Digital Signal Processing

Course Instructor
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Lecture No. 1

Third Class
Department of Computer and Software Engineering

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Course Overview

- **Signals and Systems.**
- **Classification of Discrete Digital Systems.**
- **Time and Frequency Domains Analysis.**
- **Signal Transformation Methods: Fourier, Wavelet and Z-transform.**
- **Digital Filter Types: FIR and IIR Filters.**
- **Digital Filter Design.**
- **Analog Filter Design.**
- **DSP Applications.**

Books

- J.G. Proakis and D.G. Manolakis, **Digital Signal Processing,** *4rd edition*, Prentice-Hall , 2006.

- R.G Lyons, **Understanding Digital Signal processing**, *3rd edition*, Prentice-Hall, (Amazon's top-selling for five straight year) ,2011.

- Monsons Hays, **Schaums Outline of Digital Signal processing**, *2nd edition* ,McGraw-Hill Companies, 2012.

- Richard, **The Essential Guide to Digital Signal Processing,** *1st edition* Prentice-Hall ,ePUB, 2014.

- J.G. Proakis , **Digital Signal Processing Using MATLAB,** *3rd edition*, Cengage Learning , 2012.

What is Digital Signal Processing?

Signal: It can be broadly defined as any physical quantity that varies as a time and/or space and has the ability to convey information, examples of these signals are:

- **Electrical signals**: currents and voltages in AC circuits, radio communications signals, video signals etc.
- **Mechanical signals**: sound or pressure waves, vibrations in a structure, earthquakes, etc.
- **Biomedical signals**: electro-encephalogram, lung and heart monitoring, X-ray and other types of images.
- **Finance**: time variations of a stock value or a market index.

Digital Signal: operating by the use of discrete signals to represent data in the form of numbers.

What is Digital Signal Processing?

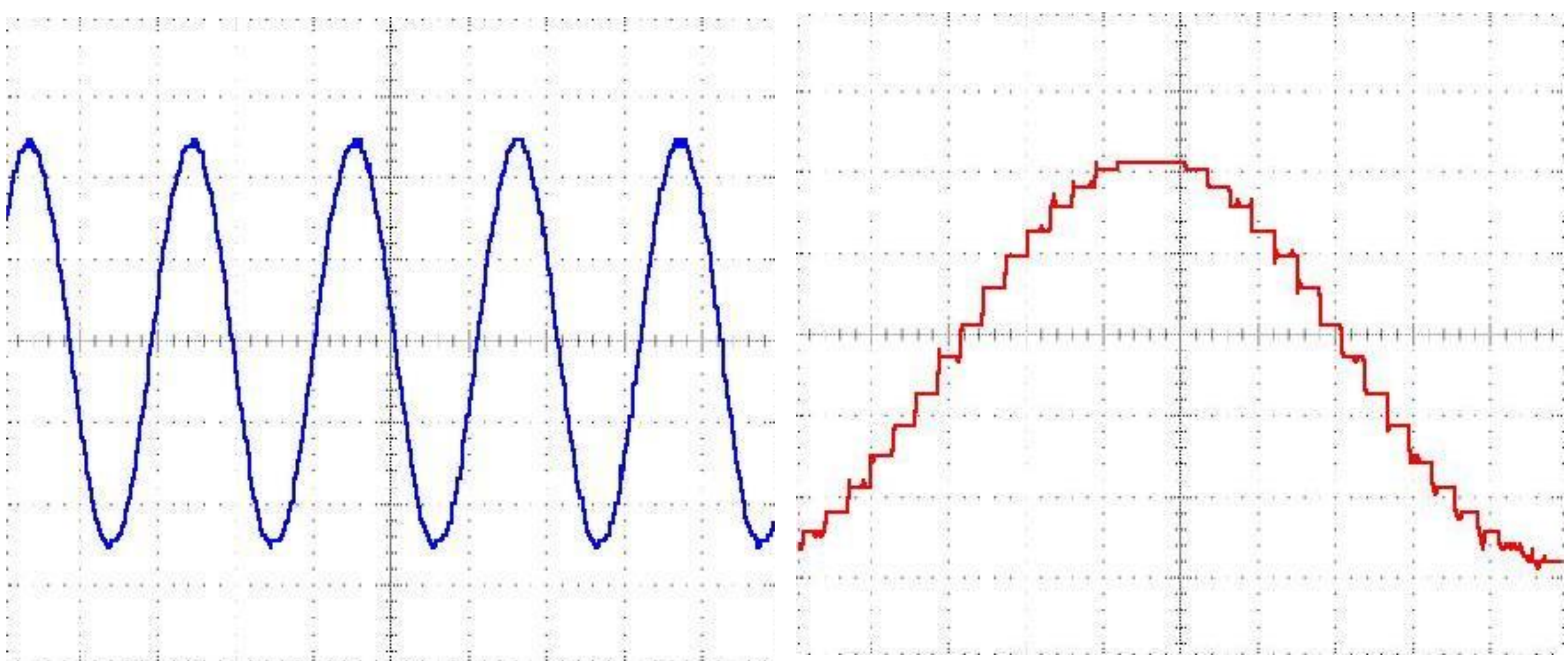
Processing: a series operations performed according to programmed instructions.

