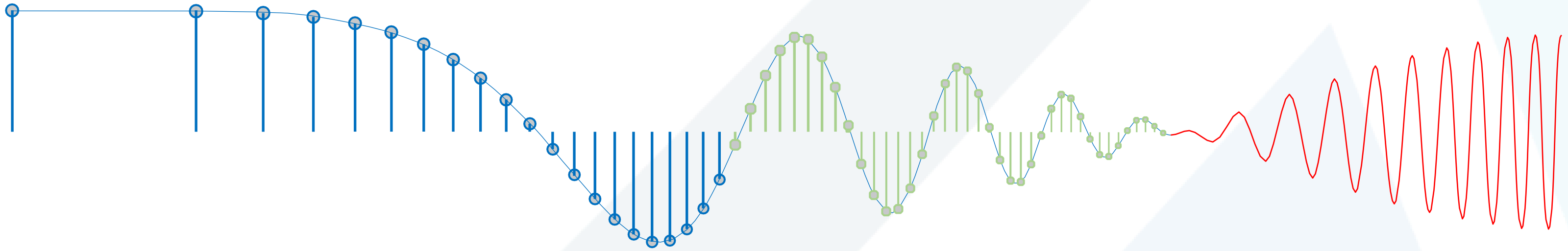
CEDC606: Digital Signal Processing

Lecture Notes 1: Introduction



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Chapter 1
Introduction

1. Signals
2. Systems
3. Analog, digital, and mixed signal processing
4. Applications of digital signal processing

Introduction

- Signal processing emerged soon after World War I in the form of electrical filtering.
- With the invention of the digital computer and the rapid advances in VLSI technology during the 1960s, a new way of processing signals emerged: **digital signal processing**.

