Biomedical Signal Analysis

Dr. Aslı AYKAÇ
Department of Biophysics

Signal and System

- A signal is a function of independent variables that carry some information about the behavior of a natural or artificial system.
- A signal is a physical quantity that varies with time, space or any other independent variable by which information can be conveyed.

A **system** is any physical set of components that takes a signal, and produces another signal.

- A system process (extract, modify, transform, or manipulate) input signals to produce output signals.

- Excitation signals are applied at system inputs and response signals are produced at system outputs

Block diagram of a simple system

Signal

- **Analog Signal:** It is a signal that has a continuous nature rather than a pulsed or discrete one.
- **Digital Signal:** only takes discrete values

- **Analog** and **digital signals** are used to transmit information, usually through electric signals.
- In both these technologies, the information, such as any audio or video, is transformed into electric signals.

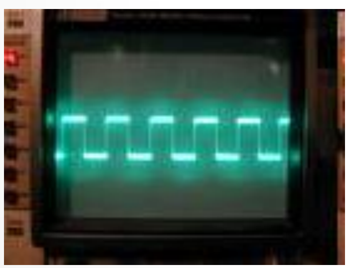
- The **difference between analog and digital** technologies is that in analog technology, information is translated into electric pulses of varying amplitude. In digital technology, translation of information is into binary format (zero or one) where each bit is representative of two distinct amplitudes.

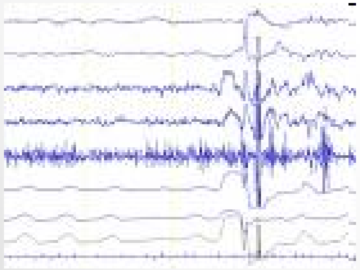
Analog Signal

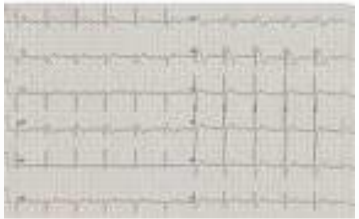
Analog signal varies in a continuous manner.

Because of a continuous function, it consists of infinite number of values.

Examples: signals on oscilloscope/CRT-screen (TV signals on CRT-screen, X-ray films, EEG, EMG, ECG signals & anjiography images on CRT-screen/paper) etc.



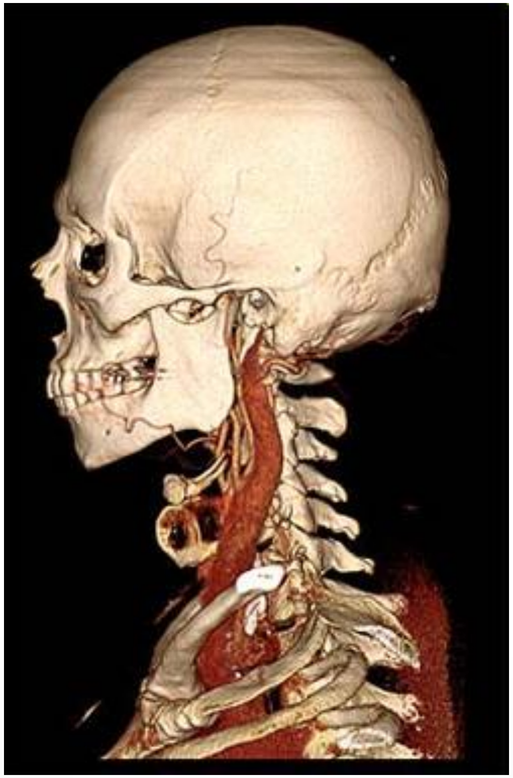




Digital Signal

Digital Signal takes only discrete & computer-storable values.

Examples: ECG / EEG/ EMG, ultrasonography/ echocardiography signals etc.



Digital signals = vector or matrix of finite numbers

- We need to convert analog signals to digital numbers
- **OTHERWISE**
    - We cannot display them on digital screens.
    - We cannot store them on servers/computers
    - We cannot apply digital filters on them (to remove noise etc.)
    - We cannot make automatic calculations on them
    - WE CANNOT EVALUATE AND USE EASILY.
    - etc.

Analog-to-digital conversion: sampling and quantization

- Analog signals come from sensors or transducers that capture a signal (sound, pressure, light, radio waves, and so on) are transformed into a voltage that is proportional to the amplitude of that signal.
- Sampling
- Sampling is taking an instantaneous snapshot of the ADC's input voltage and freezing it for the duration of the conversion (*Sample-and-Hold* (S/H).
- The S/H briefly opens its aperture window to capture the input voltage on the rising edge of the clock signal, and then closes it to hold its output at the newly acquired level.

