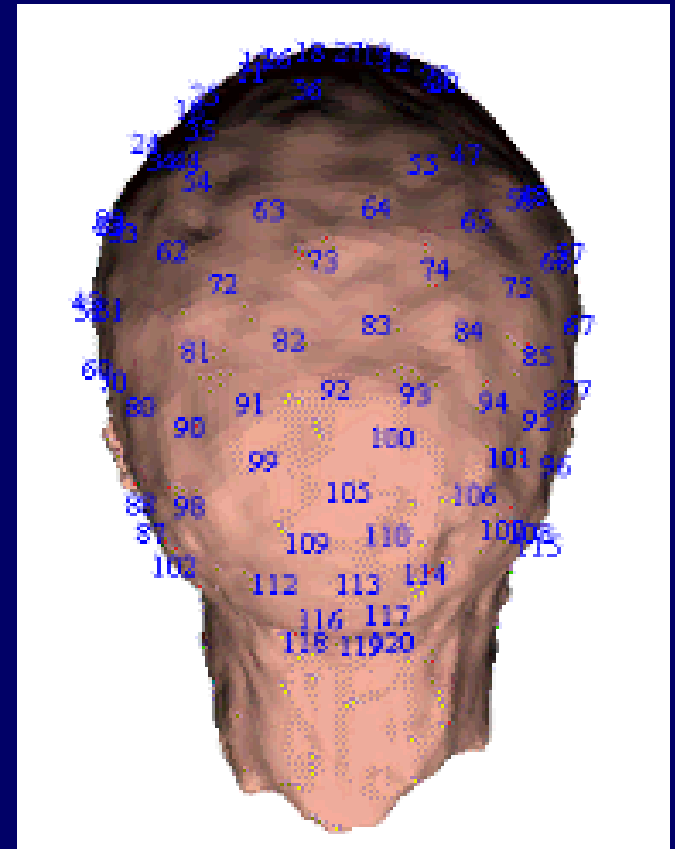
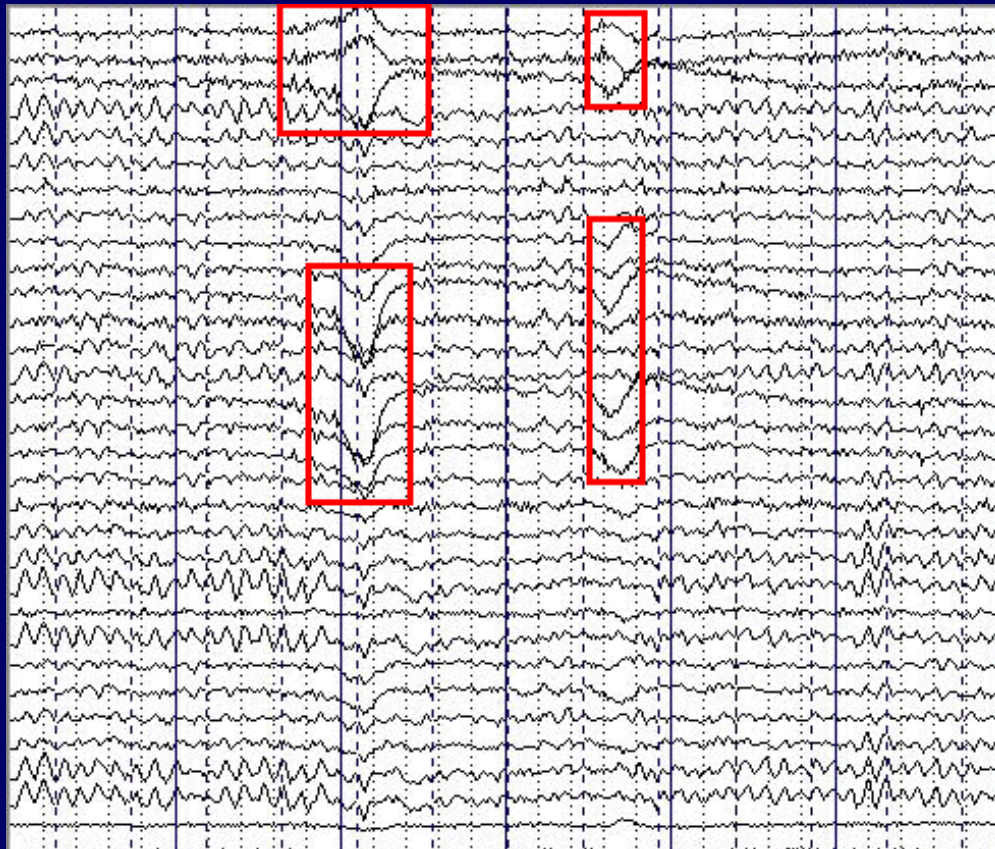
- Electrical potential fluctuations of the brain.
- Under normal circumstances, action potentials in axons are asynchronous.
- If simultaneous stimulation, projection of action potentials are detectable.
- The analysis is based more on frequency than morphology.

EEG: Instrument

Electroencephalography Recording System



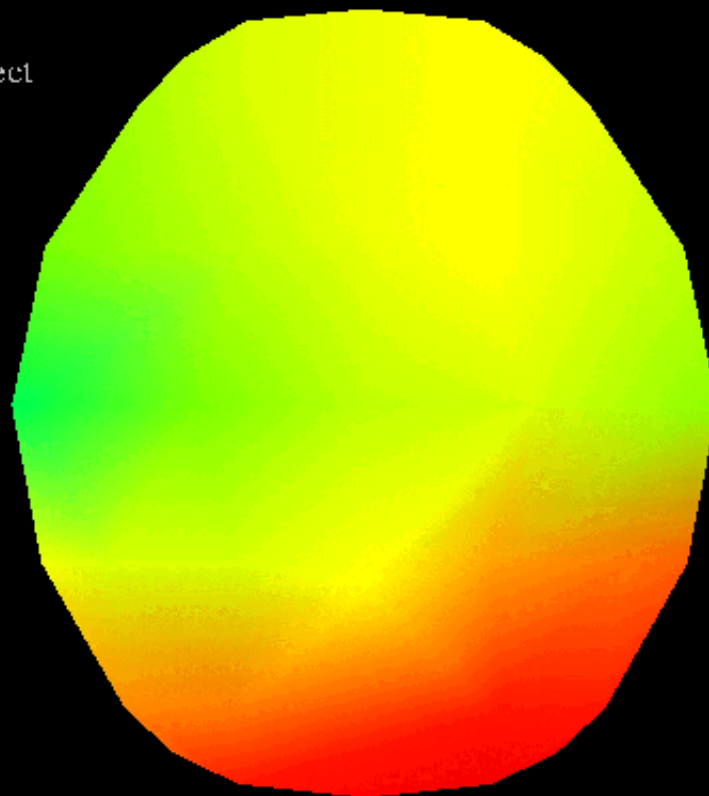
EEG: Spatial and Temporal Characteristics



