BME 350

Signals & Systems for Bioengineers

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Lecture 1: Biosignals

Resources for Biosignals :
PhysioNet (http://physionet.org/) and PhysioBank (http://physionet.org/physiobank/database/)

Images/data used in this lecture are from Physiobank or Wikipedia

Goals for today

1) Define and describe signals and system
2) Understand graphical representation of signals
3) Understand the origin of various types of Biological signals

What is a signal?

A physical phenomenon mathematically representable by a function of one or more variable(s)

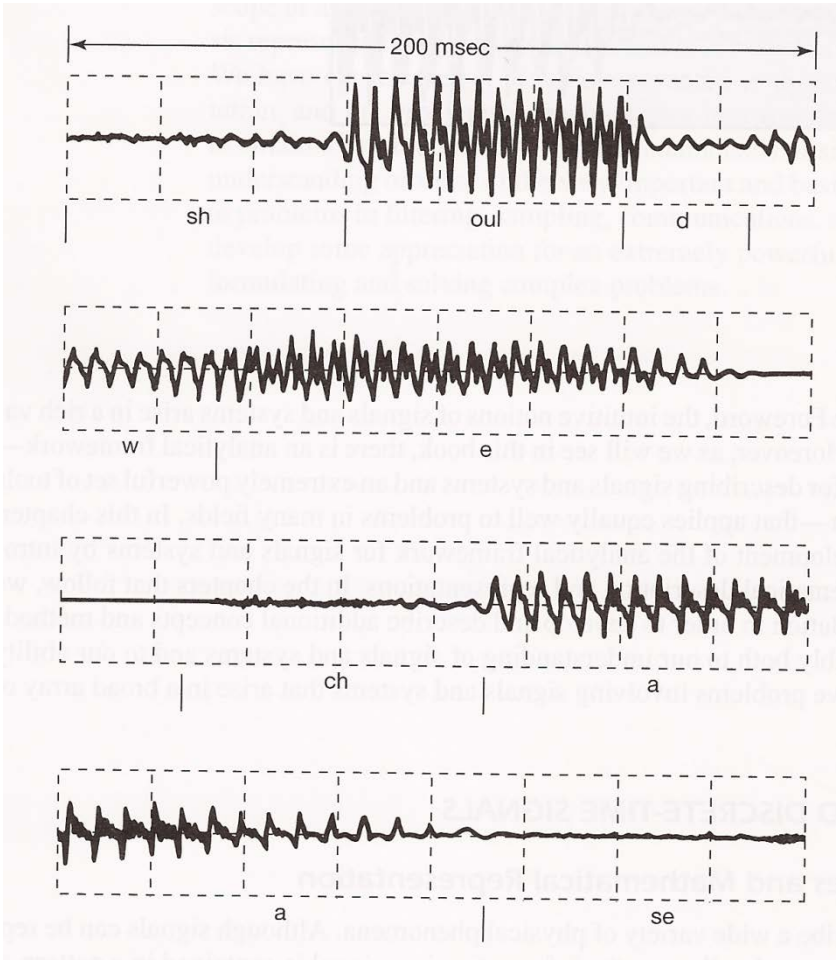
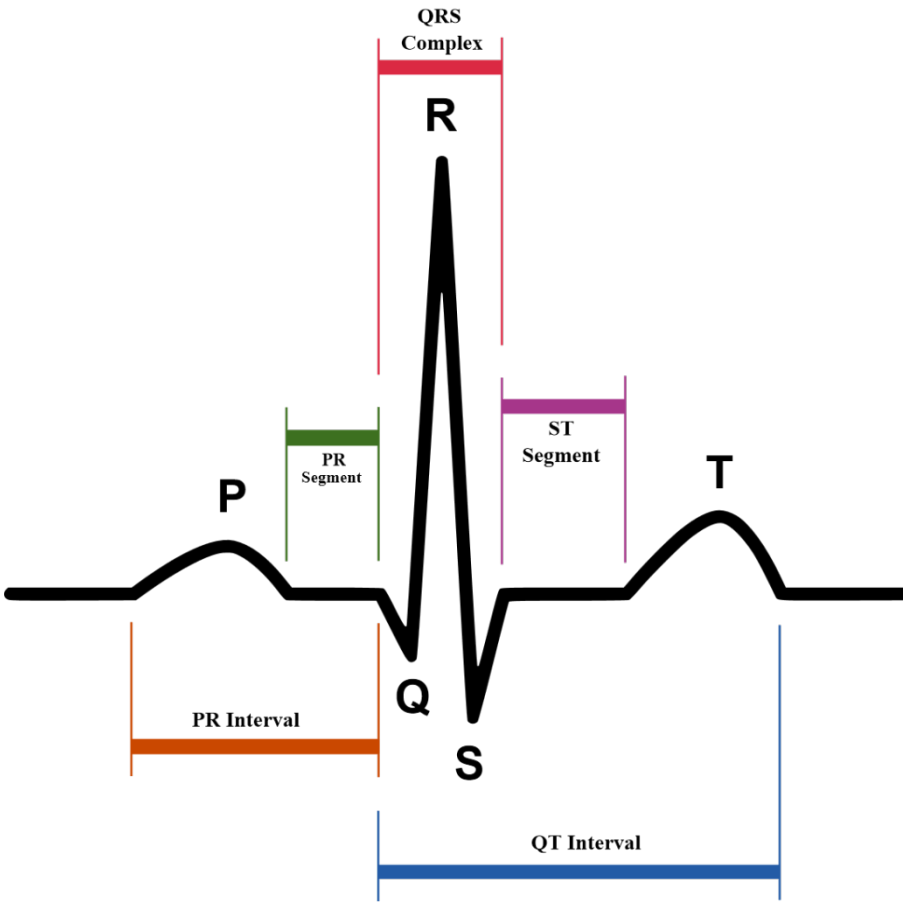


Figure 1.3 from text

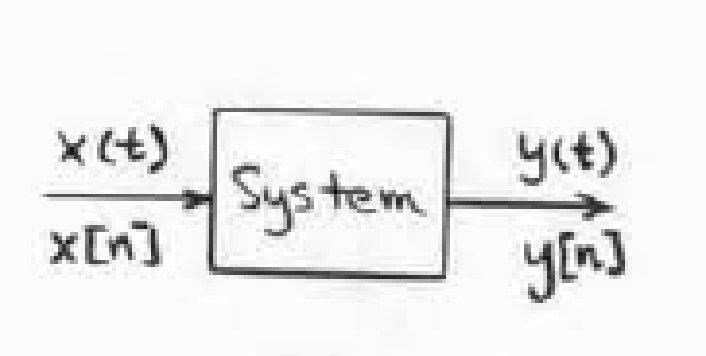


What is this? What is being measure?

What is a System?