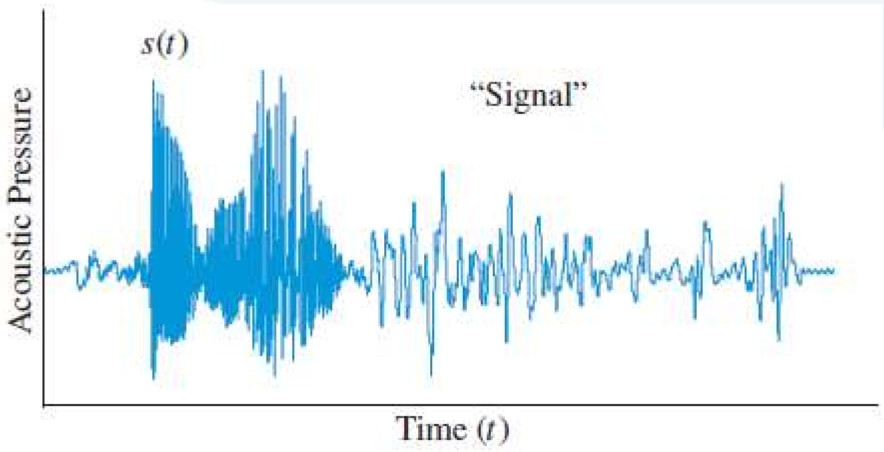
1. Signals

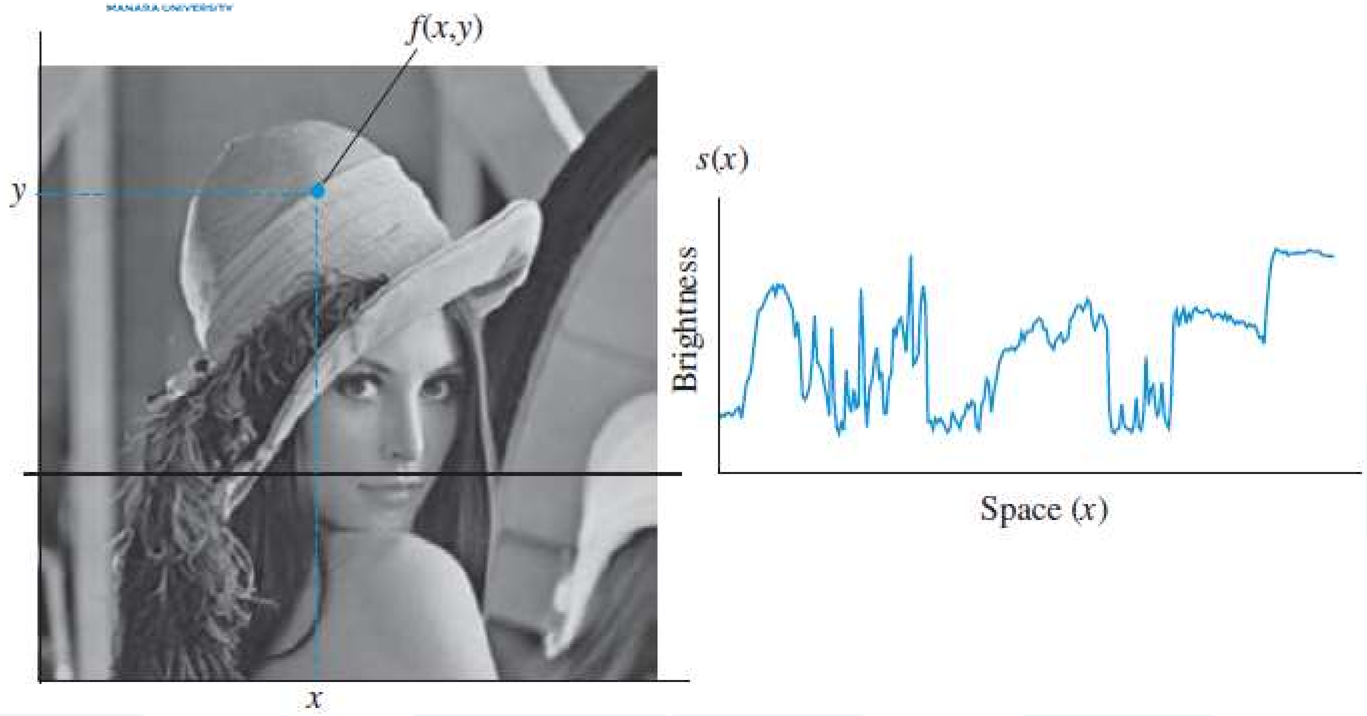
- A signal is defined as any physical quantity that varies as a function of time, space, or any other variable(s).
- Signal conveys information about the state or behavior of a physical system.
- Some of the signals are natural, but most of the signals are man-made.

- Natural signals are found, for example, in:
  - Acoustics, e.g., speech signals, sounds made by dolphins and whales.
  - Astronomy, e.g., cosmic signals originating in galaxies and pulsars, astronomical images.
  - Biology, e.g., signals produced by the brain and heart.
  - Seismology, e.g., signals produced by earthquakes and volcanoes.
  - Physical sciences, e.g., signals produced by lightnings, the room temperature, the atmospheric pressure.
- Man-made signals are found in:
  - Audio systems, e.g., music signals.
  - Communications, e.g., radio, telephone, TV signals.

- Telemetry, e.g., signals originating from weather stations and satellites.
- Control systems, e.g., feedback control signals.
- Medicine, e.g., electrocardiographs, X-rays, magnetic resonance imaging.
- Space technology, e.g., the velocity of a space craft.
- Economics, e.g., the price of a stock at the TSX, the TSX index.

- Some signals are necessary (speech), some are pleasant (music), while many are unwanted or unnecessary in a given situation.
- It is almost always necessary to represent signals by mathematical functions of one or more independent variables.
- For example, the speech signal is a function $s(t)$, represents the variations of acoustic pressure converted into an electric signal by a microphone.





- While a monochromatic picture is a function $f(x, y)$, describing the brightness as a function of 2 spatial variables x and y. The brightness at a horizontal line at $y = y_0$ is a function $s(x) = f(x, y = y_0)$ of the horizontal space variable x, only.

