Acquisition and Analysis of Biosignals DTEK0042

Origins, Significance and Acquisition of Biosignals: Cardiovascular System

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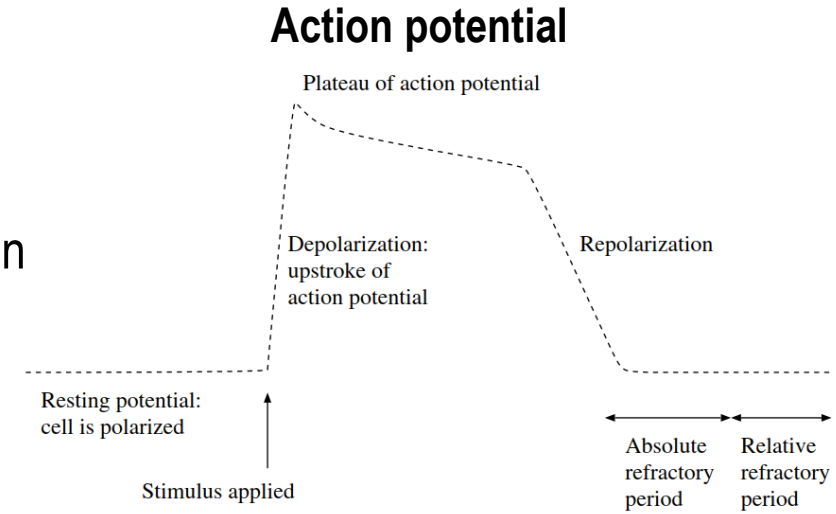
Introduction

In the previous session, we learned:

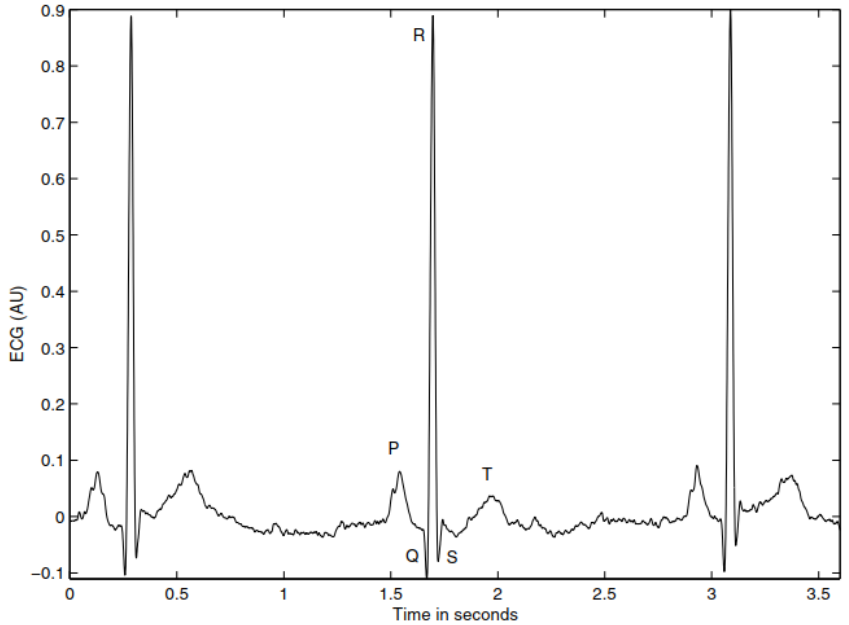
- ❑ About the action potential, i.e., the origin of electric signal
- ❑ Different biosignals, e.g., EMG, EEG and EDA



In this session, we will learn:

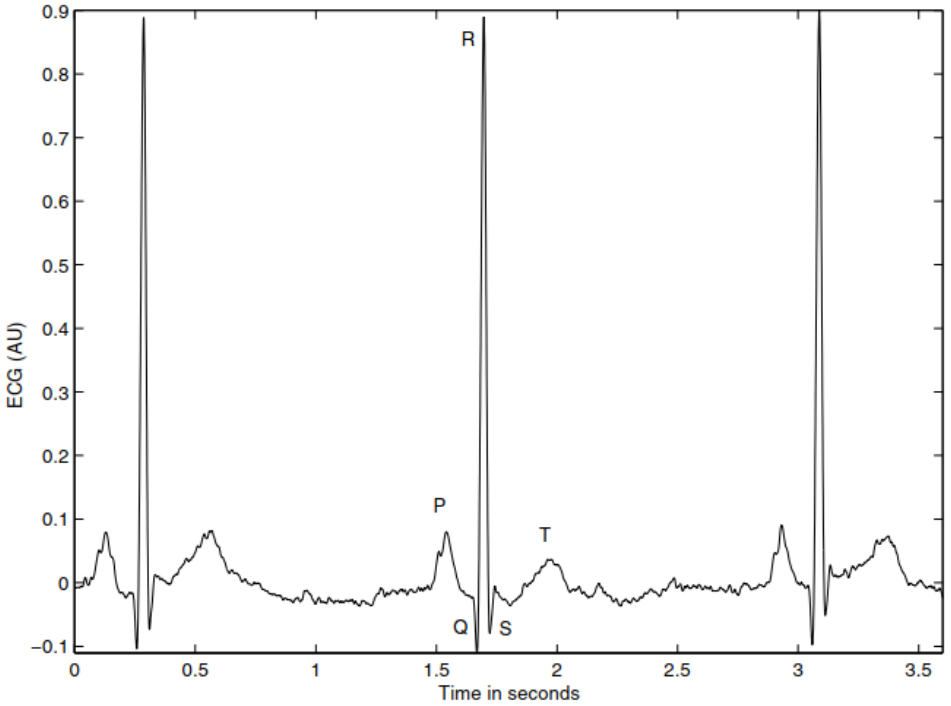
- ❑ Biosignals collected to monitor the cardiovascular system
  - ECG, PCG, SCG, and PPG

Electrocardiogram (ECG)



Electrocardiogram (ECG)

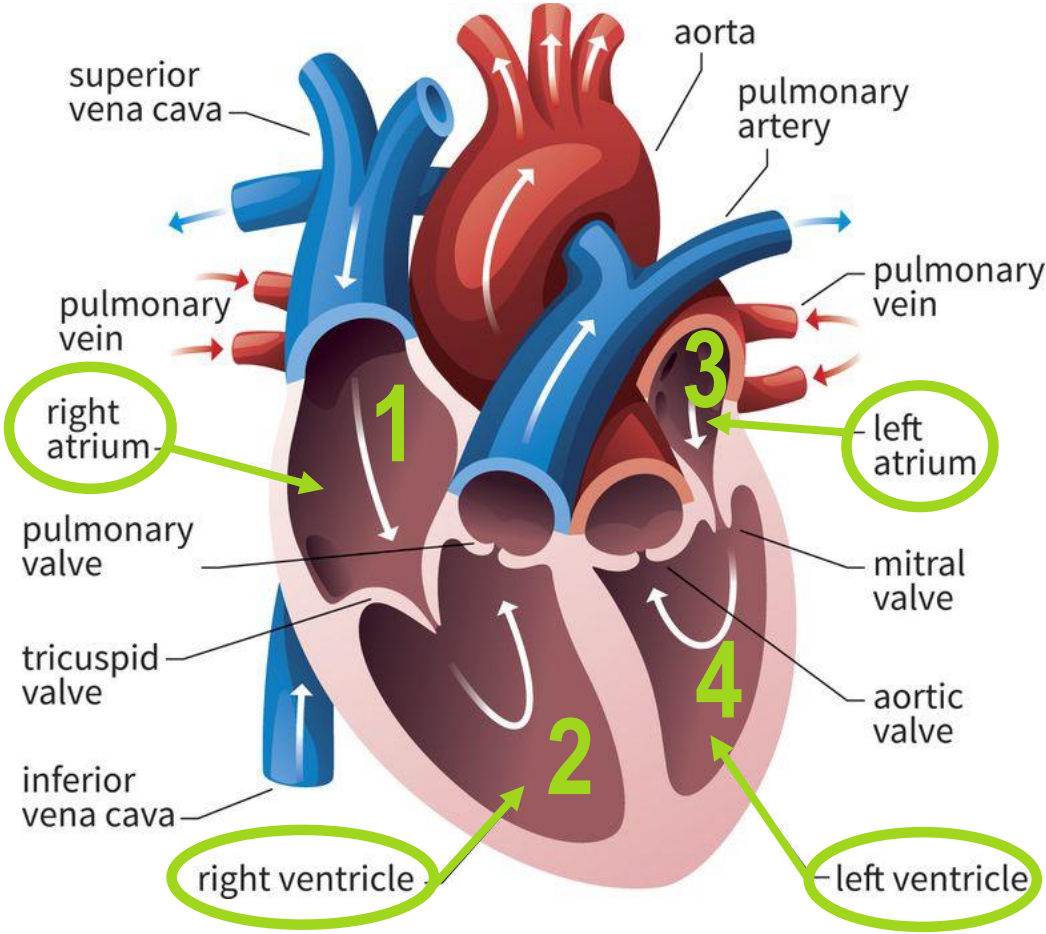
- ECG is an electrical signal generated from the activities of heart
- ECG is the most commonly known & used biomedical signal
- The rhythm of the heart is estimated by counting the readily identifiable waves.
- ECG wave shape is altered by cardiovascular diseases and abnormalities (arrhythmias)



Rangayyan, R. M. *Biomedical signal analysis*. 2nd Edition, Vol. 33. John Wiley & Sons, 2015.