In context of this class:

A physical set of components which is mathematically representable and converts an input x into an output y

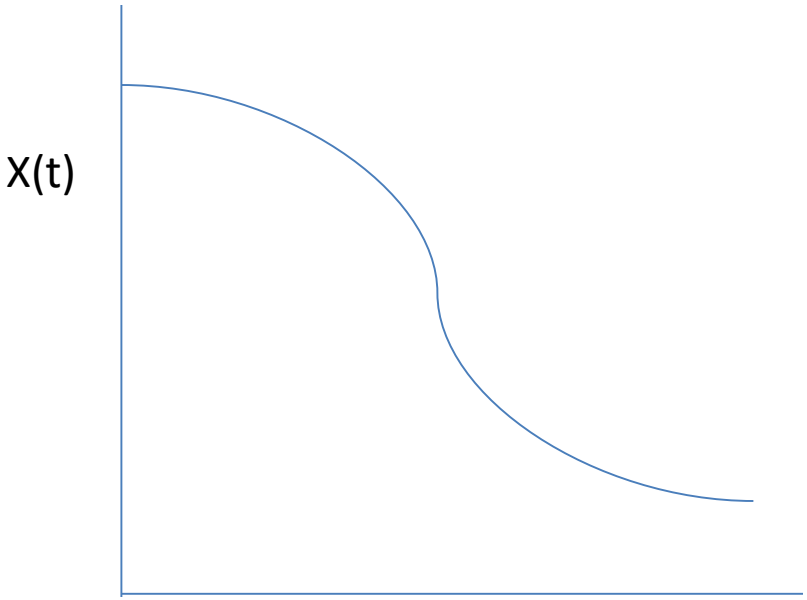


Can you give examples of a system?

How about a system of systems?

It is all about what is inside the “Box”!

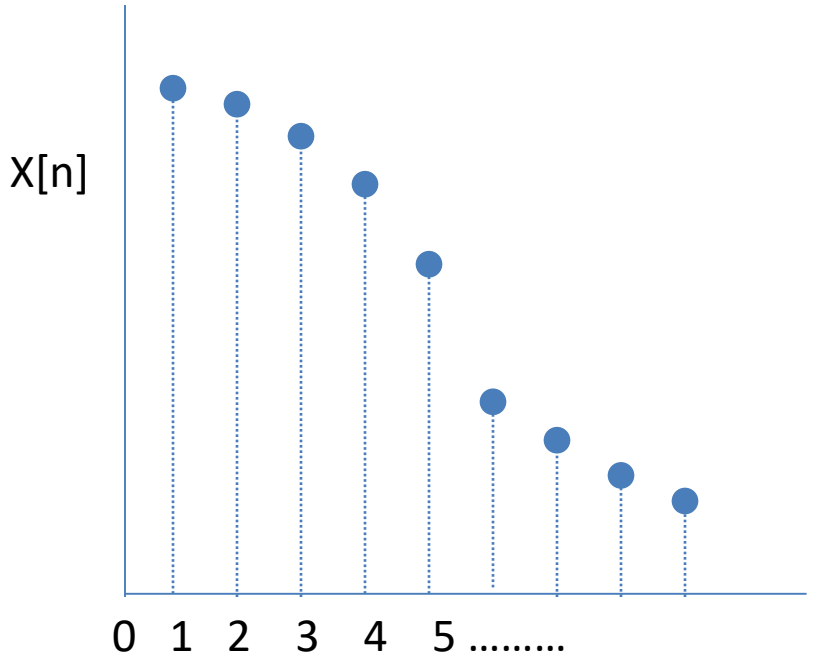
Continuous Vs Discrete Signals



t

t is a real number

Continuous

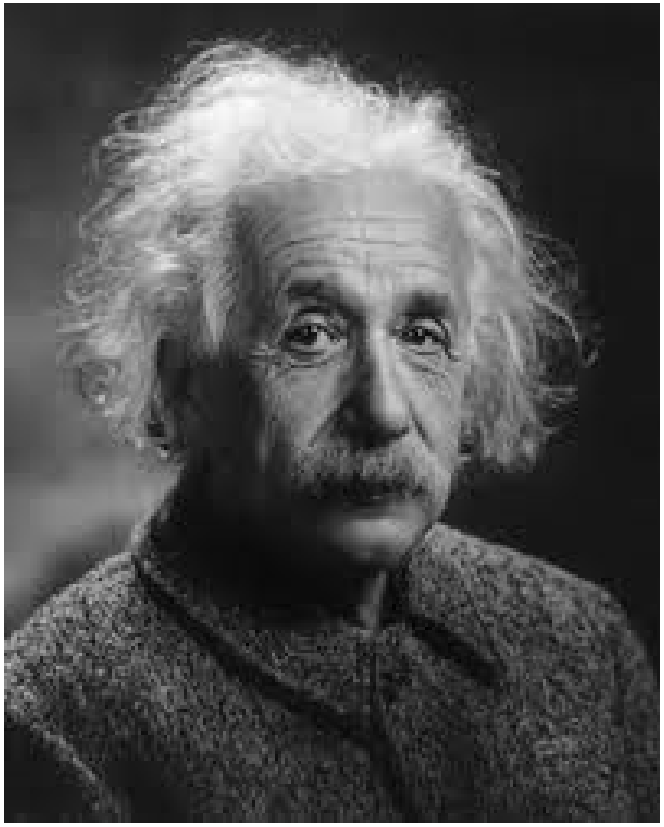


n

n is an integer

Discrete

Is the real-world continuous or discrete?



- Who is this?
- Great analytical mathematician and physicist
- Modeled gravity, light,…using analytical (continuous) mathematics

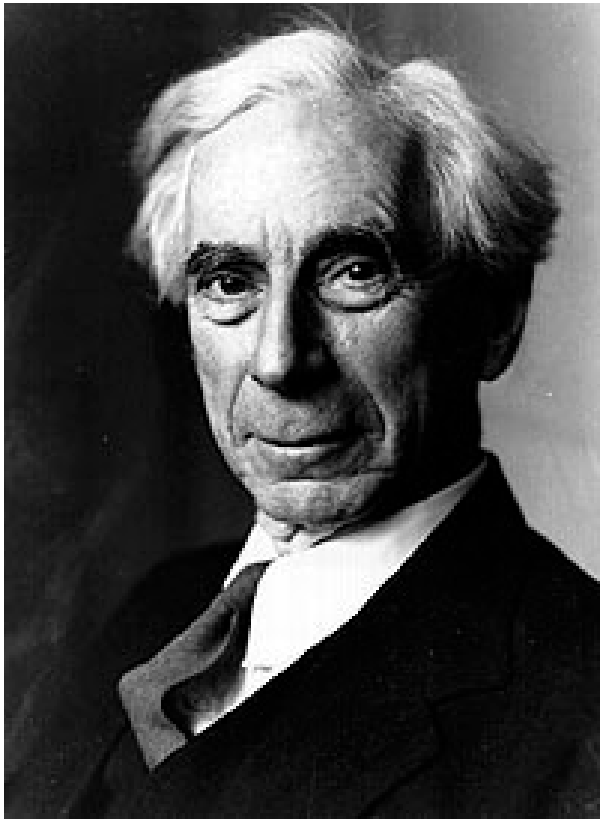
Is the real-world continuous or discrete?

- Who is this?
- Great mathematician and logician
- Proved using logic & math that all mathematical systems are inherently incomplete
- Some things you just have to measure (Discrete)

Is the real-world continuous or discrete?