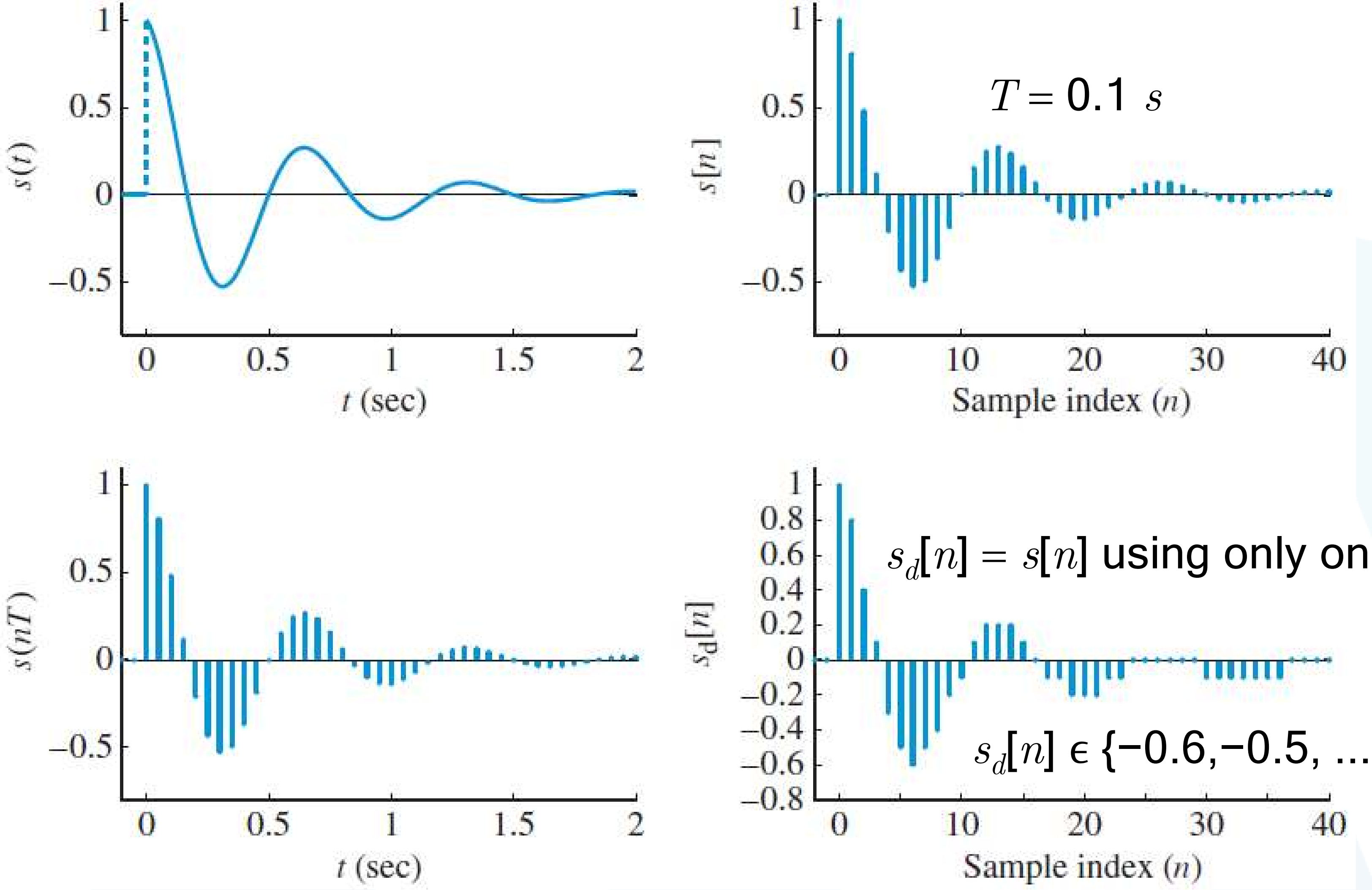
- Here, we will focus our attention on signals with a single independent variable. For convenience, we refer to the dependent variable as amplitude and the independent variable as time.
- Signals can be classified into different categories depending on the values taken by the amplitude (dependent) and time (independent) variables.
- Two natural categories, that are the subject of this course, are continuous-time (CT) signals and discrete-time (DT) signals.
- The speech signal is an example of a continuous-time signal because its value $s(t)$ is defined for every value of time t.
- The temperature reading of a room every day at the same time, is an example of a discrete-time signal. Discrete-time signals are defined only at discrete times, that is, at a discrete set of values of the independent variable.

- Most signals of practical interest arise as continuous-time signals. However, the use of digital signal processing technology requires a discrete-time signal representation.
- This is usually done by sampling a continuous-time signal at isolated, equally spaced points in time (periodic sampling). $s[n] = s(t)\big|_{t=nT} = s(nT),\ n \in Z$

  T is the sampling period. The quantity $F_s = 1/T$, known as sampling frequency.

