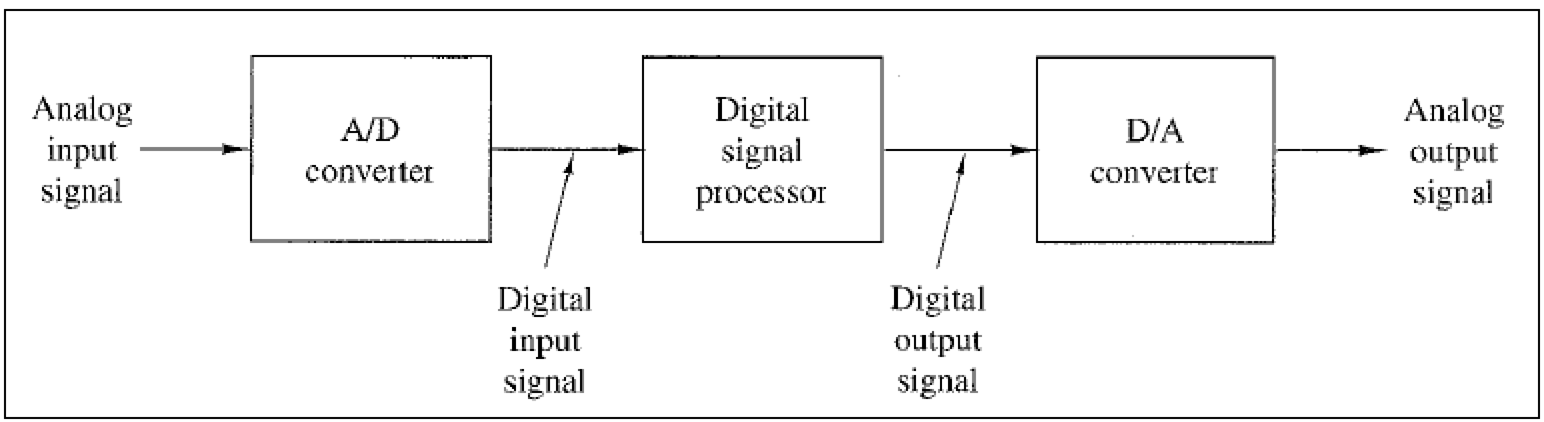
Overview

- What is DSP?
- Converting Analog into Digital
- Signals and signal processing
- Classification of signals
- Signal processing operations
- Advantages of DSP
- Some applications of DSP

What is DSP?

DSP process digital signals:

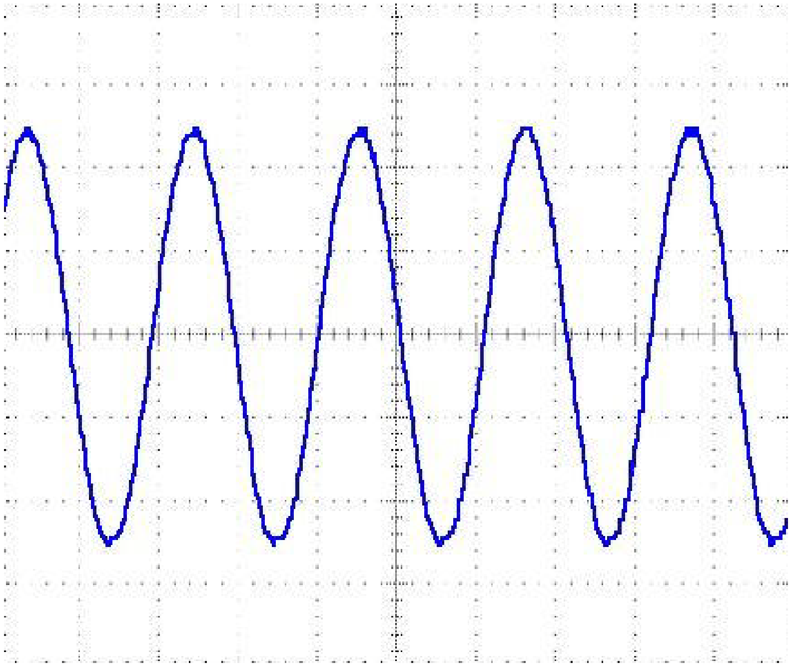
- Analog-to-Digital Converter (ADC)
  - Binary representation of the analog signal
- Digital-to-Analog Converter (DAC)
  - Digital representation of the signal is converted to continuous analog signal.