EEG: Presentation

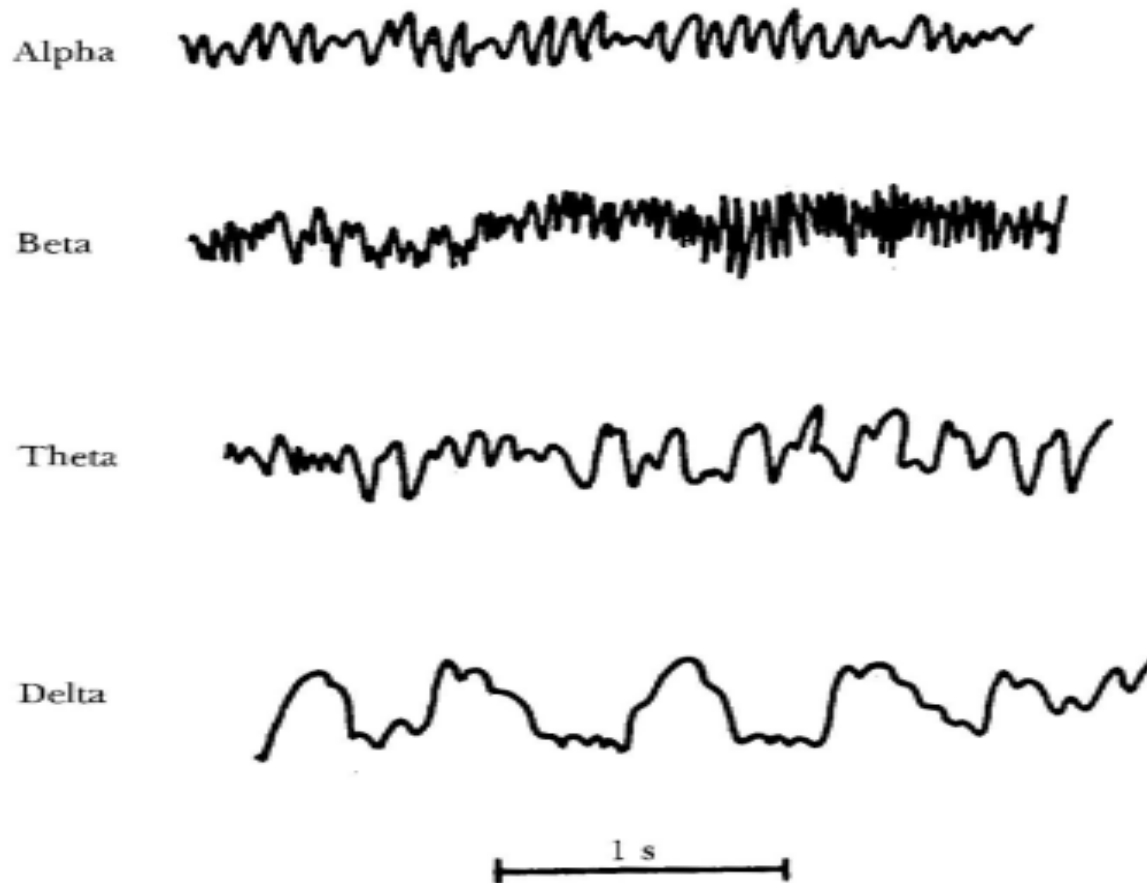
EEG Topographic Map

Young Subject
Eyes Closed



Voltage

EEG Classification



EEG Classification

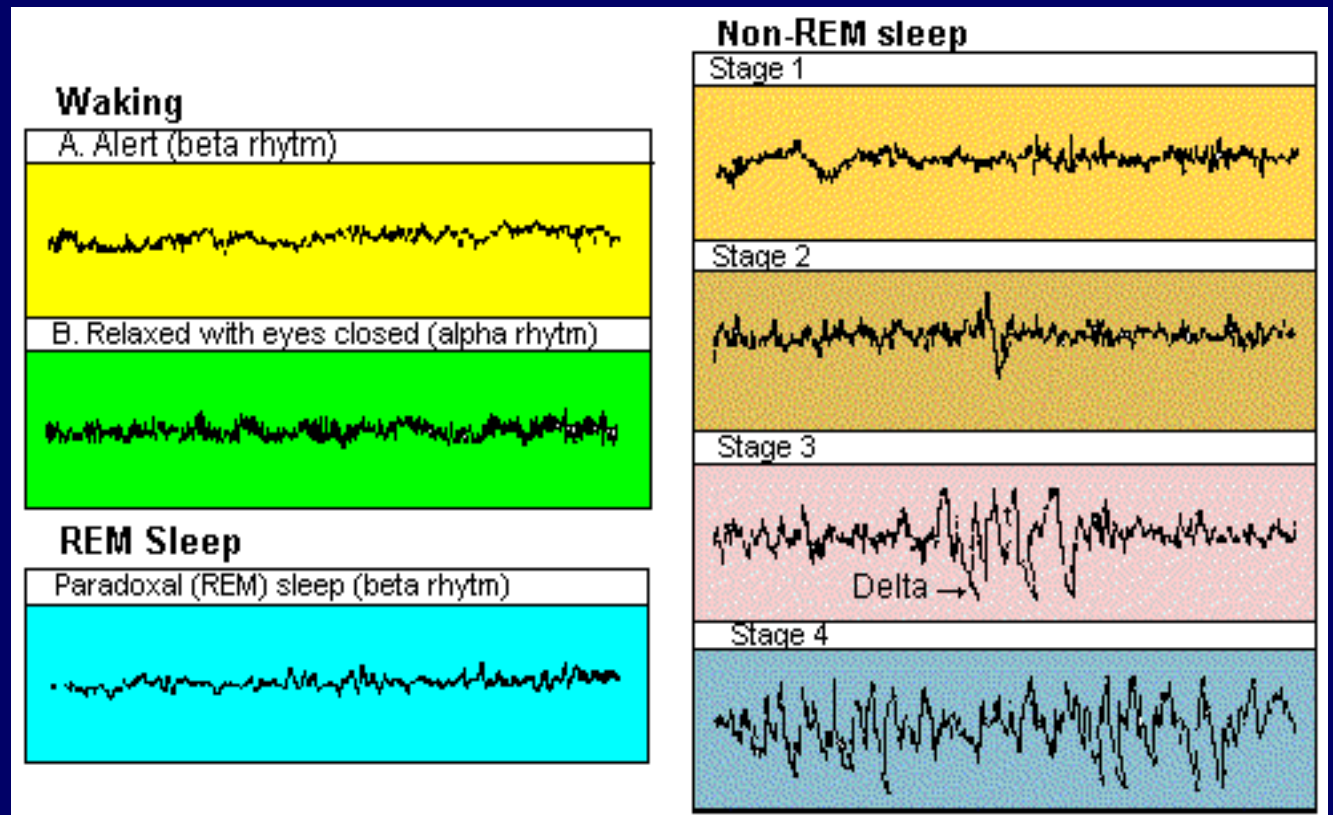
- Alpha:
 - 8 to 13Hz.
 - Normal persons are awake in a resting state.
 - Alpha waves disappear in sleep.
- Beta:
 - 14 to 30Hz.
 - May go up to 50Hz in intense mental activity.
 - Beta I waves: frequency about twice that of the alpha waves and are influenced in a similar way as the alpha waves.
 - Beta II waves appear during intense activation of the central nervous system and during tension.

EEG Classification

- Theta waves:
 - 4 to 7Hz.
 - During emotional stress.
- Delta waves
 - Below 3.5Hz.
 - Deep sleep or in serious organic brain disease.

EEG Applications

- Epilepsy.
- Dream:



Other Biomedical Signals

- Electrical:
 - Electroneurogram (ENG)
 - Electromyogram (EMG)
 - Electroretinogram (ERG)
 - Electrogastrogram (EGG).

Other Non-Electrical Biomedical Signals

- Circulatory system
 - Blood pressure
 - Heart sound
 - Blood flow velocity
 - Blood flow volume

Other Non-Electrical Biomedical Signals

- Respiratory system
 - Respiratory pressure
 - Gas-flow rate
 - Lung volume
 - Gas concentration

