Advanced biomedical signal and image processing

Master: Plasturgy & Biomedical Engineering

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Faculté de Science Meknes

Professor Omar ELOUTASSI

Omar ELOUTASSI o.eloutassi@umi.ac.ma

Section 1 :

Introduction to Digital Signal and Image Processing

Chapter 1:

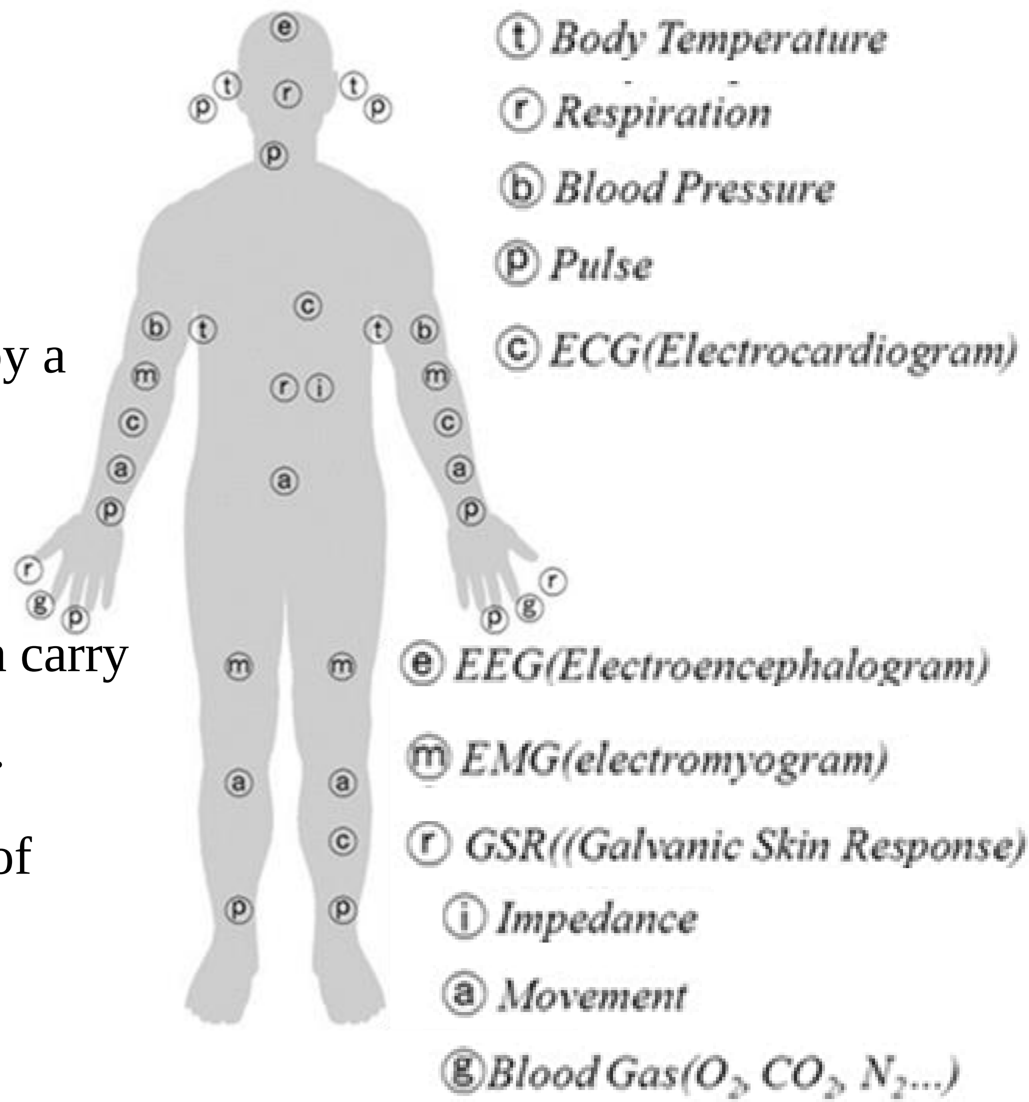
Introduction to signals and systems

Introduction

➢A biomedical signal is a signal derived from a biological system (human or animal) or generated by a physiological process.

➢Nearly every part of the body produces electrical signals, which carry important diagnostic information.

➢These signals serve as carriers of both relevant and irrelevant data



Introduction

The frequencies of some common biomedical signals

BIOSIGNAL	FREQUENCY
ECG Electrocardiogram	0,05Hz-150Hz
EEG Electroencephalogram	0,1HZ-100Hz
Blood Pressure	0Hz-20Hz
Bioimpedance Signals	1Hz-1MHz
Respiration	0.1Hz-1Hz
EMG Electromyograph	10Hz-500Hz
Nerve action potentials	10Hz-10kHz

Introduction

SOURCES OF BIOMEDICAL SIGNALS

- **Bioelectric Signals:** Generated by nerve and muscle cells, including action potentials and electric field propagation. Examples include ECG (electrocardiogram), EEG (electroencephalogram), EMG (electromyogram), and GSR (galvanic skin response).
- **Biochemical Signals:** Derived from living tissues or laboratory-analyzed samples, such as pO_2 (partial oxygen pressure), pCO_2 (partial carbon dioxide pressure), ion concentrations, and glucose levels.
- **Biomechanical Signals:** Often requiring invasive measurements, these signals include motion, tension, displacement, blood pressure, and blood flow.