→ changing or analysing information which is measured as discrete sequences of numbers

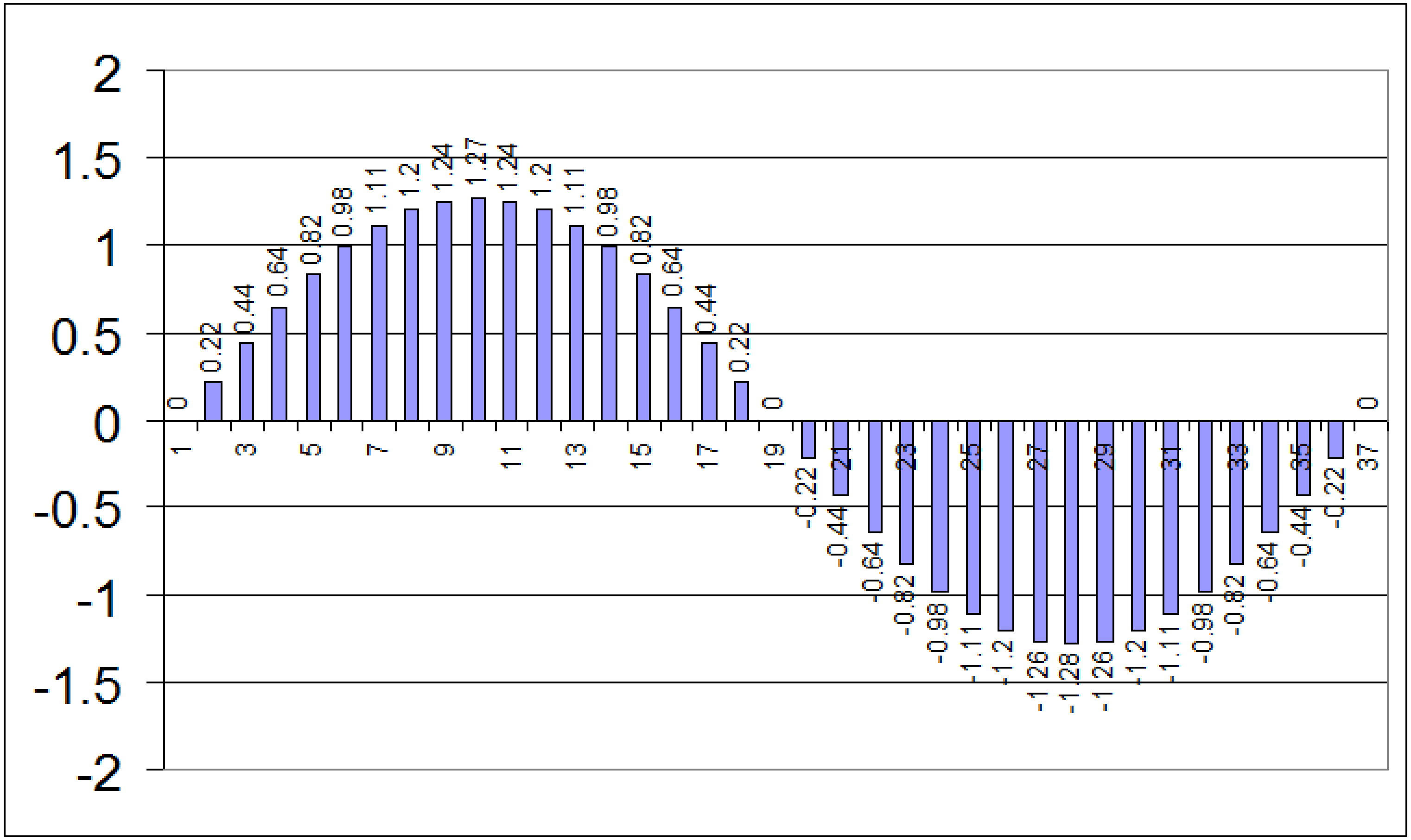
"*Learning digital signal processing is not something you accomplish; it's a journey you take*".