Applications of Signal Processing Techniques

Sampling

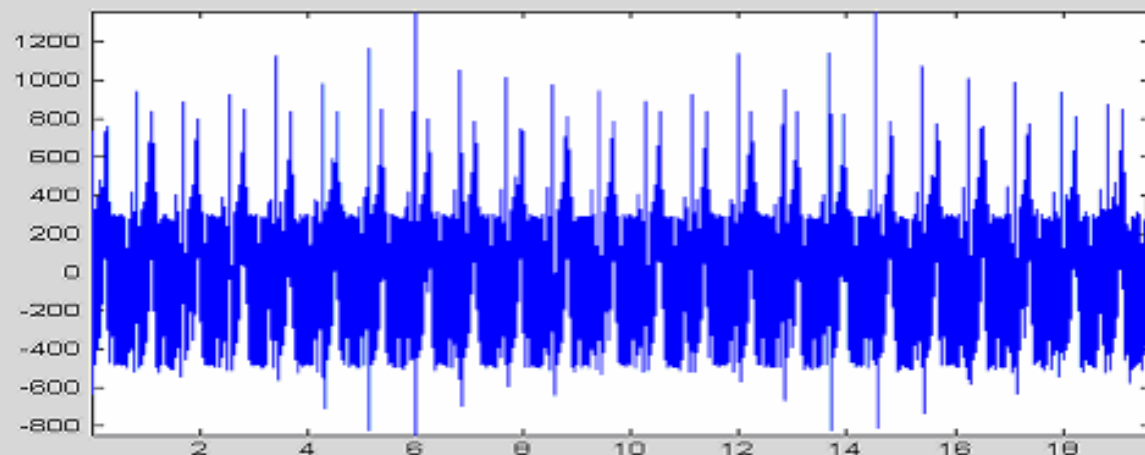
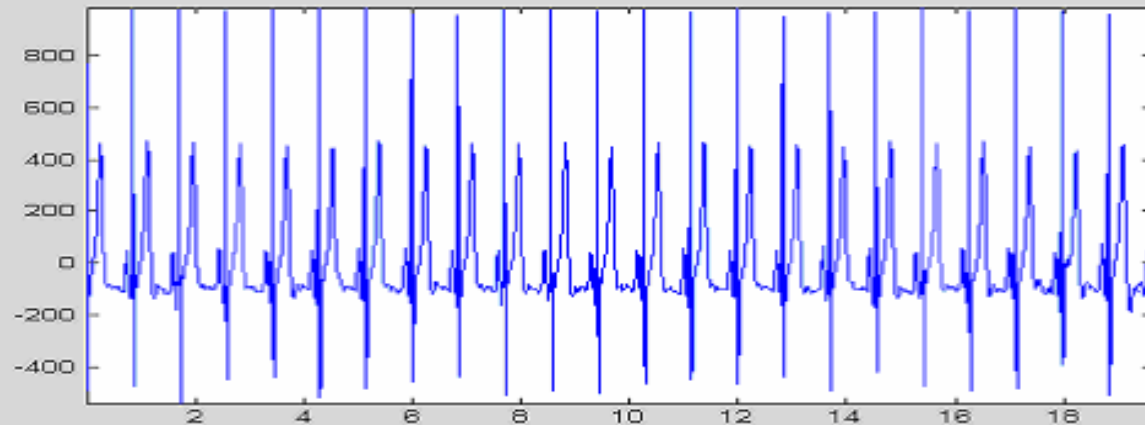
- Digital analysis and presentation of biomedical signals.
- Sampling requirements.
 - Low frequencies.
 - Frequency ranges of different physiological signals may be overlapping.
 - Electronic noise and interference from other physiological signals.
 - Very weak (maybe μV level), the pre-amp circuit is often very challenging.

Filtering

- Digital filters are used to keep the in-band signals and to reject out-of-band noise.
- Low-pass, band-pass, high-pass and band-reject.
- Similar to those of other applications.

Noise Sources of ECG

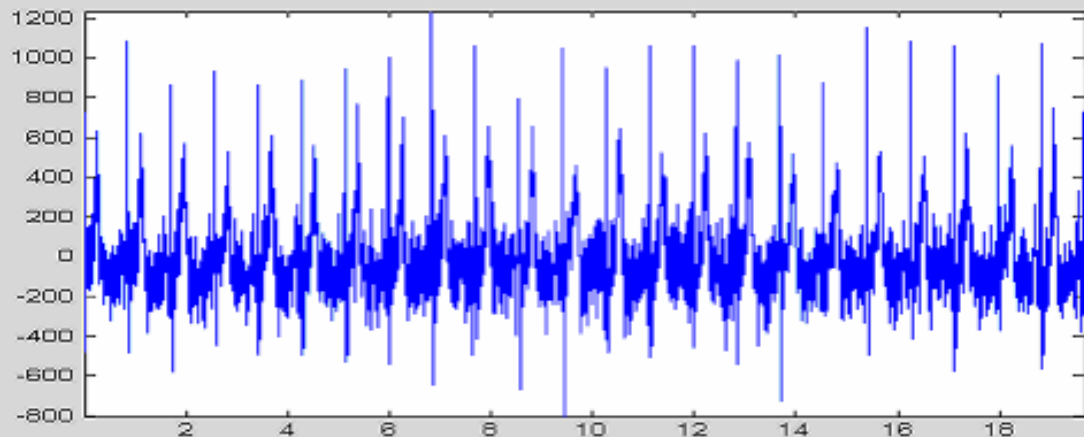
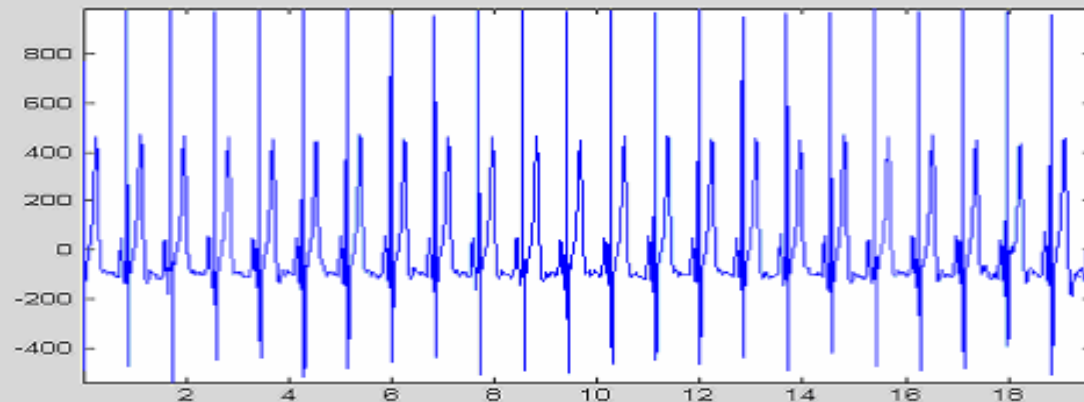
Ideal Signal Vs. Signal with Powerline Noise



Ideal Signal Vs. Signal with Powerline Noise

- Powerline interference consists of 60Hz tone with random initial phase.
- It can be modeled as sinusoids and its combinations.
- The characteristics of this noise are generally consistent for a given measurement situation and, once set, will not change during a detector evaluation. Its typical SNR is in the order of 3dB.

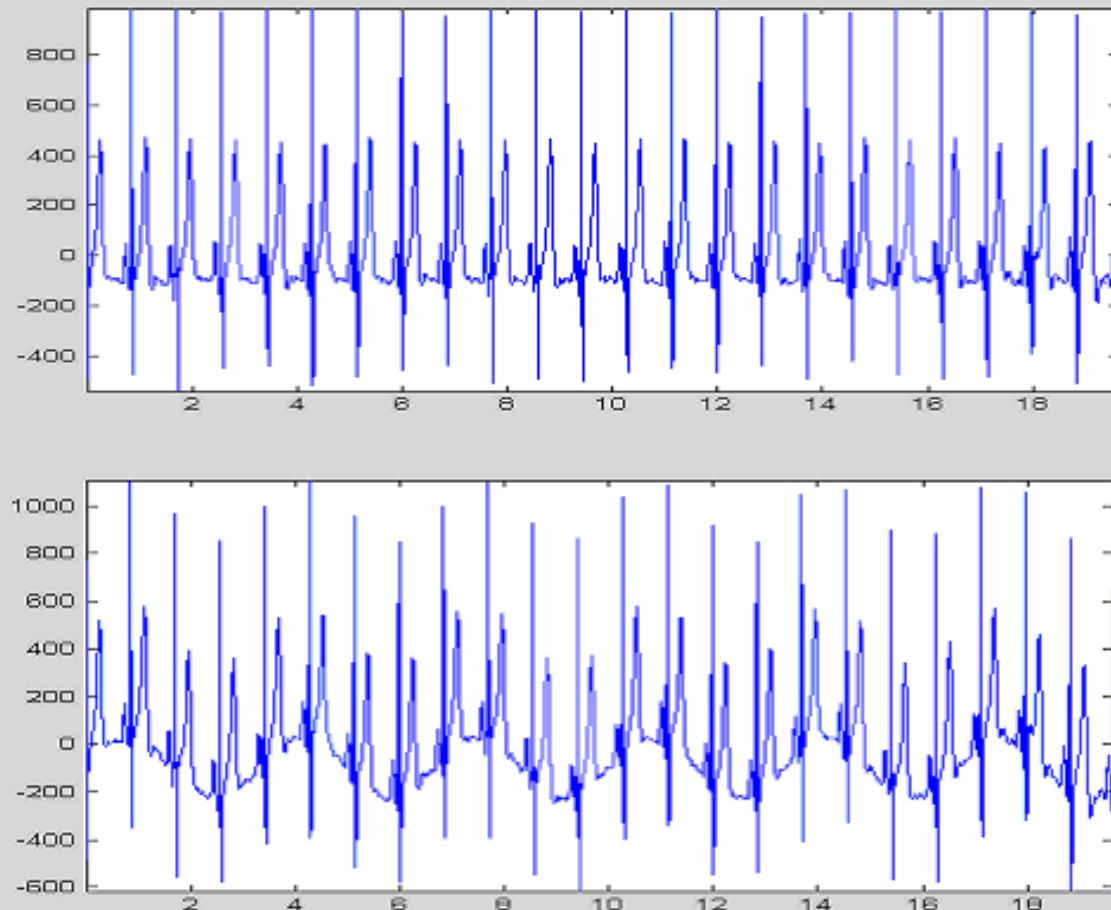
Ideal Signal Vs. Signal with Electromyographic Noise