Introduction

SOURCES OF BIOMEDICAL SIGNALS

- **Biomagnetic Signals:** Magnetic fields generated by the brain, heart, and lungs.
- **Bioacoustic Signals:** Sounds produced by biological activities, including heart sounds, respiratory sounds, and muscle contractions or joint movements.
- **Bio-optical Signals:** Optical properties of biological fluids or tissues, such as fluoroscopic properties of amniotic fluid and cardiac output measurements using dye dilution techniques.

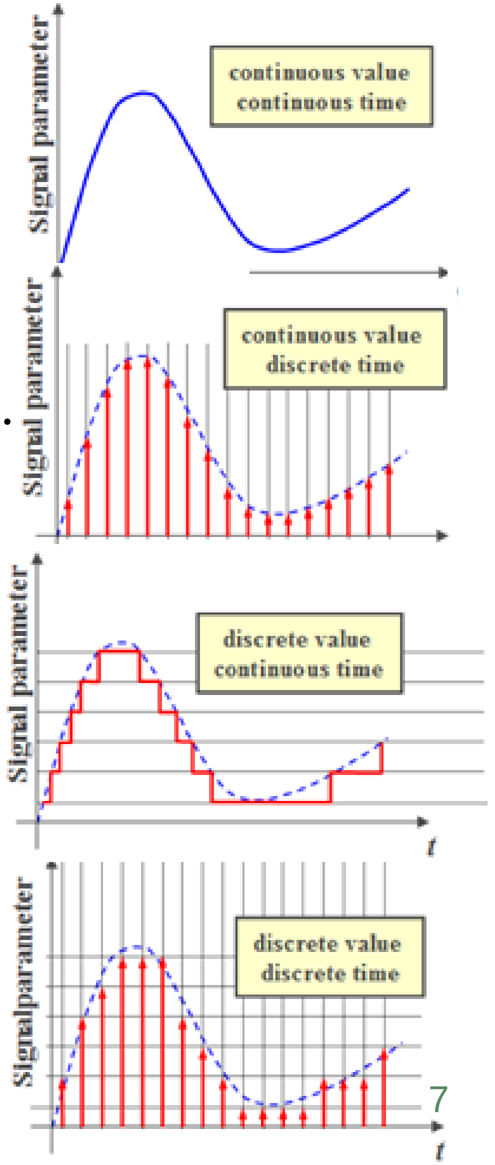
Introduction

BIOMEDICAL SIGNAL CLASSIFICATION

Classification of Signals:

(Biomedical signals are mainly continuous in nature)

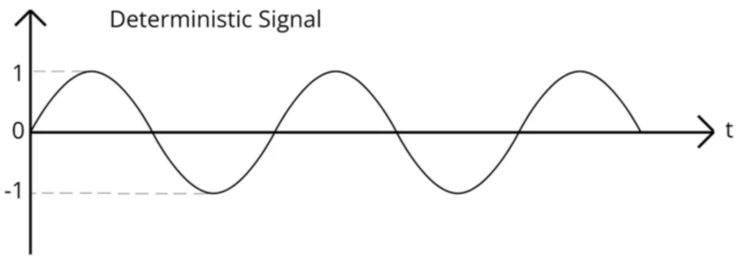
- **Continuous Signals:**
  - ❑ Defined over a continuous range of time or space.
  - ❑ Represented as continuous variable functions.
- **Discrete Signals:**
  - ❑ Defined at specific points in time or space.
  - ❑ Represented as sequences of numbers.



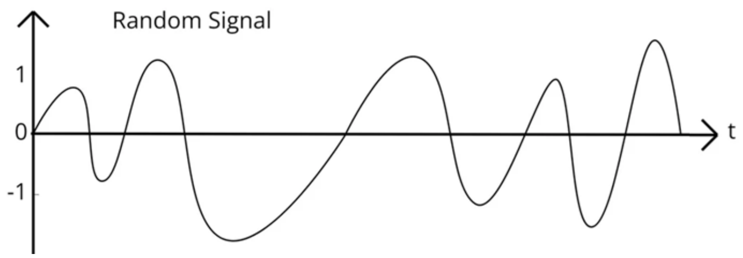
Introduction

BIOMEDICAL SIGNAL CLASSIFICATION

- **Deterministic**
  - Defined by mathematical functions or rules
    - Periodic signals are deterministic (sums of sinusoids) $s(t)=s(t+nT)$
    - Transient signals can be deterministic: signal characteristics change with time



- **Random**
  - Are described by statistical or distribution properties
  - Stationary signals remain the same over time
    - Statistical
    - Frequency spectra



BIOMEDICAL SIGNAL CLASSIFICATION

- Real biomedical signals are not necessarily deterministic
  - Unpredictable noise
  - Non-stationary
- Change in cardiac waveform over time
  - Identification of stationary segments of random signals is an
- important part of signal processing and pattern analysis
- Physiological and time domain signals can often be decomposed into a summation of sinusoidal component waveforms. *Fourier* analysis.
- The frequency and phase spectra contribute to the time domain behavior or shape of the signal.
- Modification of a signal in the frequency domain will affect the time domain behavior of the signal.