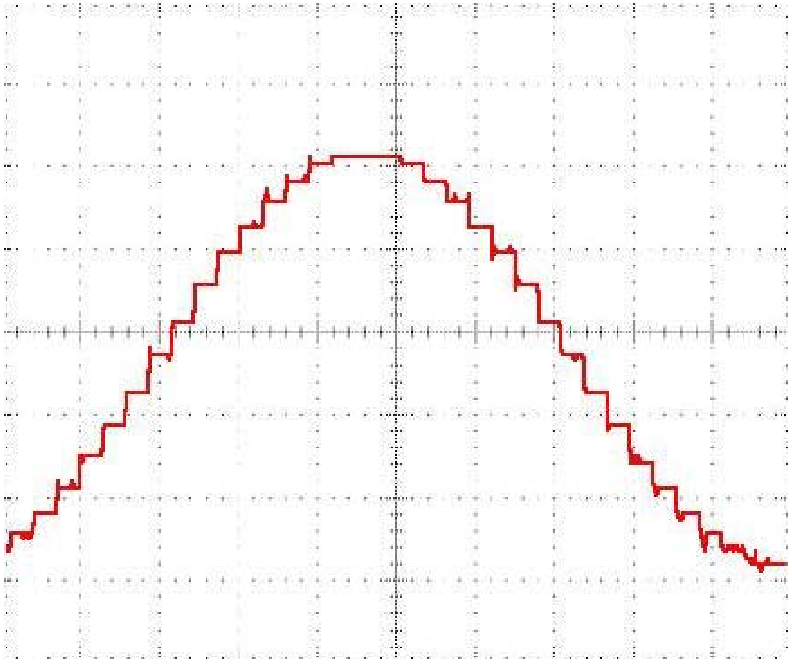


Human sense organs are analog. We are analog !!!

What is DSP?

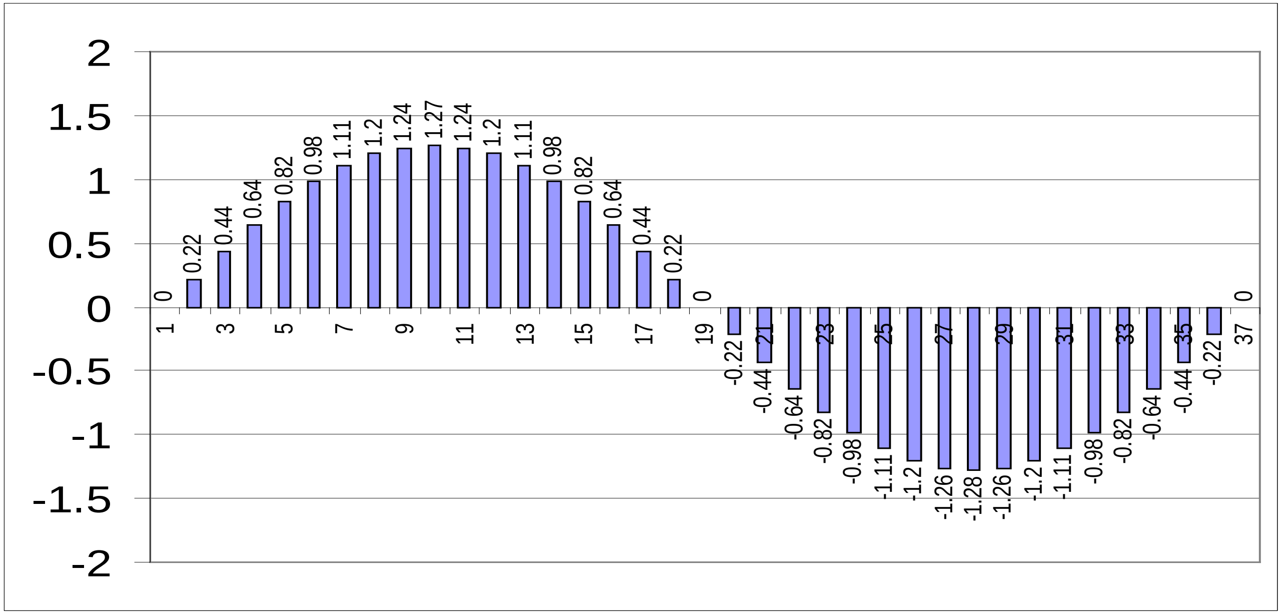
- Converting a continuously changing waveform (analog) into a series of discrete levels (digital)