Ideal Signal Vs. Signal with Electromyographic Noise

- EMG noise is caused by muscular contractions, which generate millivolt-level potentials.
- It is assumed to be zero mean Gaussian noise. The standard deviation determines the SNR, whose typical value is in the order of 18dB.

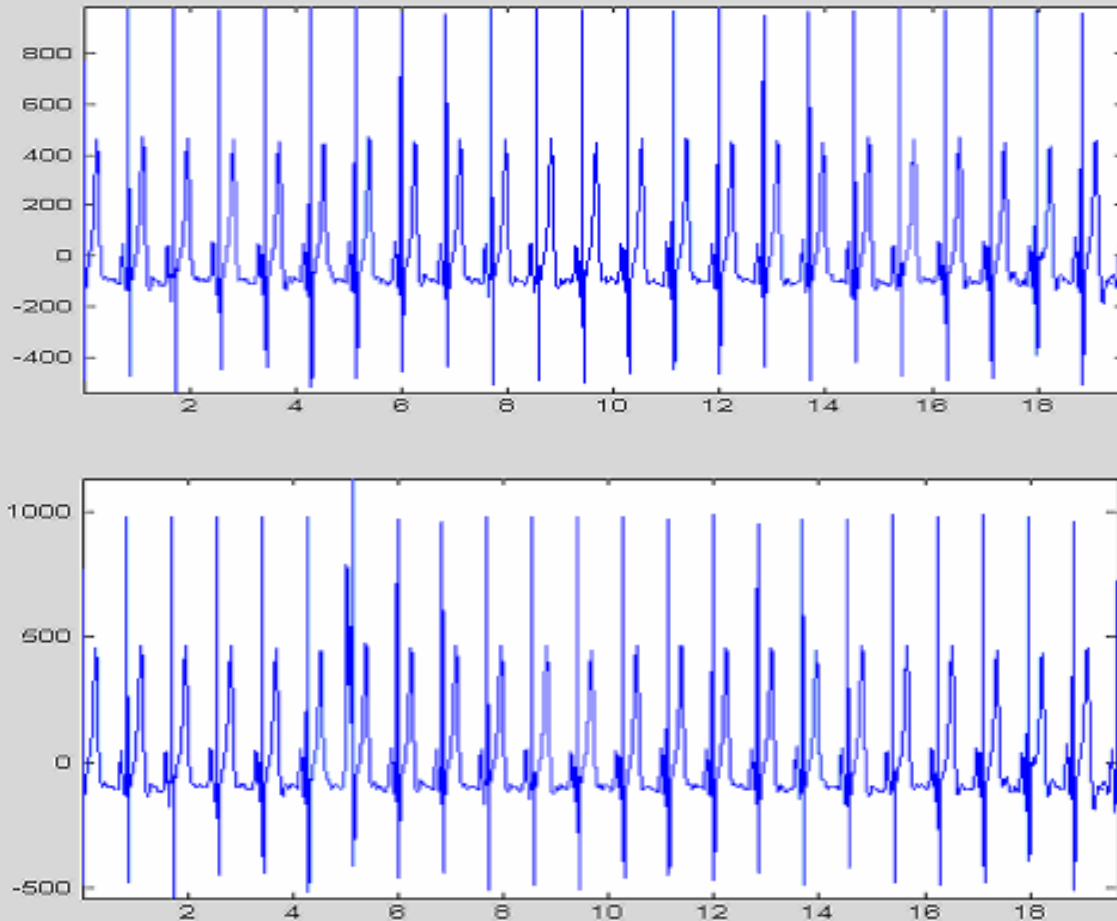
Ideal Signal Vs. Signal with Respirational Noise



Ideal Signal Vs. Signal with Respirational Noise

- Respiration noise considers both the sinusoidal drift of the baseline and the ECG sinusoidal amplitude modulation.
- The drift can be represented as a sinusoidal component at the frequency of respiration added to the ECG signal.
- The amplitude variation is about 15 percent of peak-to-peak ECG amplitude. It is simulated with a sinusoid of 0.3Hz frequency with typical SNR 32dB.
- The modulation is another choice of representing respiration noise. It can be simulated with 0.3Hz sinusoid of 12dB SNR.

Ideal Signal Vs. Signal with Motion Artifacts



Ideal Signal Vs. Signal with Motion Artifacts

- Motion artifact is caused by displacements between electrodes and skin due to patients' slow movement.
- It is simulated with an exponential function that decays with time.
- Typically the duration is 0.16 second and the amplitude is almost as large as the peak-to-peak amplitude.
- The phase is random with a uniform distribution.

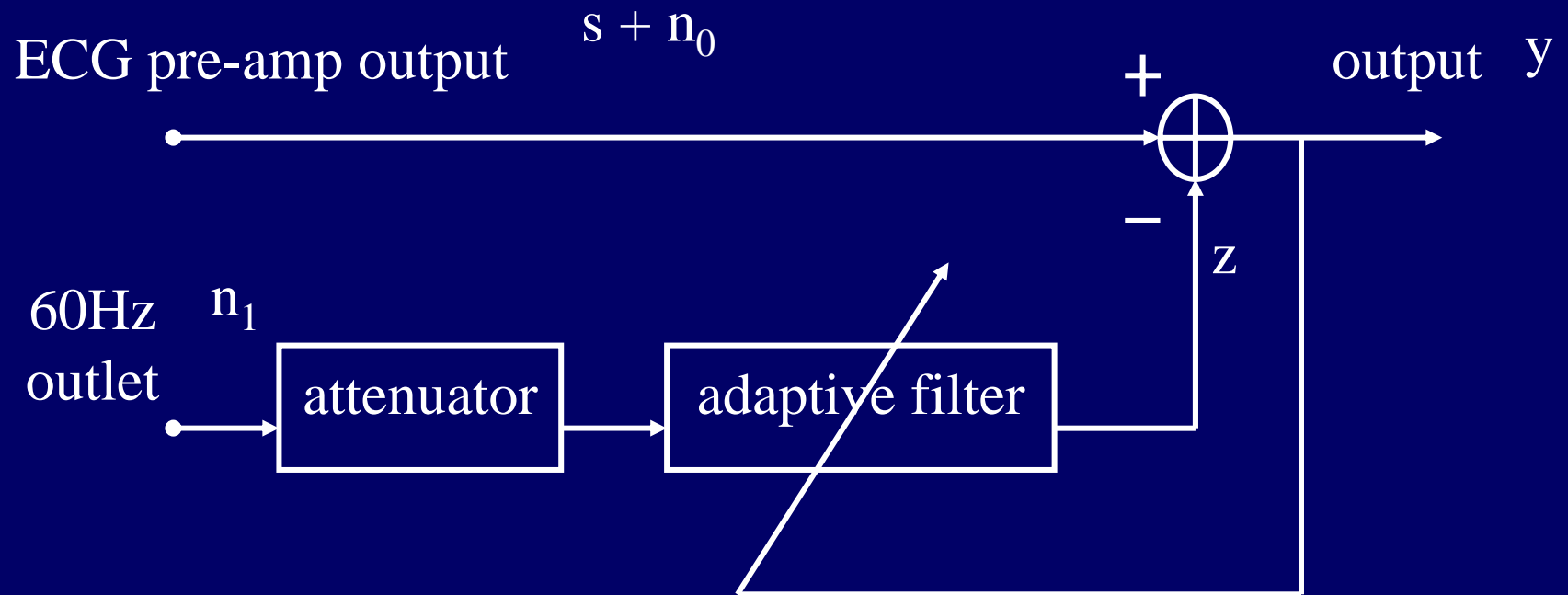
Noise Removal

- The four types of noises are mostly sinusoidal or Gaussian. The sinusoidal noises are usually removed with a notch filter. Other distortions are zeroed out using the moving average.