  $s[m,n] = s(m\Delta x, n\Delta y)$ $s[m, n]$ is called a picture element or pixel.
- A discrete-time signal $s[n]$ whose amplitude takes values from a finite set of K real numbers $\{a_1, a_2, ..., a_K\}$, is known as a digital signal.

$$s(t) = \begin{cases} e^{-2t}\cos(3\pi t), & t \ge 0 \\ 0, & t < 0 \end{cases} \qquad s[n] = s(nT) = \begin{cases} e^{-0.2n}\cos(0.3\pi n), & n \ge 0 \\ 0, & n < 0 \end{cases}$$



$T = 0.1\ s$

$s_d[n] = s[n]$ using only one decimal point

$s_d[n] \in \{-0.6, -0.5, \ldots, 1\}$, $K = 17$

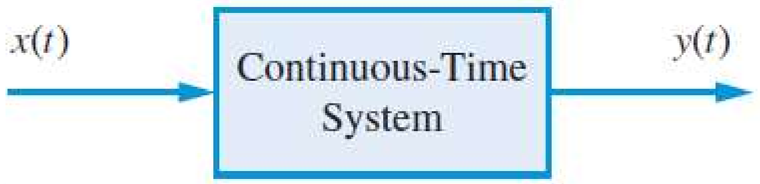
2. Systems

- A system may be defined as a physical device that performs an operation on a signal. For example, a filter used to remove the noise from a signal is called a system.
- A system is also defined as a process where a signal called input is transformed into another signal called output.
- When we pass a signal through a system, as in filtering, we say that we have processed the signal.
- In general, the system is characterized by the type of operation that it performs on the signal. For example, if the operation is linear, the system is called linear. If the operation on the signal is nonlinear, the system is said to be nonlinear.

- Such operations are usually referred to as signal processing.
- Systems are classified based on the category of input and output signals.
- A continuous-time (CT) system is a system which transforms a CT input signal $x(t)$ into a CT output signal $y(t)$. $y(t) = \mathcal{T}\{x(t)\}$,

  where $\mathcal{T}$ denotes the mathematical operator (transformation) characterizing the system.

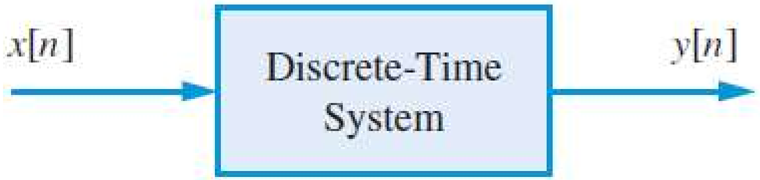
  For example, $y(t) = \int_{-\infty}^{t} x(\tau)d\tau$ integral of the input signal.



- Continuous-time systems are physically implemented using analog electronic circuits, like resistors, capacitors, inductors, and operational amplifiers.
- The physical implementation of a continuous-time system is known as an analog system.

- Some common analog systems are audio amplifiers, AM/FM receivers.
- A discrete-time (DT) system is a system which transforms a DT input signal $x[n]$ into a DT output signal $y[n]$. $y[n] = \mathcal{T}\{x[n]\}$

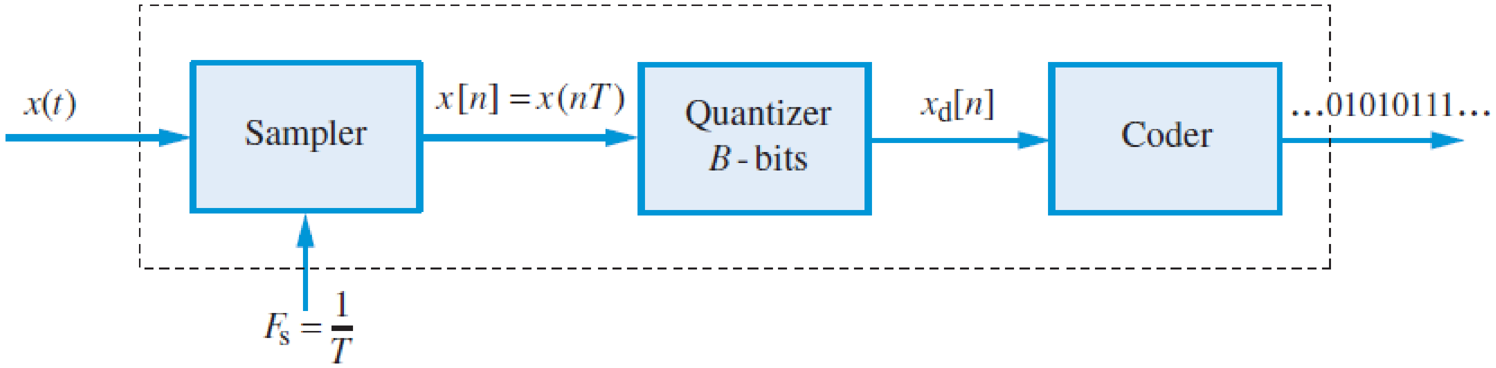
  For example, $y[n] = \sum_{k=-\infty}^{n} x[k]$ accumulator