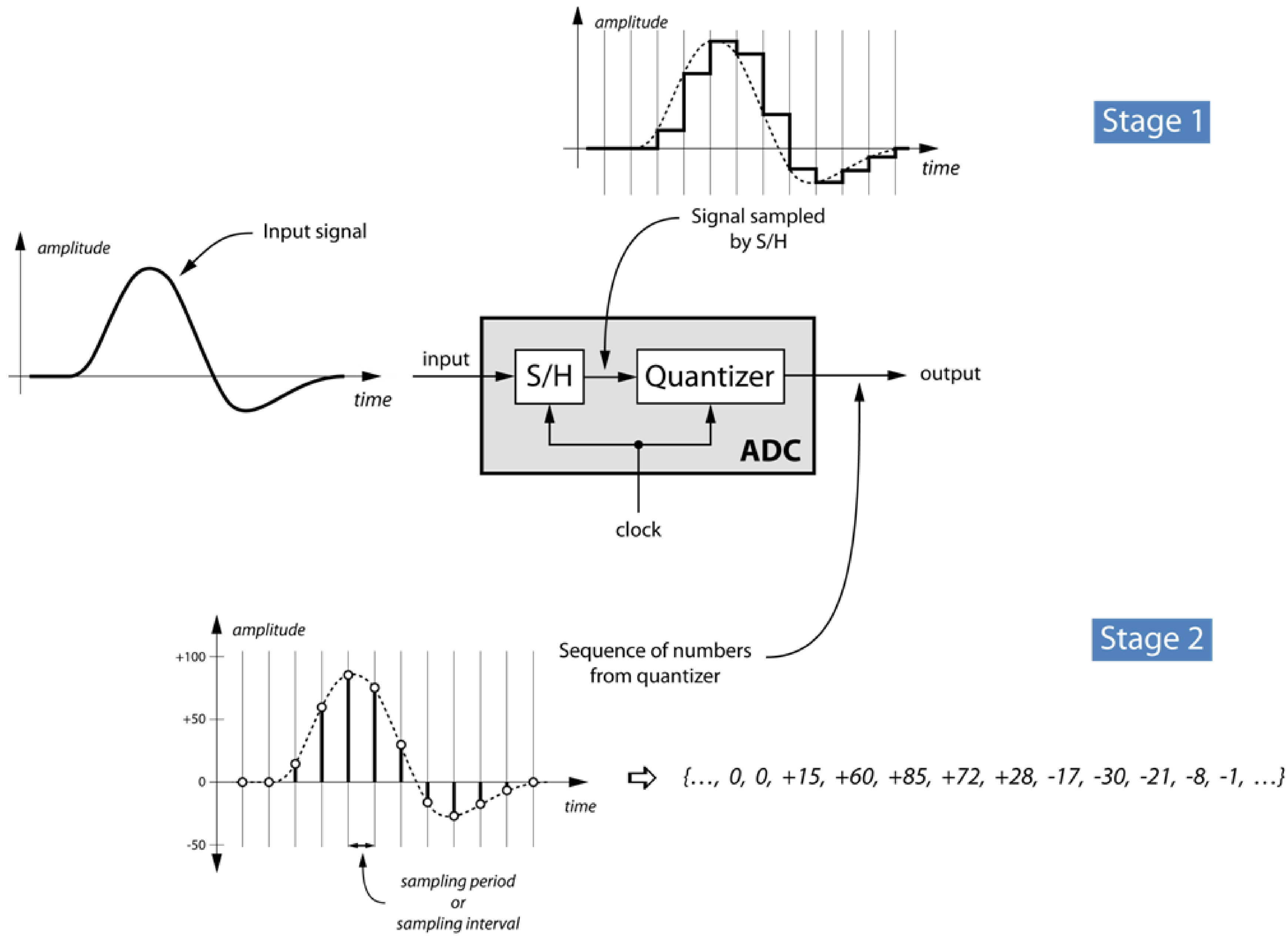
Quantization

- The second step assigns a numerical value to the voltage level present at the output of the S/H. This process, known as *quantization*, searches for the nearest value corresponding to the amplitude of the S/H signal out of a fixed number of possible values covering its complete amplitude range.
- The *quantizer* can't search over an infinite number of possibilities and must restrict itself to a limited set of potential values.

- Advantages in working with digitized signals :
- 1-There is a very large amount of intrinsic data reduction when you only have to work with a limited quantity of information (discrete samples) instead of a continuous and infinitely detailed signal.

- 2-If handled properly, numbers won't degrade, so digitized information can theoretically last forever .

- 3-Digital numbers are expressed as series of 0s and 1s that can be moved around, stored, transmitted, transformed into other numbers, and so on. As long as information remains in a digital format, it can be manipulated and processed using common media and tools. This can't be said of analog signals, which require dedicated means to process each specific type of signal.

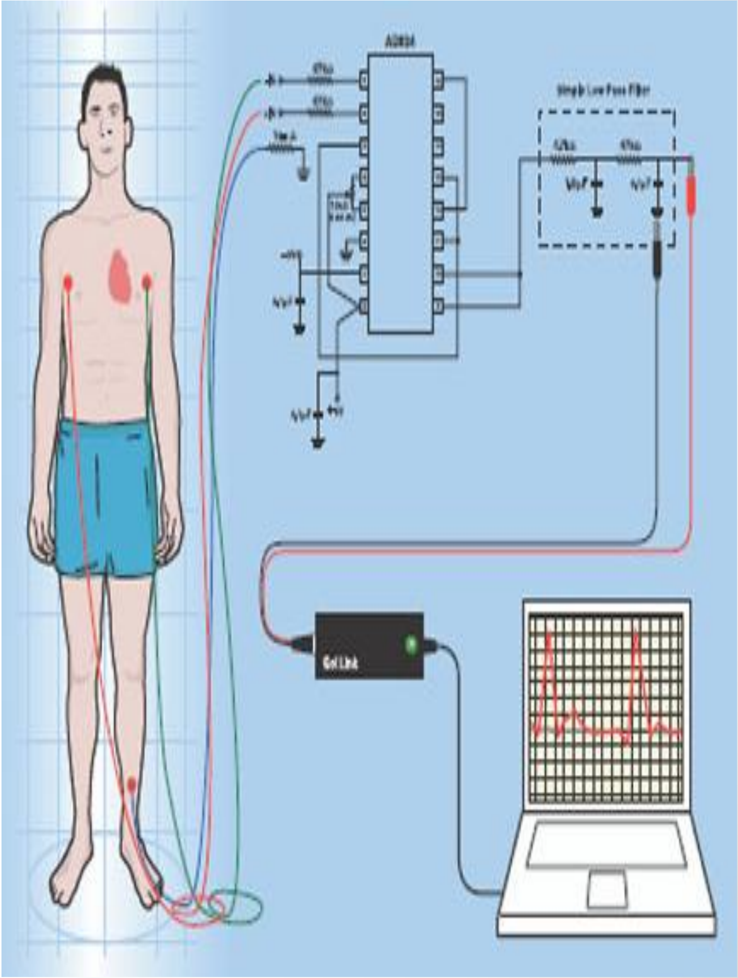

amplitude
time
Stage 1
Signal sampled
by S/H
amplitude
Input signal
time
input
S/H
Quantizer
ADC
output
clock
amplitude
Stage 2
Sequence of numbers
from quantizer
+100
+50
0
-50
time
{..., 0, 0, +15, +60, +85, +72, +28, -17, -30, -21, -8, -1, ...}
sampling period
or
sampling interval

Biomedical Signal and System

- The generation of many biological signals found in the human body is traced to the electrical activity of large group of nerve cells or muscle cells.
- A biomedical signal is generally acquired by a sensor, a transducer or/and electrode, and it is converted to a proportional voltage or current for processing and storage.

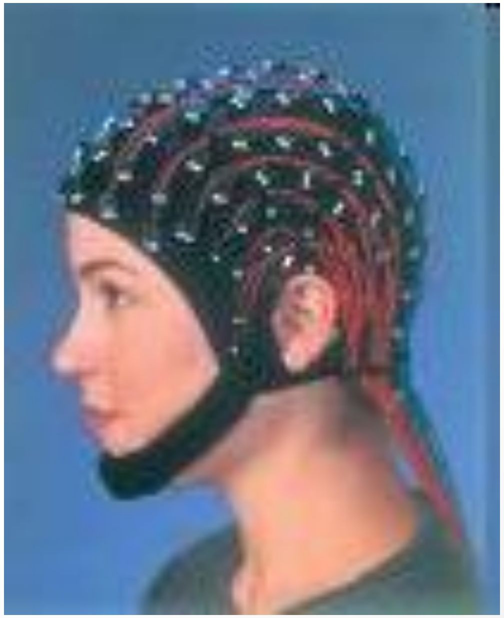
Example of Biomedical Signals

1. Electrocardiogram (ECG)
   - A record of the electrical activity of the heart.
   - To measure the rate and regularity of heartbeats as well as the size and position of the chambers, the presence of any damage to the heart, and the effects of drugs or devices used to regulate the heart (such as a pacemaker).
   - Represents changes in the potential (voltage) due to electrochemical processes involved in the formation and spatial spread of electrical excitations in the heart cells.