R.G Lyons, Understanding Digital Signal processing

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

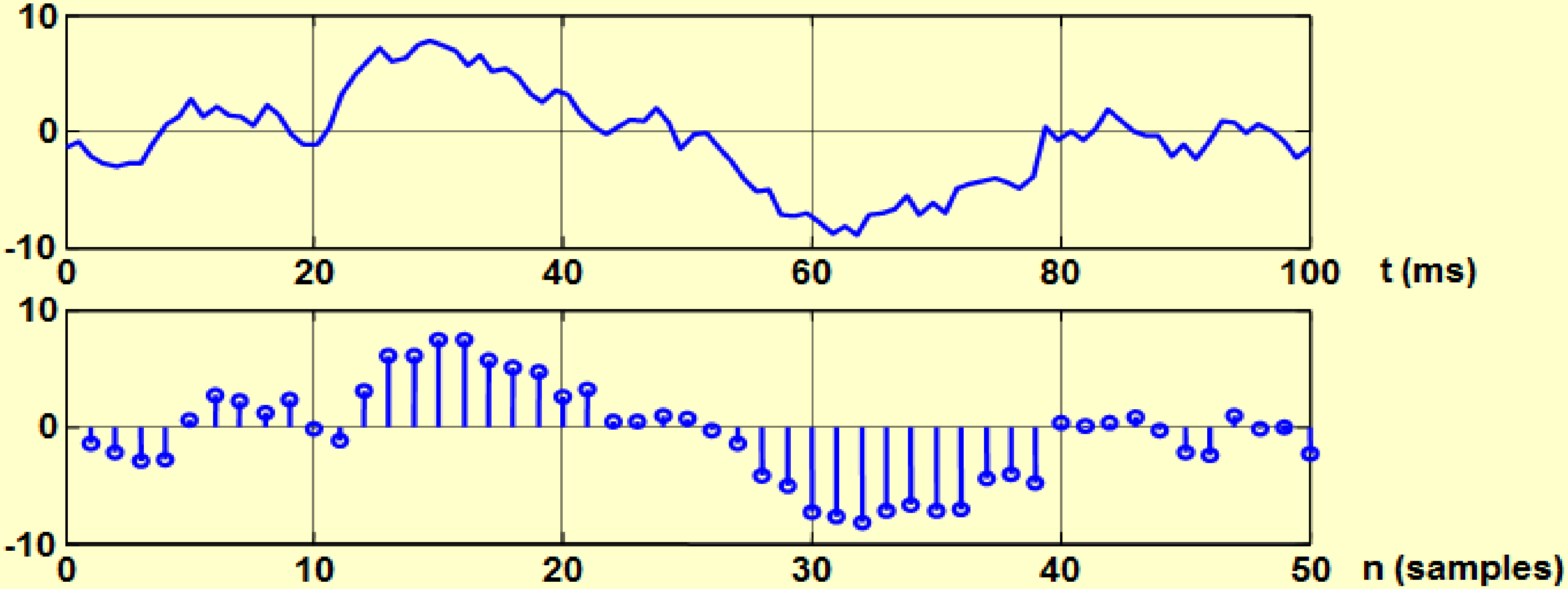


What is Digital Signal Processing?

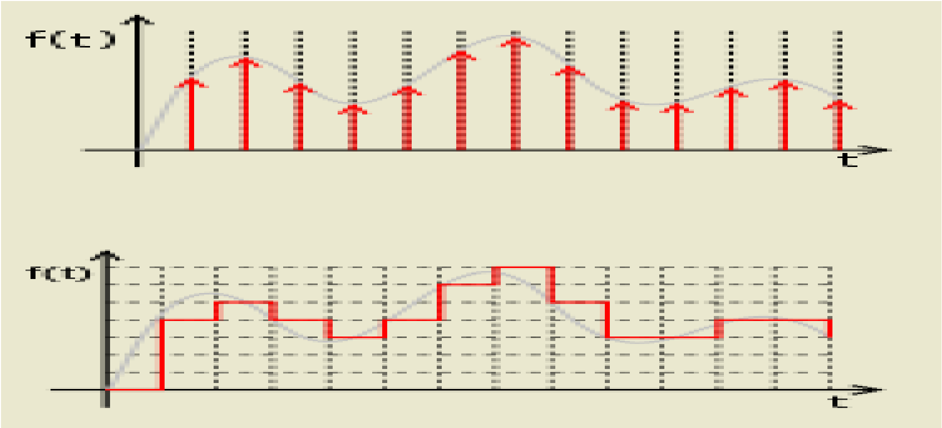


What is Digital Signal Processing?

- Discrete-time signals are represented by sequence of numbers
  - The n^{th} number in the sequence is represented with x[n]
- Often times sequences are obtained by sampling of continuous-time signals
  - In this case x[n] is value of the analog signal at $x_c(nT)$
  - Where T is the sampling period



What is Digital Signal Processing?



discrete signal is discrete in time but continuous in amplitude.

digital signal is discrete in both time and amplitude.

The Concepts of Signals and Systems

- The most convenient mathematical representation of a signal is via the concept of a function, say ***x*(*t*)**. In this notation:

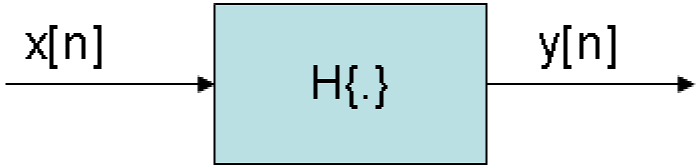
  x represents the dependent variable (e.g. voltage, pressure, etc.)

  t represents the independent variable (e.g. time, space, etc.).