- Einstein joined Institute for Advanced Study at Princeton in large part to hang out with Kurt Godel

Is the real-world continuous or discrete?



- Who is this?
- Great mathematician and logician
- Wrote the Principia Mathematica
- Derive all mathematics from basic axioms

Is the real-world continuous or discrete?

$*54{\cdot}43.\quad \vdash :. \alpha, \beta \in 1 . \supset : \alpha \cap \beta = \Lambda . \equiv . \alpha \cup \beta \in 2$

Dem.

$\vdash . *54{\cdot}26 . \supset \vdash :. \alpha = \iota`x . \beta = \iota`y . \supset : \alpha \cup \beta \in 2 . \equiv . x \neq y .$

[$*51{\cdot}231$] $\equiv . \iota`x \cap \iota`y = \Lambda .$

[$*13{\cdot}12$] $\equiv . \alpha \cap \beta = \Lambda \qquad (1)$

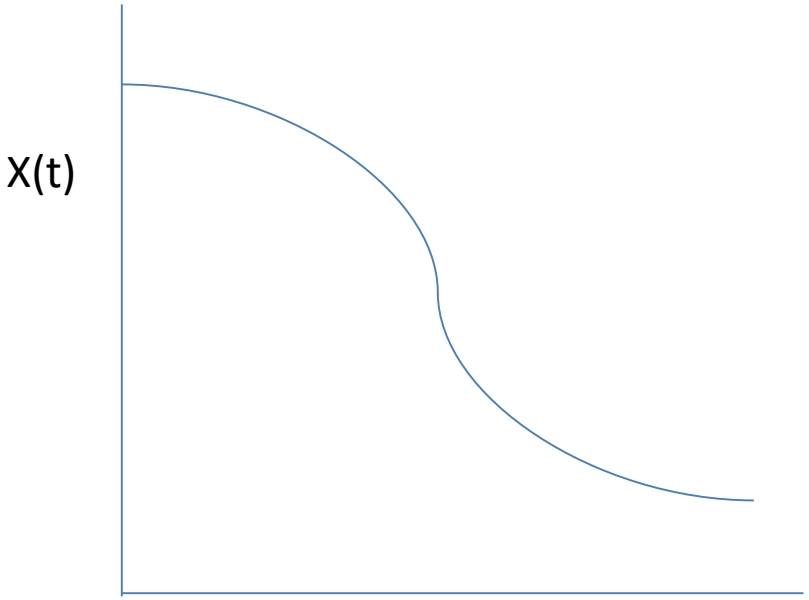
$\vdash . (1) . *11{\cdot}11{\cdot}35 . \supset$

$\vdash :. (\exists x, y) . \alpha = \iota`x . \beta = \iota`y . \supset : \alpha \cup \beta \in 2 . \equiv . \alpha \cap \beta = \Lambda \qquad (2)$

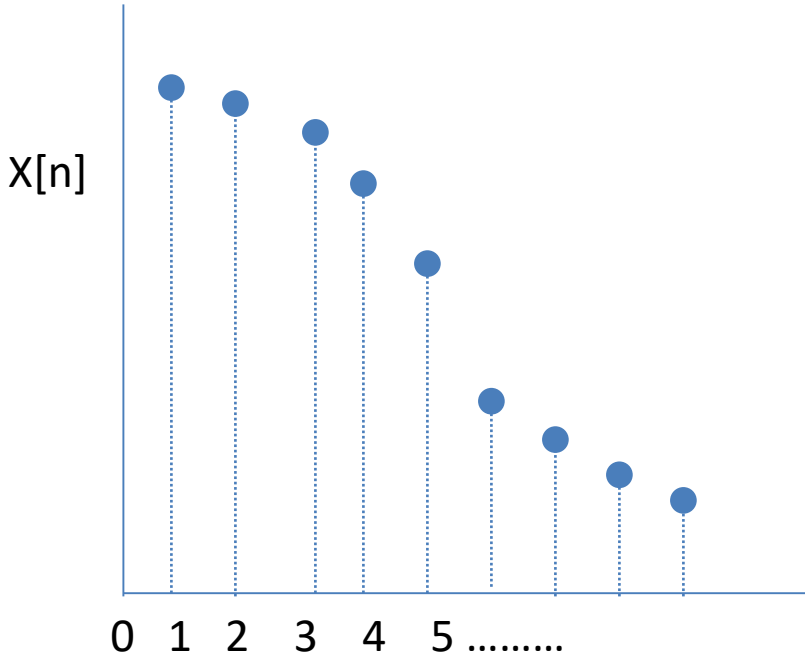
$\vdash . (2) . *11{\cdot}54 . *52{\cdot}1 . \supset \vdash .$ Prop

From this proposition it will follow, when arithmetical addition has been defined, that $1 + 1 = 2$.

Continuous Vs Discrete



Analytical



Numerical

- Is this Reality: Continuous or Discrete (Analytical or Numerical)?
  - How do you perform and integration – analytically or numerically?
- Godel: analytical mathematics cannot capture all aspects of reality
- Physics: Wave-particle duality; quantum mechanics (Einstein didn't like this)

Real life continuous signals

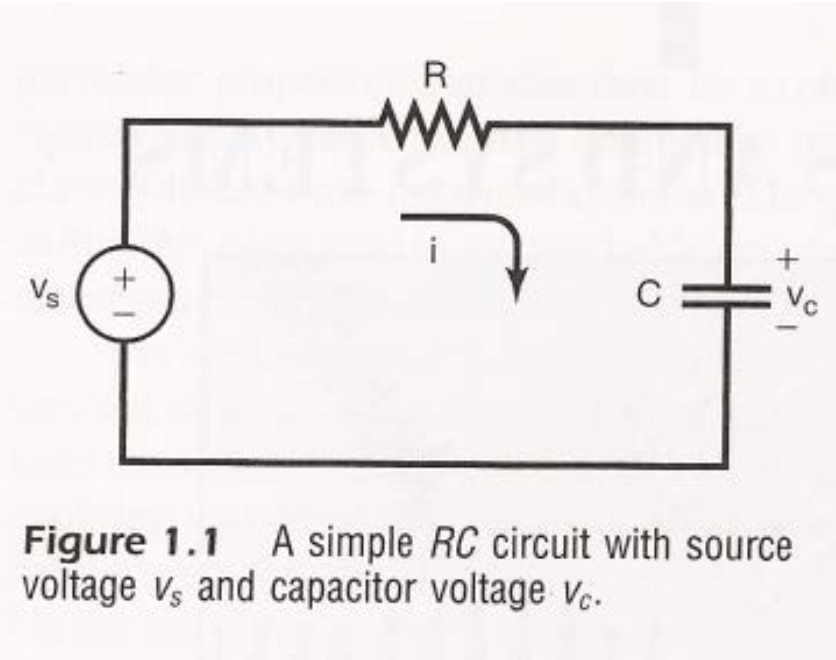
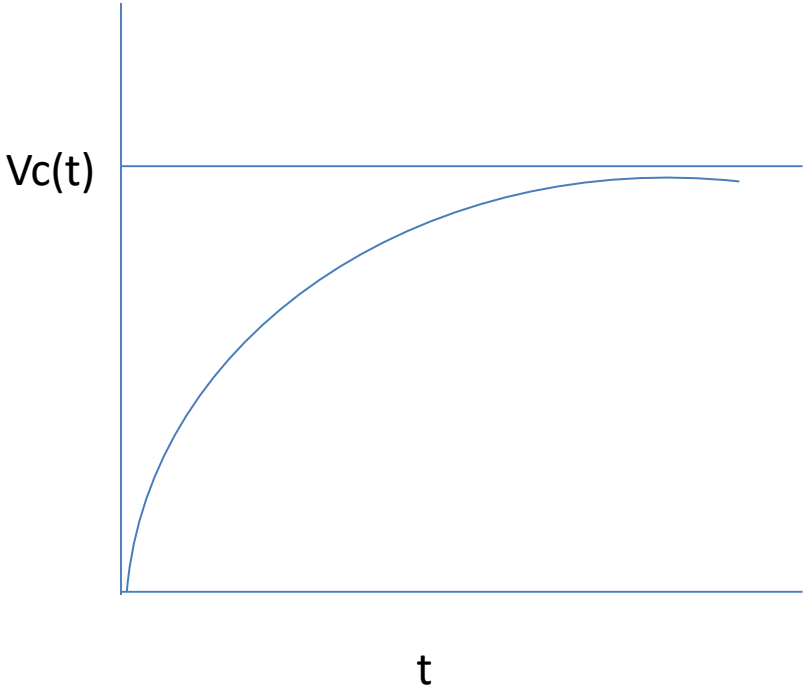