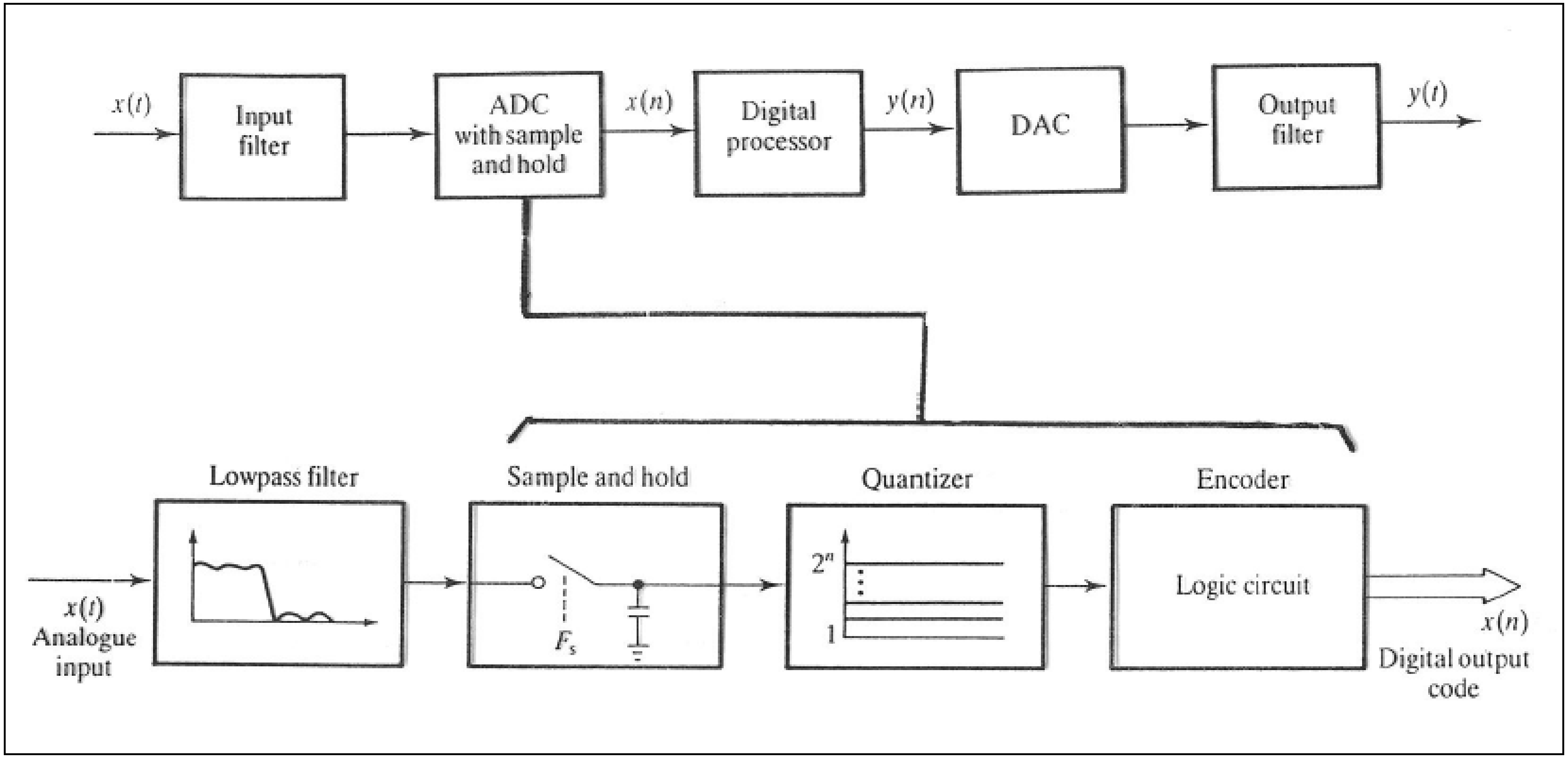


What is DSP?

- The analog waveform is sliced into equal segments and the waveform amplitude is measured in the middle of each segment
- The collection of measurements make up the digital representation of the waveform

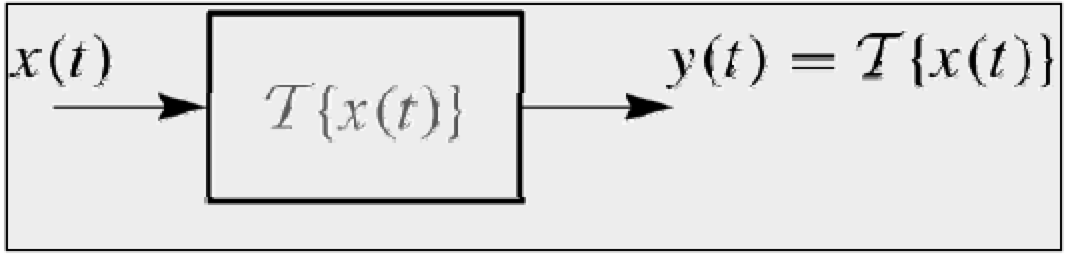


Analog to Digital Conversion details



Signal & Signal Processing

- Signal: quantity that carries information
- Signal Processing is to study how to represent, convert, interpret, and process a signal and the information contained in the signal
- DSP: signal processing in the digital domain