BIOMEDICAL SIGNAL PROCESSING

Biomedical Signal Processing: the application of signal processing methods on biomedical signals

- involves the analysis of signals to provide useful information upon which measures can make decisions
- is an a ‘operation’ designed for extracting, enhancing, storing and transmitting useful information.
- is especially useful in the critical care setting, where patient data must be analyzed in real-time. Real-time monitoring can lead to better management of chronic diseases, earlier detection of adverse events such as heart attacks and strokes and earlier diagnosis of disease.

BIOMEDICAL SIGNAL PROCESSING

The four stages of biomedical signal processing

- **Acquisition:**
  - Collection of raw biomedical signals from sensors or electrodes.
  - Examples: ECG, EEG, EMG recordings.
- **Preprocessing:**
  - Noise reduction, filtering, and artifact removal.
  - Signal enhancement to improve quality for further analysis.
- **Feature Extraction:**
  - Identifying relevant characteristics or patterns in the signal.
  - Examples: Peak detection, frequency analysis, waveform parameters.
- **Interpretation & Analysis:**
  - Applying algorithms and models for diagnosis or decision-making.
  - Includes machine learning, statistical analysis, and medical interpretation.

HISTORY

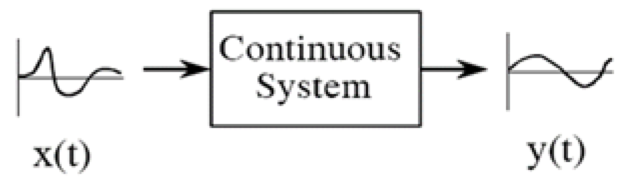
- Signal processing principles date back to 17th-century numerical analysis techniques.
- Newton used finite-difference methods, and Gauss discovered the core idea of the Fast Fourier Transform (FFT) in 1805, predating Fourier's work on harmonic series.
- Until the early 1950s, signal processing relied on analog systems. Digital processing began with oil prospecting but was not real-time.
- The FFT was formally introduced by Cooley and Tukey in 1965.
- The rise of microprocessors enabled cost-effective digital signal processing, and by the mid-1980s, advancements in IC technology led to high-speed Digital Signal Processors (DSPs) optimized for discrete-time signal processing.

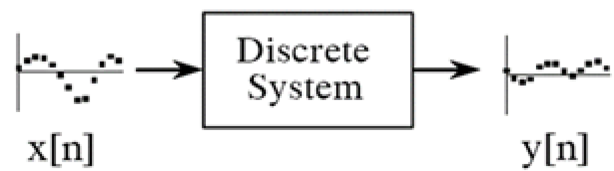
BASICS OF DSP (digital signal processing)

Signals and LTI-Systems (linear time-invariant):