2. Electroencephalogram (EEG)

- a record of fluctuations in the electrical activity of large groups of neurons in the brain.
- Measures the electrical fields associated with the current flowing through a group of neurons.



To record EEG or ECG, at least two electrodes are needed.

- an active electrode is placed over the particular site of neuronal activity that is of interest

- a reference electrode is placed at some remote distance from this site

❖ EEG or ECG is measured as the voltage or potential difference between the active and the reference electrodes

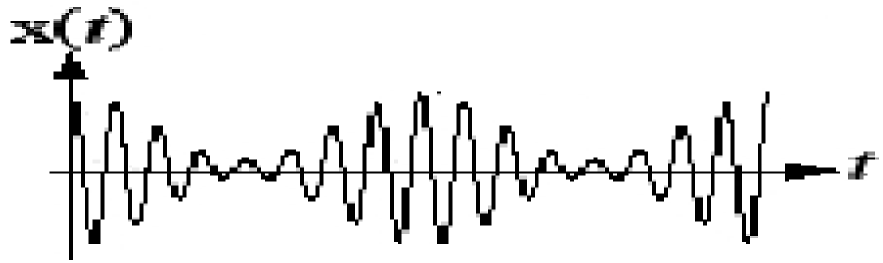
Classification of Signals

There are several broad classification of signals :

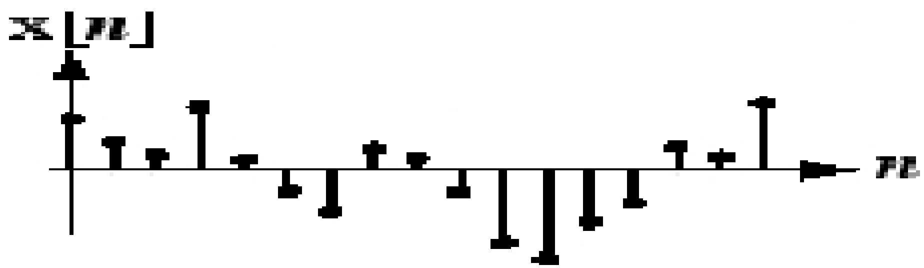
1. Continuous-time and Discrete-time Signal
2. Even and Odd Signals
3. Periodic Signals, Nonperiodic Signals
4. Deterministic Signals, Random Signals
5. Causal, Anti-causal and Noncausal Signals
6. Right-Handed and Left-Handed Signals

1. Continuous-time and discrete-time signal
   - A signal, $x(t)$ is said to be a continuous-time signal if it is defined for all time t.
   - A discrete-time signal, $x[n]$ is defined only at discrete instants of time.
   - A discrete-time signal is often derived from a continuous-time signal by sampling it at a uniform rate.

Continuous-time signal



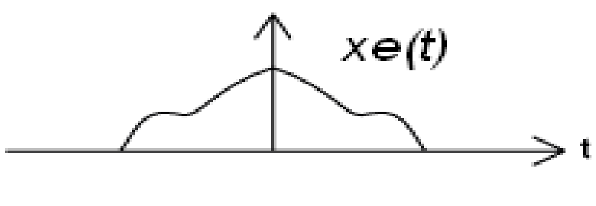
Disrete-time signal



2. Even and odd signals

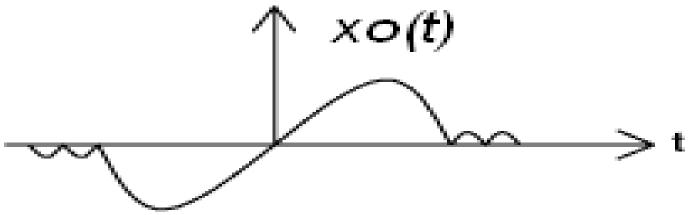
- A continuous-time signal,
- ✓ $x(t)$ is said to be an even signal if it satisfies the condition below:

$$x(-t) = x(t) \text{ for all } t$$



- ✓ x be an odd signal if it satisfies the condition below:

$$-x(-t) = x(t) \text{ for all } t$$



- o even signals are symmetric about the vertical axis or time origin, whereas odd signals are antisymmetric (asymmetric) about the time origin.

3. *Periodic signals, nonperiodic signals*

- A periodic signal $x(t)$ is a function that satisfies the condition below:

  $$x(t) = x(t+T) \text{ for all } t \qquad (1)$$

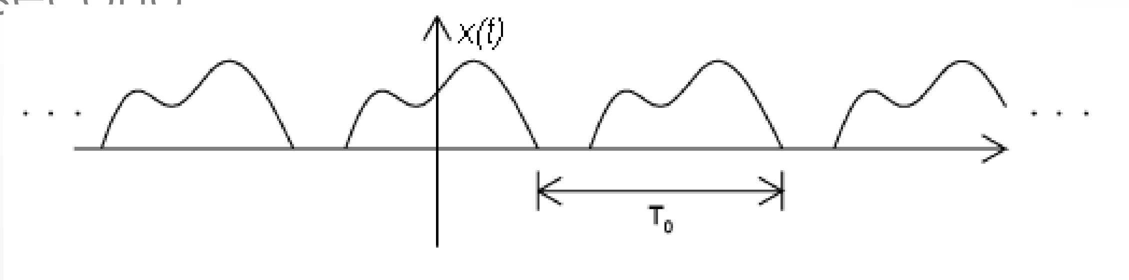
- T that satisfied the above equation is called fundamental period of $x(t)$.

- The reciprocal of fundamental period is called fundamental frequency.

  $$f = \frac{1}{T}$$

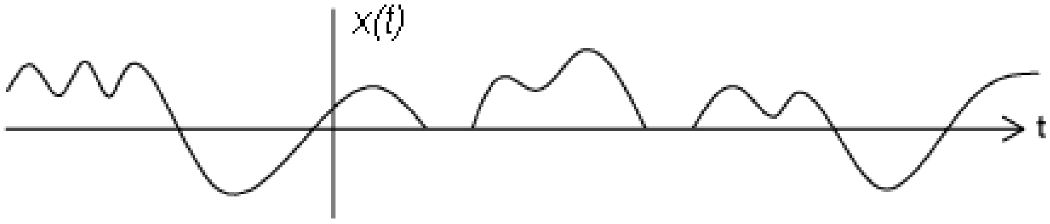
- The frequency f is measured in hertz (Hz) or cycles per second.
- The angular frequency is measured in radians per second.

  $$\omega = \frac{2\pi}{T}$$



A Periodic signal with period T

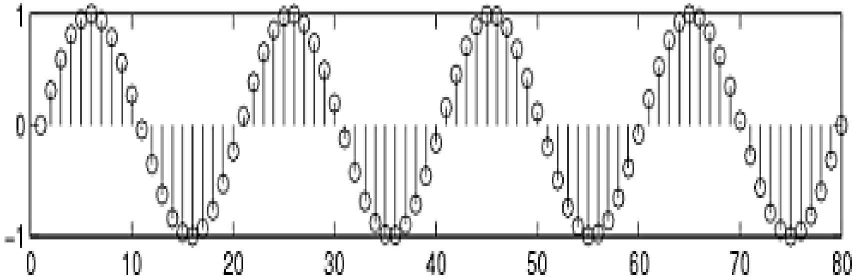
Any signal *x(t)* for which there is no value of *T* to satisfy the condition of equation [$x(t) = x(t+T)$ for all *t*] is called aperiodic or nonperiodic signal.