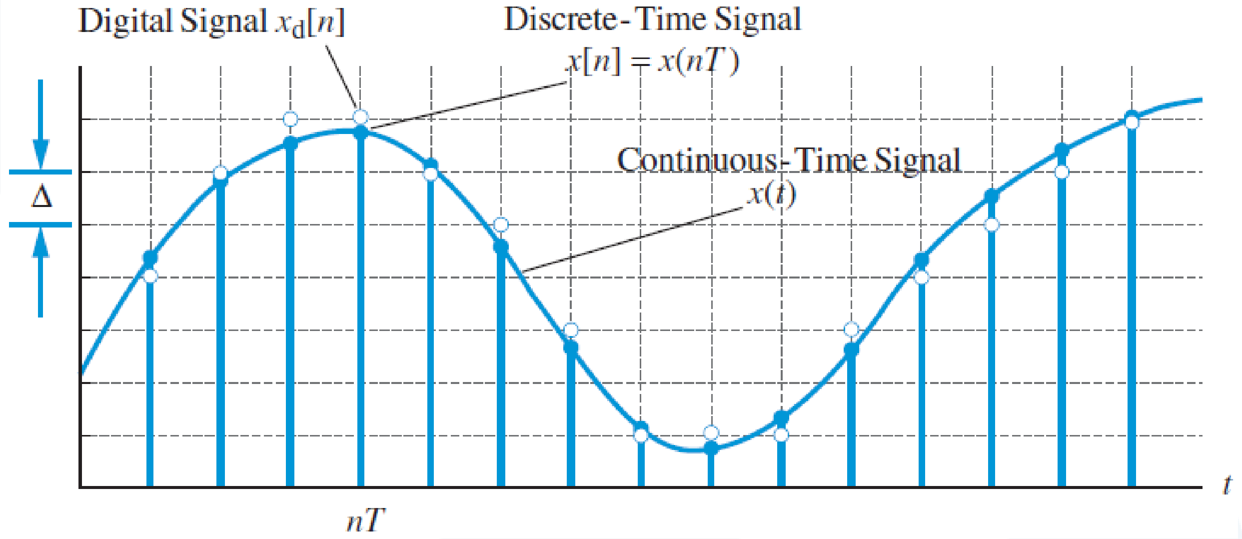
- The physical implementation of discrete-time systems can be done either in software (program) or hardware (logic circuits).
- Most of signals encountered in science and engineering are analog in nature. Such signals may be processed directly by appropriate analog systems.
- To perform the processing digitally, there is a need for an interface between the analog signal and the digital processor. This interface is called an analog-to-digital (A/D) converter.

Analog-to-digital conversion

- The conversion of an analog (continuous-time, continuous-amplitude) signal into a digital (discrete-time, discrete-amplitude) signal (A/D) consists of two parts: sampling and quantization.
- Sampling converts a continuous-time signal to a discrete-time signal by measuring the signal value at regular intervals of time.
- Quantization converts a continuous-amplitude x into a discrete-amplitude x_d.



