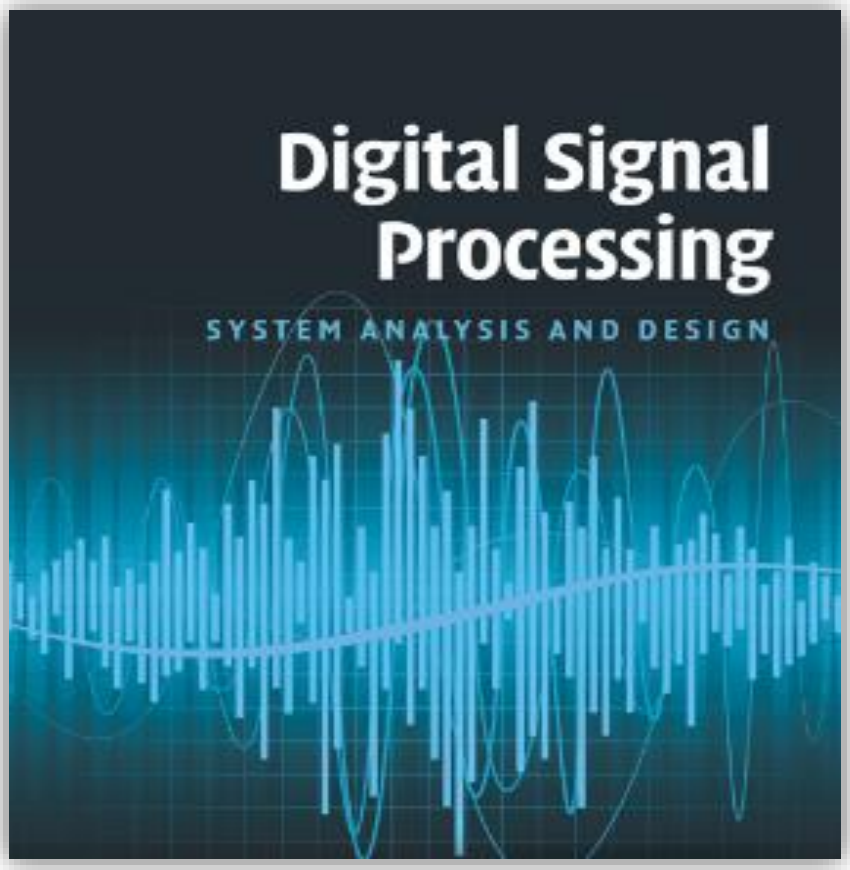

Computer Science Dept.

Third Class

Lecture 1

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- **Signals** are time - varying quantities which carry information in their patterns of variation. They may be, for example, audio signals (speech, music), images or video signals, sonar signals or ultrasound, biological signals such as the electrical pulses from the heart, communications signals, or many other types. The manipulation of this information involves the acquisition, storage, transmission, and transformation of signals. The speech signal, shown as a time waveform in Figure 1, represents the variations of acoustic pressure converted into an electric signal by a microphone. A signal, which is continuous in nature is known as continuous signal.

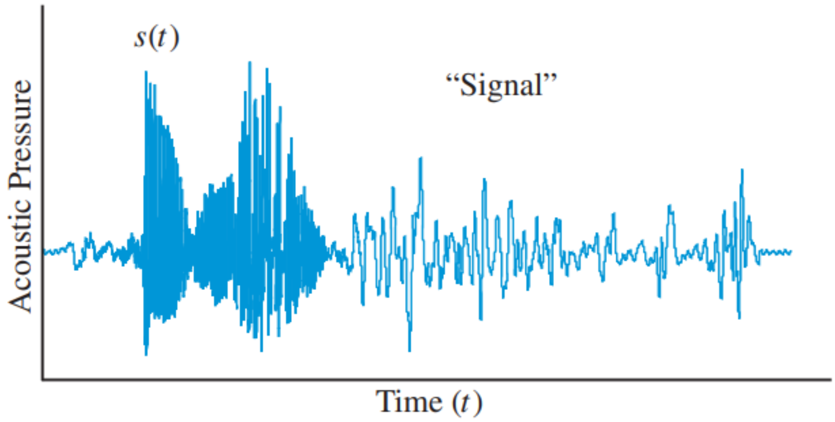

Figure 1: Example of a recording of speech signal

General format of a sinusoidal signal is shown in Figure 2 and it is:

$$v(t) = A \sin(\omega t + \Phi)$$

where

A is the magnitude of the signal $v(t)$
ω is the angular frequency ($\omega = 2\pi f$)
f is the frequency in hertz ($f = 1/T$)
Φ is the phase angle in radians