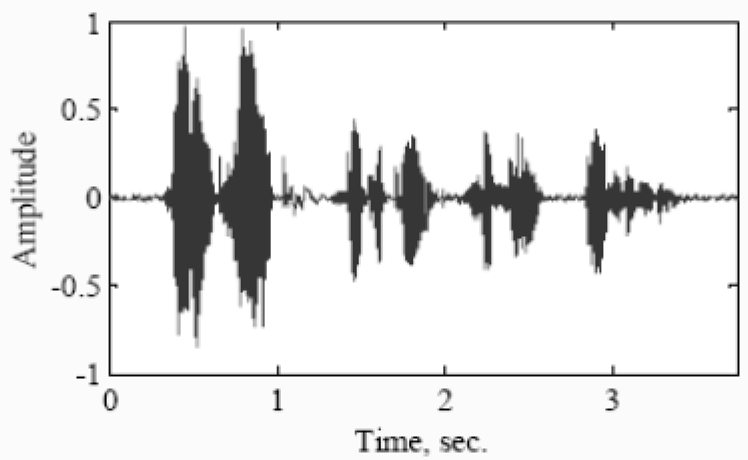


"Discrete-Time" Signals vs. "Digital" Signals

- Discrete-Time signal
  - A "sampled" version of a continuous signal
  - What should be the sampling frequency which is enough for perfectly reconstructing the original continuous signal?
    - Nyquist rate (Shannon sampling theorem)
- Digital Signal
  - Sampling + Quantization
  - Quantization: use a number of finite bits (e.g., 8 bits) to represent a sampled value

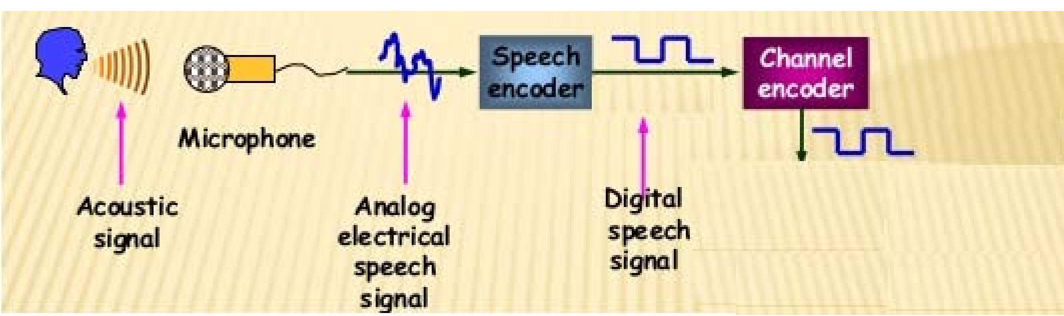
Examples of Typical Signals

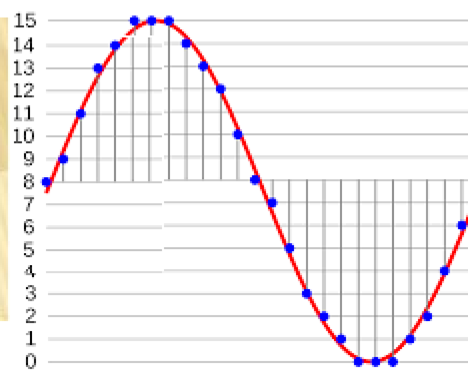
- **Speech and music signals -** Represent air pressure as a function of time at a point in space
- Waveform of the speech signal