A nonperiodic signal

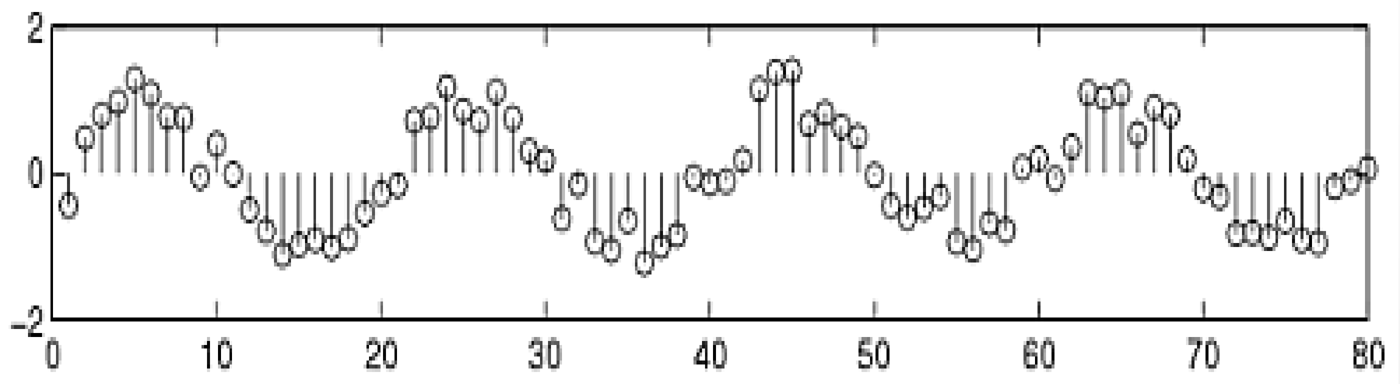
4. Deterministic signals, random signals

- A deterministic signal is a signal in which each value of the signal is fixed and can be determined by a mathematical expression, rule, or table.
- Because of this the future values of the signal can be calculated from past values with complete confidence.



Deterministic signal

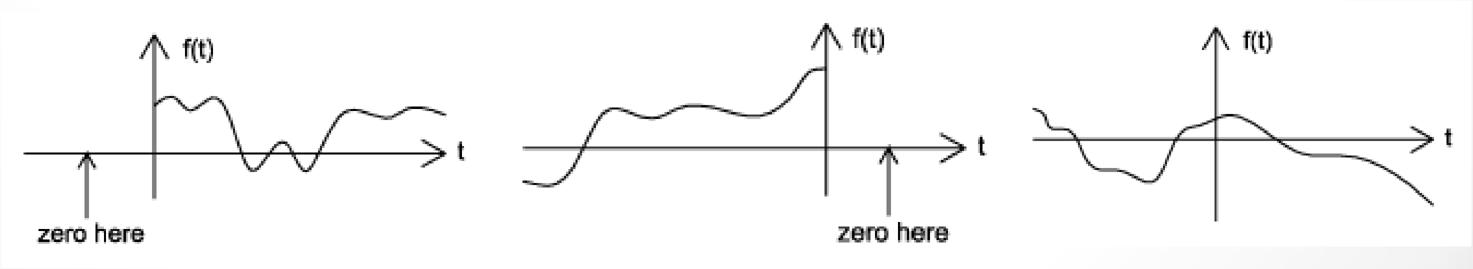
- A random signal has a lot of uncertainty about its behavior.
- The future values of a random signal cannot be accurately predicted and can usually only be guessed based on the averages of sets of signals.



Random signal

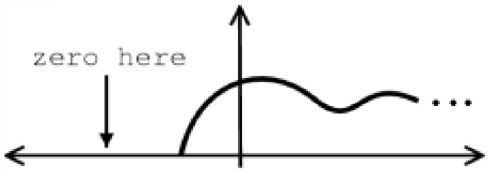
5. *Causal, anti-causal and noncausal signals*

- Causal signals are signals that are zero for all negative time.
- Anticausal are signals that are zero for all positive time.
- Noncausal signals are signals that have nonzero values

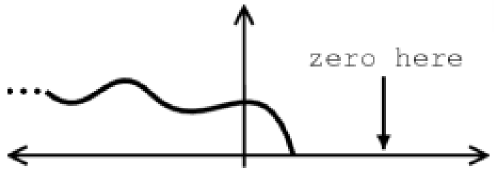


A causal signal An anticausal signal A noncausal signal

6. *Right-Handed and Left-Handed Signals*



Right-handed signal



Left-handed signal

ALIASING

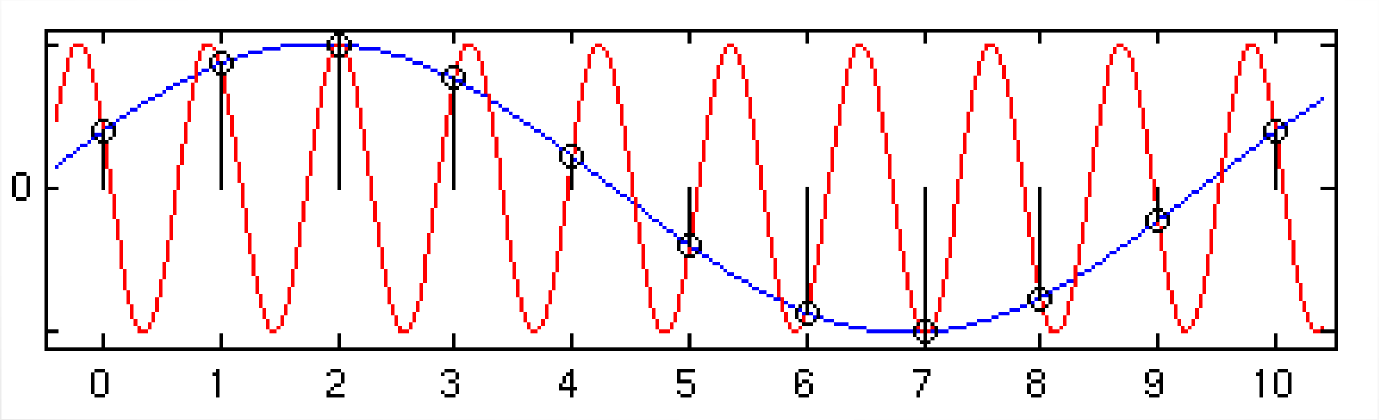
A type of distortion that occurs when digitally recording high frequencies with a low sample rate.