The heart (1)

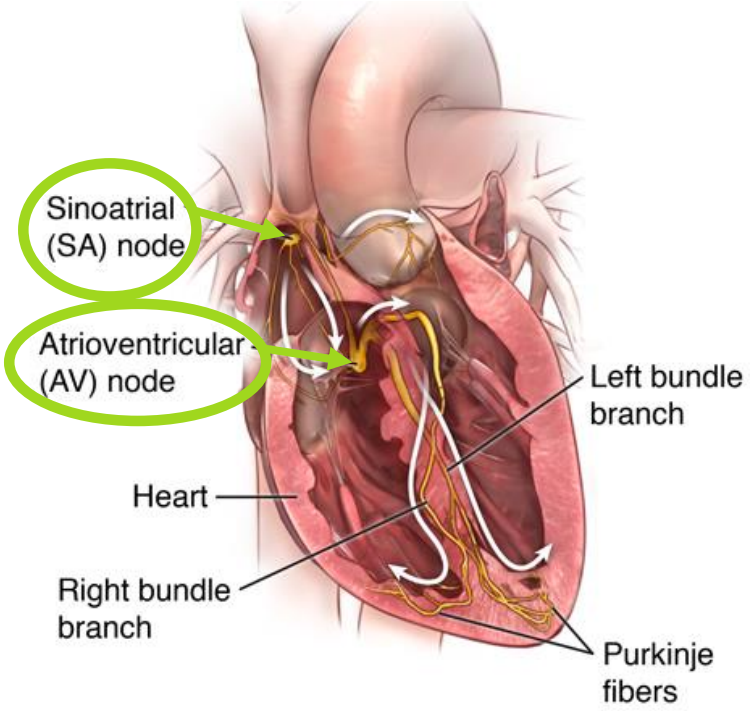
- A four-chambered pump:
  1. **Right atrium (RA)**: collect deoxygenated blood from the systemic circulation (body)
  2. **Right ventricle (RV)**: pump out to the lungs
  3. **Left atrium (LA)**: collect oxygenated blood from the lungs
  4. **Left ventricle (LV)**: pump out to the systemic circulation (body)



https://www.thoughtco.com/anatomy-of-the-heart-valves-373203

The heart (2)

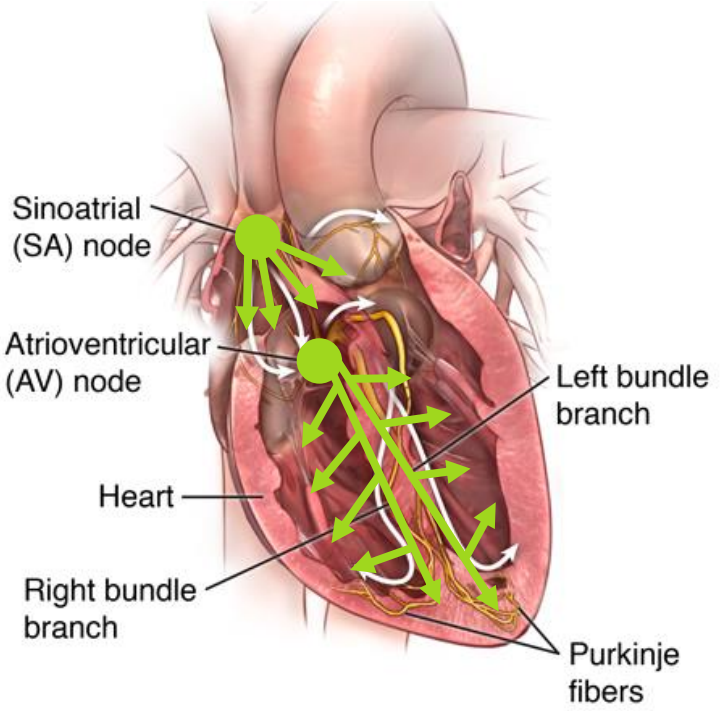
- In general there are two phases:
  1. **Systole**: contracting or pumping phase
  2. **Diastole**: resting or filling phase of a cardiac chamber
- Cardiac rhythm or Heart rate (HR) is controlled by the autonomic nervous system (ANS)
- **For the pumping:** There are two regions with specialized pacemaker cells:
  1. Sinoatrial (SA) node
  2. Atrioventricular (AV) node



https://www.hopkinsmedicine.org/health/conditions-and-diseases/anatomy-and-function-of-the-hearts-electrical-system

The electrical system of the heart

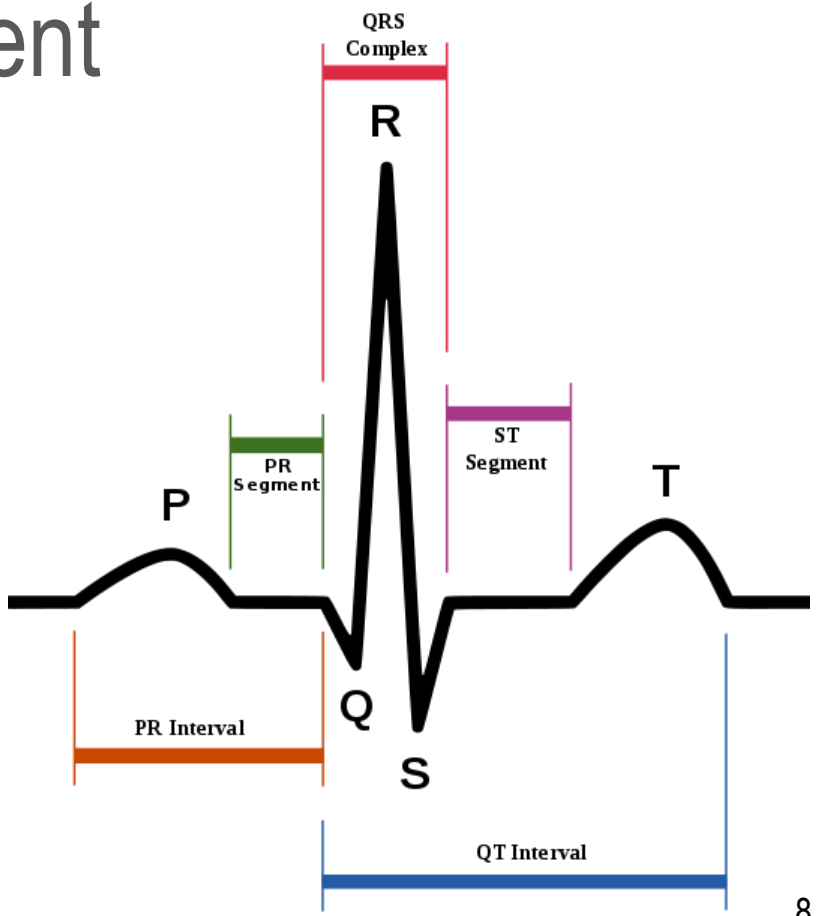
- In each cardiac cycle:
  1. The SA node triggers its own train of action potentials
  2. Electrical activity propagates through atrial at comparatively low rates => slow-moving depolarization (contraction) of atria
  3. The AV node fires (Propagation delay at the AV node => transfer blood from the atria to ventricle)
  4. The bundle branches and purkinje system propagate the stimulus
  5. Electrical activity propagates through ventricles at a high rate => depolarization (contraction) of ventricle
  6. A normally isoelectric segment is caused after the action potential of the ventricular muscle cells
  7. Repolarization (relaxation) of the ventricles is occurred



https://www.hopkinsmedicine.org/health/conditions-and-diseases/anatomy-and-function-of-the-hearts-electrical-system

The ECG signal component

- In a regular cardiac cycle, we measure:
  - **P-wave**: depolarization of atria
    - (0.1 − 0.2 mV , 60 − 80 ms)
  - **PQ segment**: delay at the AV node
    - (60 − 80 ms)
  - **QRS complex**: depolarization of ventricle
    - (1 mV , 80 ms)
  - **ST segment**: a normally isoelectric segment
    - (100 − 120 ms)
  - **T-wave**: repolarization of the ventricles
    - (0.1 − 0.3 mV, 120 − 160 ms)