Digital Speech Signals

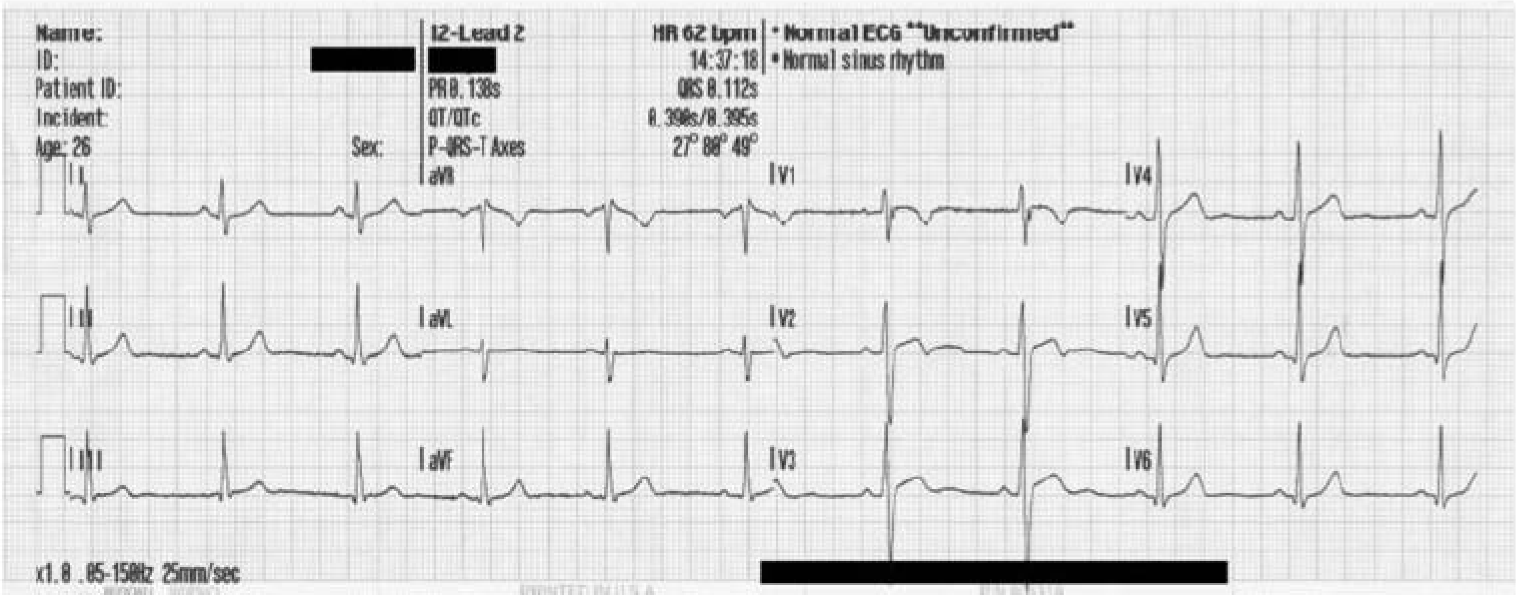
- Voice frequency range: 20Hz ~ 3.4 KHz
- Sampling rate: 8 KHz (8000 samples/sec)
- Quantization: 8 bits/sample
- Bit-rate: 8K samples/sec * 8 bits/sample = 64 Kbps (for uncompressed digital phone)
- In current Voice over IP (VOIP) technology, digital speech signals are usually compressed (compression ratio: 8~10)





Examples of Typical Signals

- **Electrocardiography (ECG) Signal -** Represents the electrical activity of heart



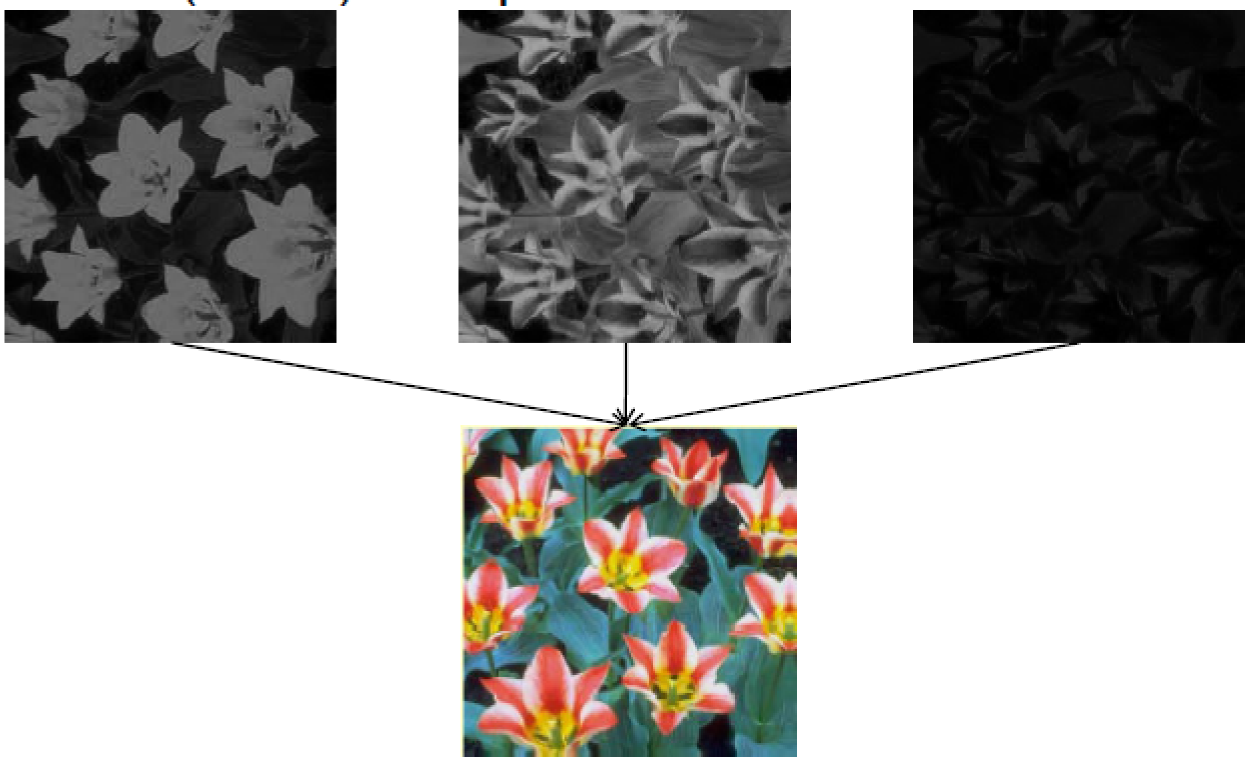
Examples of Typical Signals

- Black-and-white picture - Represents light intensity as a function of two spatial coordinates