Circles: Sampled signal points

Red: Analog signal,

Blue: Reconstituted (from sampled points) analog signal

NOTE THAT aliasing occurs (Volt vs. second)



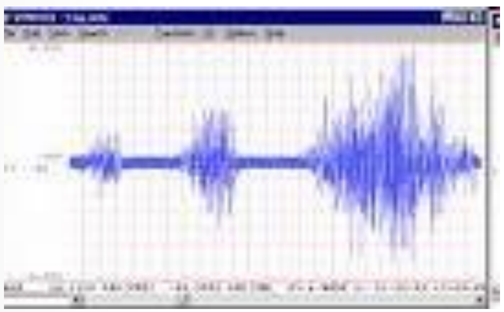
Biomedical Signal Analysis

- Signals in Medicine
  - **1D:** EEG,EMG,EOG, ECG, etc.,
  - **2D:** X-ray films, USG, MRI, CT, Nuclear Medicine, etc
  - **3D:** MRI, CT, video, etc.

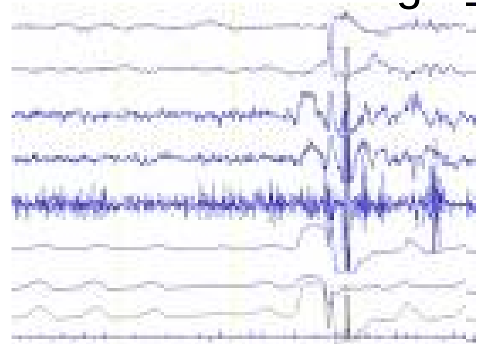
Types of Signals-1D

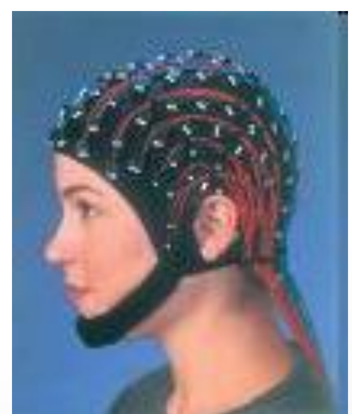
1D: amplitude vs. time signals (EEG/ EOG/ ECG/ EMG) etc.

1D signal



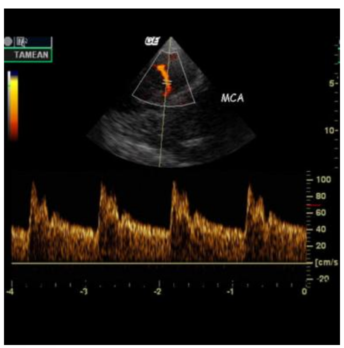
multichannel 1D signal

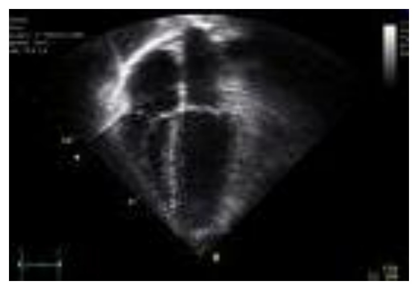


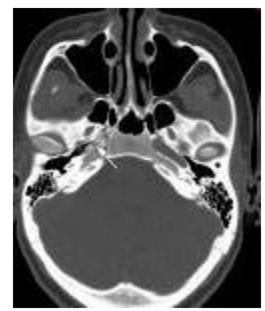


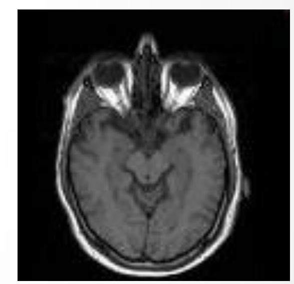
Types of Signals-2D

~images (Rx, one slice of USG, Doppler, CT, MR signals etc.) etc.