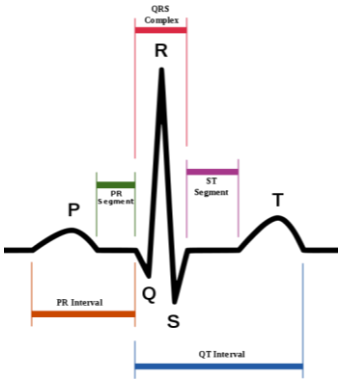


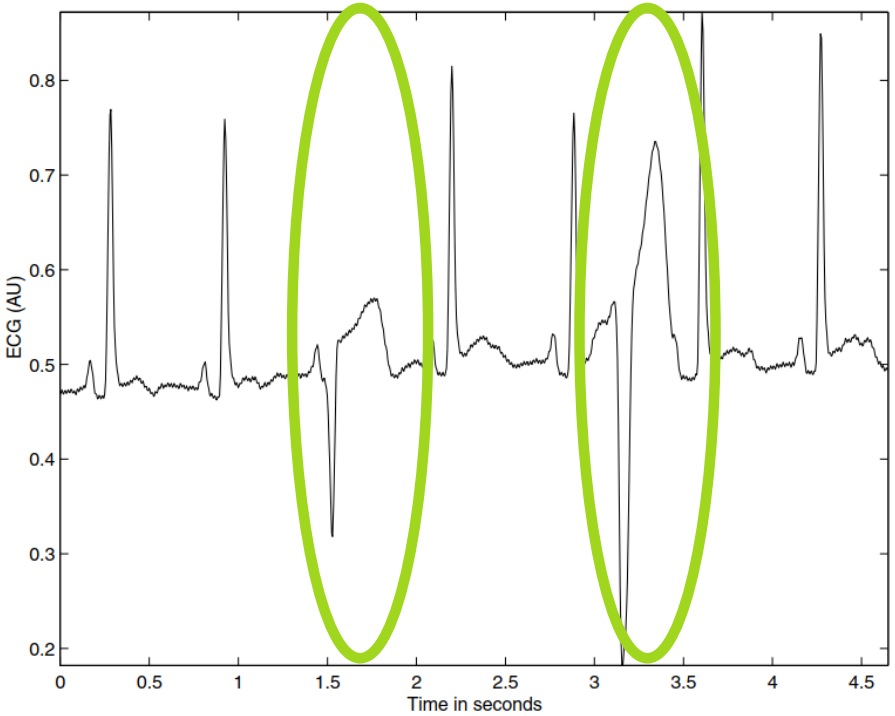
Arrhythmia: disturbance in the cardiac cycle

- ❑ Irregular firing patterns from the SA node
- ❑ Abnormal and additional pacing activity from other parts of the heart
- ❑ If the SA node is depressed or inactive, other parts (e.g., AV node, purkinje fibers) may take over the role of the pacemaker
- ❑ Different arrhythmias result from variations in the site and frequency of impulse formation
  - Premature ventricular contractions => ventricular fibrillation
- ❑ Bundle-branch block causes a widened and jagged QRS
- ❑ ST segment might be elevated or depressed due to reduced blood supply to a part of the heart muscles (a block in the coronary arteries) or dead tissue

Arrhythmia – example (1)

- Ventricular fibrillation in third and sixth beats





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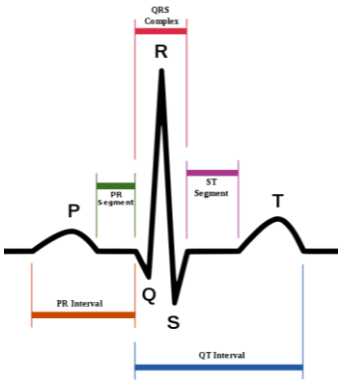
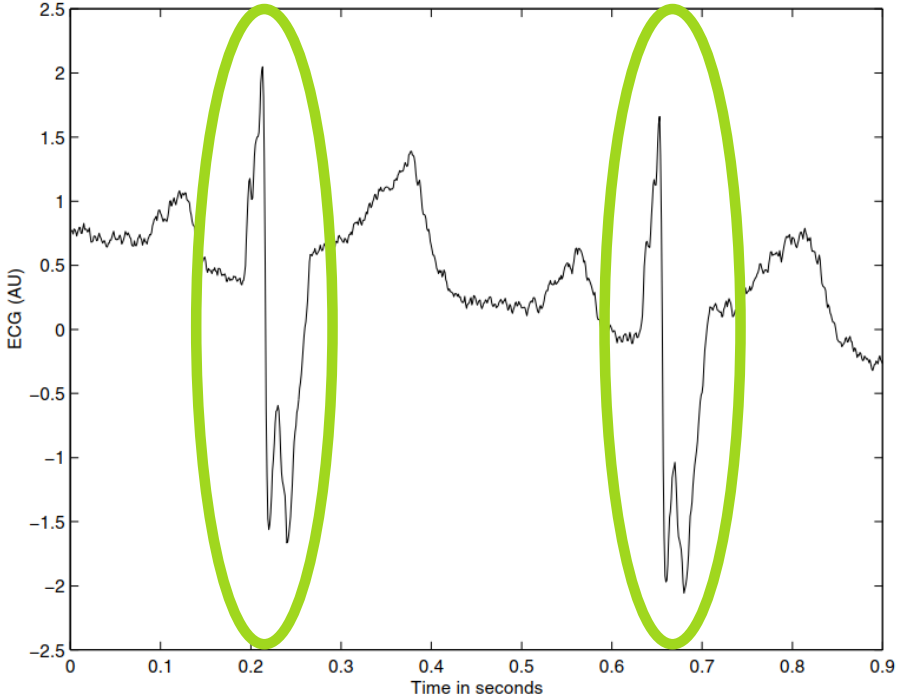
Arrhythmia – example (2)

- Right bundle-branch block and hypertrophy
  - QRS complex is wider than normal

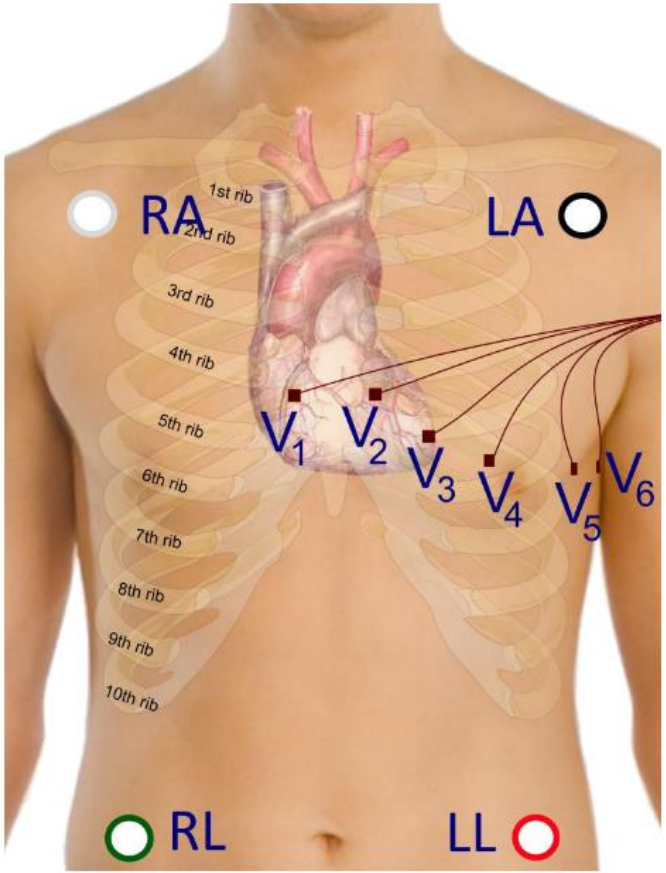




Rangayyan, R. M. *Biomedical signal analysis*. 2nd Edition, Vol. 33. John Wiley & Sons, 2015.

ECG signal acquisition

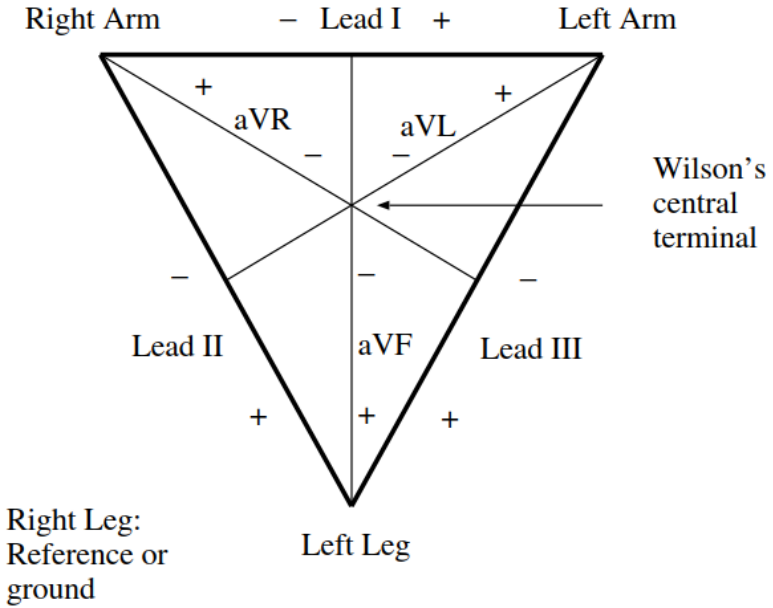
- ❑ Standard 12-channel ECG obtained
  - Using 4 **limb leads**
    - Left arm
    - Right arm
    - Left leg
    - Right leg (ground)
  - Using 6 **chest leads**



http://www.shimmersensing.com/images/uploads/docs/ECG_User_Guide_Rev1.12.pdf

ECG acquisition – limb (1)