$I(x, y)$

Examples of Typical Signals

- **Color Image –** Consists of Red, Green, and Blue (RGB) components



Digital Image

- An one mega-pixel image (1024x1024)
- Quantization: 24 bits/pixel for the RGB full-color space, and 12 bits/pixel for a reduced color space (YCbCr)
- Bit-rate: 1024x1024 samples/sec * 12 bits/pixel = 12 Mbits = 1.5 Mbytes (for uncompressed digital phone)
- How many uncompressed images can be stored in a 2G SD flash-memory card?

Example of Digital Image Processing

Original Image

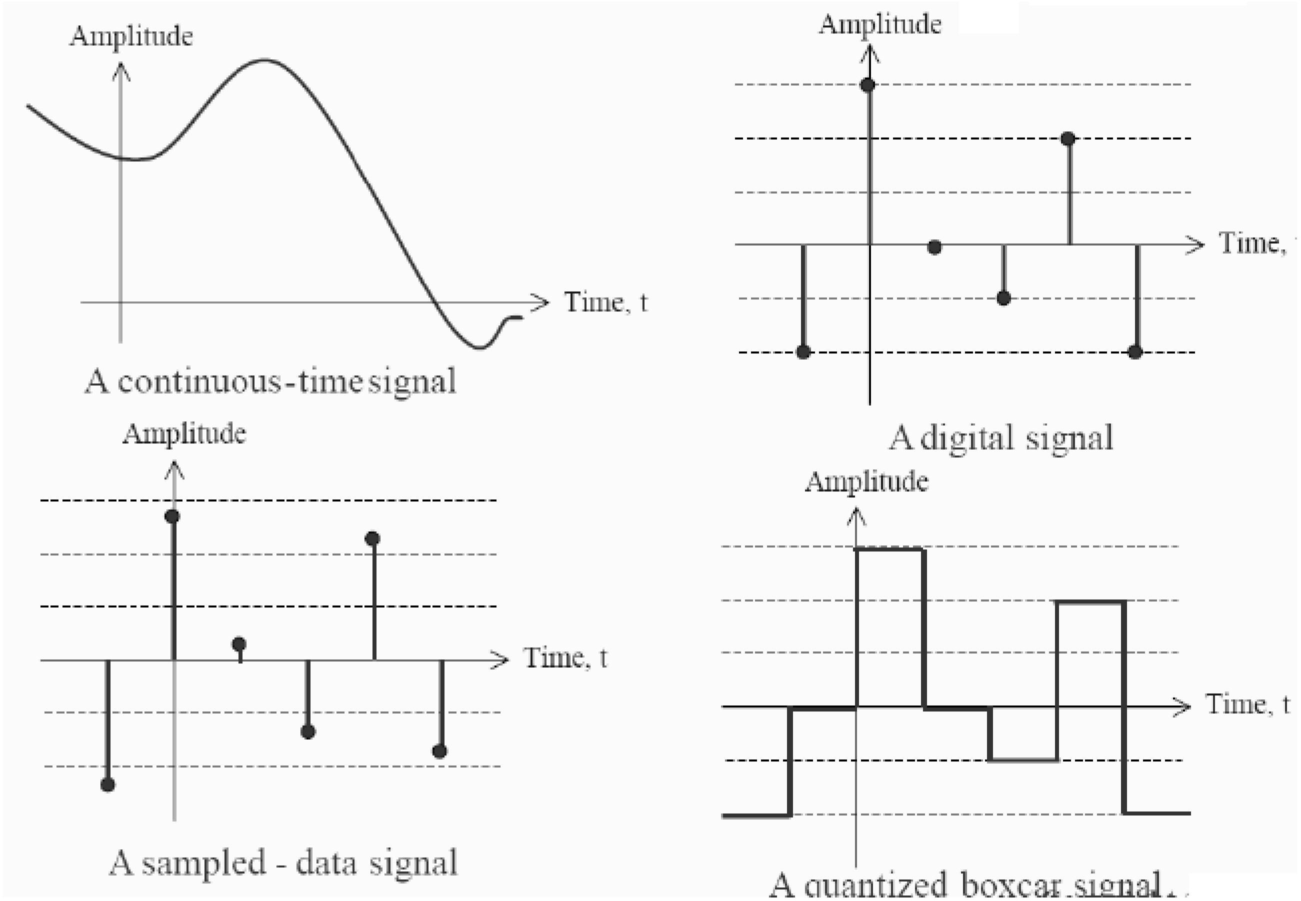
Edge Detection

Blurring

Classifications of Signals

- A **continuous-time signal** is defined at every instant of time
- A **discrete-time signal** is defined at discrete instants of time, and hence, it is a sequence of numbers
- A continuous-time signal with a continuous amplitude is usually called an **analog signal** (e.g., speech)
- A discrete-time signal with discrete-valued amplitudes represented by a finite number of digits is referred to as a **digital signal**
- A discrete-time signal with continuous-valued amplitudes is called a **sampled-data signal**
- A continuous-time signal with discrete-value amplitudes is usually called a **quantized boxcar signal**

Classification of Signals



Typical Signal Processing Operations

- Most signal processing operations in the case of analog signals are carried out in the time-domain
- In the case of discrete-time signals, both time-domain or frequency-domain operations are usually employed