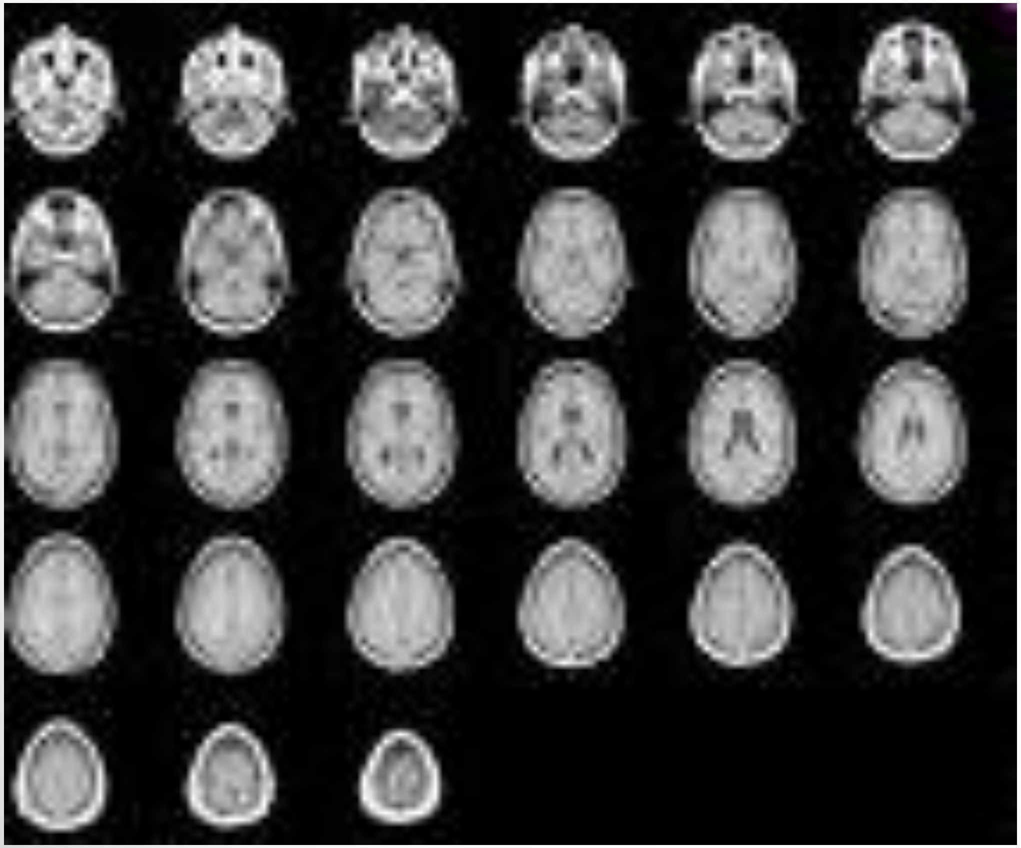


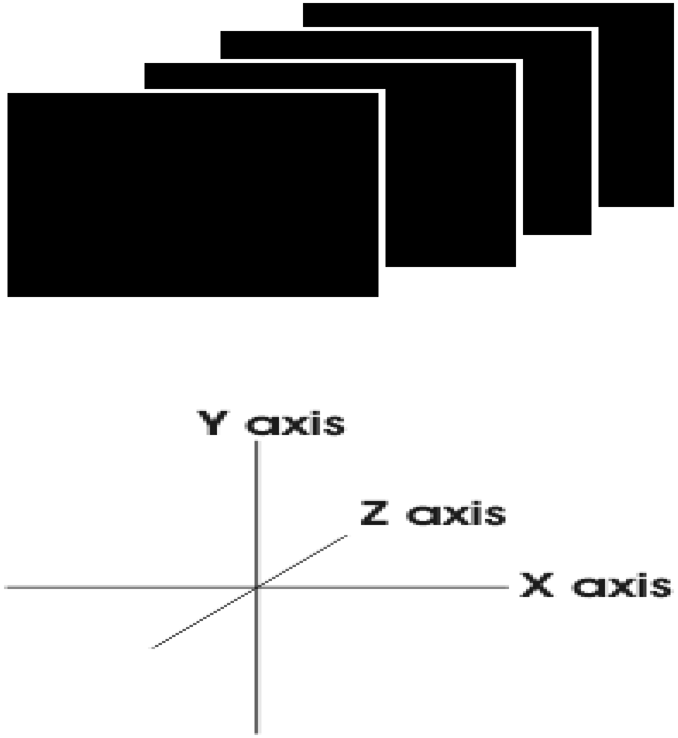




Types of Signals-3D

video (echocardiography,USG video signals etc.), **3D** MR, **3D** CT data

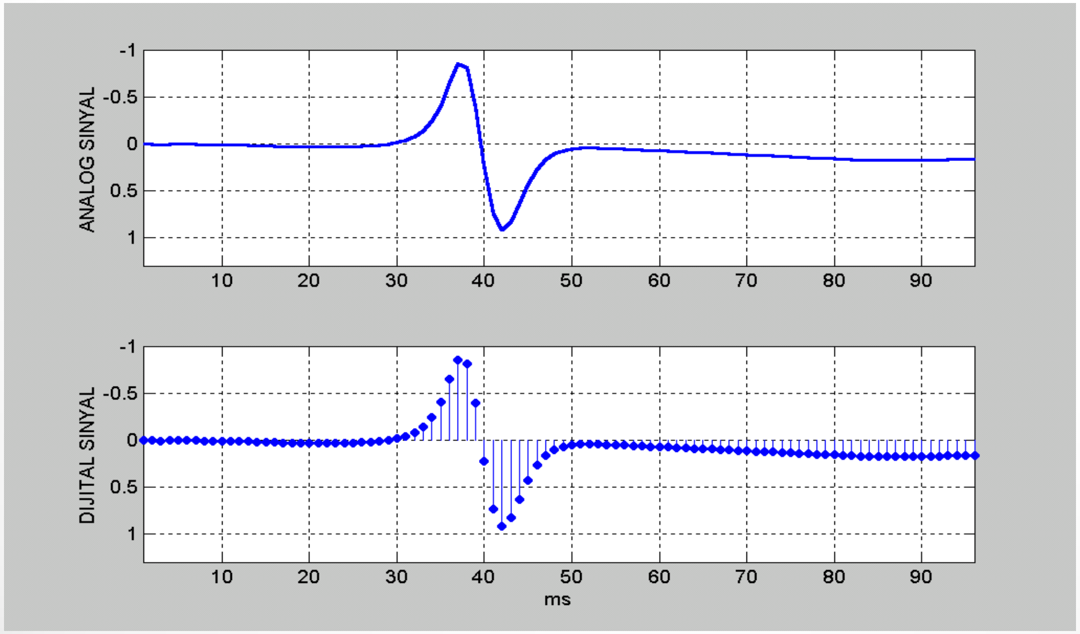




•

SAMPLING OF 1D SIGNALS

Sampling Period (T): the time between 2 consecutive samples.
Sampling rate/frequency (f_s=1/T): acquired samples in one seconds.



SAMPLING OF 2D SIGNALS

There are TWO sampling rates (or periods) for 2 dimensions.

X-Ray film

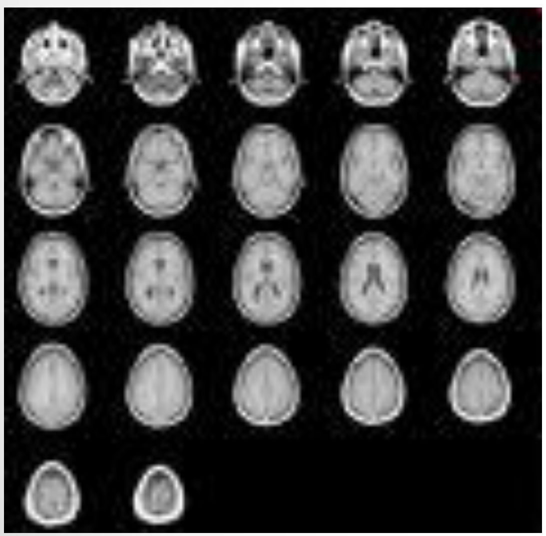
=>

2D matrix of numbers

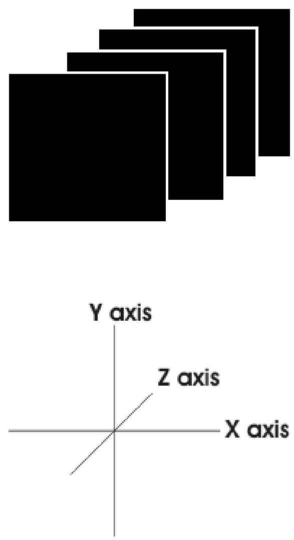
...	...	...	...	...
...	256	127	46	...
...	256	121	46	...
...	128	110	45	...
	...	...	...	...

SAMPLING OF 3D SIGNALS

There are THREE sampling rates/periods for 3 dimensions.