- Generation of an output signal in response to an input signal

- Continuous and discrete systems



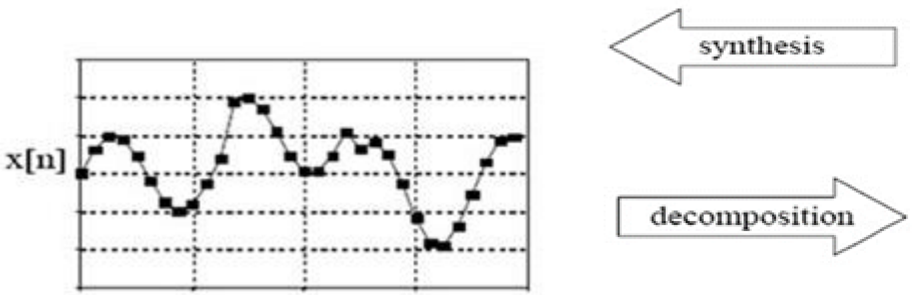


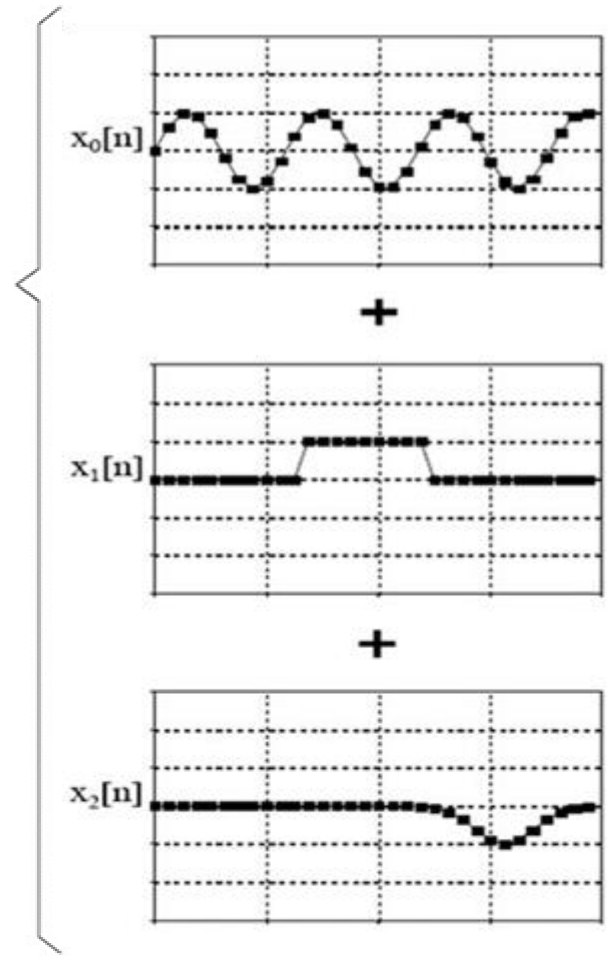
Linear, Time invariant systems properties :

- additivity $x_1[n] \longrightarrow y_1[n]$, $x_2[n] \longrightarrow y_2[n]$ $\Rightarrow x_1[n] + x_2[n] \longrightarrow y_1[n] + y_2[n]$
- homogeneity $x[n] \longrightarrow y[n] \Rightarrow kx[n] \longrightarrow ky[n]$
- shift invariance $x[n] \longrightarrow y[n] \Rightarrow x[n+s] \longrightarrow y[n+s]$

BASICS OF DSP (digital signal processing)

Signals and LTI-Systems (linear time-invariant):

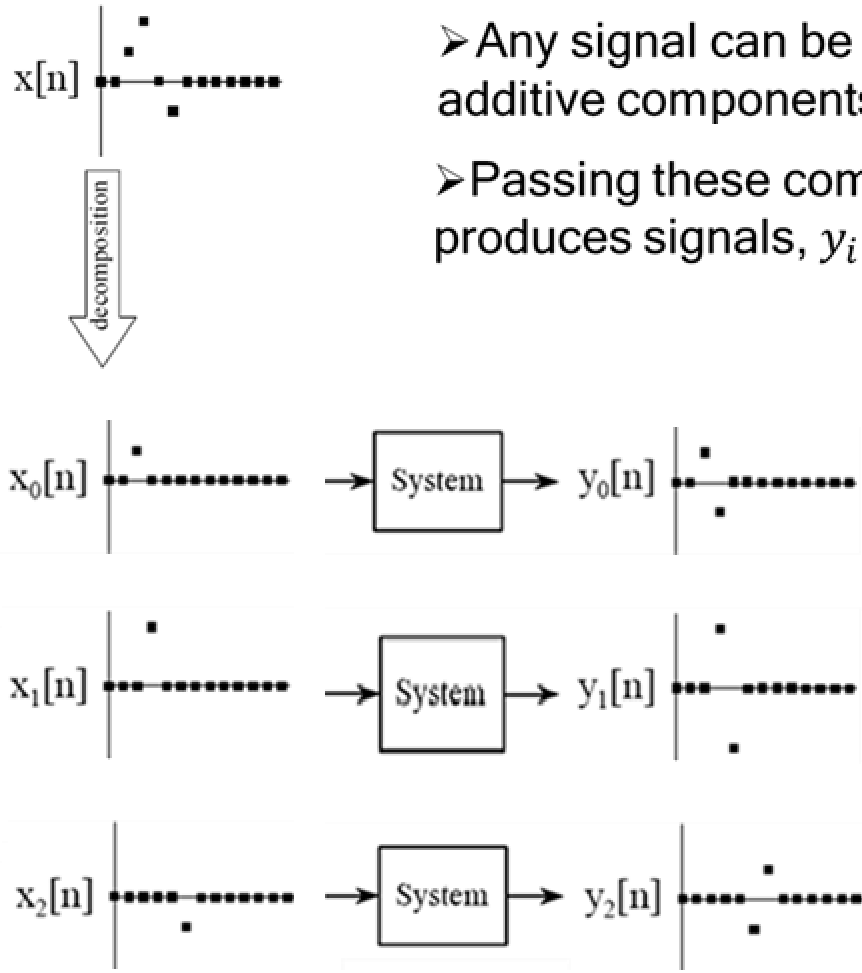




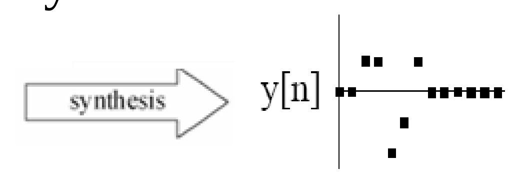
- **Synthesis**: in linear systems, signals can be combined by scaling and addition