Figure 1.1 A simple *RC* circuit with source voltage v_s and capacitor voltage v_c.

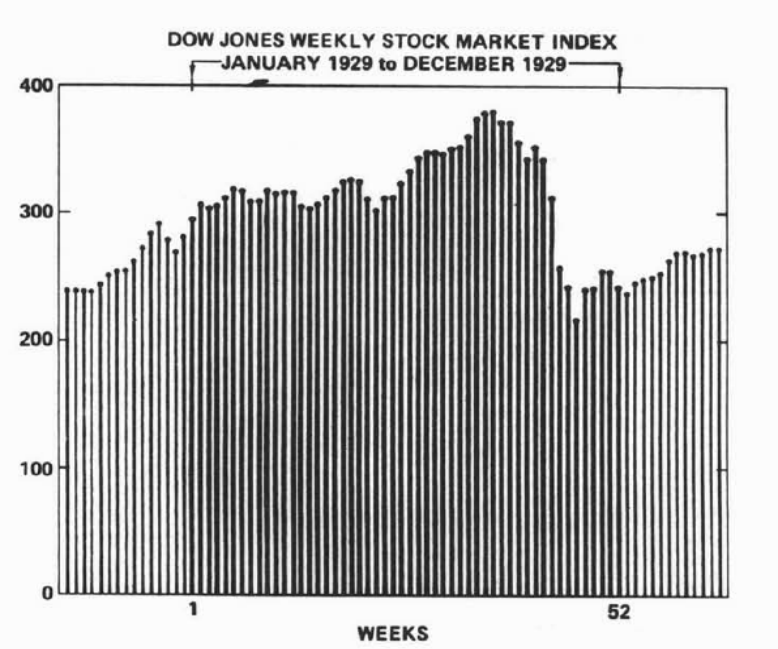


How do electrons on the other side of the dielectric know when electrons arrive on the plus-side of the dielectric?

Relative scale of electron to measurement

Would perform integration on this system analytically or numerically?

Real life discrete signal



Stock market crash of the 30s

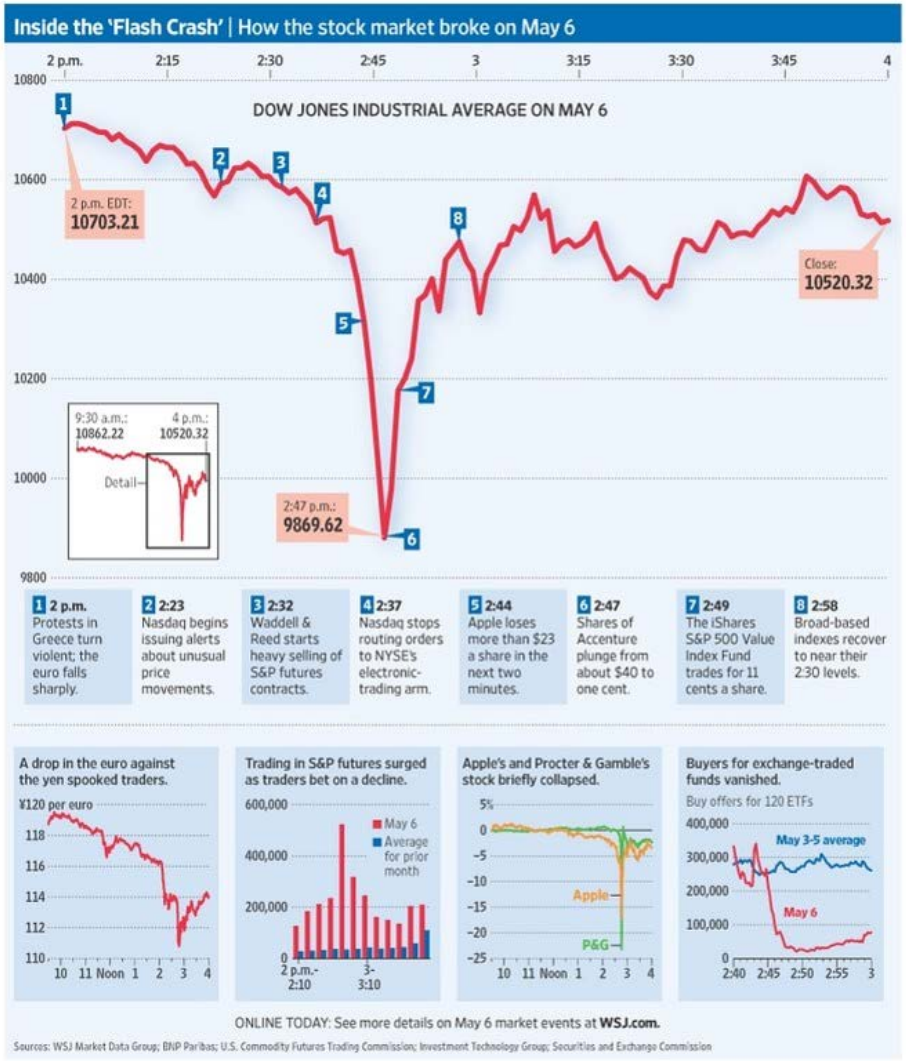
Would perform integration on this system analytically or numerically?

Real life discrete signal

https://www.google.com/finance?q=INDEXDJX%3A.DJI&ei=EB-4VLnYFKibiQLw_4HADg

What about 2001 and 2008?

Signal & System Interaction



- What is the signal?
- What is the system?
- What went wrong?
  - Bad signals and systems can cause real-world pain!

Flash Crash of May 6th 2010?