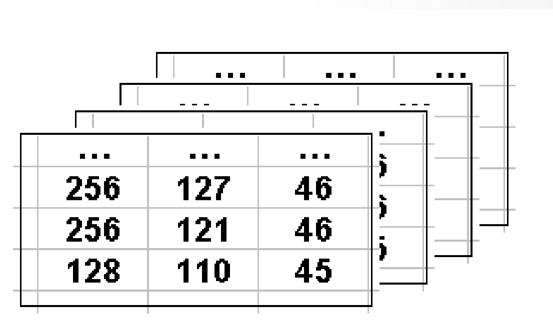


=>



=>

3D matrix of numbers

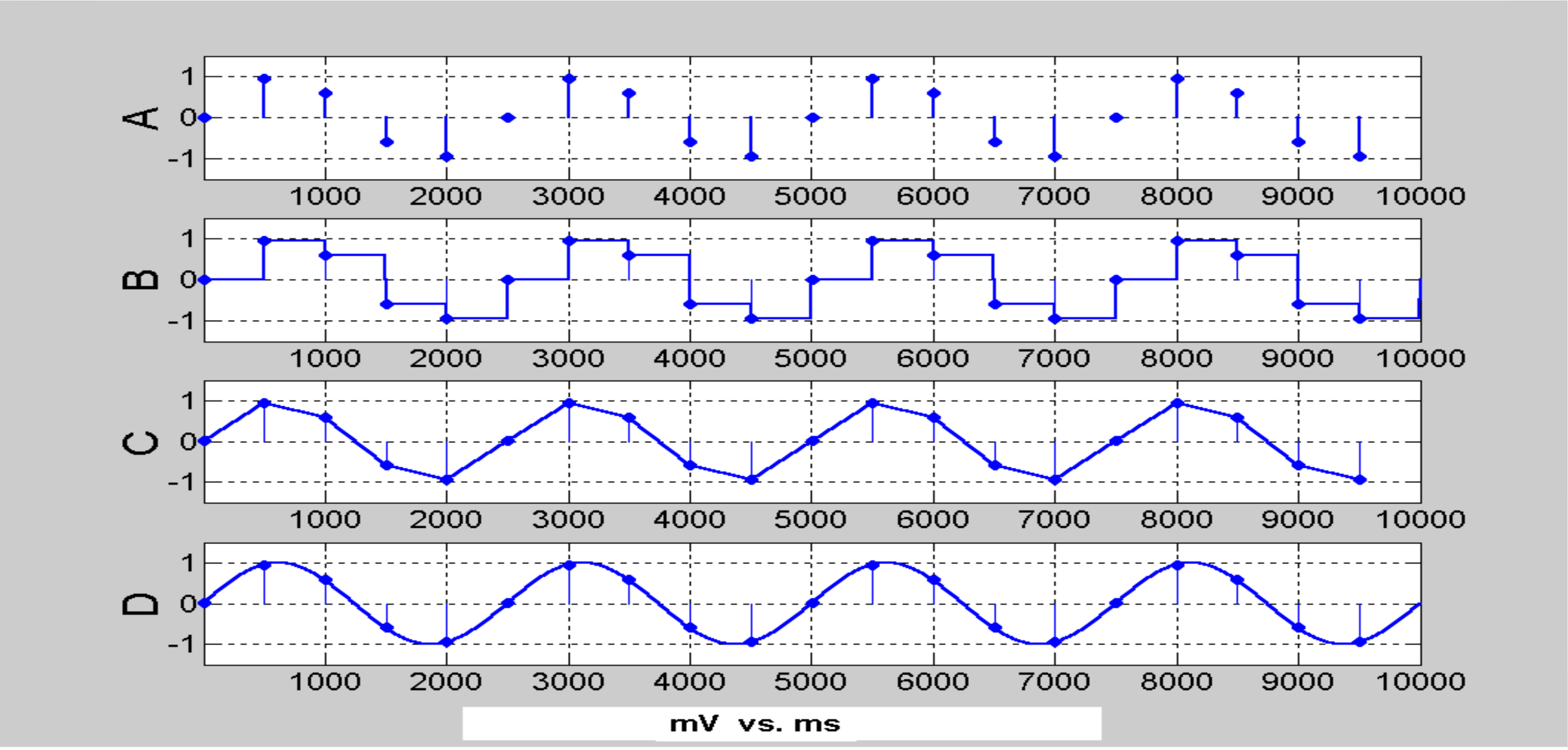


Interpolation, Decimation and Downsampling of Digitial Signals

- **Interpolation** is a method of constructing new data points within the range of a discrete set of known data points.
- **Downsampling** (or "subsampling") is the process of reducing the sampling rate of a signal.
- **Decimation** is a technique for reducing the number of samples in a digital signal. It is a two-step process:
  - 1. Low-pass anti-aliasing filter, then
  - 2. Downsampling

Interpolation in 1D

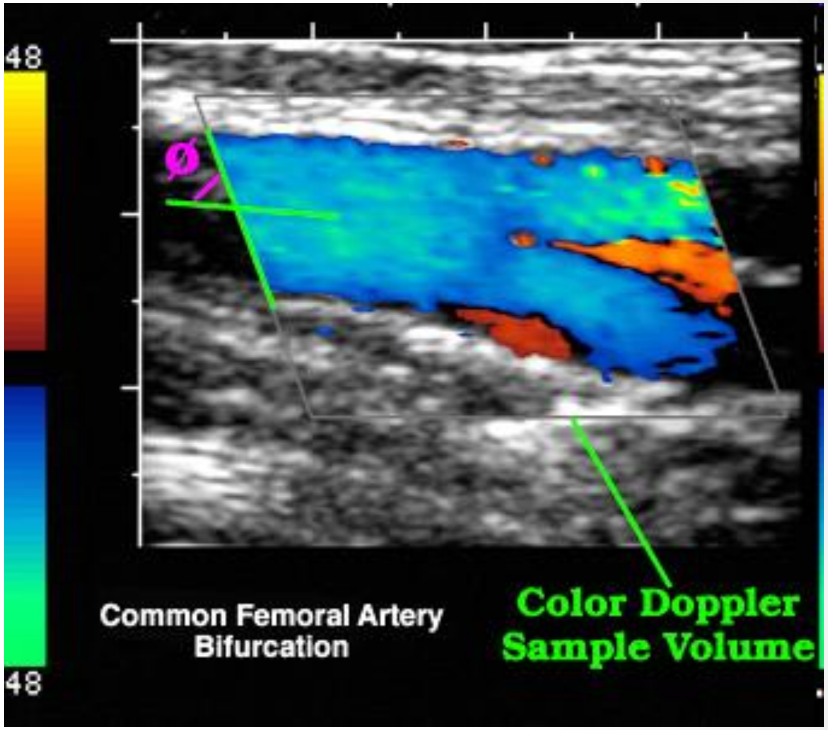
- There are many methods for interpolation
- In the following figure, empty parts of the signal in **A**, were filled with different (**B**, **C**, **D**) interpolation methods