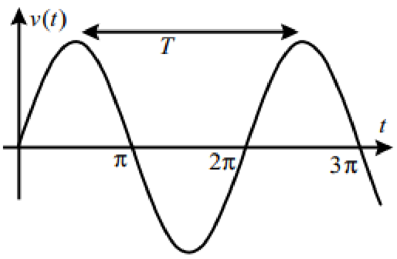

Figure 2: a sinusoidal signal

- To simplify the analysis and design of signal processing systems it is almost always necessary to represent signals by mathematical functions of one or more independent variables. For example, the speech signal in Figure 1 can be represented mathematically by a function s(t) that shows the variation of acoustic pressure as a function of time. On the other hand, the independent variable in the mathematical representation of a signal may be either continuous or discrete. Continuous-time signals are defined along a continuum of time and are thus represented by a continuous independent variable. Continuous-time signals are often referred to as analog signals.

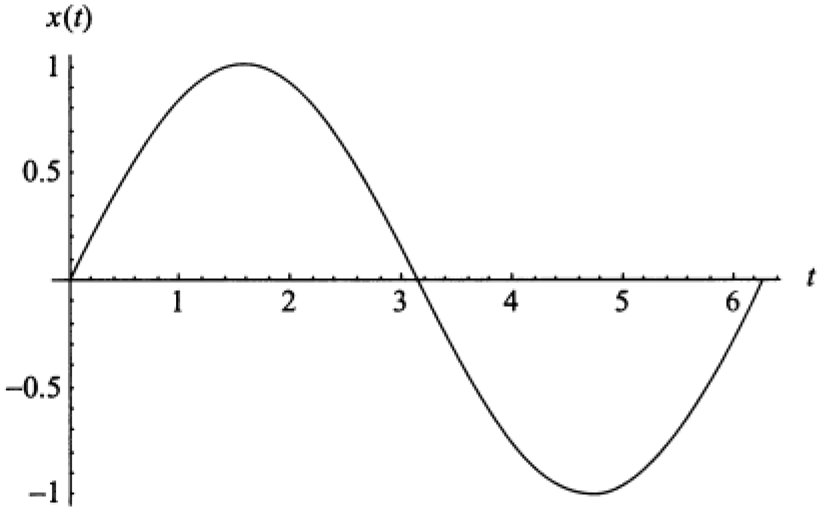

Figure 3: An example of a continues time, sine wave

- Discrete-time signals are defined at discrete times, and thus, the independent variable has discrete values; that is, discrete-time signals are represented as sequences of numbers. Digital signals are those for which both time and amplitude are discrete.

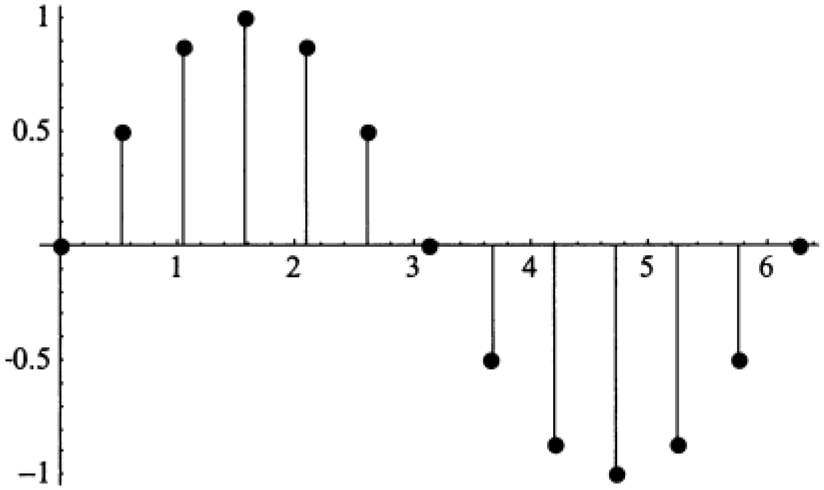

Figure 4: A discrete time signal formed by sampling the sine function

- **Signal processing** is a discipline concerned with the acquisition, representation, analysis, manipulation, and transformation of signals. Signal processing involves the physical realization of mathematical operations and it is essential for a tremendous number of practical applications. Some key objectives of signal processing are to improve the quality of a signal or extract useful information from a signal, to separate previously combined signals, and to prepare signals for storage and transmission. Signal processing can be grouped into two classes:

  - Analog Signal Processing
  - Digital Signal Processing

- **Analog 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. The parts of a typical analog signal processing system are illustrated in Figure 5

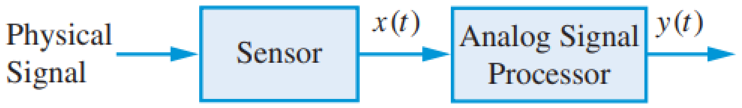

Figure 5: Simplified block diagram of an analog signal processing system

- **Digital signal processing** The rapid evolution of digital computing technology which started in the 1960s, marked the transition from analog to digital signal processing. 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. Digital signal processing has evolved through parallel advances in signal processing theory and the technology that allows its practical application. A typical system for discrete-time processing of continuous-time signals is shown in Figure 6.

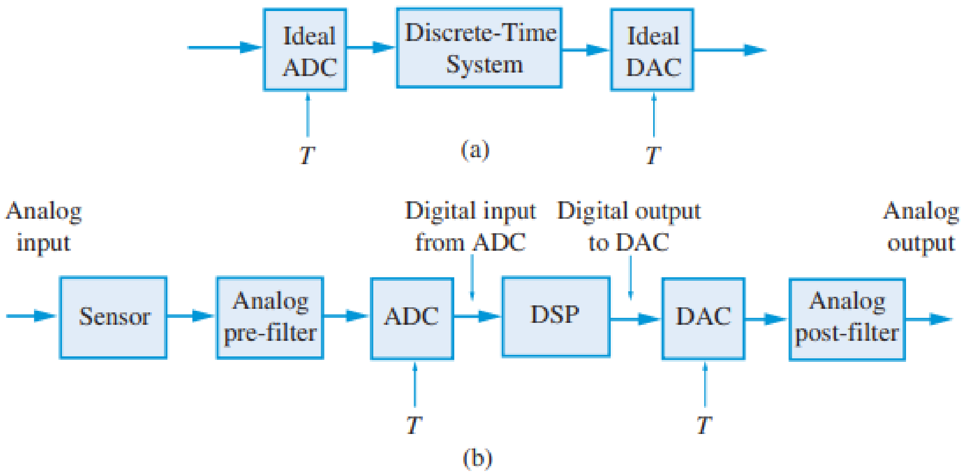

Figure 6: Simplified block diagram of idealized system for (a) continuous-time processing of discrete-time signals, and (b) its practical counterpart for digital processing of analog signals

- In practice, due to inherent real-world limitations, a typical system for the digital processing of analog signals includes the following parts (see Figure 6 (b)): -

1. A sensor that converts the physical quantity to an electrical variable. The output of the sensor is subject to some form of conditioning, usually amplification, so that the voltage of the signal is within the voltage sensitivity range of the converter.

2. An analog filter (known as pre-filter or antialiasing filter) used to "smooth" the input signal before sampling to avoid a serious sampling artifact known as aliasing distortion.

3. An A/D converter that converts the analog signal to a digital signal. After the samples of a discrete-time signal have been stored in memory, time-scale information is lost. The sampling rate and the number of bits used by the ADC determine the accuracy of the system.

4. A digital signal processor (DSP) that executes the signal processing algorithms. The DSP is a computer chip that is similar in many ways to the microprocessor used in personal computers. A DSP is, however, designed to perform certain numerical computations extremely fast. Discrete-time systems can be implemented in real-time or off-line, but ADC and DAC always operate in real-time.

5. A D/A converter that converts the digital signal to an analog signal. The DAC, which reintroduces the lost time-scale information, is usually followed by a sample-and-hold circuit. Usually, the A/D and D/A converters operate at the same sampling rate.

6. An analog filter (known as reconstruction or anti-imaging filter) used to smooth the staircase output of the DAC to provide a more faithful analog reproduction of the digital signal

- **Signal-processing systems** may be classified along the same lines as signals. That is, continuous-time systems are systems for which both the input and the output are continuous-time signals, and discrete-time systems are those for which both the input and the output are discrete-time signals. Based on the type of input and output signal, there are three classes of practical system: analog systems, digital systems, and analog-digital interface systems. The different types of system are summarized in Figure 7