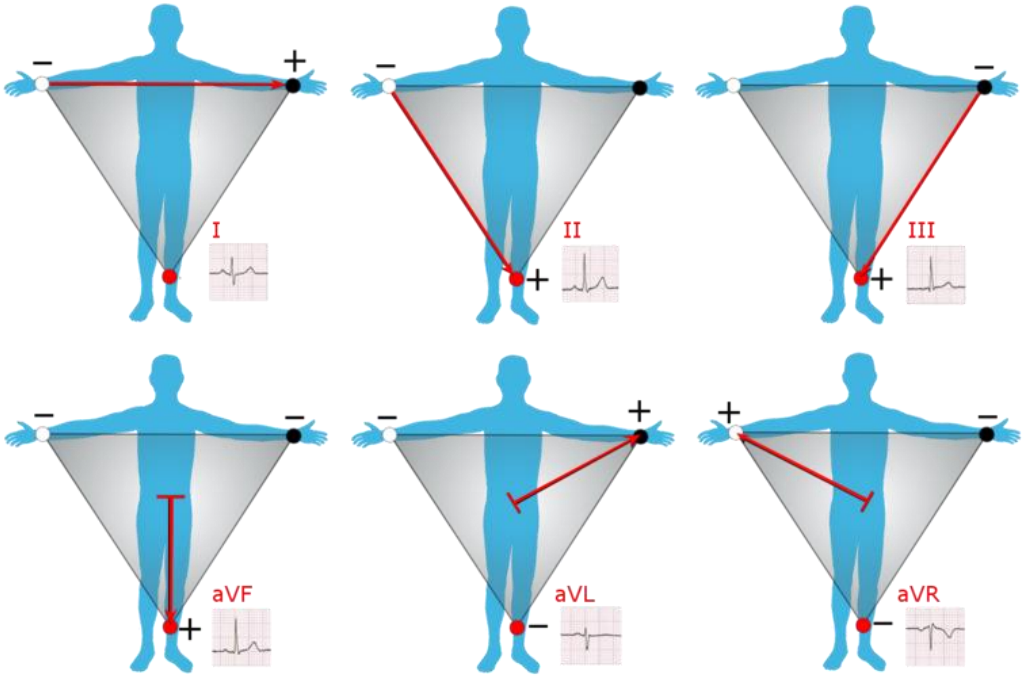
- 6 channels are obtained using the 4 limb leads
- We assume a hypothetical equilateral triangle named as "**Einthoven's triangle**"
- Center of the triangle is **Wilson's central terminal** which is:
  - Formed by combining left arm, right arm, and left leg leads
  - Reference for chest leads
  - Schematically, location of the heart



Rangayyan, R. M. *Biomedical signal analysis*. 2nd Edition, Vol. 33. John Wiley & Sons, 2015.

ECG acquisition – limb (2)

- **6 channels** are obtained using the 4 limb leads
  - Lead I = LA – RA
  - Lead II = LL – RA
  - Lead III = LL – LA
  - aVR
  - aVL
  - aVF
- The leads measure projections of the 3D cardiac electrical vector on to the axes of the leads.

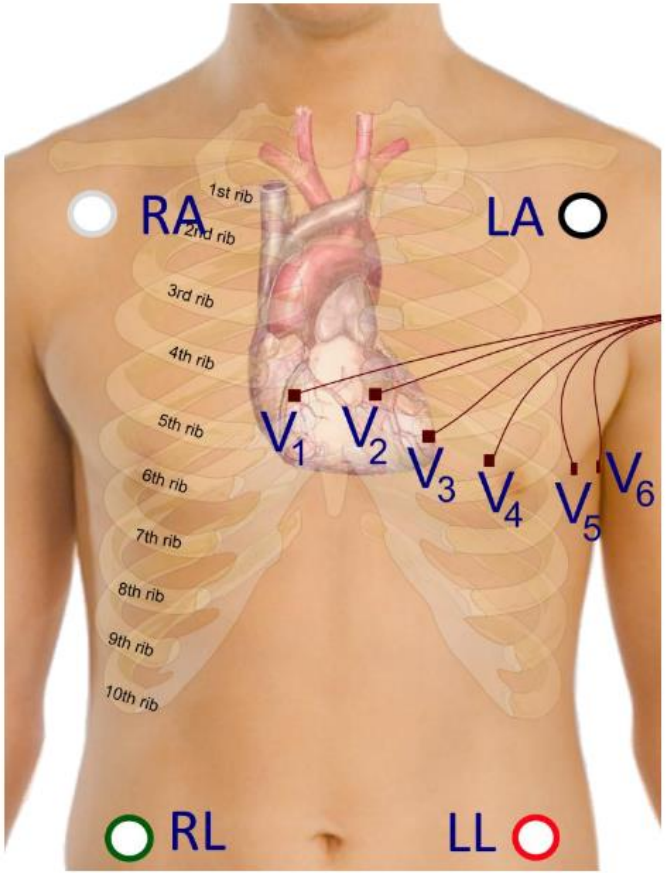


https://en.wikipedia.org/wiki/File:Limb_leads_of_EKG.png

ECG acquisition – chest

- **6 channels** are obtained using the 6 chest leads
  - V1
  - V2
  - V3
  - V4
  - V5
  - V6

- V1 and V2: activity in the right-half of the heart
- V3 and V4: septal activity
- V5 and V6: left-ventricular activity



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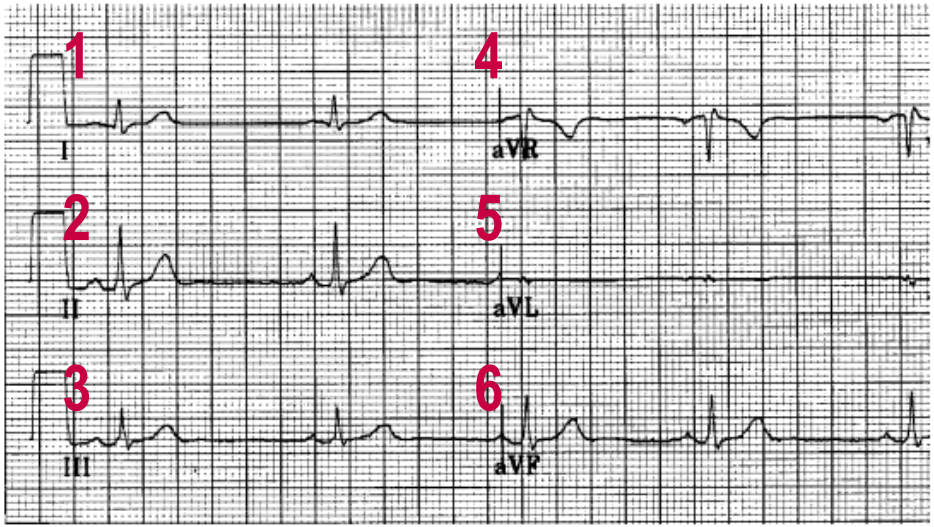
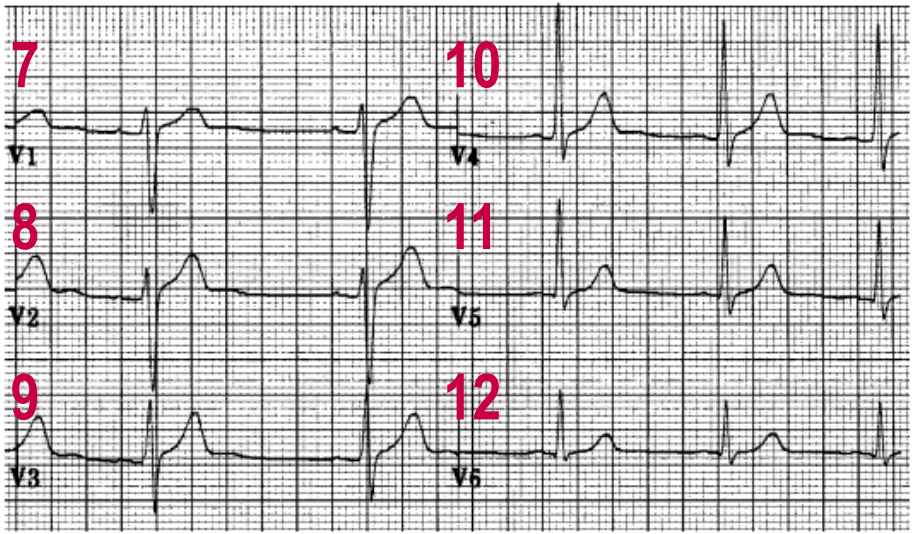
12-channel ECG - example



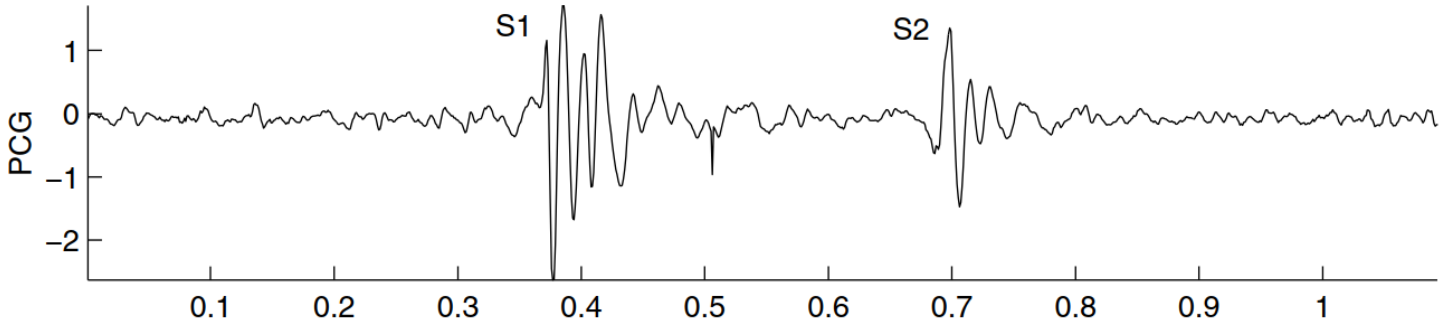


Rangayyan, R. M. *Biomedical signal analysis*. 2nd Edition, Vol. 33. John Wiley & Sons, 2015.