- Interpolation increases size of signal vector/matrix
- X:original signal
- Y: interpolated signal
- Length of Y > Length of X

Interpolation in 2D- 1

- There are many methods for interpolation in 2D also
- Example: In color doppler imaging (CDI), every color corresponds to a velocity
  - Many pixel are INTERPOLATED on the image.
  - Question marks are filled w.r.t. their neighbours
  - Sometimes, errors can be seen due to interpolation

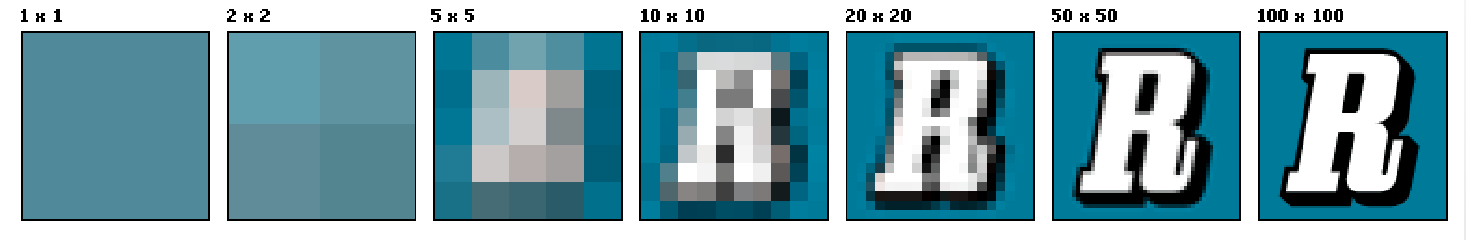


Downsampling & Decimation

- Downsampling/decimation decreases size of signal vector/matrix
- X:original signal
- Y: downsampled signal
- Length of Y < Length of X

More Definitions

- **Amplitude:** greatness of magnitude
- **Resolution:** capability of making distinguishable the neighbour parts of an object.
- There are many definitions w.r.t. topic (CT, MRI, USG videos, images etc.).
  - The term *resolution* is often used as a pixel count in digital imaging etc.



DIGITAL SIGNAL COMPRESSION

- Definitions
  - 1 Byte=8-bit
  - 1 KByte=10^3 byte,
  - 1 MByte=10^6 byte,
  - 1 GByte=10^9 byte,
  - 1 TByte=10^{12} byte,

EXAMPLES

- An ECG signal: 16-bit x 1000 sample/sec
  - Bit-rate (Byte/s)=16,000 bit/s=2 KByte/s
  - Traditional ECG has 10 channels, so Bit-rate= 8x20 KByte/s
- a Rx image has 4000x4000 pixel and each pixel is represented with 16 bit gray value => 4000x4000x2 bytes =32 MBytes
- A medical video has 24 bits RGB pixels +1000x600 image frames + 30 fps video speed (3x1000x600@30 fps).
  - Bit-rate =8x3.1000.600.30 Byte/s=54.10^6 Byte/s ≈ 4.10^8 Bit/s
- Compressing medical signals for video and Rx is a requirement

Signal-to-noise ratio

Because of biomedical signals are generally contaminated with noise

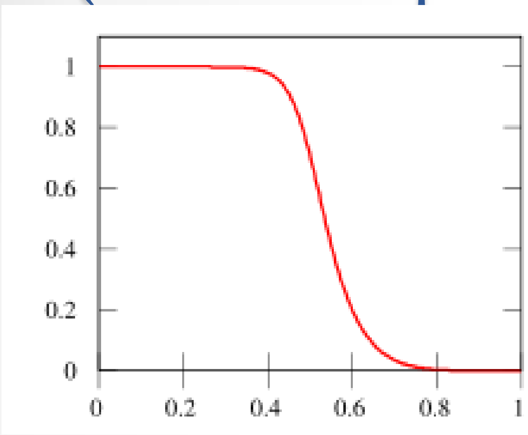
their signal noise ratios (SNRs) can be improved by filtering (analog or discrete filters).

Filters

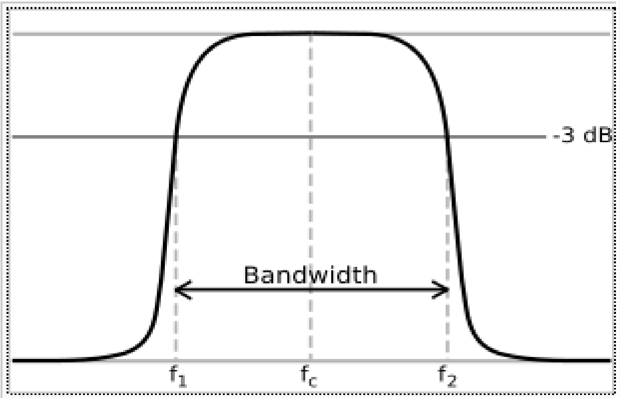
- Filters are devices/programs so that stop or pass some parts of frequency spectrum.
- **Low pass filter**: passes only low frequencies
- **High pass filter**: passes only high frequencies
- **Band pass filter**: passes only a band of spectrum
- **Band stop filter**: stops only a band of spectrum

Filter Types

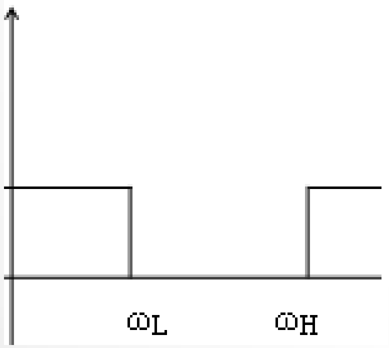
(Filter Amplitude vs. Frequency graphs of filters)



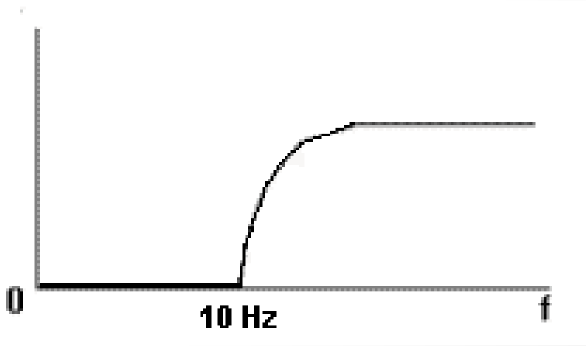
Low Pass (LP) filter, cut-off frequency is 0.5 Hz



Band Pass (BP) filter, cut-off frequencies are f_1 and f_2



Band Stop (BS) filter, cut-off frequencies are w_L and w_H



High Pass (HP) filter, cut-off frequency is 10 Hz