- Continuous-time Fourier transform (CTFT) is used to transform a signal into the frequency domain

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

Elementary Time-Domain Operations

- Three most basic time-domain signal operations: scaling, delay, and addition
- Integration

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

- Differentiation

$$w(t) = \frac{dx(t)}{dt}$$

- More complex operations are implemented by combining two or more elementary operations

Filtering

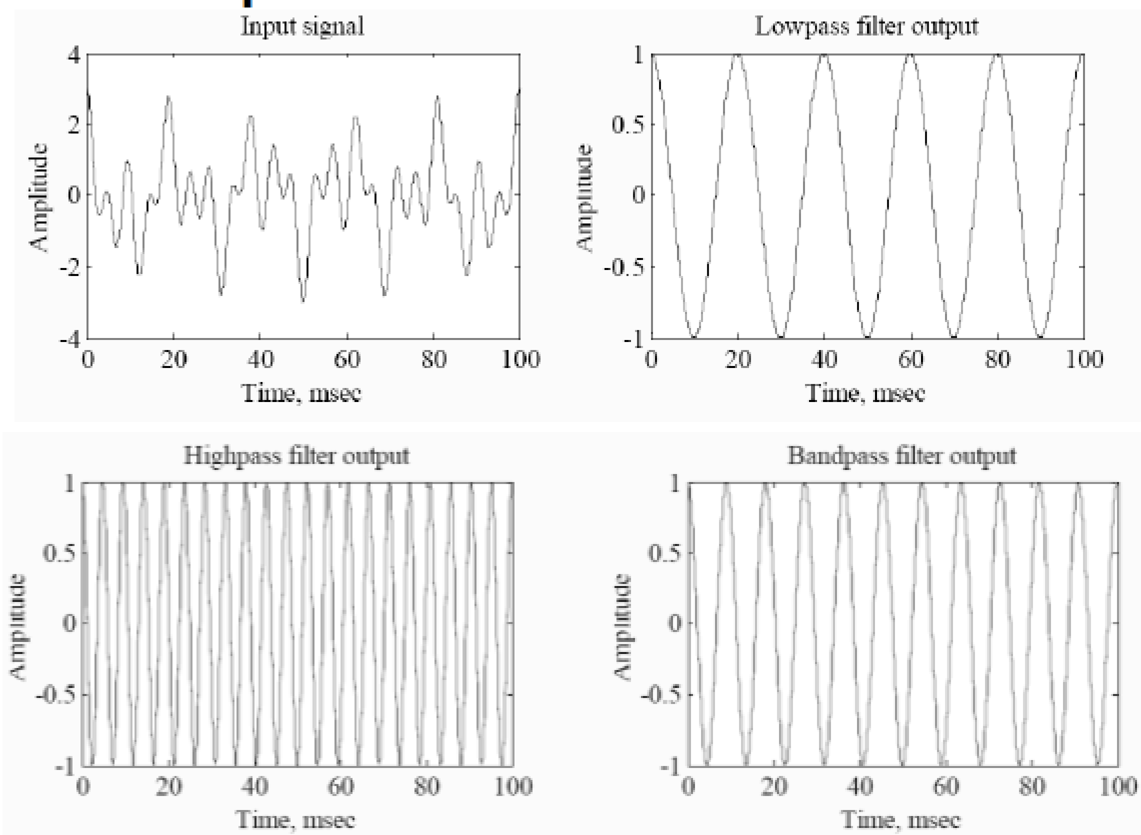
- Filtering is one of the most widely used complex signal processing operations
- A filter passes certain frequency components and blocks other frequency components
- Passband vs. stopband of a filter
- The filtering operation of a linear analog filter is described by the convolution integral

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

where $x(t)$ *is the input signal,* $y(t)$ *is the* output of the filter, and $h(t)$ *is the impulse* response of the filter

Filtering

- Frequency-selective filters can be classified into the following types according to their passbands and stopbands: **low-pass**, **high-pass**, **bandpass**, and **bandstop** filters



Modulation

- For efficient transmission of a low-frequency signal over a channel, it is necessary to transform the signal to a high-frequency signal by means of a modulation operation
- Four major types of modulation of analog signals:
  - Amplitude modulation
  - Frequency modulation
  - Phase modulation
  - Pulse amplitude modulation

Why DSP?