analog-to-digital conversion (ADC) process

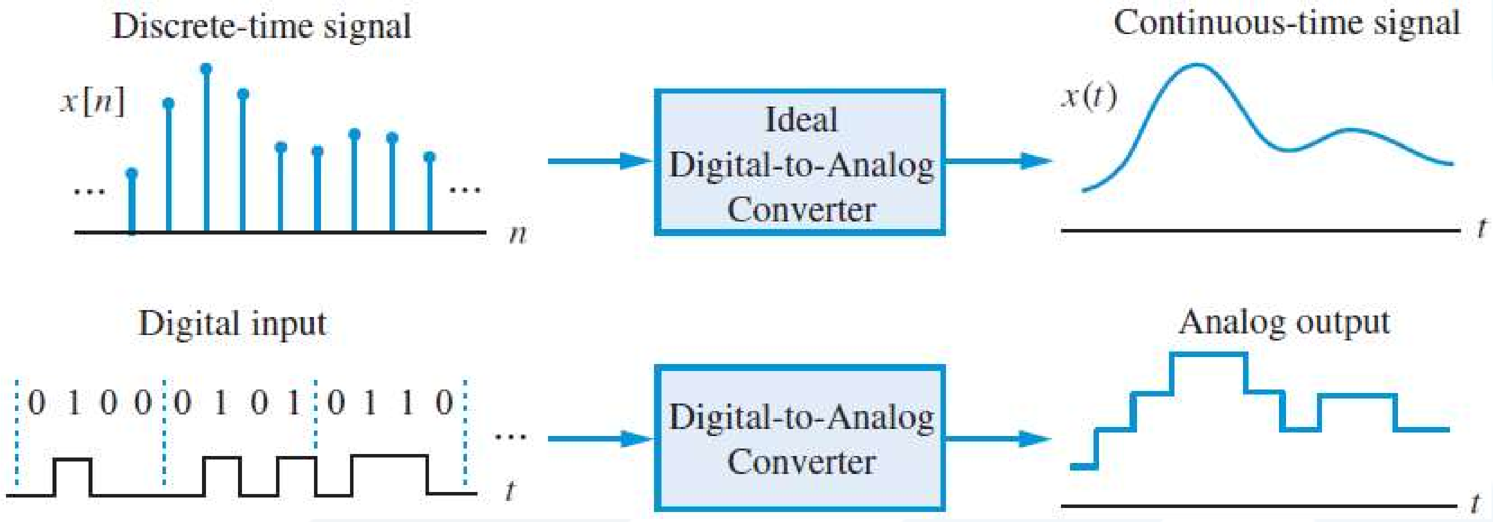


ideal analog-to-digital converter

practical analog-to-digital converter

Digital-to-analog conversion

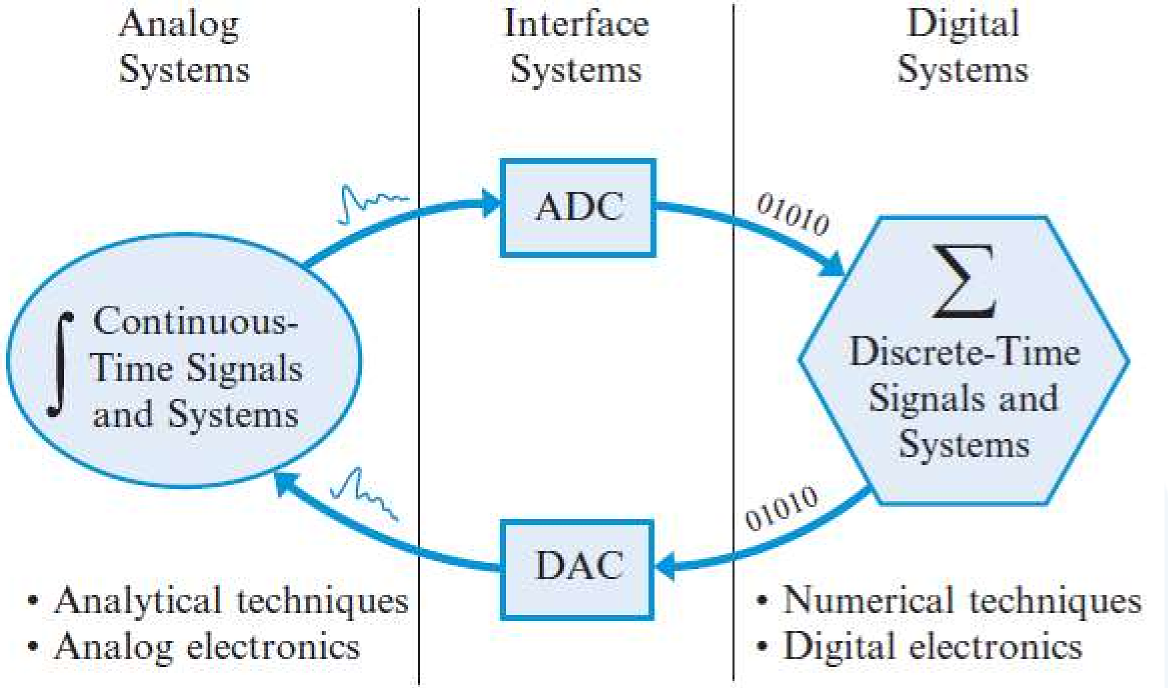
- The conversion of a discrete-time signal into continuous form is done with an interface system called digital-to-analog (D/A) converter (DAC).