- Depending on the nature of the independent and dependent variables, different types of signals can be identified such as:
  - ✓ Analog signals
  - ✓ Discrete signals
  - ✓ Digital signals
  - ✓ Multi-channel signals
  - ✓ Multi-dimensional signals

The Concepts of Signals and Systems

- **System**: A physical entity that operates on a set of primary signals (the inputs) to produce a corresponding set of resultant signals (the output).
- **The operations, or processing, may take several forms**: modification, combination, decomposition, filtering, extraction of parameters, etc.
- **System characterization**: a system can be represented mathematically as a transformation between two signal sets , as in $\boldsymbol{x[n]} \rightarrow \mathbf{y[n]}$:



The Concepts of Signals and Systems

- Depending on the nature of the signals on which the system operates, different basic types of systems may be identified:
  - Analog or continuous-time system: the input and output signals are analog in nature.
  - Discrete-time system: the input and output signals are discrete.
  - Digital system: the input and outputs are digital.
  - Mixed system: a system in which different types of signals (i.e.analog,discrete and/or digital) coexist.

The Concepts of Signals and Systems

Discussion:

- Early education in engineering focuses on the use of calculus to analyze various systems and processes at the analog level:
  - motivated by the prevalence of the analog signal model
  - e.g.: circuit analysis using differential equations
- Yet, due to extraordinary advances made in micro-electronics, the most common/powerful processing devices today are digital in nature.
- Thus, there is a strong, practical motivation to carry out the processing of analog real-world signals using such digital devices.
- This has lead to the development of an engineering discipline know as digital signal processing DSP.

Digital Signal Processing:

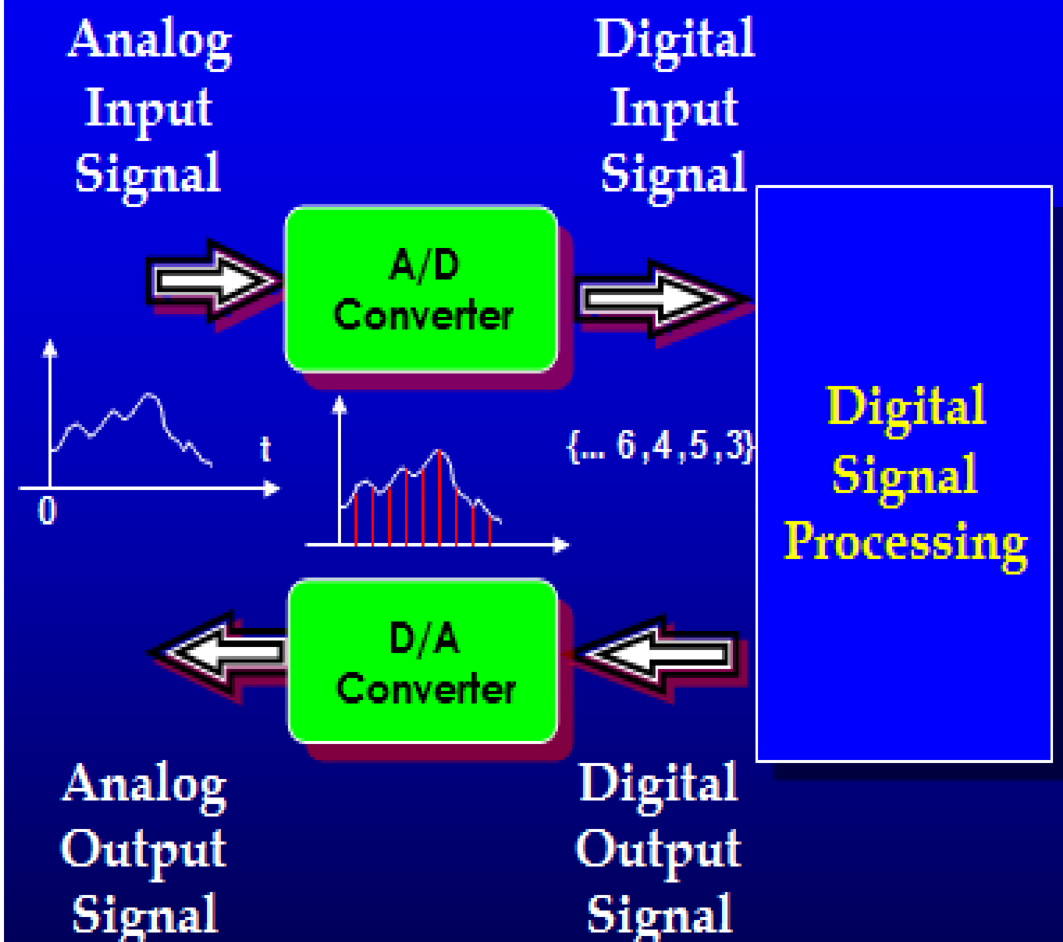
- In its most general form, DSP refers to the processing of analog signals by means of discrete-time operations implemented on digital hardware.