Adaptive Noise Cancellation

- Noise from power line (60Hz noise).
- The noise is also in the desired frequency range of several biomedical signals (e.g., ECG), notch filter is required.
- Adaptive filtering: The amplitude and exact frequency of the noise may change.

Adaptive Filter



Adaptive Filter

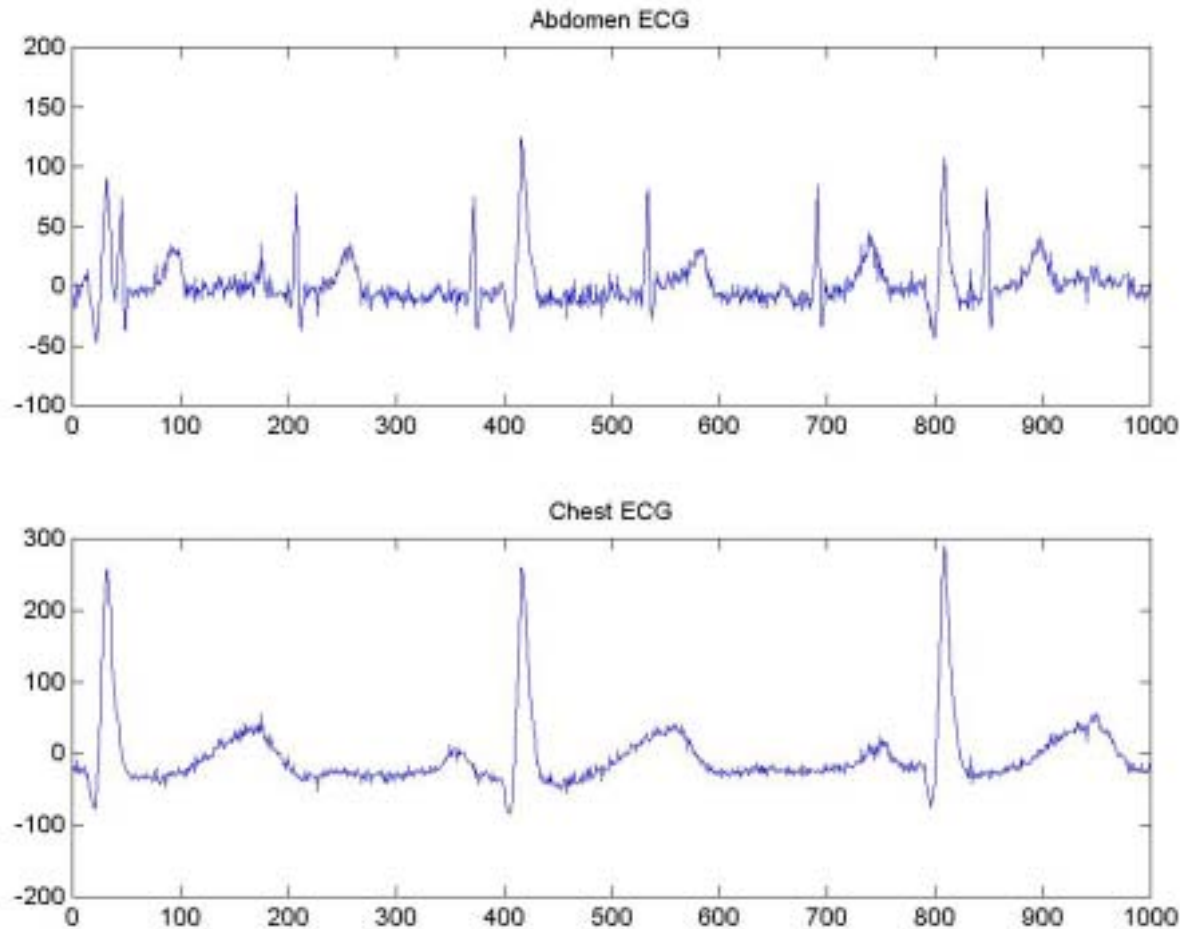
$$y(nT) = s(nT) + n_0(nT) - z(nT)$$

$$y^2 = s^2 + (n_0 - z)^2 + 2s(n_0 - z)$$

$$E[y^2] = E[s^2] + E[(n_0 - z)^2] + 2E[s(n_0 - z)] = E[s^2] + E[(n_0 - z)^2]$$

$$\min E[y^2] = E[s^2] + \min E[(n_0 - z)^2]$$

Adaptive Filtering for Fetal ECG



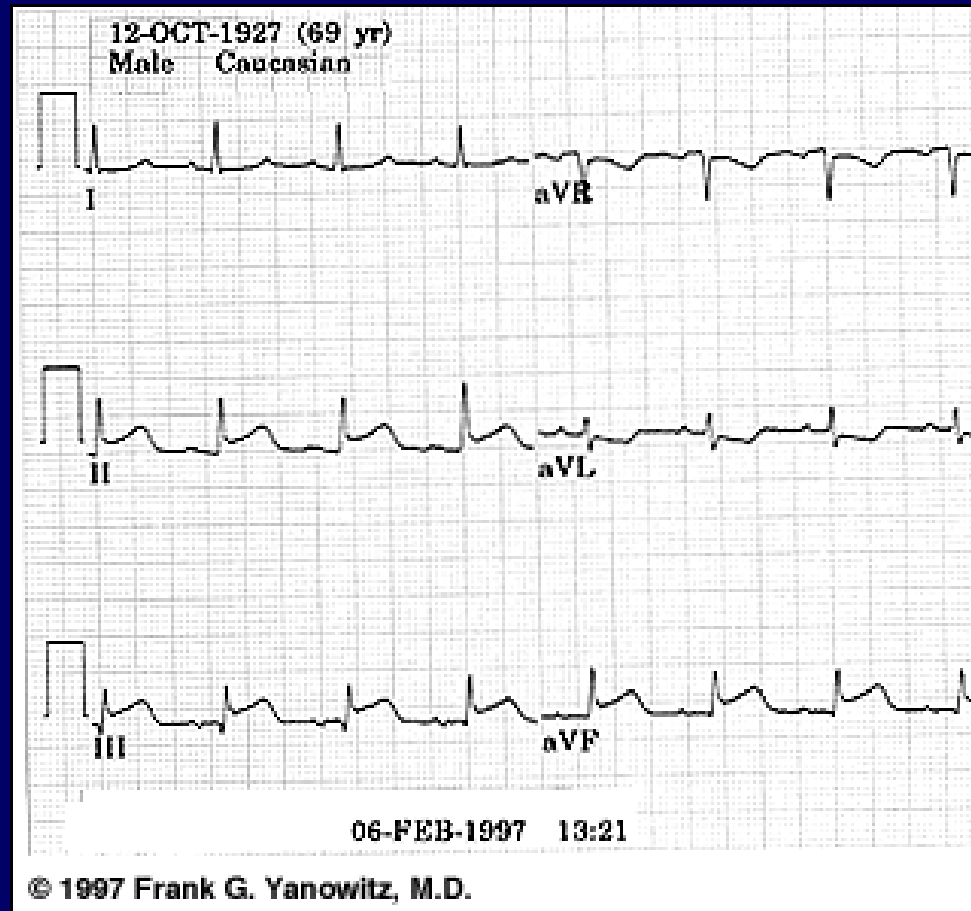
Pattern Recognition

- Abnormal physiological signals vs. the normal counterparts.
- An average of several known normal waveforms can be used as a template.
- The new waveforms are detected, segmented and compared to the template.
- Correlation coefficient can be used to quantify the similarity.

$$\rho = \frac{\sum_{i=1}^N (T_i - \mu_T)(X_i - \mu_X)}{\sqrt{\sum_{i=1}^N (T_i - \mu_T)^2} \sqrt{\sum_{i=1}^N (X_i - \mu_X)^2}}$$

Pattern Recognition

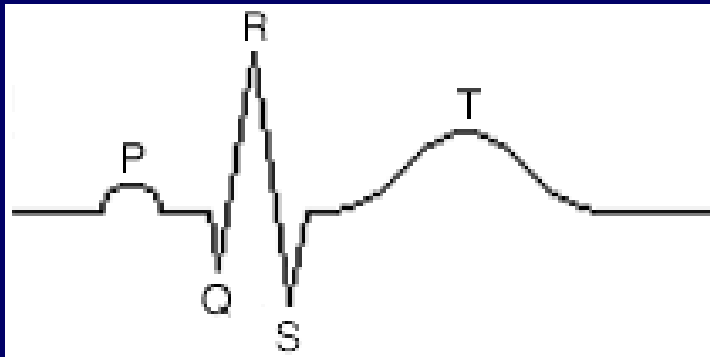
Ex. ECG



Data Compression

- For large amount of data (e.g., 24 hour ECG).
- Must not introduce distortion, which may lead to wrong diagnosis.
- Formal evaluation is necessary.