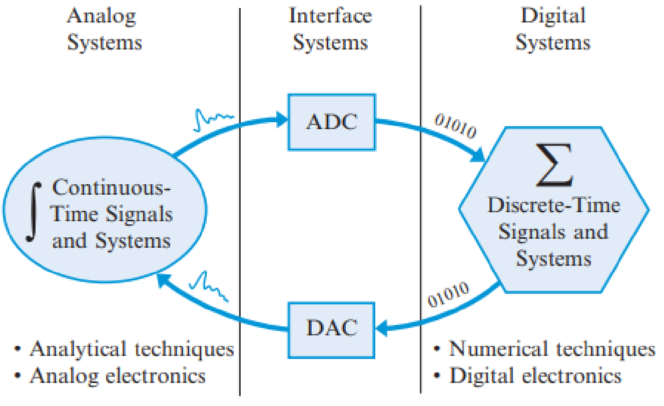

Figure 7: The three classes of system: analog systems, digital systems, and interface systems from analog-to-digital and digital-to-analog

- Continuous-time signals are typically processed using analog systems composed of electrical circuit components such as resistors, capacitors, and inductors together with semiconductor electronic components such as diodes, transistors, and operational amplifiers, among others.

- Discrete time signals, on the other hand, are represented mathematically sequences of numbers and processing them requires numerical manipulation of these sequences. Simple addition, multiplication, and delay operations are enough to implement many discrete-time systems. Thus, digital signal processing systems are easier to design, develop, simulate, test, and implement than analog systems by using flexible, reconfigurable, and reliable software and hardware tools. A sequence of numbers x, in which the nth number in the sequence is denoted x[n], is formally written as

$$x = \{x[n]\}, \qquad -\infty < n < \infty,$$

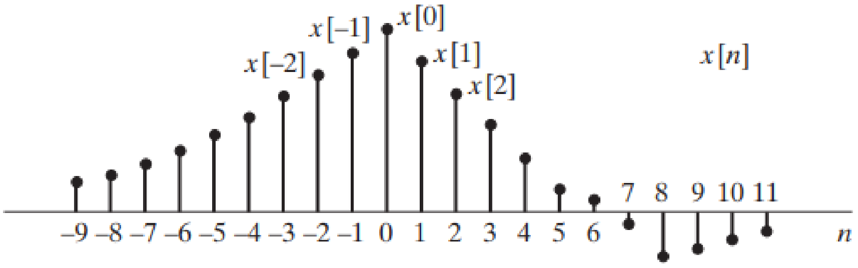

Figure 8: Graphic representation of a discrete-time signal.

- Digital signal processing applications often require heavy arithmetic operations, e.g., repeated multiplications and additions, and as such dedicated hardware is required. Possible **implementations** for a real-time implementation of the developed algorithms are:

  - General-purpose microprocessors (μPs) and micro-controllers (μCs).
  - General-purpose digital signal processors (DSPs).
  - Field-programmable gate arrays (FPGAs).

  Selecting the best implementation hardware depends on the requirements of the application such as performance, cost, size, and power consumption.

- Digital signal processing systems are employed these days in many applications such as cell phones, household appliances, cars, ships and airplanes, smart home applications, and many other consumer electronic devices. Table 1 shows the importance of digital signal processing technology in real-world applications.

Table 1 Examples of digital signal processing applications and algorithms.

Application area	DSP algorithm
Key operations	convolution, correlation, filtering, finite discrete transforms, modulation, spectral analysis, adaptive filtering
Audio processing	compression and decompression, equalization, mixing and editing, artificial reverberation, 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, geometric transformations, feature extraction, video coding, motion detection, and tomographic image reconstruction
Telecommunications (transmission of audio, video, and data)	modulation and demodulation, error detection and correction coding, encryption and decryption, acoustic echo cancelation, multipath equalization, computer networks, radio and television, and cellular telephony
Computer systems	sound and video processing, disk control, printer control, modems, internet phone, radio, and television
Military systems	guidance and navigation, beamforming, radar and sonar processing, hyperspectral image processing, and software radio

- Digital signal processing has many **advantages** compared to analog signal processing. The most important are summarized in the following list:

  1. Digital programmable systems allow flexibility. DSP programs can be configured by simply making alterations in our program. Reconfiguration of an analog system usually implies a redesign of the hardware.

  2. Digital signal processing systems exhibit high accuracy.

  3. DSP programs can be stored on magnetic media (disk) without any loss in signal. As a consequence, the signals become portable and can be processed off-line in a remote laboratory.

  3. Digital systems are inherently more reliable, more compact, and less sensitive to environmental conditions and component aging than analog systems.

  4. Processing in DSP reduces the cost by time-sharing of the processor among a number of different signal processing functions.

  5. Digital circuits are less sensitive to tolerance of a component value.

  6. The implementation of highly sophisticated signal processing algorithms is made possible with DSP. It is very difficult to perform precise mathematical operations on signals in the analog form.