- **Decomposition**: the inverse operation/

BASICS OF DSP (digital signal processing)
Fundamental concept of DSP



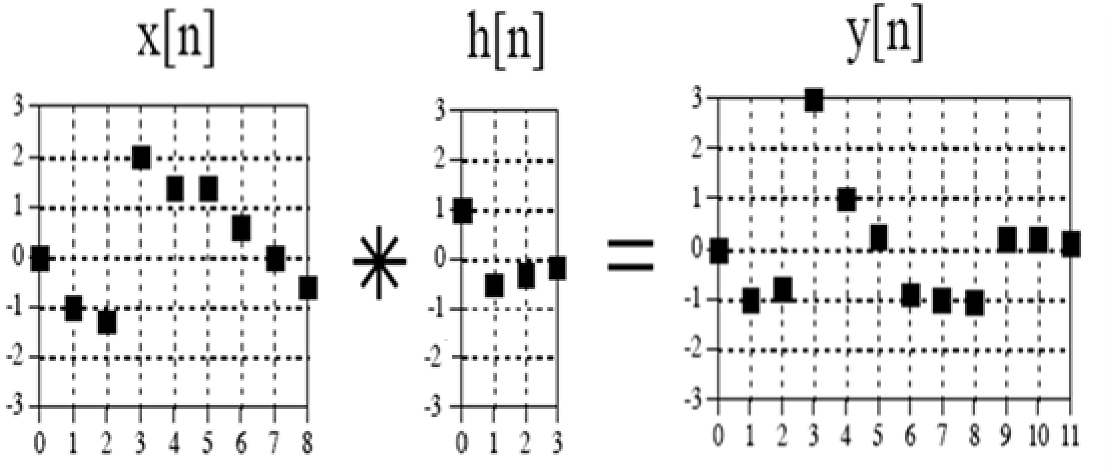
- Any signal can be **decomposed** into a group of additive components x_i
- Passing these components through a linear system produces signals, y_i
- The **synthesis** of these output signals produces the same signal as when *x* [*n*] is passed through the system



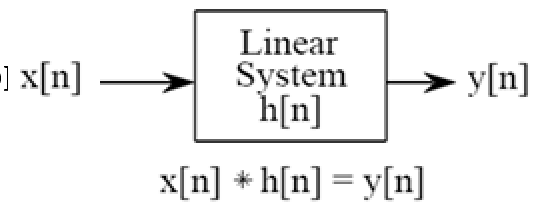
Omar ELOUTASSI o.eloutassi@umi.ac.ma

BASICS OF DSP DSP-Convolution

- combined two signals into a third one



- applies a linear system to a signal via it‘s impulse response, which fully describes the system behavio



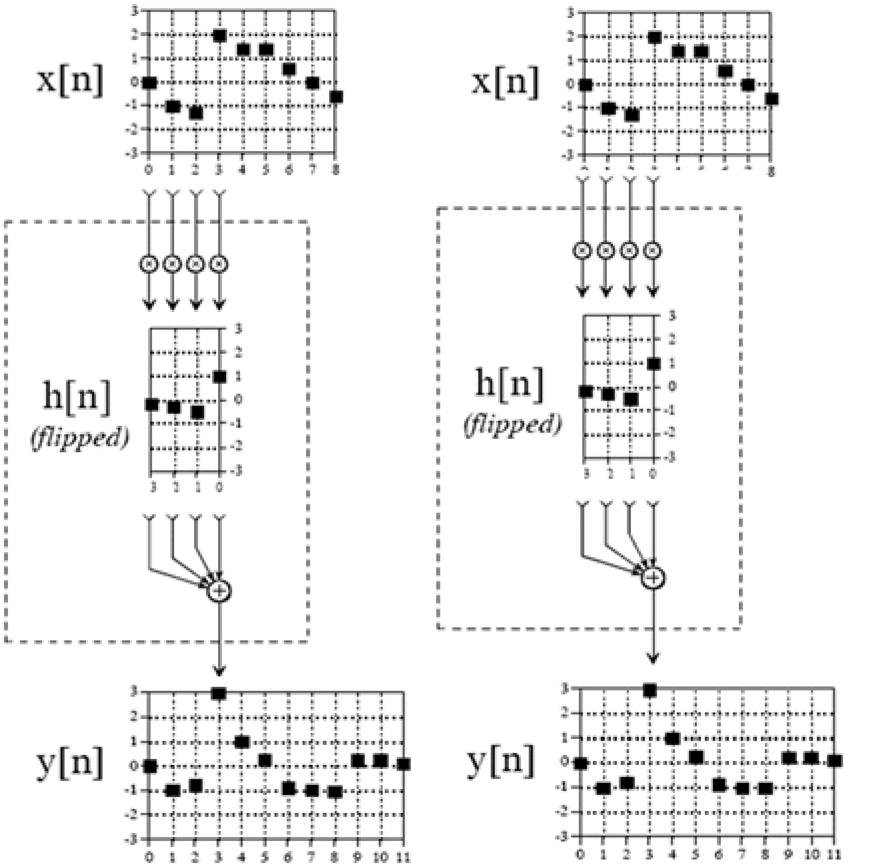
$$y[i] = x[i] * h[i] \Leftrightarrow y[i] = \sum_{j=0} h[j]x[i-j]$$