ECG Data Compression



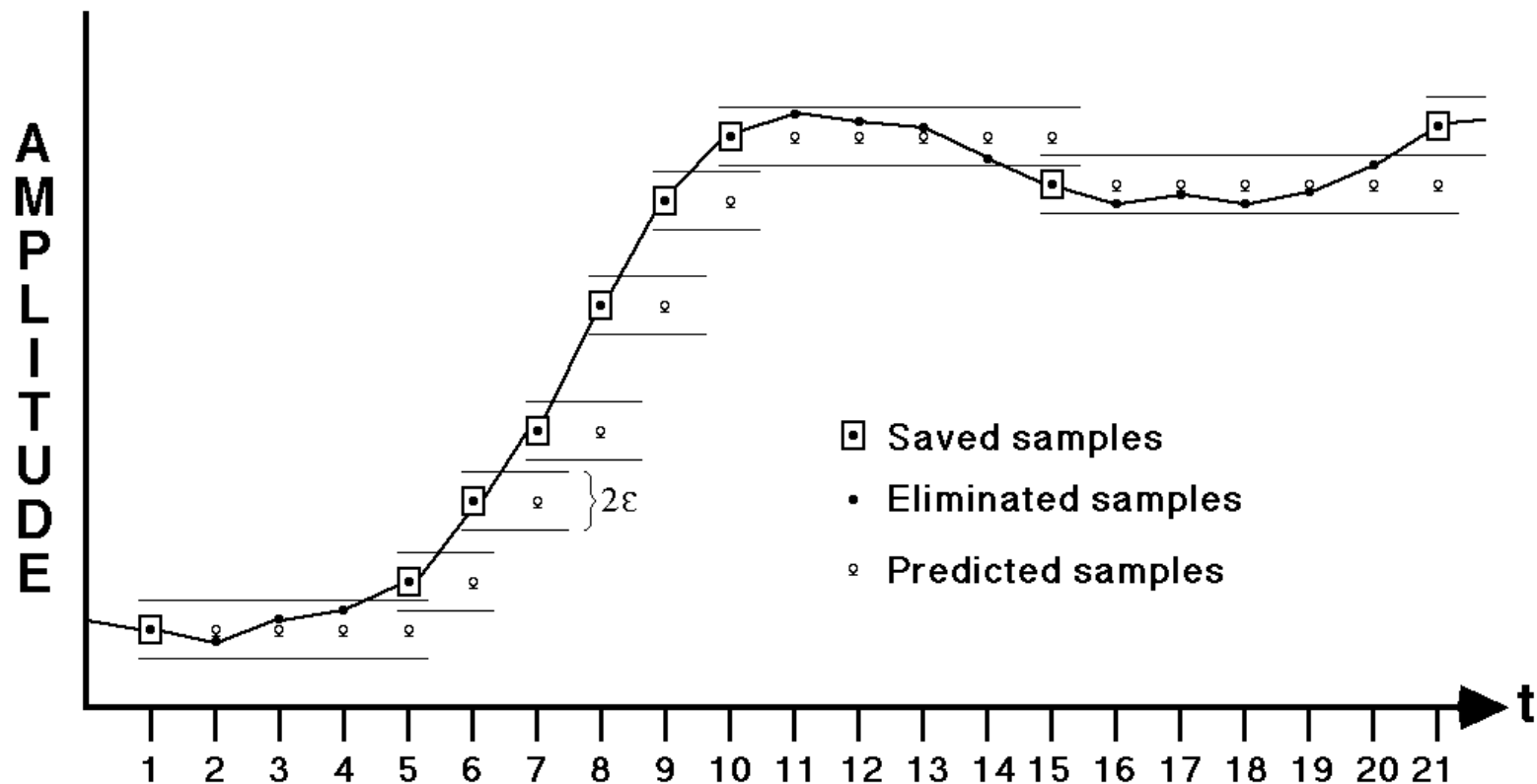
$$PRD = 100 \cdot \sqrt{\frac{\sum_{i=1}^n (\text{ORG}(i) - \text{REC}(i))^2}{\sum_{i=1}^n (\text{ORG}(i))^2}}$$