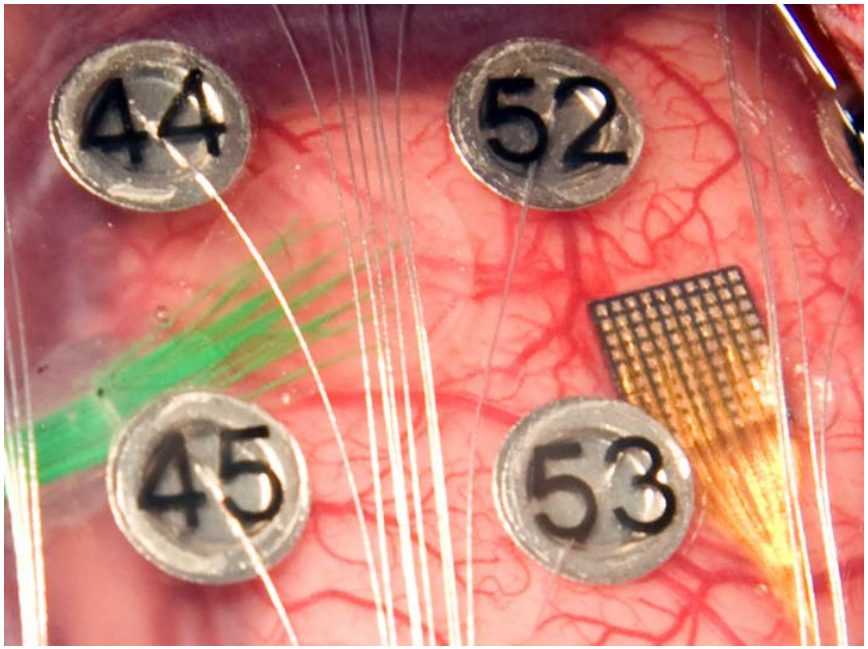
Image as signal

Continuous or Discrete?

Image as signal

How many dimensions?

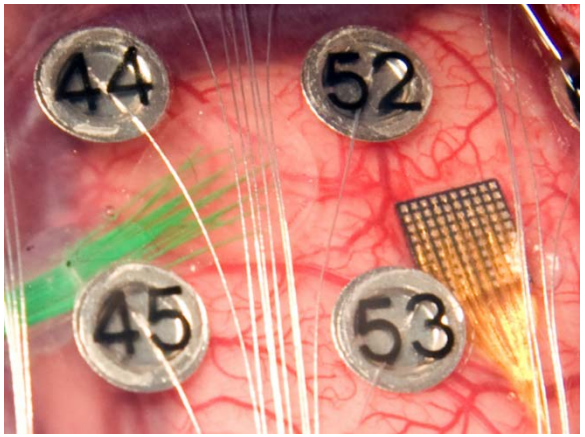
Voltage as signal



How many dimensions?

Dimensionality in Signals?

- Physical: dimensions of space and time
  - Can be treated independently or all at once
  - Max of four dimensions (at are current understanding)
- Sensors: number of inputs to system, i.e. the number of measurements being taken
  - Each sensor can be thought of as dimension
  - How many “dimensions” in this picture?
    - 116!



Mathematical representation of signals x(t)

1. x=0, is this a “good” signal in terms of biosignal? What would it mean – heart function, brain function?

2. x=3

3. x =3-t

4. x = 0 for t<0
   = 1 for 0<=t<1
   = 2-t for 1<=t<2
   =0 for 2<=t

Real life signals v. models

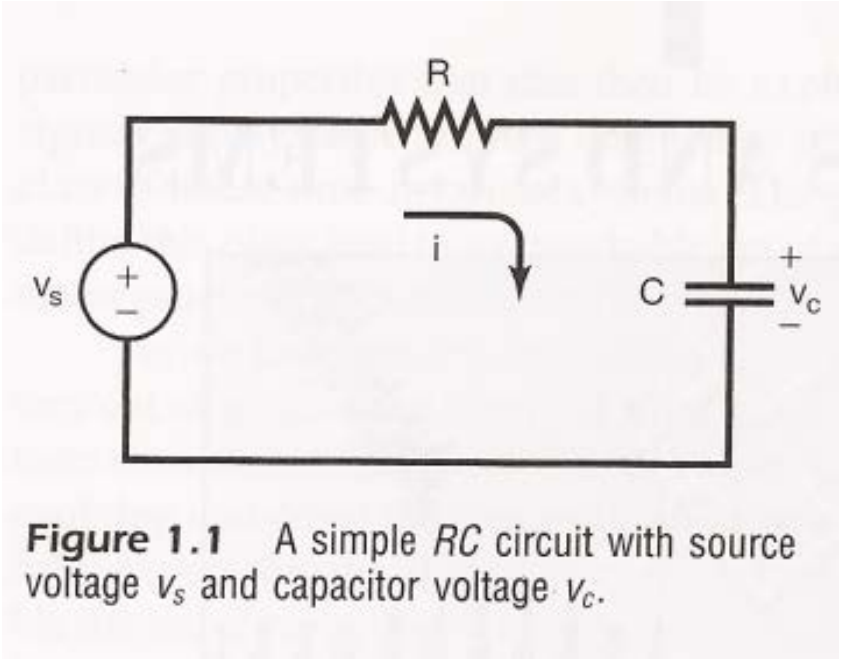


Figure 1.1 A simple *RC* circuit with source voltage v_s and capacitor voltage v_c.

- Functions as <u>models</u> of physicals systems
- Using Matlab to examine systems/functions
- Is the <u>model/function</u> the same thing as the <u>physical system</u>?
- How far can you zoom in on Matlab functions?

What are biosignals?

- Are spatial, temporal or spatio-temporal records/signatures of a biological event (e.g. beating heart, brain activity or a contracting muscle).
- The electrical/magnetic/chemical/mechanical activity that occurs during these biological event often produces signals that can be measured (as currents or voltages) and analyzed.
  - Or on smoked glass!
- Contain useful information that can be used to understand the underlying physiological mechanisms of a specific biological event or system, and which may be useful for medical diagnosis.
- Deviations from a “normal” pattern may indicate underlying physiological problem or disease

Bioelectric Signals

- Generated by nerve and muscle cells as a result of electrochemical changes within and between cells

- Can be measured with intracellular or extracellular electrodes

Examples:

- Electrocardiograph (ECG, also EKG)- heart activity
- Electroencephalogram (EEG)- brain activity
- Electromyograph (EMG)- muscle activity