Acquisition - notes

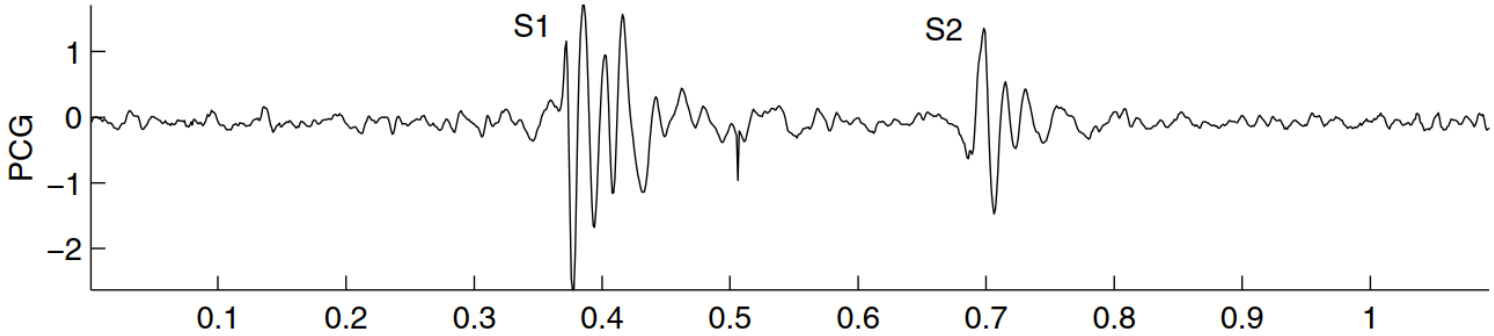
- In spite of being redundant, the 12-lead system serves as the basis of the standard clinical ECG.
- Clinical ECG for diagnosis
  - filtered to 0.05 − 100 Hz bandwidth
  - Sampling rate: 500 Hz
- ECG for heart-rate monitoring
  - filtered to 0.05 − 50 Hz bandwidth

Phonocardiogram (PCG)



Phonocardiogram (PCG)

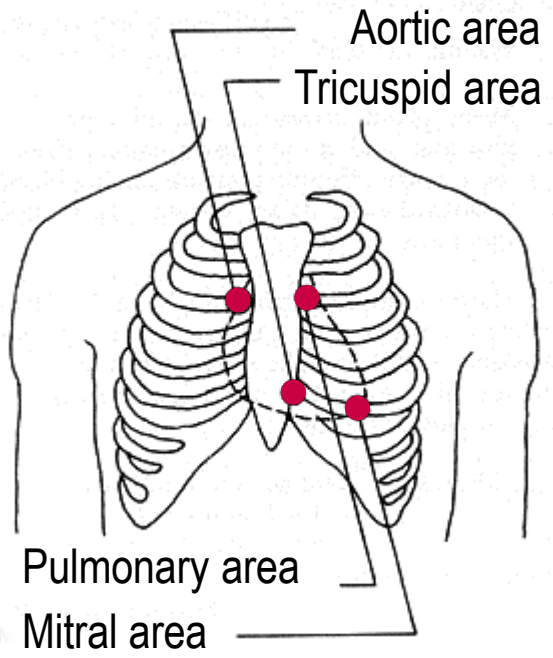
- PCG is the sound signal generated from the activities of heart.
- The sound was traditionally collected by stethoscopes.
- Recording the PCG requires a transducer to convert the sound signal into an electronic signal => E.g., microphones and pressure transducers
- **Diagnosis**: Cardiovascular diseases cause changes or additional sounds and murmurs



Rangayyan, R. M. *Biomedical signal analysis*. 2nd Edition, Vol. 33. John Wiley & Sons, 2015.

Heart sounds

- Heart sounds are the vibrations of the whole cardiovascular system triggered by pressure gradients.
- Heart sound components are best heard at certain locations on the chest
- 4 auscultatory areas:
  - Mitral area
  - Aortic area
  - Pulmonary area
  - Tricuspid area



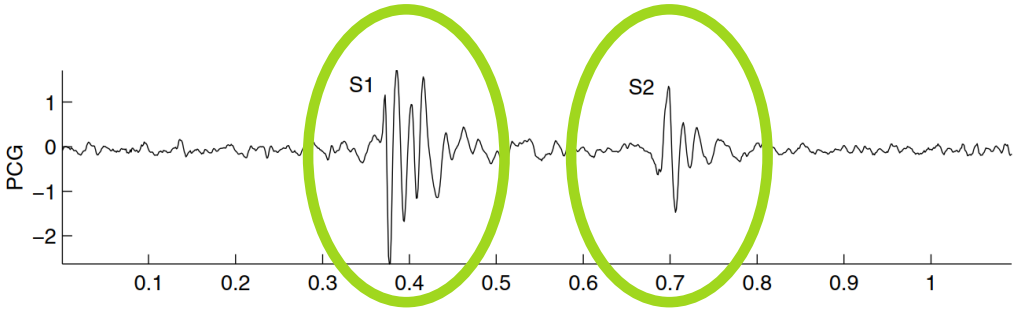
http://biology.creighton.edu/courses/BIO450/Lab09.html

PCG signal acquisition

- ❑ Using a Piezoelectric contact sensors
  - bandwidth 0.05 − 1, 000 Hz
- ❑ PCG recording performed in a quiet room
- ❑ Patient is in supine position
- ❑ PCG transducer placed firmly at the desired position on the chest

PCG signal components

- **Intensity**, **frequency content**, and **timing** of the heart sounds are important features
- A normal cardiac cycle contains two major sounds:
  - **S1**: Occurs at the onset of ventricular contraction
    - Caused by the closure of the heart valves, oscillation of the blood, etc.
  - **S2**: Closure of the semilunar valves (pulmonary and aortic valves)



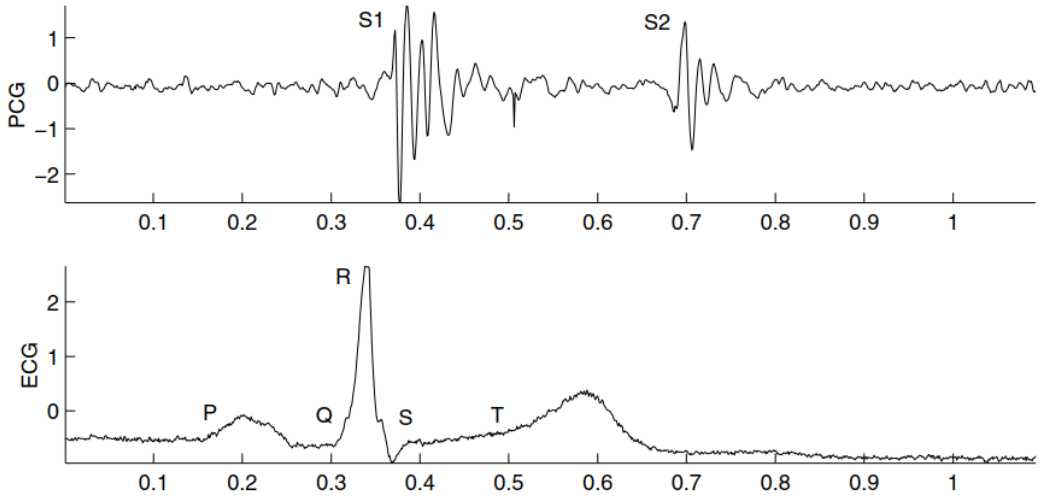
Rangayyan, R. M. *Biomedical signal analysis*. 2nd Edition, Vol. 33. John Wiley & Sons, 2015.