- Mathematical **abstractions** lead to generalization and discovery of new processing techniques Computer implementations are **flexible**

Advantages of DSP

- Absence of drift in the filter characteristics
  - Processing characteristics are fixed, e.g. by binary coefficients stored in memories
  - Independent of the external environment and of parameters such as temperature and device aging
- Improved quality level
  - Quality of processing limited only by economic considerations
  - Desired quality level achieved by increasing the number of bits in data/coefficient representation

Advantages of DSP

- Reproducibility
  - Component tolerances do not affect system performance with correct operation
  - No adjustments necessary during fabrication
  - No realignment needed over lifetime of equipment
- Ease adjustment of processor characteristics
  - Easy to develop and implement adaptive filters, programmable filters and complementary filters
- Time-sharing of processor (multiplexing & modularity)
- No loading effect
- Realization of certain characteristics not possible or difficult with analog implementations

Advantages of DSP

- More flexible.
- Often easier system upgrade.
- Data easily stored -memory.
- Better control over accuracy requirements.
- Reproducibility.
- Cheaper
- No drift with time and temperature

Limitations of DSP

- Limited Frequency Range of Operation
  - Frequency range technologically limited to values corresponding to maximum computing capacities (e.g., A/D converter) that can be developed and exploited
- Digital systems are active devices, thereby consuming more power and being less reliable
- Additional Complexity in the Processing of Analog Signals
  - A/D and D/A converters must be introduced adding complexity to overall system
- Inaccuracy due to finite precision arithmetic

Application Examples of DSP

- Cellular Phone
- Discrete Multitone Transmission (ADSL)
- Digital Camera
- Digital Sound Synthesis
- Signal Coding & Compression
- Signal Enhancement

•Telecommunications
•Consumer Electronics
•Medicine
•Speech process
•Seismology
•Military

Signal Compression Example

Original Lena Image
File Size = 256K bytes

Compressed Lena Image
File Size = 13K bytes

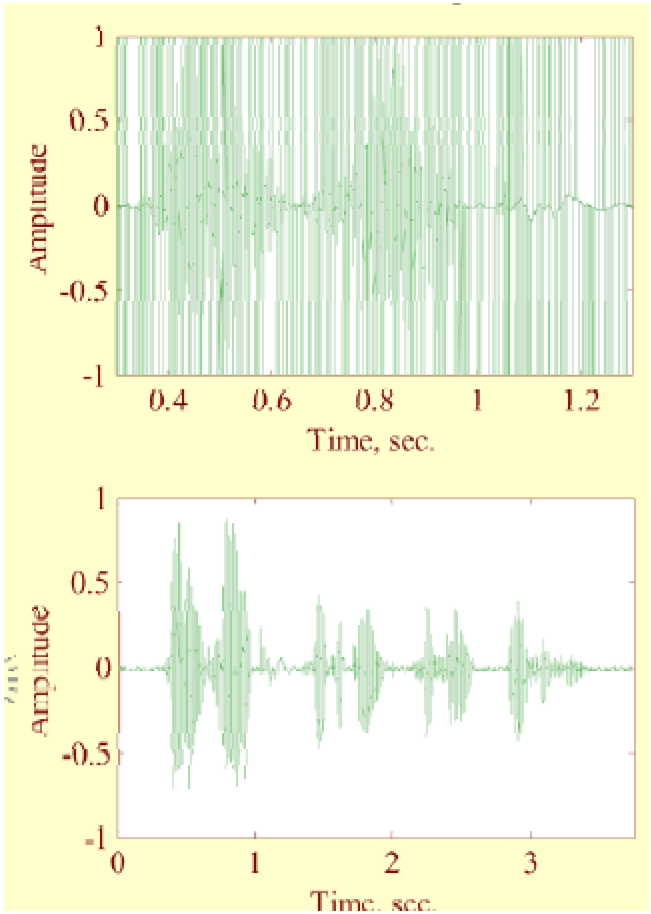
Applications: Signal Enhancement

- Purpose: To emphasize specific signal features to provide maximum quality to the listener or viewer
- For speech signals, algorithms include removal of background noise or interference
- For image or video signals, algorithms include contrast enhancement, sharpening and noise removal

Signal Enhancement Examples

- Noisy speech signal (10% impulse noise)

- Noise removed speech



Signal Enhancement Examples

- Noisy image & denoised image

20% pixels corrupted with additive impulse noise

Noise-removed version