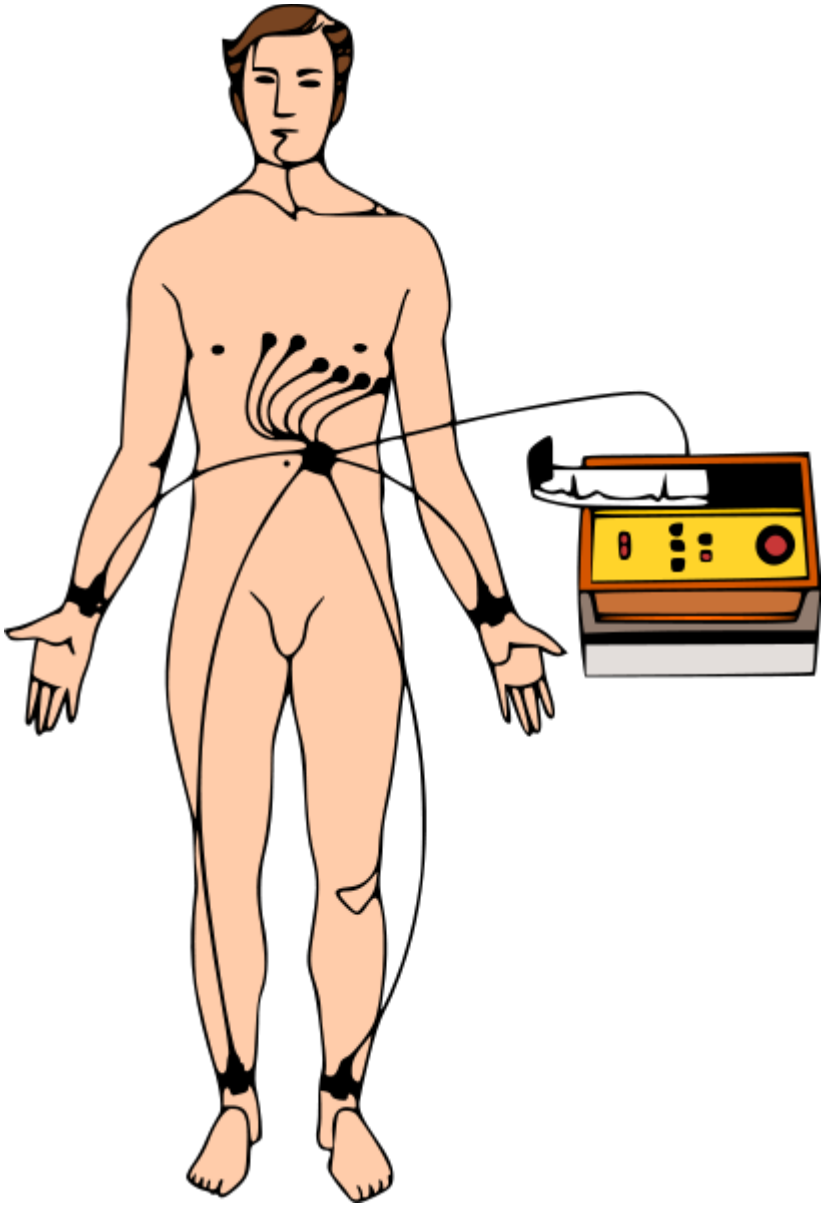
Example: EMG

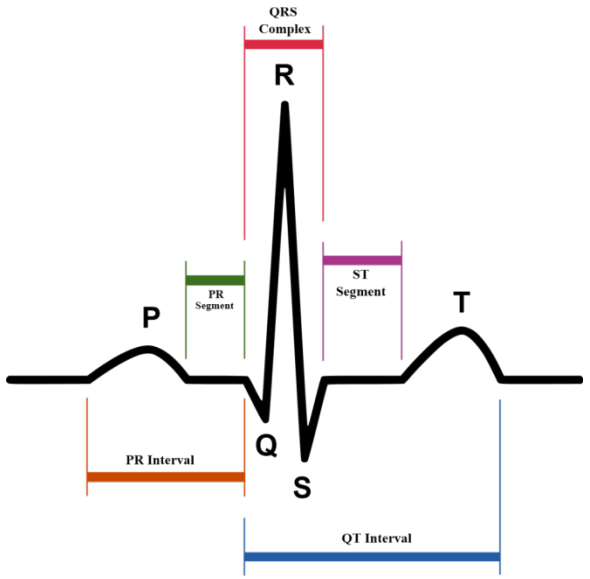
How many dimensions?

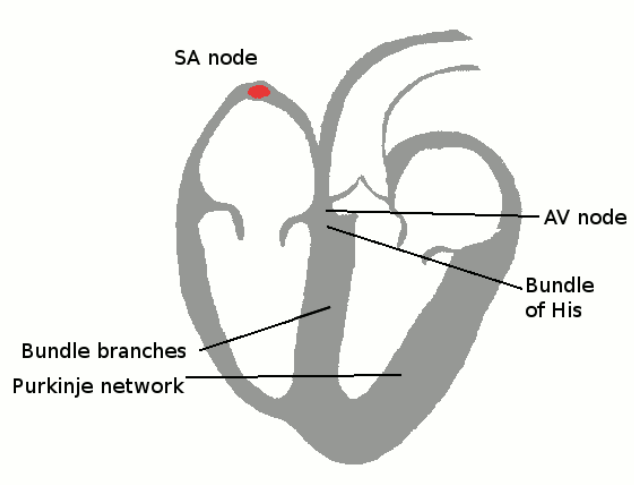
Example: EMG

http://www.military.com/video/specialties-and-personnel/amputees/amazing-imes-system-for-prosthetics/3067187963001/