Other sounds

- Other sounds:
  - S3: Sudden termination of the ventricular rapid-filling phase
  - S4: atrial contractions displacing blood into the distended ventricles.
  - Valvular clicks and snaps.
- Murmurs:
  - Caused by cardiovascular diseases
  - Are systolic and diastolic murmurs
  - Are high-frequency, noise-like sounds
  - Arise when the velocity of blood becomes high (flows through an irregularity)

PCG and ECG

- ECG is electrical and PCG is mechanical (sound)
- Analysis of ECG is easier, especially if there are murmurs in the PCG.
- ECG can be used in the analysis of PCG
  - Use the QRS complex in the ECG to detect S1 in PCG



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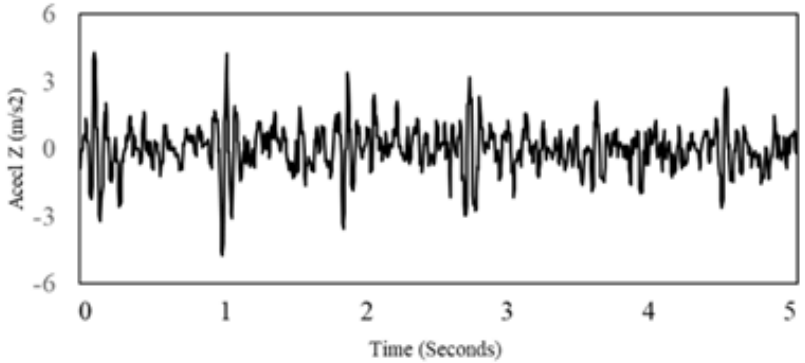
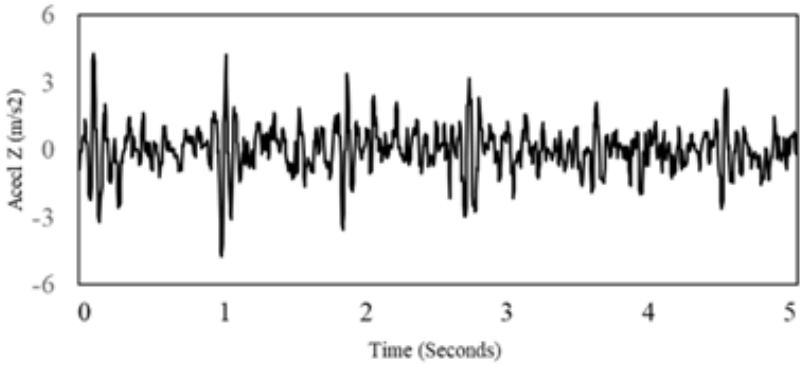
Seismocardiogram (SCG)



Seismocardiography (SCG)

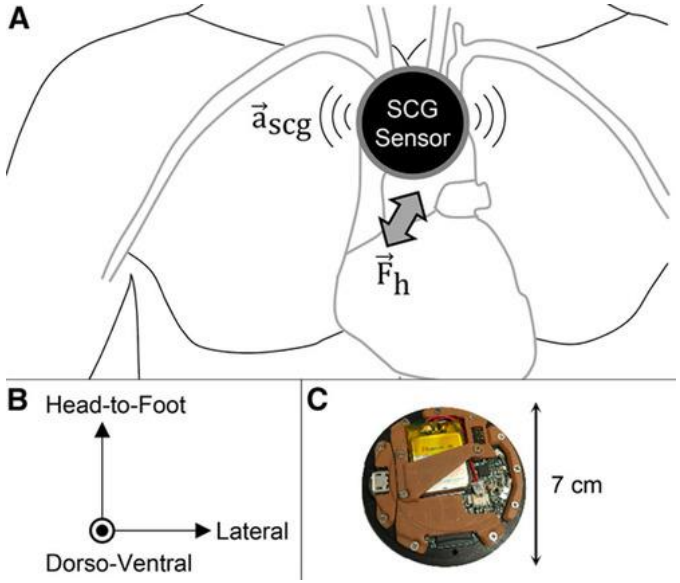
- SCG is the signal which represents the local vibrations generated by the heart's contraction and the ejection of blood from the ventricles.
- SCG is characterized by several peaks and valleys reflecting specific events of the beating heart
- SCG can be used to detect heart rate and to diagnose diseases.



Lee, H., Lee, H., & Whang, M. (2018). An enhanced method to estimate heart rate from seismocardiography via ensemble averaging of body movements at six degrees of freedom. Sensors, 18(1), 238.

SCG signal acquisition

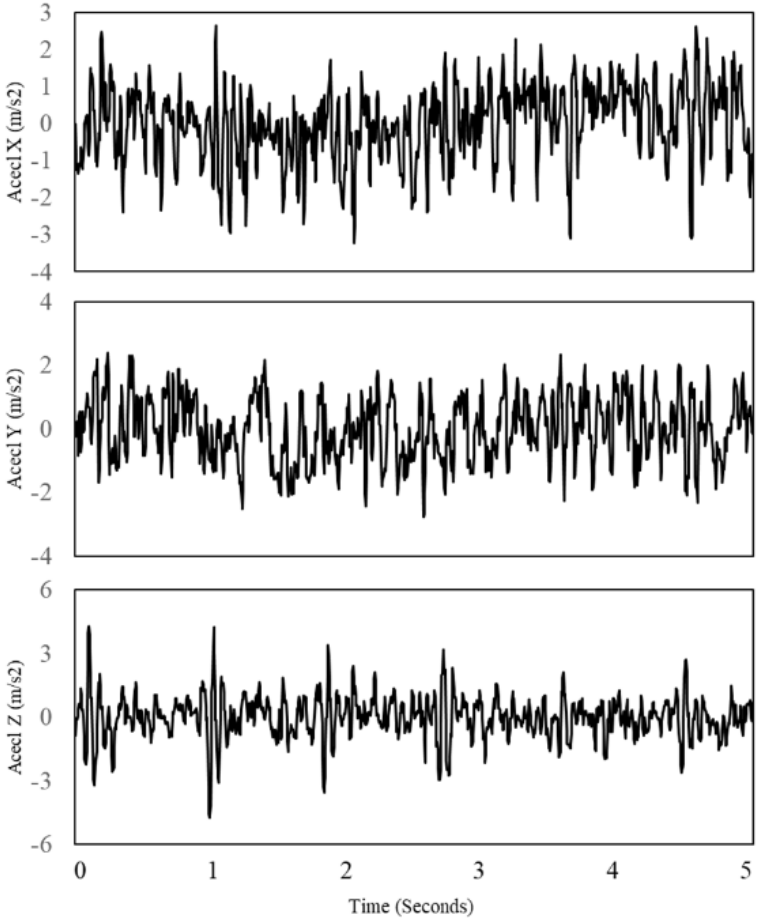
- SCG can readily be detected by placing a low-noise accelerometer on the chest
  - Using wearables
- The precise location of the sensor on the chest impacts the measured signal
- A widely used position is on the sternum
- Patient is in supine position



Inan, Omer T., et al. "Novel wearable seismocardiography and machine learning algorithms can assess clinical status of heart failure patients." Circulation: Heart Failure 11.1 (2018): e004313.

SCG signal acquisition

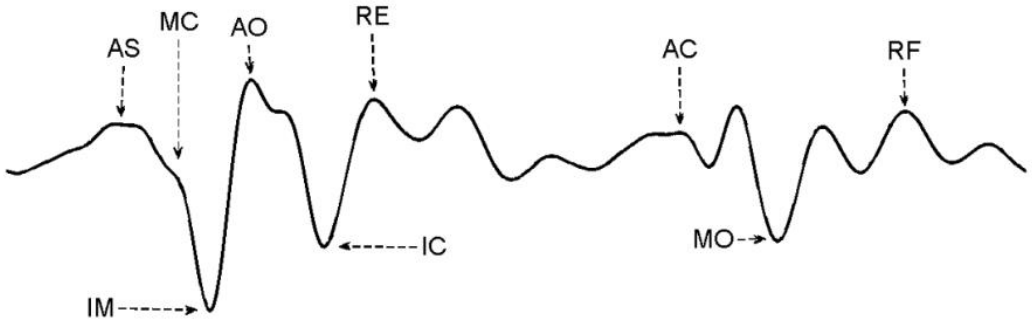
- SCG is presented in three axes (i.e., X,Y, and Z)
  - Most studies focus on **Z axis** (dorso–ventral)
  - However, additional biological information could be derived also from the X axis (right-left) and Y axis (head-foot).



Lee, H., Lee, H., & Whang, M. (2018). An enhanced method to estimate heart rate from seismocardiography via ensemble averaging of body movements at six degrees of freedom. Sensors, 18(1), 238.