BASICS OF DSP DSP-Convolution

Application of a LTI:

➢multiplication of the input samples with the flipped impulse response

➢addition of the values gives result for the corresponding output sample

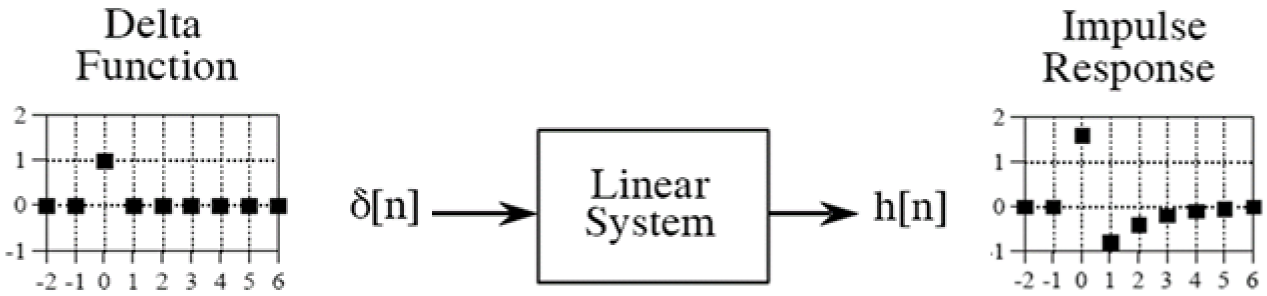


Set to calculate y[0]   Set to calculate y[3]

Note: Convolution in time domain = multiplication in frequency domain

BASICS OF DSP DSP-Convolution

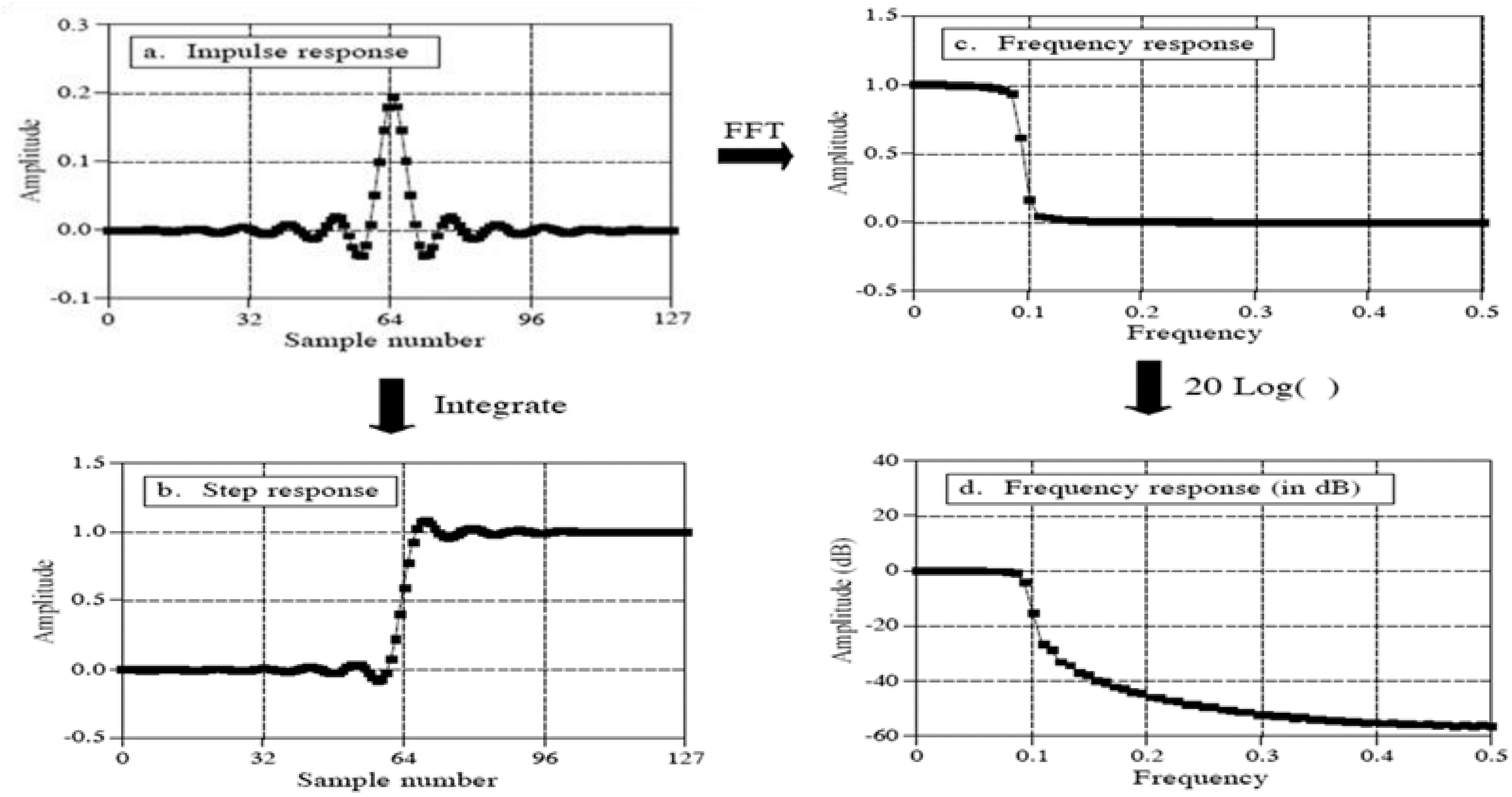
- many samples of the input signals contribute to one output sample