Basic components of a DSP System

- In its most general form, a DSP system will consist of three main components, as illustrated below:

- The analog-to-digital (A/D) converter transforms the analog signal $x_c(t)$ at the system input into a digital signal $x_d[n]$.
- The digital system performs the desired operations on the digital signal $x_d\ [n]$ and produces a corresponding output $y_d\ [n]$ also in digital form.
- The digital-to-analog (D/A) converter transforms the digital output $y_d\ [n]$ into an analog signal $y_c\ (t)$ suitable for interfacing with the outside world.

Basic components of a DSP System



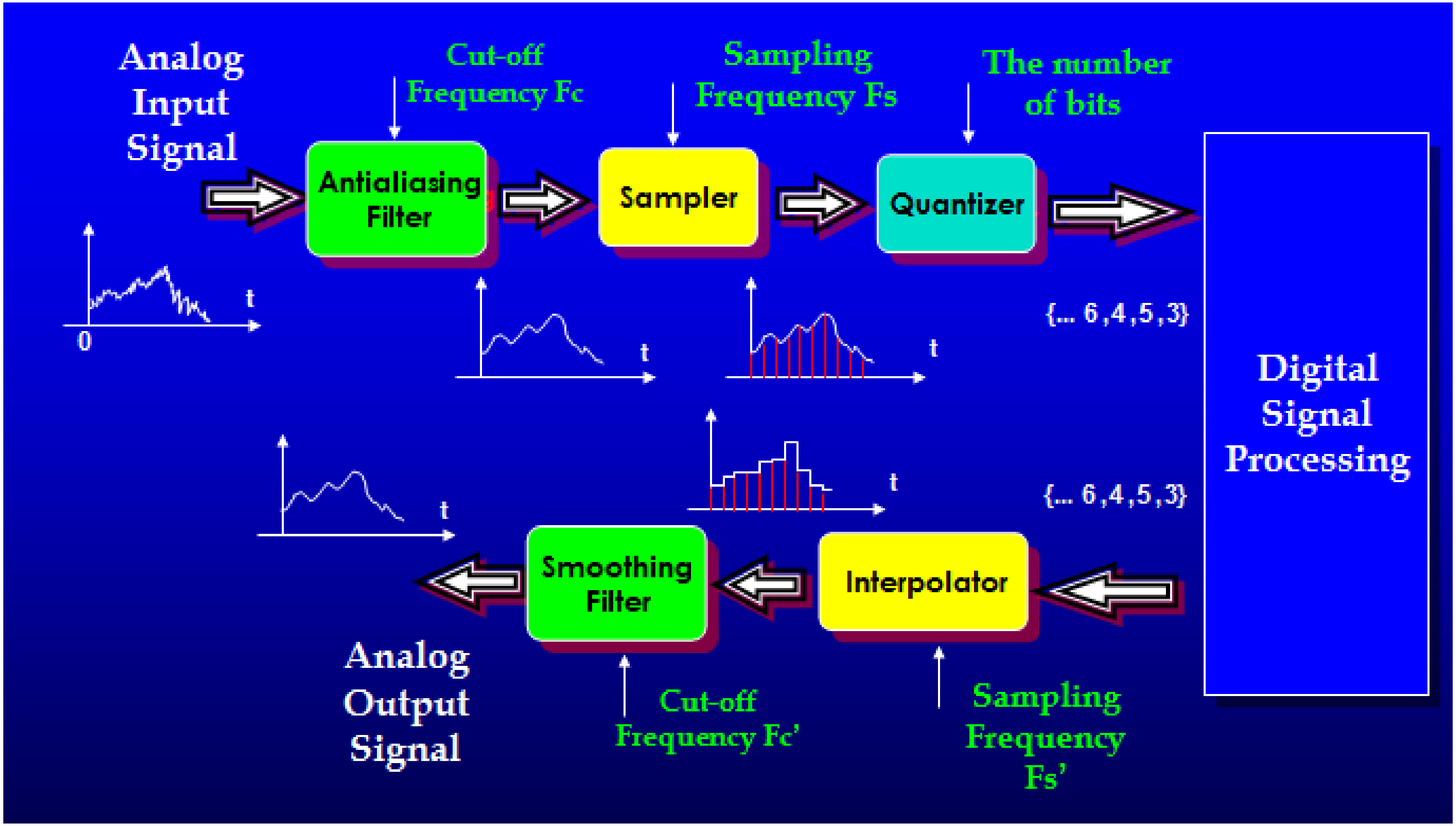
A/D Converter

Converts an analog signal into a sequence of digits

D/A Converter

Converts a sequence of digits into an analog signal

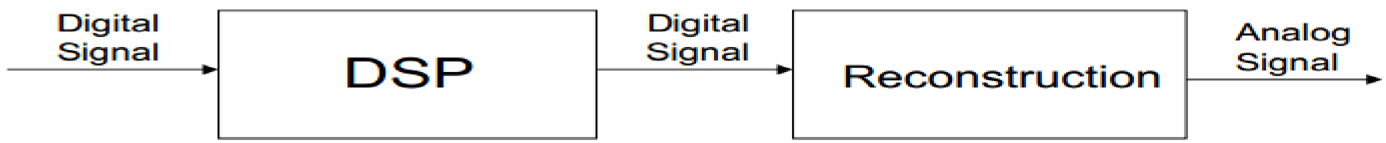
Basic components of a DSP System



DSP Implementation –Analog/Digital Conversion

To implement DSP we must be able to:

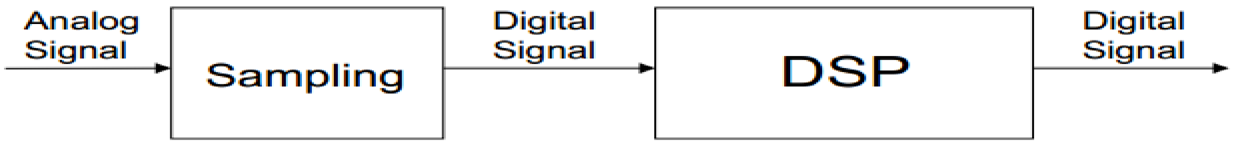
(1) perform numerical operations including, for example, additions, multiplications, data transfers and logical operations either using computer or special-purpose hardware.



(2) convert the digital information, after being processed back to an analog signal – involves digital-to- analog conversion and reconstruction .
e.g. text-to-speech signal (characters are used to generate artificial sound)

DSP Implementation –Analog/Digital Conversion

To implement DSP we must be able to:



3) convert analog signals into the digital information - sampling & involves analog-to-digital conversion.

e.g. Touch-Tone system of telephone dialling (when button is pushed two sinusoid signals are generated (tones) and transmitted, a digital system determines the frequencies and uniquely identifies the button – digital (1 to 12) output

perform both A/D and D/A conversions

e.g. digital recording and playback of music (signal is sensed by microphones, amplified, converted to digital, processed, and converted back to analog to be played.

DSP Chips : Special Purpose Hardware

Introduction of the microprocessor in the late 1970's and early 1980's meant DSP techniques could be used in a much wider range of applications.

DSP chip – a *programmable* device, with its own native instruction code

designed specifically to meet numerically-intensive requirements of DSP

capable of carrying out millions of floating point operations per second

Bluetooth headset

Household appliances

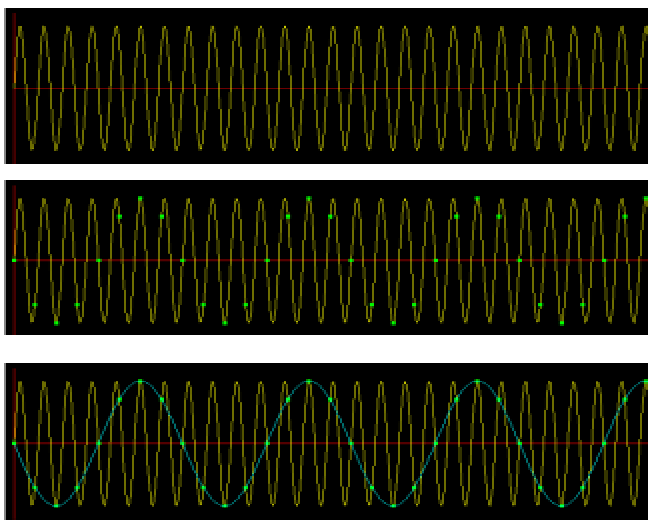
Home theatre system

Limitations of DSP-Aliasing

Most signals are analog in nature, and have to be sampled.

loss of information

we only take samples of the signals at intervals and don’t know what happens in between



Gjendemsjø, A. Aliasing Applet, Connexions, http://cnx.org/content/m11448/1.14

aliasing

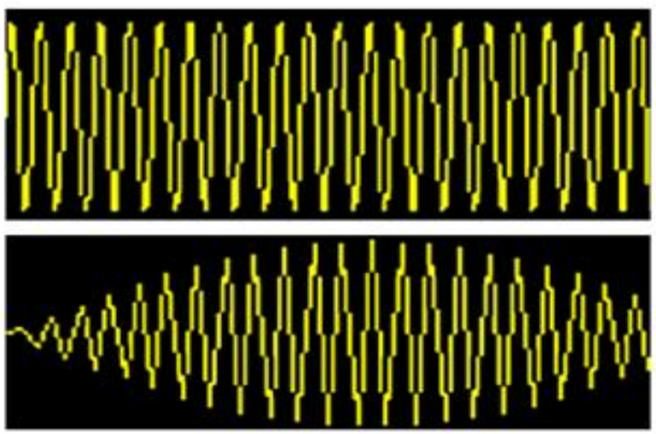
cannot distinguish between higher and lower frequencies

(recall from 1B Signal and Data Analysis)

Sampling theorem: to avoid aliasing, sampling rate must be at least twice the maximum frequency component (`bandwidth’) of the signal