SCG signal components

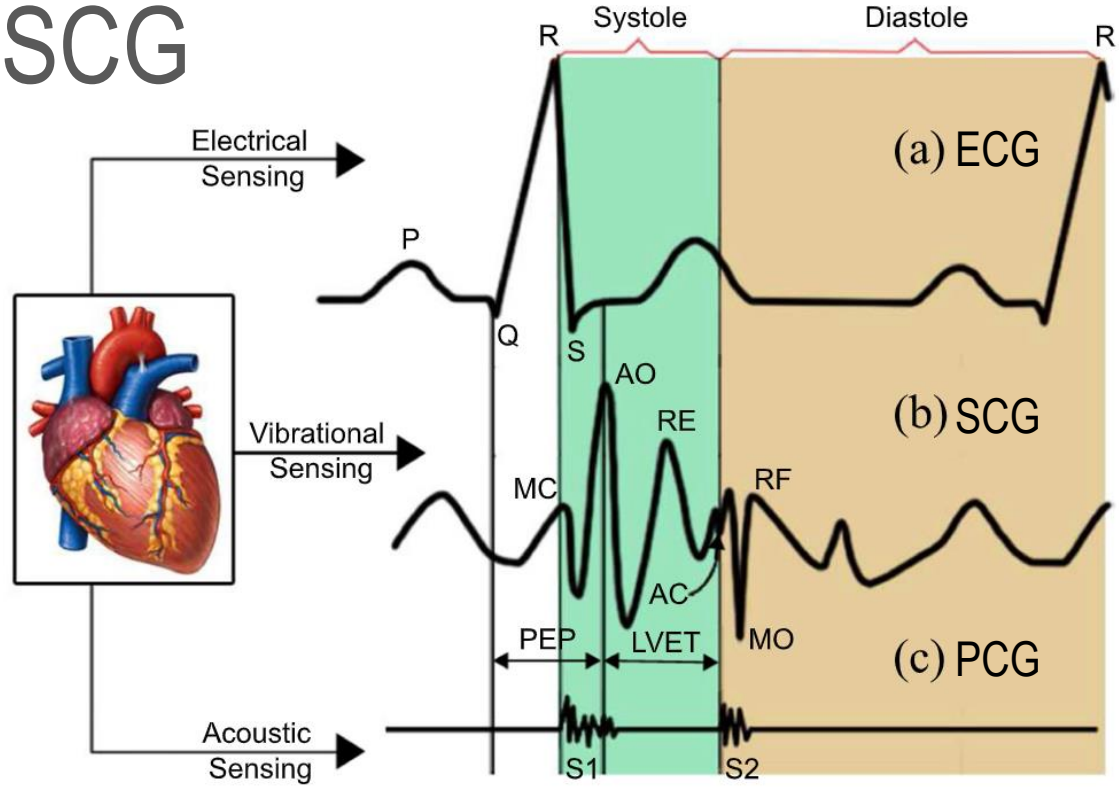
- **Amplitude**, **timing**, or **morphology** of the signal are important features
- A normal cardiac cycle contains peaks and valleys showing heart functions
  - E.g.: atrial systole (AS), mitral valve closure (MC), and aortic valve opening (AO)



Paukkunen, M. (2014). Seismocardiography: Practical implementation and feasibility.

ECG, PCG, and SCG

- ECG is electrical, PCG is acoustic, and SCG is vibrational
- SCG is more sensitive to motion artifacts
- SCG shows the opening/closure of heart valves



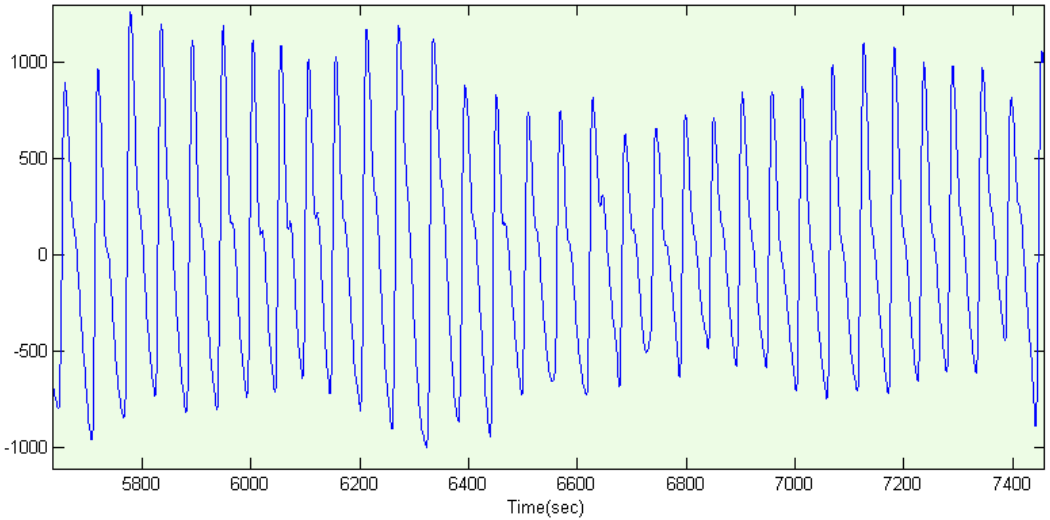
Choudhary, T., Sharma, L. N., & Bhuyan, M. K. (2018). Heart sound extraction from sternal seismocardiographic signal. IEEE Signal Processing Letters, 25(4), 482-486.

Relevant signals to SCG

- Gyrocardiogram[1]
  - It shows heart motions using a sensor of angular motion, **gyroscope**, attached to the skin of the chest.
- Ballistocardiogram[2]
  - It shows the movement of the body caused by cardiac ejection of blood using an **accelerometer** sensor attached under the body (on the bed).

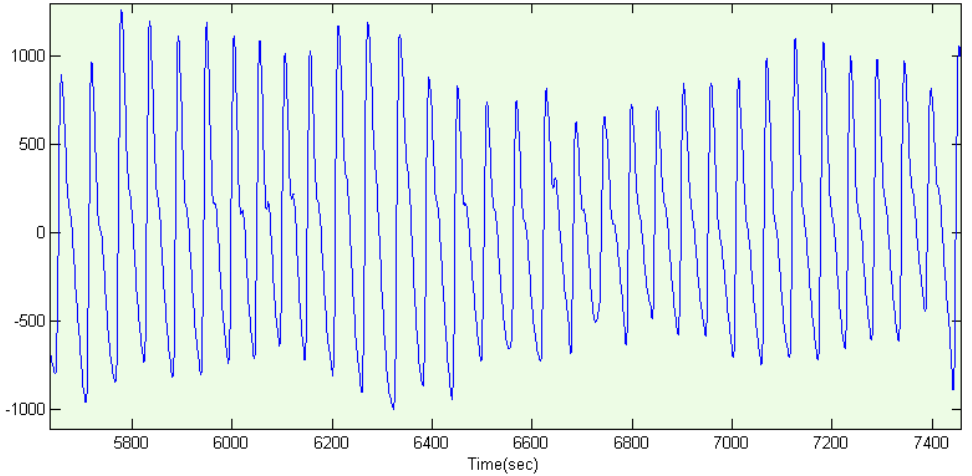
1. M. Jafari Tadi, et al. "Gyrocardiography: A new non-invasive monitoring method for the assessment of cardiac mechanics and the estimation of hemodynamic variables." Scientific reports 7.1 (2017): 6823.
2. Omer T. Inan, et al. "Ballistocardiography and seismocardiography: A review of recent advances." IEEE journal of biomedical and health informatics 19.4 (2014): 1414-1427.

Photoplethysmogram (PPG)



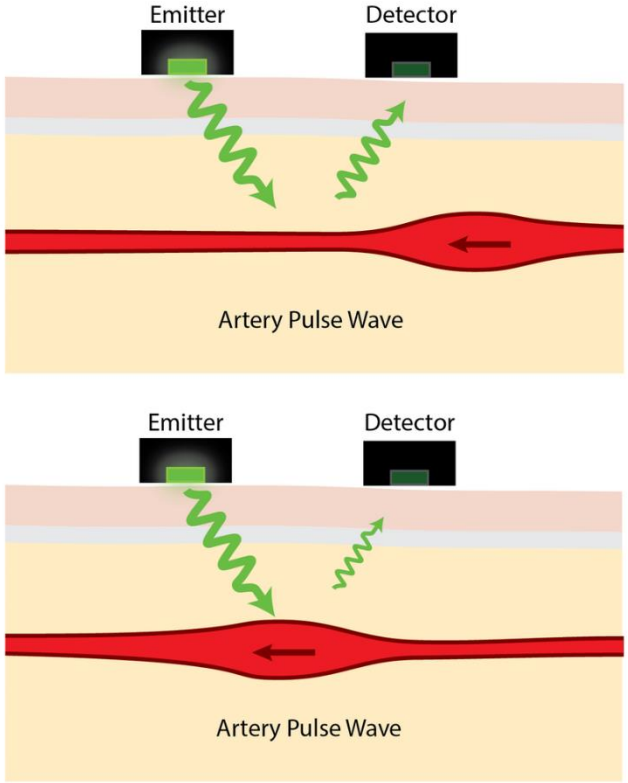
Photoplethysmogram (PPG)

- PPG is the signal which indicates blood volumetric changes in the tissue
- The optical characteristics of red blood cells changes according to the amount of oxygen it carries via hemoglobin



PPG signal acquisition

- **Emitter** or **light source**: to emit light to the skin
- **Detector** or **light sensor**: to absorb the reflected light
- The hemoglobin light absorption coefficient differs with different light wavelength:
  - Red
  - Infrared
  - Green



https://theconversation.com/some-heart-rate-monitors-give-less-reliable-readings-for-people-of-colour-121007

Tamura, Toshiyo, et al. "Wearable photoplethysmographic sensors—past and present." Electronics 3.2 (2014): 282-302.