WGAQQQQQQRBCCCCCHZY

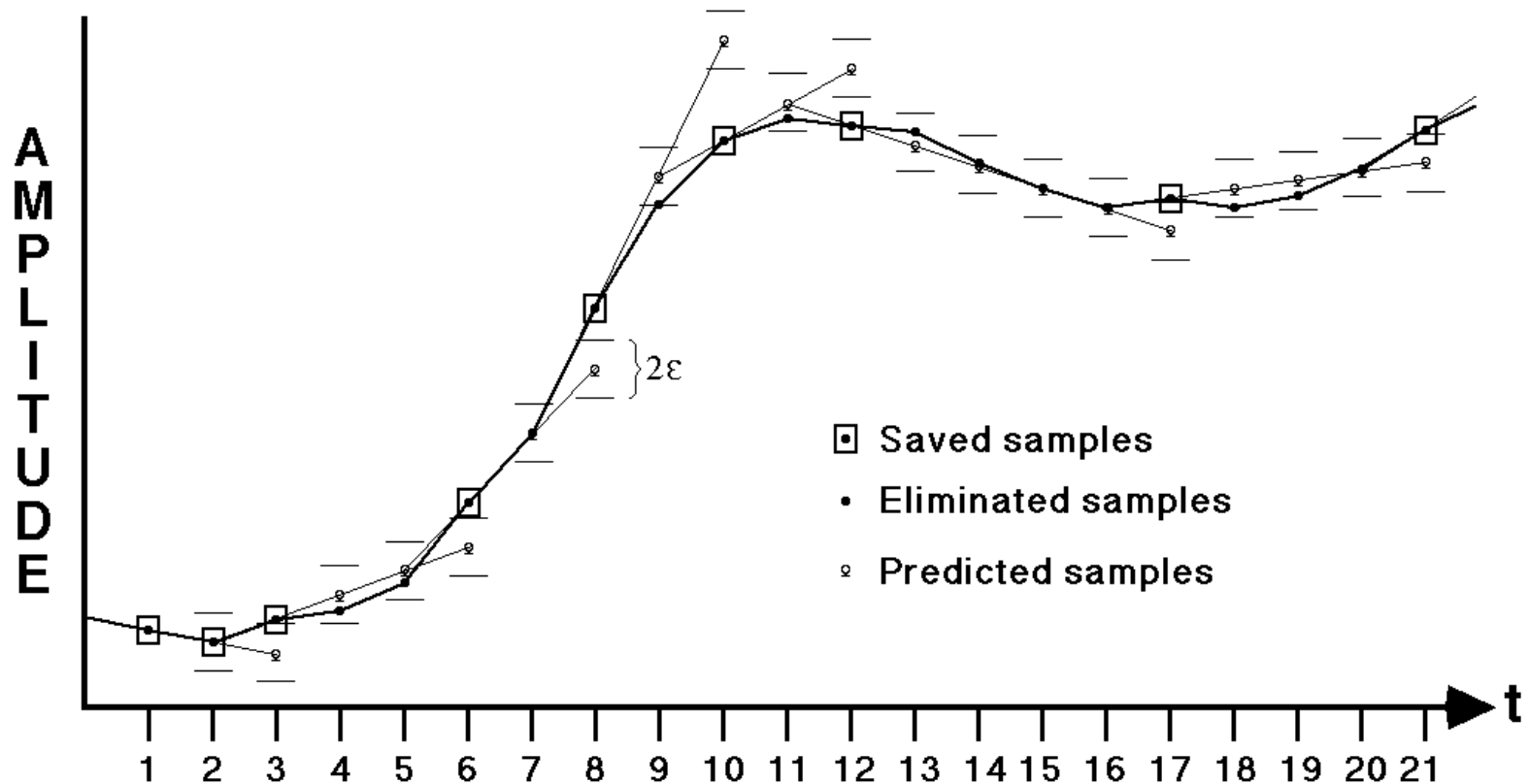


WGAQ*6RBC*5HZY

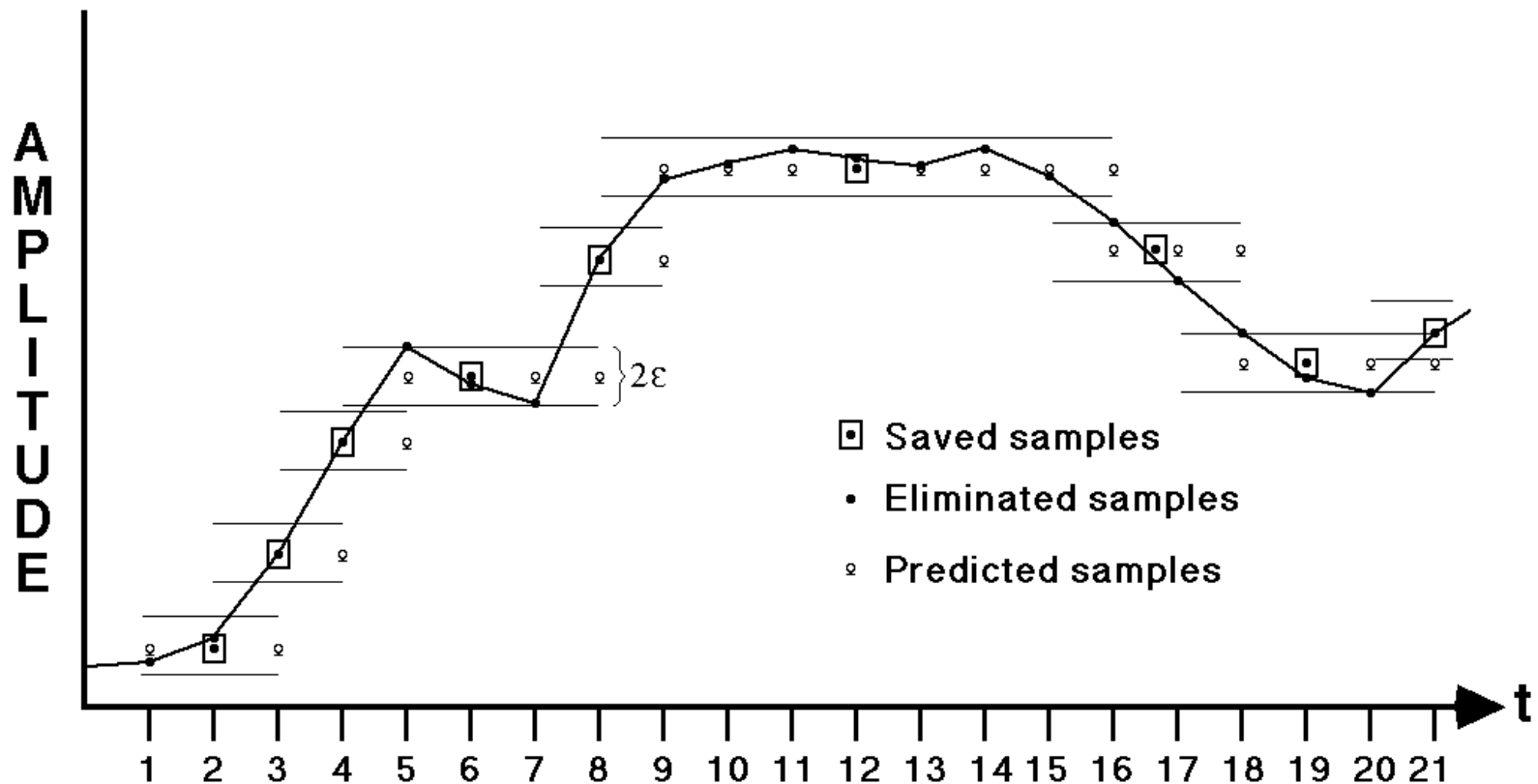
ECG Data Compression



ECG Data Compression



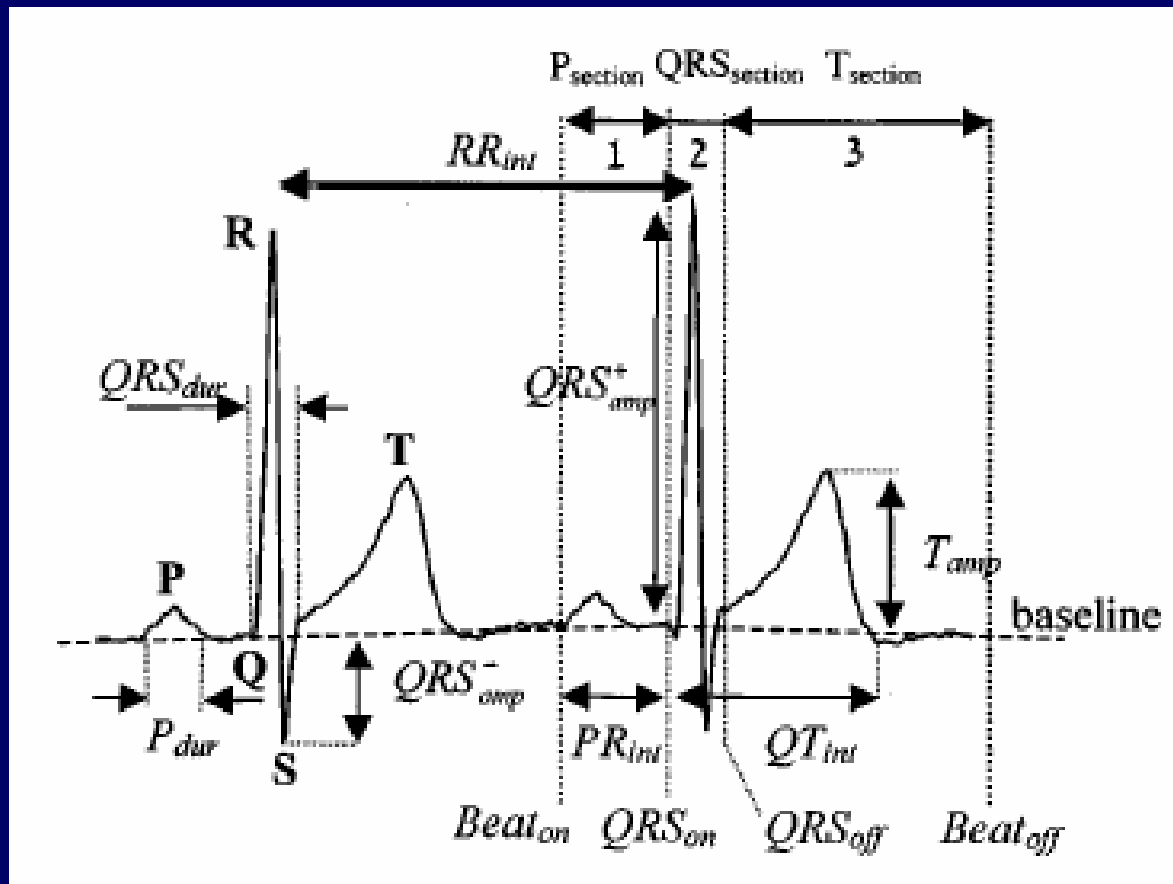
ECG Data Compression



Is *straightforward*
implementation sufficient for
biomedical signals?