Limitations of DSP - Antialiasing Filter

- Sampling theorem says there is enough information to reconstruct the signal, which does not mean sampled signal looks like original one



Each sample is taken at a slightly earlier part of a cycle

➡ correct reconstruction is not just connecting samples with straight lines

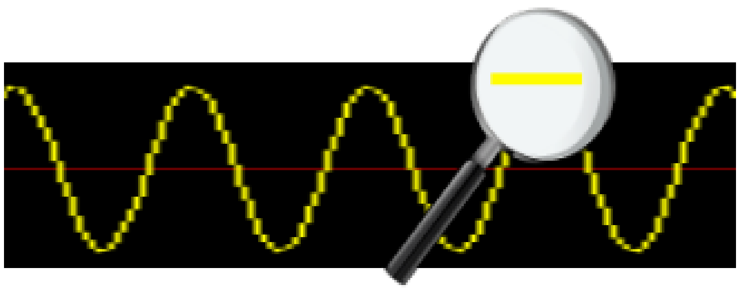
needs antialias filter (to filter out all high frequency components before sampling) and the same for reconstruction – it does remove information though

Limitations of DSP – Frequency Resolution

Most signals are analog in nature, and have to be sampled

→ loss of information

- we only take samples for a limited period of time



→ **limited frequency resolution**

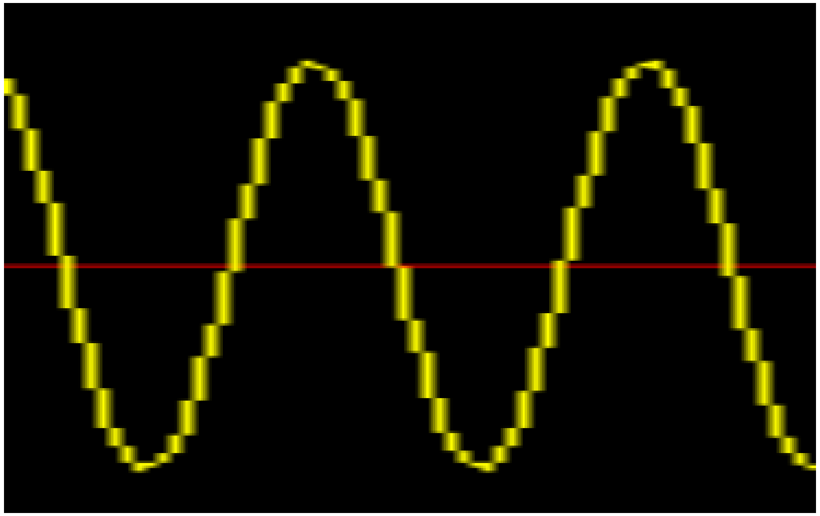
does not pick up “relatively” slow changes

Limitations of DSP – Quantization Error

Most signals are analog in nature, and have to be sampled

➡ loss of information

- limited (by the number of bits available) precision in data storage and arithmetic



➡ **quantisation error**

smoothly varying signal represented by "stepped" waveform

Why still do it?

- Digital system can be simply reprogrammed for other applications / ported to different hardware / duplicated (Reconfiguring analog system means hardware redesign, testing, verification)
- DSP provides better control of accuracy requirements (Analog system depends on strict components tolerance, response may drift with temperature)
- Digital signals can be easily stored without deterioration (Analog signals are not easily transportable and often can't be processed off-line)
- More sophisticated signal processing algorithms can be implemented

(Difficult to perform precise mathematical operations in analog form)

Advantages of Digital over Analog Signal Processing

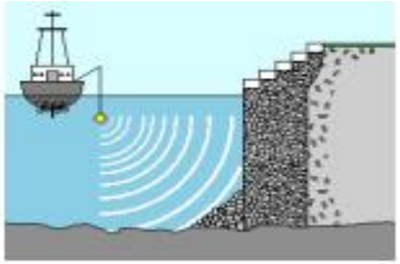
Advantages:

- Robustness:
- Signal levels can be regenerated.
- Precision not affected by external factors
- Storage capability:
- DSP system can be interfaced to low-cost devices for lasting storage
- allows for off-line computations
- Flexibility:
- Easy control of system accuracy via changes in sampling rate and number of representation bits.
- Software programmable → reconfiguring the DSP operations simply by changing the program.
- Structure:
- Easy interconnection of DSP blocks (no loading problem)
- Possibility of sharing a processor between several tasks

Disadvantages:

- Cost/complexity added by A/D and D/A conversion.
- Input signal bandwidth is technology limited.
- Quantization effects.