- the samples of the impulse response act as weighing coefficients

- feeding a delta function into a linear system gives the impulse response:

BASICS OF DSP-Relationships between impulse , step and frequency response:



BASICS OF DSP-Convolution and FIR Filters

The shape of the impulse response determines phase- and frequency response of an LTI system. The impulse response is also called “filter kernel“.

- Finite Impulse response filters can be implemented by a single convolution of an input signal with the filter kernel

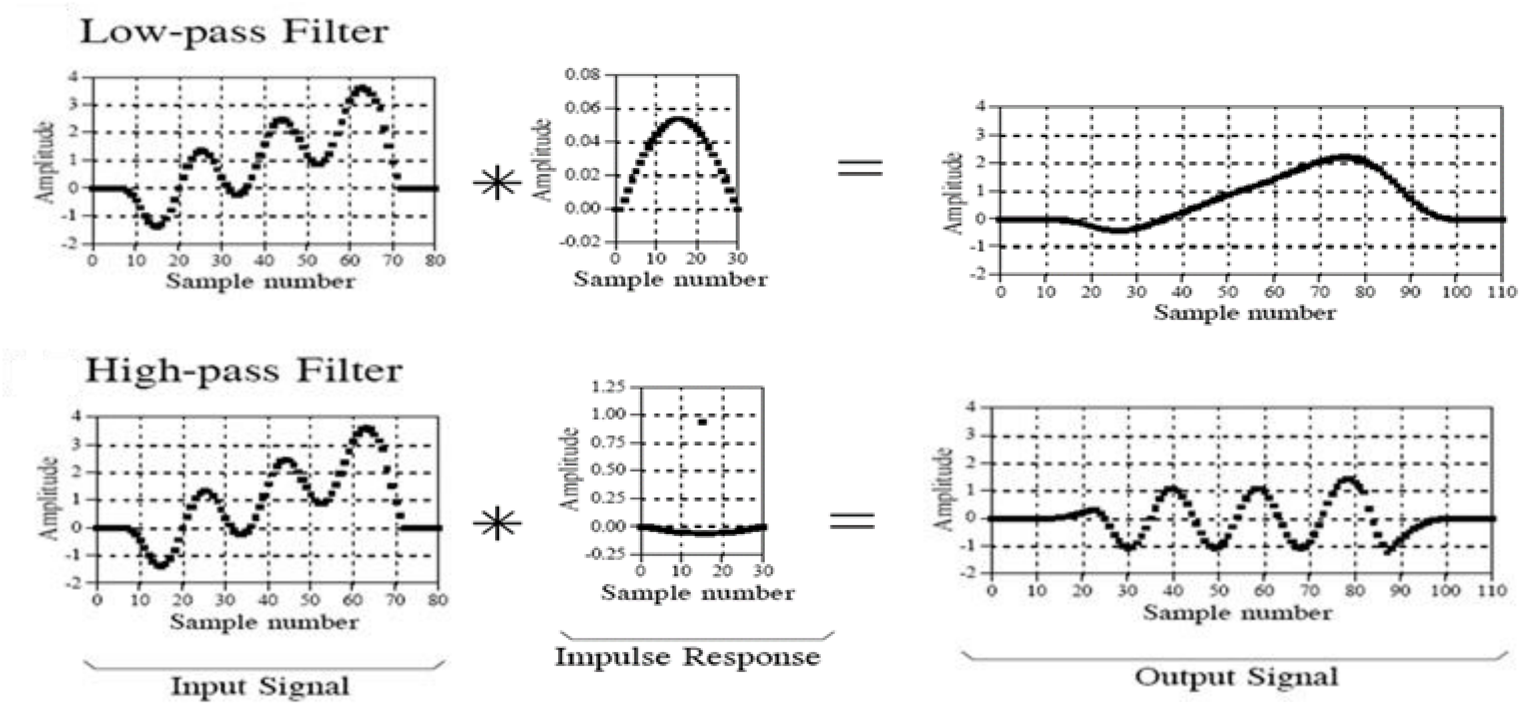
- Several positive values in the impulse response give an averaging (low-pass) filter

- Subtracting a low-pass filter kernel from the delta function gives a high pass filter kernel

- A symmetrical impulse response gives a linear phase response

BASICS OF DSP-Convolution and FIR Filters

➤ Example High and Lowpass Filter-Kernels:



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Dirac delta and impulse response

Impulse response

We often analyze a physical system by applying a short pulse as input and observing its response.