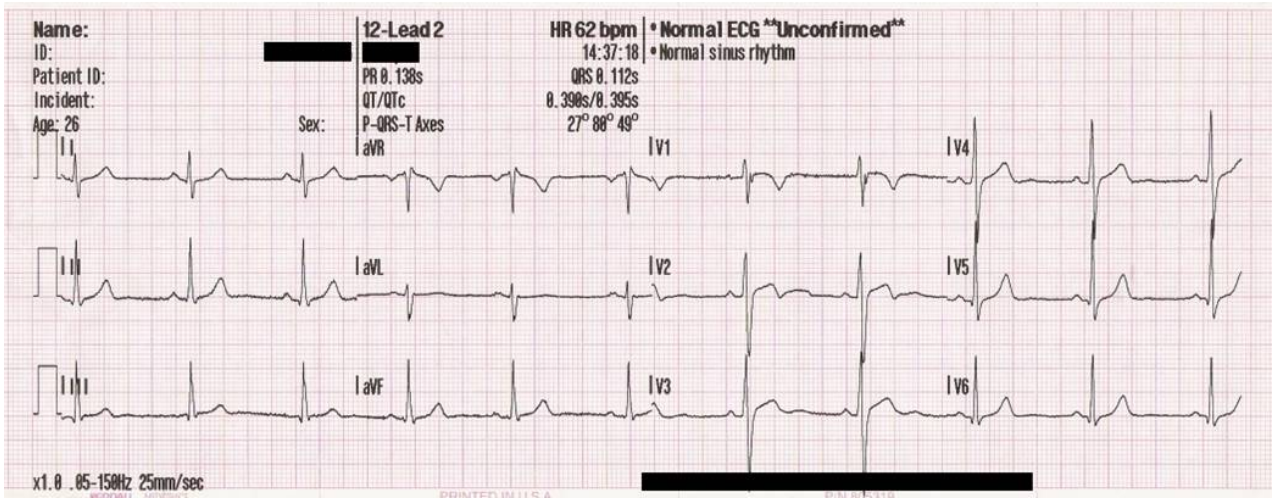
Example: ECG



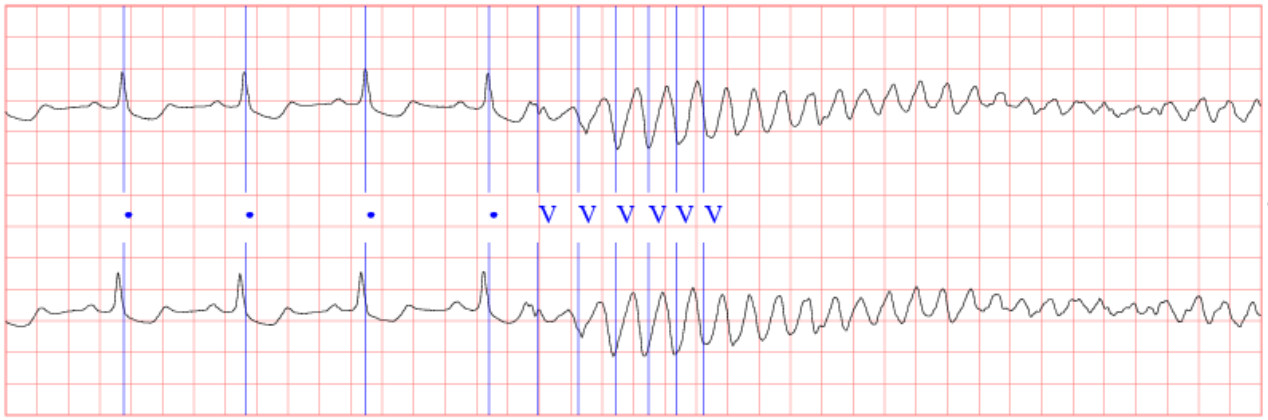

QRS Complex
R
PR Segment
ST Segment
P
T
Q
S
PR Interval
QT Interval


SA node
AV node
Bundle of His
Bundle branches
Purkinje network

ECG: normal vs arrhythmia

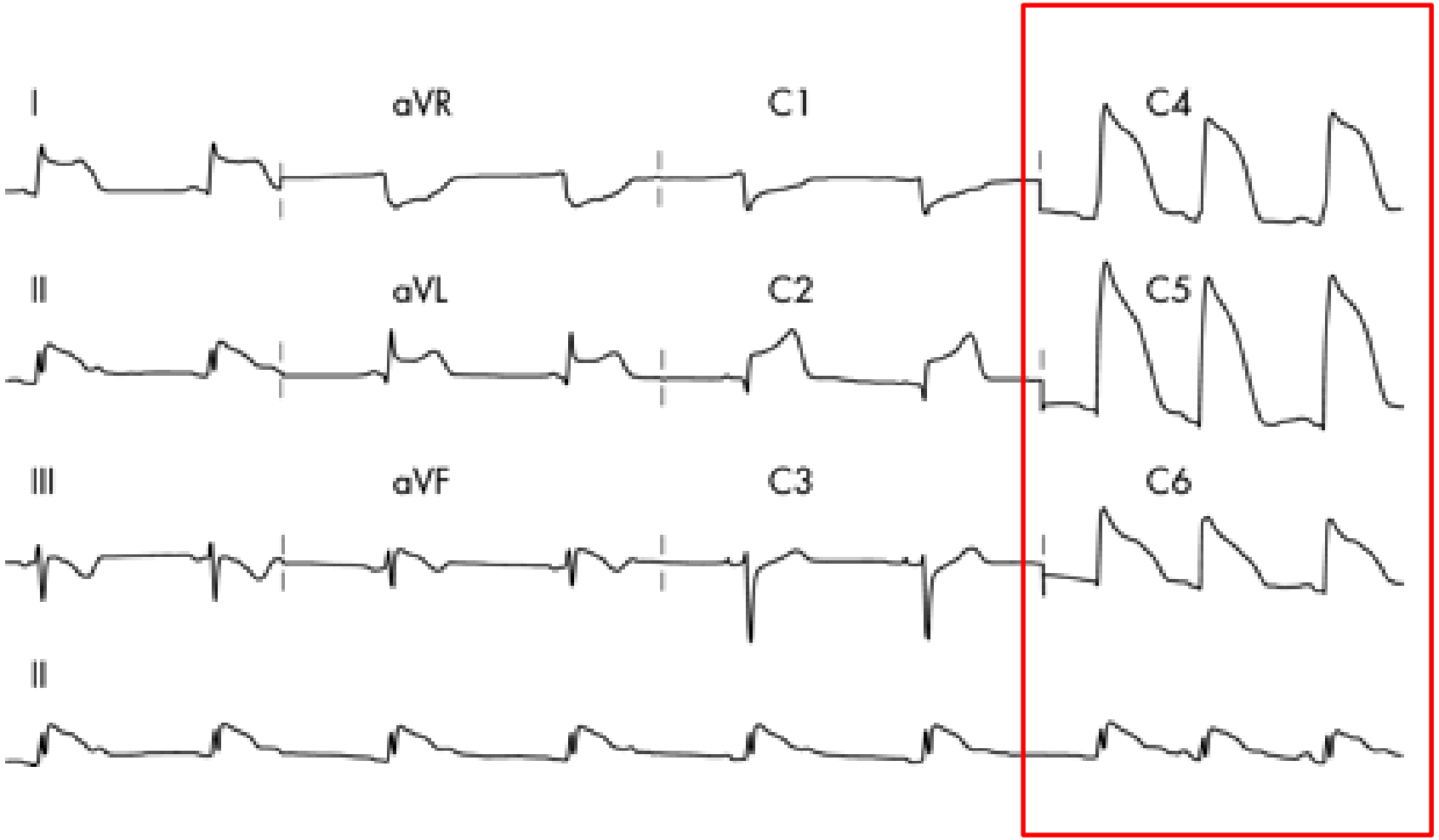


Normal



Ventricular Tachyarrhythmia

ECG: “Tomb Stone” marker of acute myocardial infarction

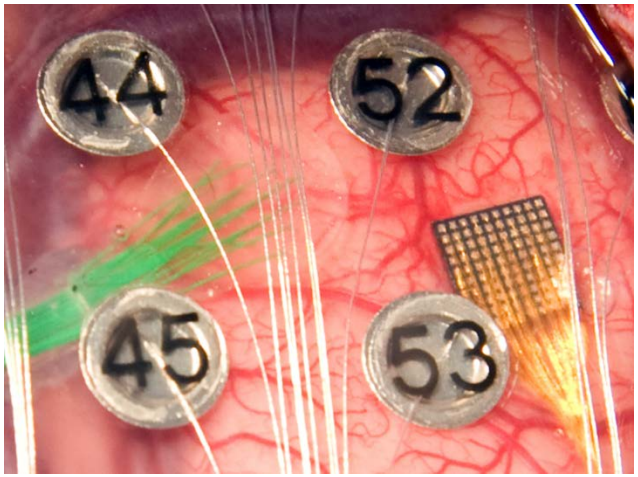


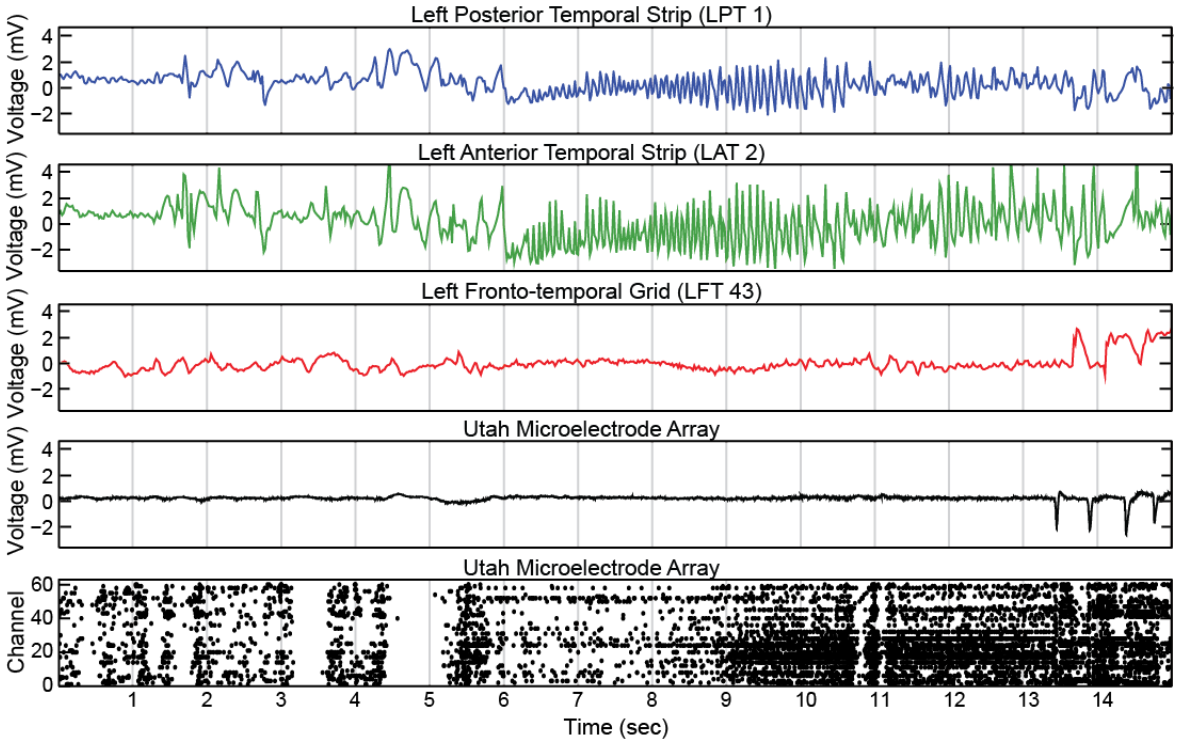
Example: EEG

EEG leads on a normal volunteer

Onset of epileptic seizure in a pediatric patient

Example:
ECoG, Micro-ECoG, Micro-electrode





Onset of seizure in an adult patient

Biomagnetic signals

- Electrical activity of various organs(heart, lungs & brain) induces weak magnetic fields
- Uses very precise magnetic sensors such as SQUID (Superconducting Quantum Interference Device) magnetometers to detect changes in weak magnetic fields

Examples

- Magnetoencephalography (MEG)- brain
- Magnetoneurography (MNG)- peripheral nerves
- Magnetogastrography (MGG)- gastrointestinal tract
- Magnetocardiography (MCG)- heart

Bio-chemical signals

- Contain information about changes in concentration of various chemical agents in the body
- Provides information about the bio-chemical functioning of various physiological systems
- Real-time monitoring often using electrochemical sensors
- Examples: Determine Oxygen concentration, glucose levels, lactate and other metabolites, hormone levels

Biomechanical/Bioacoustic signals

- Biomechanical: Produced by the mechanical functions of biological signals such as: motion, displacement, tension, force, pressure, and flow
- Bioacoustic: Are special subset of biomechanical signals that involve vibrations (motion)
  - How do you test for hearing in new born babys?