Characteristics of Biomedical Signals (I): Weak Unimportant

- The information is in the details:



OK!

JPEG
Compression



4302 Bytes



2245 Bytes



1714 Bytes



4272 Bytes



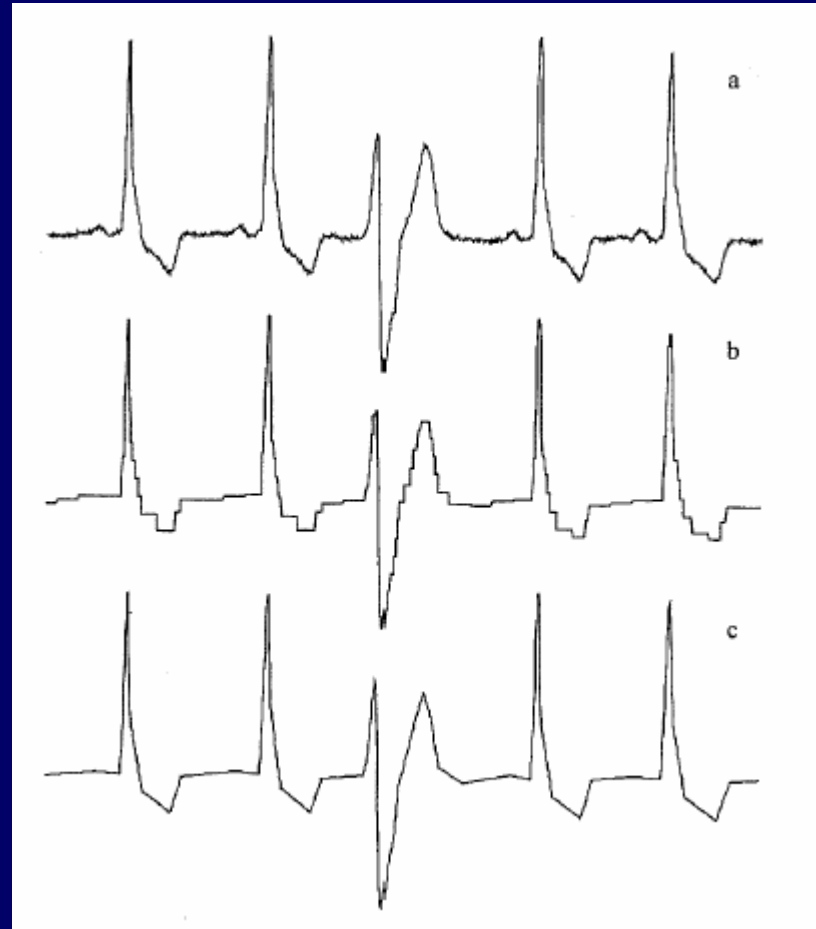
2256 Bytes



1708 Bytes

Wavelet
Compression

OK?

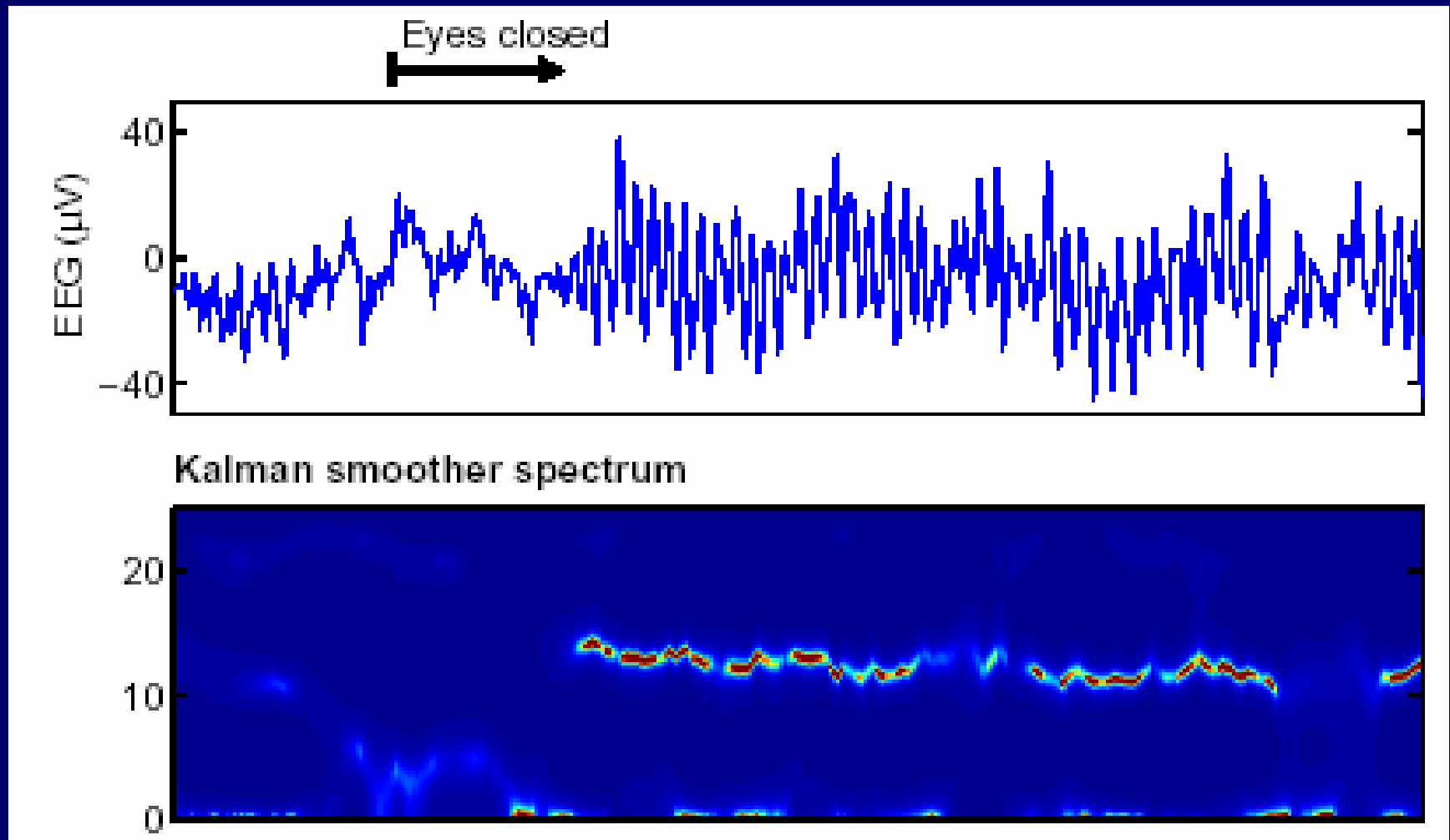


Characteristics of Biomedical Signals (II): Nonstationarity

$$\text{Fourier Transform : } X(\omega) = \int_{-\infty}^{+\infty} x(t)e^{-j\omega t} dt$$

- Fourier transform requires signal stationarity.
- Biomedical signals are often time-varying.
 - Short-time Fourier analysis
 - Time-frequency representation
 - Cyclo-stationarity

Nonstationarity: An EEG Example



Spectral Estimation for Nonstationary Signals

- Fourier Transform \rightarrow Short Time Fourier Transform

$$X(\omega) = \int_{-\infty}^{+\infty} x(t) e^{-j\omega t} dt$$



$$X(\omega, a) = \int_{-\infty}^{+\infty} x(t) g(t - a) e^{-j\omega t} dt$$

Another Example:
Signal Processing for
Blood Velocity Estimation
(Please refer to the class notes.)

Other Important Biomedical Applications

- Biomedical imaging:
 - X-ray, CT, MRI, PET, OCT, Ultrasound,...
- Genomic signal processing
- ...,etc

Term Project

<http://ultrasound.ee.ntu.edu.tw>

課程→數位訊號處理概論

Term Project

- Part I: Implementation of the Pan-Tompkins Technique + heart rate estimation.
- Part II: ECG paper survey.
- Please read the description on the web site carefully.

The Pan-Tompkins Technique

Band-Pass
Filter

Differentiator

Squaring

Moving Average
Integrator