Applications of DSP-Radar

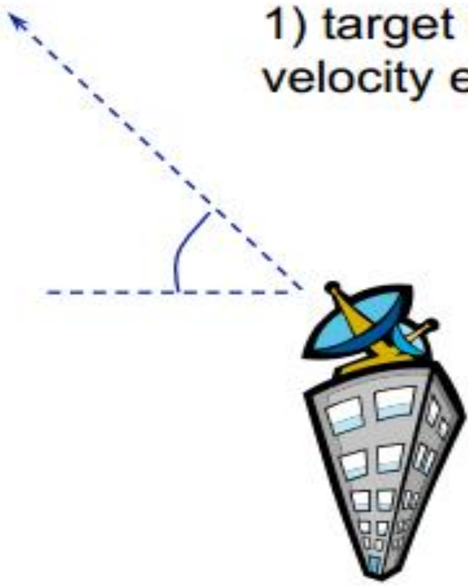


Radar and Sonar:

Examples

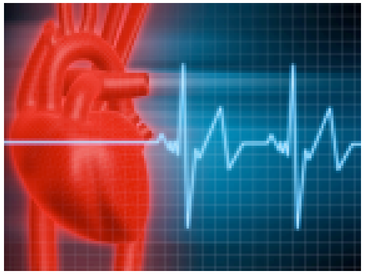
1) target detection – position and velocity estimation

2) tracking



Applications of DSP: Biomedical

Biomedical: analysis of biomedical signals, diagnosis, patient monitoring, preventive health care, artificial organs



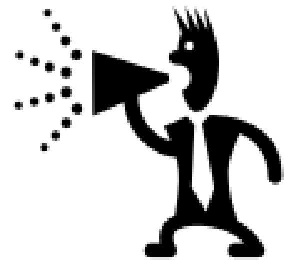
Examples:

1) electrocardiogram (ECG) signal – provides doctor with information about the condition of the patient's heart

2) electroencephalogram (EEG) signal – provides Information about the activity of the brain

Applications of DSP: Speech

Speech applications:

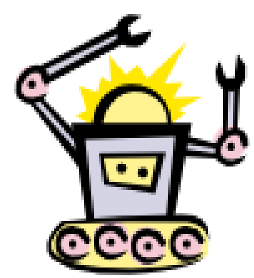


Examples

1) noise reduction – reducing background noise in the sequence produced by a sensing device (microphone)

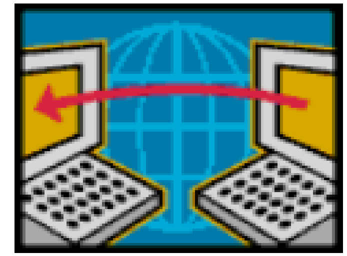
2) speech recognition – differentiating between various speech sounds

3) synthesis of artificial speech – text to speech systems for blind



Applications of DSP: Communications

Communications:



Examples

1) telephony – transmission of information in digital form via telephone lines, modem technology, mobile phones

2) encoding and decoding of the information sent over a physical channel (to optimise transmission or to detect or correct errors in transmission)

Applications of DSP: Image Processing

Image Processing:

Examples

1) content based image retrieval – browsing, searching and retrieving images from database

2) image enhancement

2) compression - reducing the redundancy in the image data to optimise transmission / storage

Applications of DSP: Music

Music Applications:

Examples:

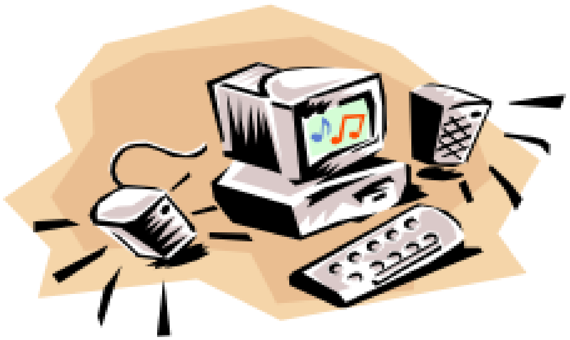
1) Recording

2) Playback

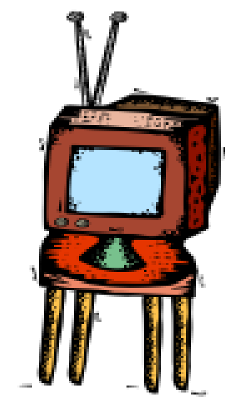
3) Manipulation (mixing, special effects)

Applications of DSP: Multimedia

Multimedia:



generation storage and transmission of sound, still images, motion pictures



Examples:

1) digital TV

2) video conferencing

Applications of DSP

DSP

SPACE
- Space photograph enhancement
- Data compression
- Intelligent sensory analysis

MEDICAL
- Diagnostic imaging (MRI, CT)
- Electrocardiogram Analysis
- Medical image storage and retrieval

COMMERCIAL
- Image and sound compression for multimedia presentation.
- Movie special effects
- Video conference calling

TELEPHONE
- Video and data compression
- echo reduction
- signal multiplexing
- filtering

MILITARY
- Radar
- Sonar
- Ordnance Guidance
- Secure communication

INDUSTRIAL
- Oil and mineral prospecting
- Process monitoring and control
- Non-destructive testing
- CAD and design tools

SCIENTIFIC
- Earth quick recording and analysis
- Data acquisition
- Spectral Analysis
- Simulation and Modeling