# EEM401 Digital Signal Processing

**http://www.ee.hacettepe.edu.tr/∼usezen/eem401/**

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These lecture slides are based on "Digital Signal Processing: A Computer-Based Approach, 4th ed." textbook by S.K. Mitra and its instructor materials. U.Sezen

# Contents

# Textbook

Main textbook:

- S.K. Mitra, *Digital Signal Processing: A Computer-Based Approach*, McGraw-Hill, 4th Ed., 2011 (or 3rd Ed., 2006).

Supplementary textbook:

- A.V. Oppenheim and R.W. Schafer, *Discrete-Time Signal Processing*, Prentice Hall, 2nd Ed., 1998.

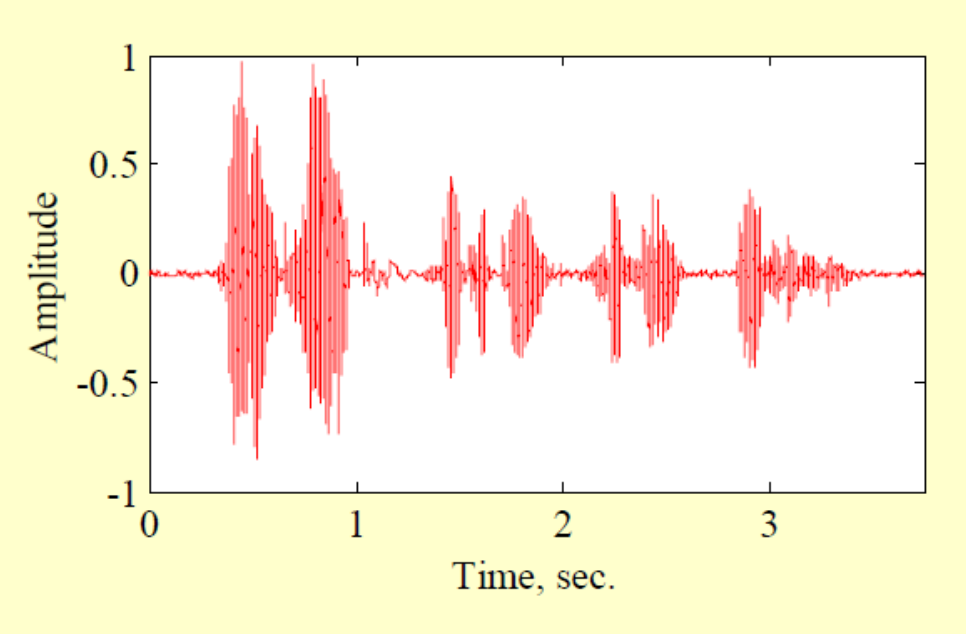
# Introduction: Signals and Signal Processing

- Signals play an important role in our daily life.
- A signal is a function of independent variables such as **time**, **distance**, **position**, **temperature** and **pressure**.

Some examples of typical signals are shown in the next slides.

# Examples of Typical Signals - Speech

- **Speech and music signals** - Represent air pressure as a function of time at a point in space
- Waveform of the speech signal "I like digital signal processing" is shown below.



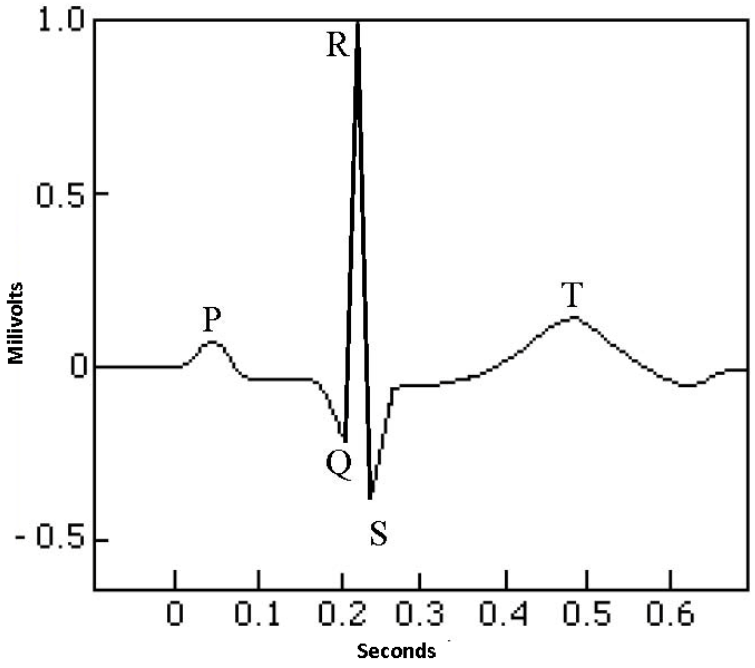

Play Sound

# Examples of Typical Signals - ECG

- **Electrocardiography (ECG) Signal** - Represents the electrical activity of the heart
- A typical ECG signal is shown below