This response is known as the **impulse response**, which helps us understand how the system behaves with any given input.

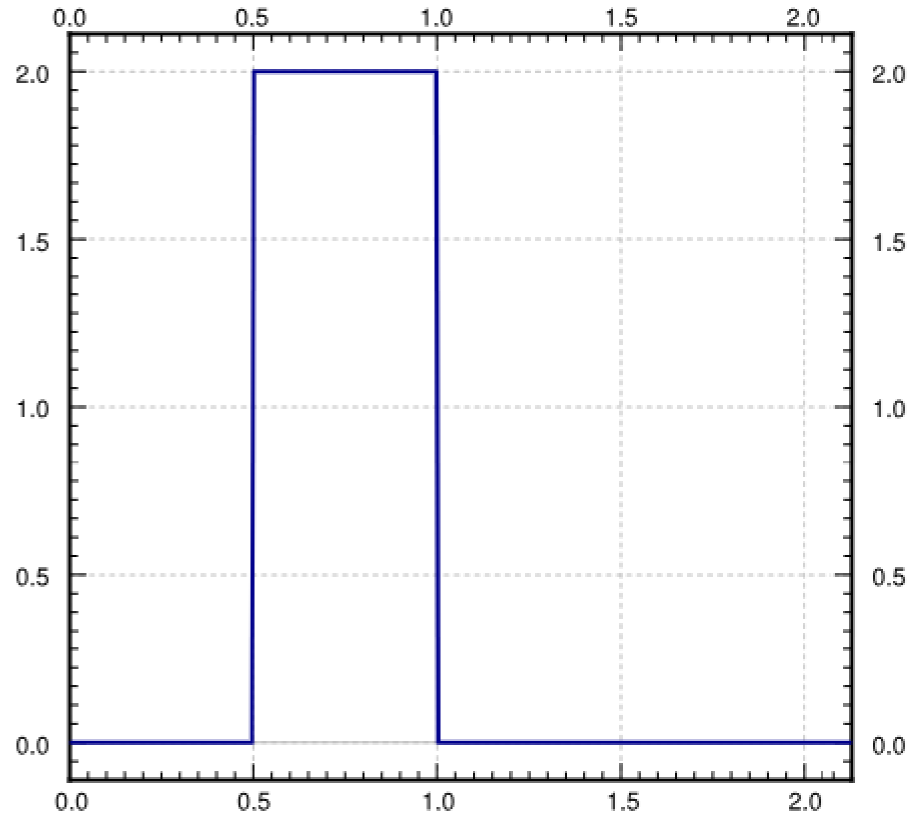
Impulse response

To define a pulse, the simplest example is a **rectangular pulse**, which is mathematically expressed as follows:

$$\varphi(t) = \begin{cases} 0 & \text{if} \quad t < a, \\ M & \text{if} \ a \le t < b, \\ 0 & \text{if} \ b \le t. \end{cases}$$

$$= M\big(u(t-a) - u(t-b)\big)$$

$u(t)$ is the unit step function.



Delta function

- The **Dirac delta function** is not a conventional function
- It is often referred to as a **generalized function**

- The key idea behind the delta function is to define a function $\delta(t)$ that satisfies the following property for any continuous function $f(t)$

$$\int_{-\infty}^{\infty} \delta(t) f(t)\, dt = f(0)$$

- Consequently we can accept δ(t) as an object that is possible to integrate

- To shift $\delta(t)$ to another point, for example $\delta(t-a)$ In continuous function $f(t)$

$$\int_{-\infty}^{\infty} \delta(t-a) f(t)\, dt = f(a)$$

Feeding a Delta function into a linear system

- When a **delta function** $\delta(t)$ is applied as an input to a **linear time-invariant (LTI) system**
- The system's output is called the **impulse response**, denoted as $h(t)$
- The impulse response characterizes the system completely and can be used to determine its response to any input

Feeding a Delta function into a linear system
Example: First-Order RC Circuit (Low-Pass Filter)

Consider a simple **RC circuit** (resistor R and capacitor C) as an LTI system.

The governing equation for the voltage across the capacitor is:

$$RC\frac{dV_c(t)}{dt} + V_c(t) = V_{in}(t)$$

- we apply an impulse function $\delta(t)$ as the input $V_{in}(t)$, the system's response is the **impulse response**:

$$h(t) = \frac{1}{RC}e^{-t/RC}u(t)$$

- where $u(t)$ is the **unit step function** ensuring causality.

Feeding a Delta function into a linear system

Interpretation

- The impulse response $h(t)$ describes how the system reacts to an instantaneous input at $t = 0$.

- For a general input signal $x(t)$, the system's output can be computed using **convolution**:

$$y(t) = x(t) * h(t) = \int_{-\infty}^{\infty} x(\tau)h(t-\tau)d\tau$$

- This example illustrates how feeding a **delta function** into a **linear system** gives the impulse response, which fully characterizes the system's behavior.

Watch this videot

END