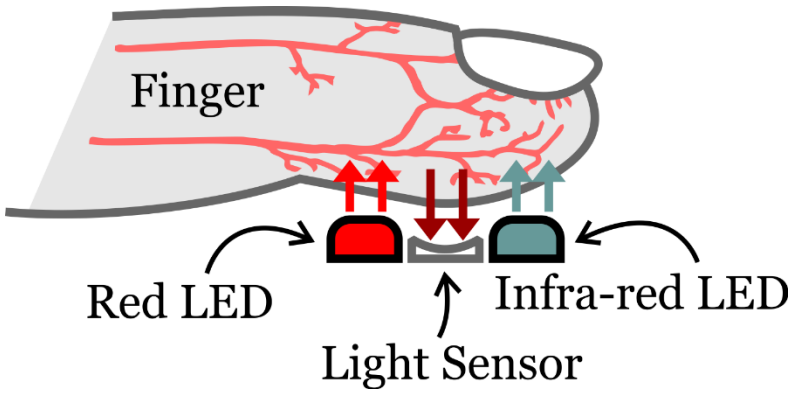
Wrist-based PPG sensor

- ❑ One light source: **green**
- ❑ Green LED has much greater absorptivity for both oxyhemoglobin and deoxyhemoglobin
  - Better signal-to-noise ratio
- ❑ Used in wristbands and smart watches
- ❑ Heart rate monitoring

https://buy.garmin.com/en-US/US/p/567813/pn/010-01755-10#overview

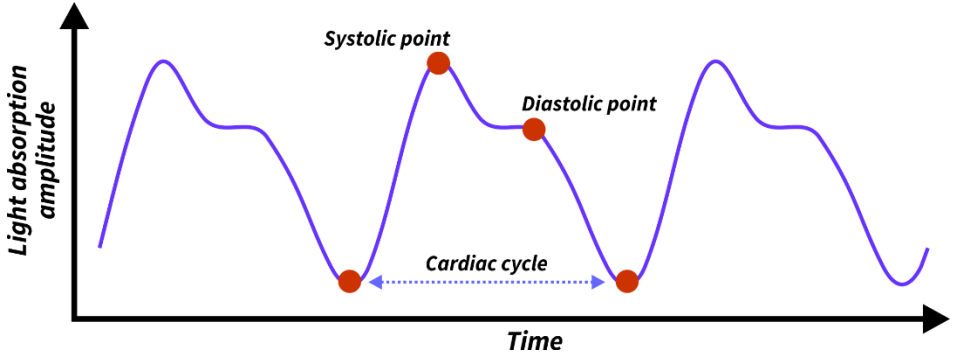
Finger-based PPG sensor

- Two light sources: **red** and **infrared**
- Two PPG signals are collected with different intensity due to the hemoglobin light absorption coefficient
  - SpO_2 or blood oxygen saturation can be obtained.



Amiri, D., et al. "Optimizing energy in wearable devices using fog computing." Fog Computing: Theory and Practice, (2019).

Vital signs detection

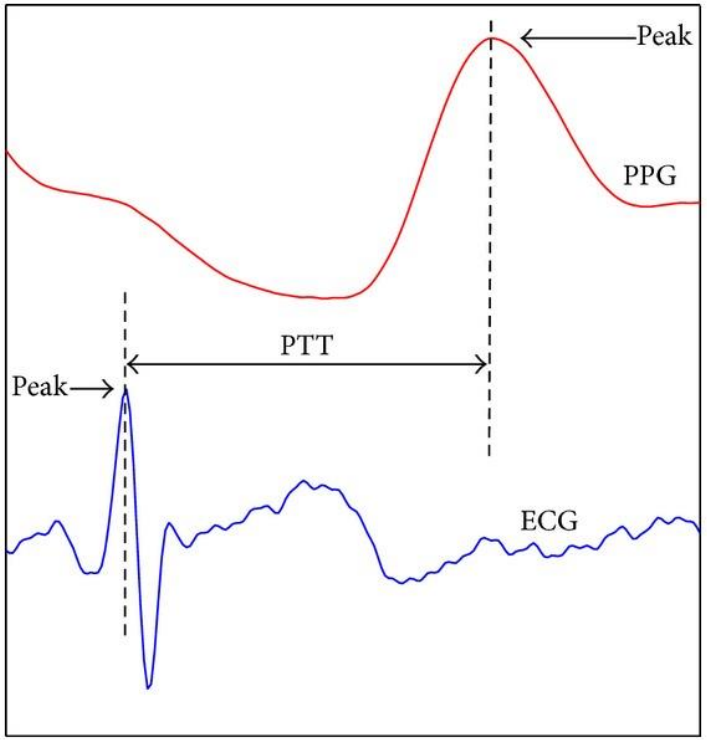


Kasaeyan Naeini, E., et al. "A Real-time PPG Quality Assessment Approach for Healthcare Internet-of-Things." Procedia Computer Science 151 (2019): 551-558.

- ❑ Variations in the PPG signal are associated with the oscillation of heartbeat and respiration
  - Heart rate, heart rate variability, and respiration rate can be tracked
- ❑ Finger-based sensor: SpO_2
- ❑ Wrist-based sensor: signal-to-noise ratio is too low to detect respiration rate

ECG and PPG

- ECG is electrical and PPG is light reflection.
- Analysis of ECG and PPG may provide new information
- E.g., Pulse transit time (PTT)
  - Interval between the peak of the R-wave in ECG and the peak in PPG
  - Can be used to estimate systolic and diastolic blood pressure



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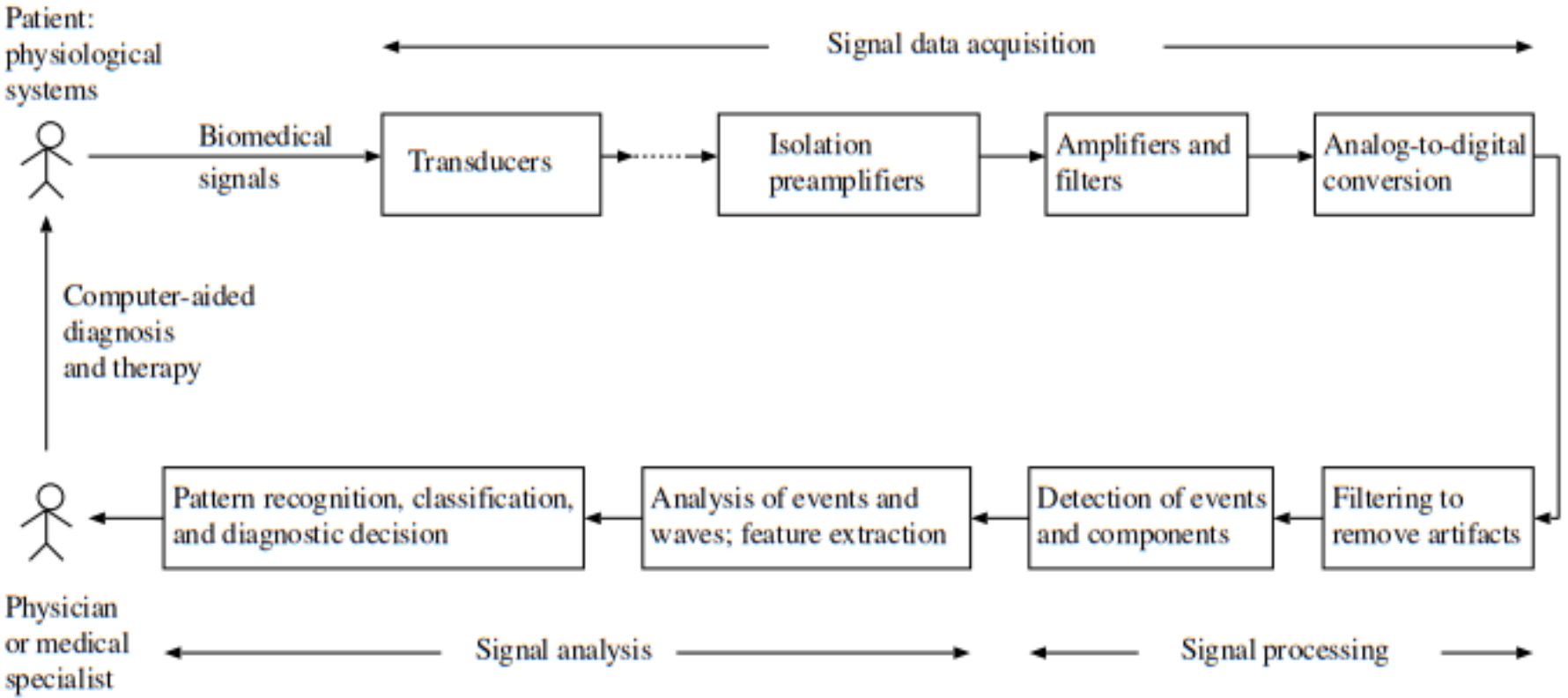

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Conclusion

In this session, we learned:

- ❑ Origin and acquisition of biosignals, collected to monitor the cardiovascular system

In the next session, we will learn:

- ❑ About noise and artifacts in biosignals
- ❑ Filtering techniques

Thank You

Questions?

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