- Measured at the skin using acoustic transducers accelerometers
- Examples: Blood pressure measurement, heartbeat by stethoscope

Bio-optical signals

- Generated by the optical, or light-induced attributes of biological systems
- May occur naturally or signals can be introduced to measure a biological parameter using an external light medium
- Example: Pulse oximetry, Optogenetics,…

Medical Images as Biosignals

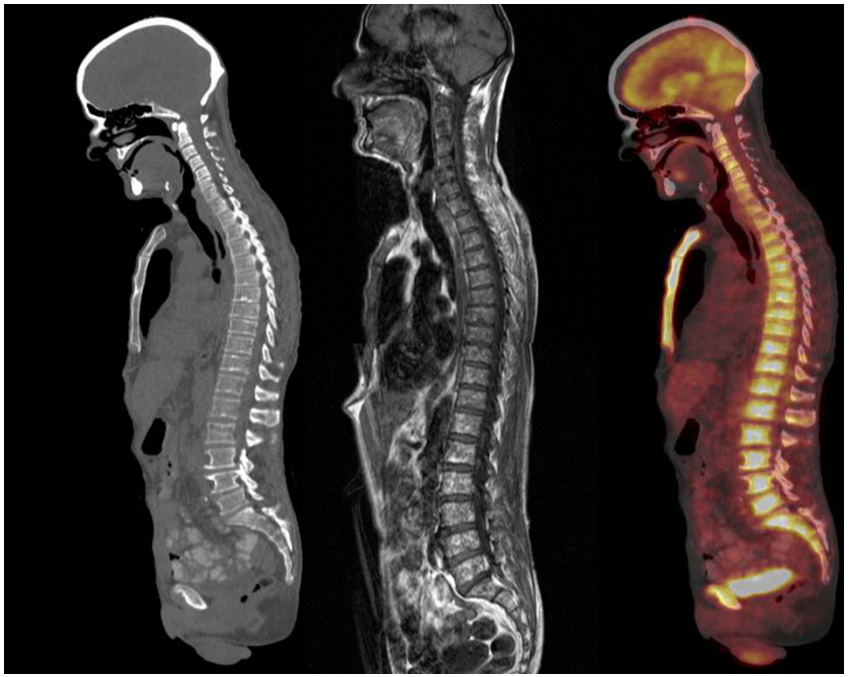
We want to **non-invasively** look inside a "sample" like human or animal body to study anatomy or diagnose disease or monitor improvement following treatment.

Need to differentiate between various tissues, organs, bone etc. i.e. **need contrast.**

Image I(x,y): A representation of a view of an object where intensity I varies as a function of coordinates x and y.

Variations in intensity which have bio-physical origins provide contrast.

Signal for different modalities has very different origins. Hence image intensity and its variations mean something different for each imaging modality



CT **MRI** **PET-CT**

Carty et al.
J Surg Radiol. 2011 Apr 1;2(2).

Steps in handling biosignals

- Data acquisition

  Very different for each type of biosignal.
- Signal analysis

  Many similarities across biosignal types but do require specific processes for each type.

  In general:
  - Amplification*
  - Digitization*
  - Filtering *
  - Processing*
  - Storage

  * Covered in this class

Goals for today

1) Define and describe signals and system
2) Understand graphical representation of signals
3) Understand the origin of various types of Biological Signals

Take home message:

Think deeply and carefully about the type and source of biosignals, and the systems you use to collect and analyze them