ideal D/A converter

practical D/A converter

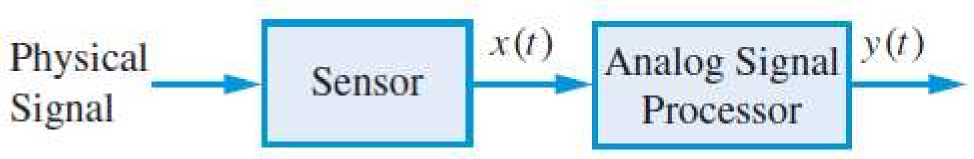
- The three classes of system: analog systems, digital systems, and interface systems from A/D and digital-to-analog are summarized in figure below:



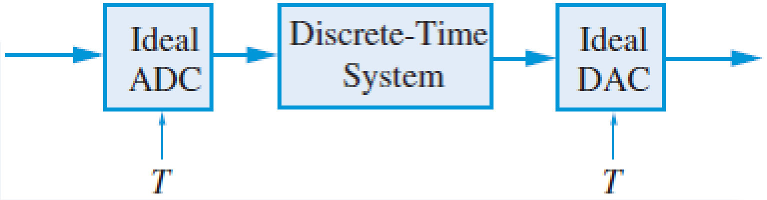
3. Analog, digital, and mixed signal processing

- Since most physical quantities are nonelectric, they should first be converted into an electric signal to allow electronic processing.

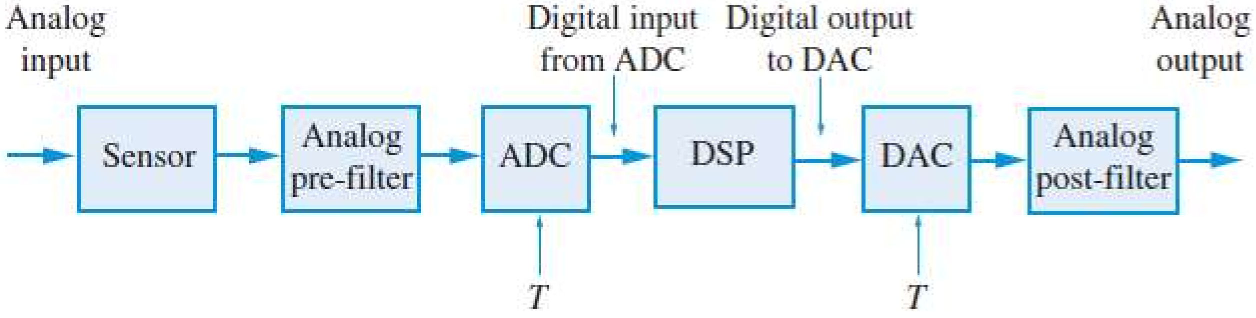
- Analog Signal Processing (ASP) is concerned with the conversion of analog signals into electrical signals by special transducers or sensors and their processing by analog electrical and electronic circuits.
- The output of the sensor requires some form of conditioning, usually amplification, before it can be processed by the analog signal processor.



- Digital Signal Processing (DSP) is concerned with the representation of analog signals by sequences of numbers, the processing of these sequences by numerical computation techniques, and the conversion of such sequences into analog signals.



idealized system



practical system

- DSP has many advantages compared to ASP:

1. Sophisticated signal processing functions can be implemented in a cost-effective way using digital techniques.
2. There exist important signal processing techniques that are difficult or impossible to implement using analog electronics.

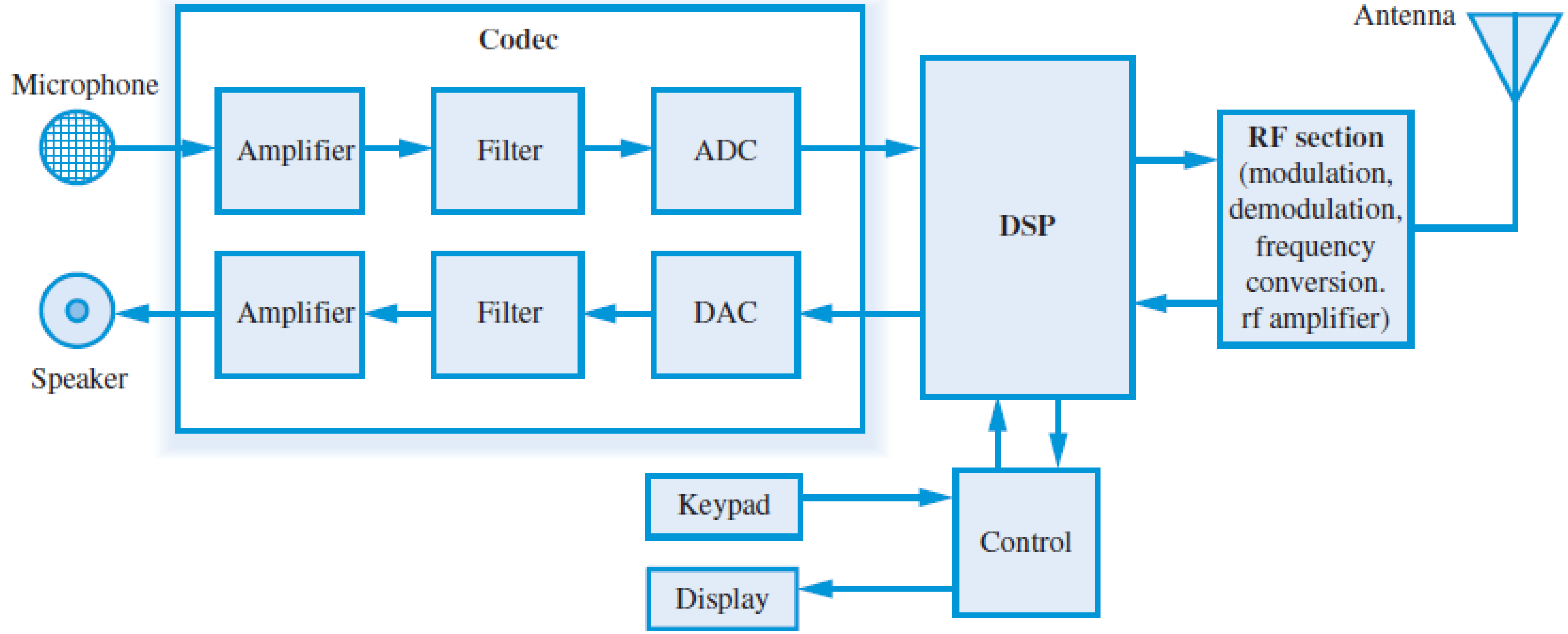
3. Digital systems are more reliable, more compact, and less sensitive to environmental conditions and component aging than analog systems.
4. The digital approach allows the possibility of time-sharing a single processing unit among a number of different signal processing functions.
5. Digital signals are easily stored on magnetic media (tape or disk) without deterioration. As a consequence, the signals become transportable and can be processed off-line in a remote laboratory.

- The principal disadvantage of DSP is the limited speed of operations, especially at very high frequencies.
- The term mixed-signal processing is sometimes used to describe a system which includes both analog and digital signal processing parts.

4. Applications of digital signal processing

- Digital signal processing applications can be classified in three major classes:
  (a) Low-cost high-volume embedded systems, for example, modems and cellular phones,
  (b) Computer-based multimedia, for example, modems, audio and video compression and decompression, and music synthesis, and
  (c) High-performance applications involving processing large volumes of data with complex algorithms, for example, radar, sonar, seismic imaging, and speech recognition.
- The first two classes rely on inexpensive digital signal processors, whereas the third class requires processors with maximum performance.

- Audio processing: compression and decompression, equalization, mixing and editing, sound synthesis, stereo and surround sound, and noise cancelation.
- Speech processing: speech synthesis, compression and decompression, speech recognition, speaker identification, and speech enhancement.
- Image and video processing: image compression and decompression, image enhancement, feature extraction, video coding, motion detection.
- Telecommunications (transmission of audio, video, and data): modulation and demodulation, error detection and correction coding, encryption and decryption, computer networks, radio and television, and cellular telephony.
- Computer systems: disk control, printer control, modems, internet phone.
- Military systems: guidance and navigation, radar and sonar processing.



Simplified block diagram of a digital cellular phone

- The DSP processor performs several functions, including: speech compression and decompression, error detection and correction, encryption, modulation and demodulation, and power management.