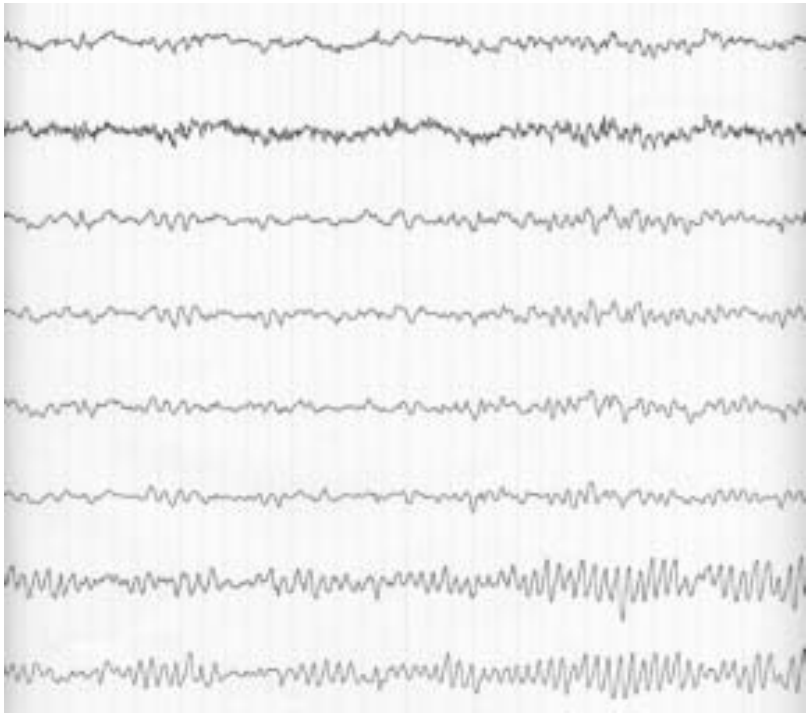
# Examples of Typical Signals - ECG

- The ECG trace is a periodic waveform
- One period of the waveform shown below represents one cycle of the blood transfer process from the heart to the arteries



# Examples of Typical Signals - EEG

- **Electroencephalogram (EEG) Signals** - Represent the electrical activity caused by the random firings of billions of neurons in the brain

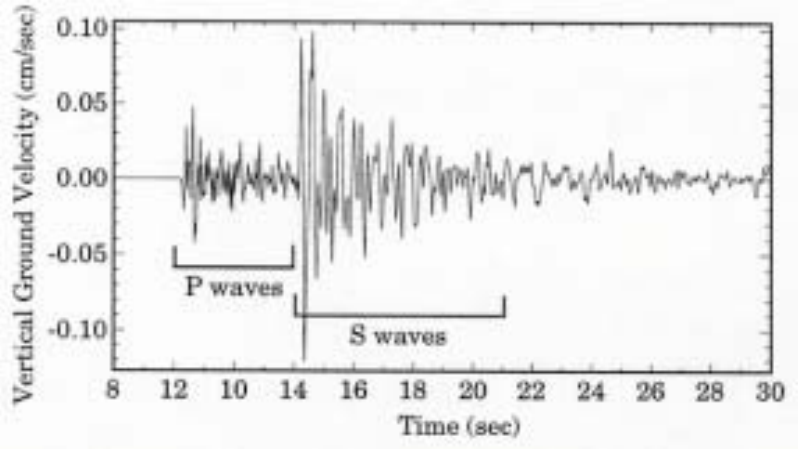


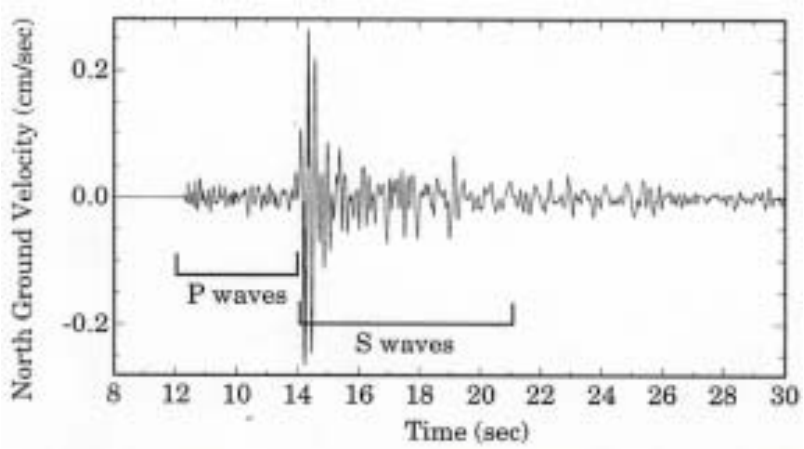
# Examples of Typical Signals - Seismic

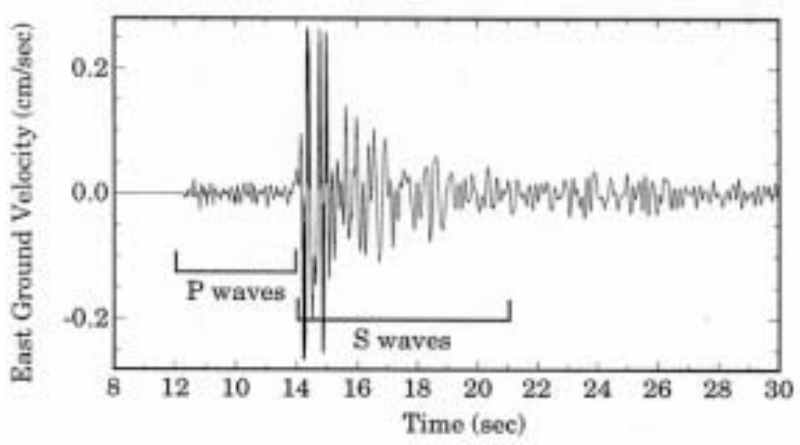
- **Seismic Signals** - Caused by the movement of rocks resulting from an earthquake, a volcanic eruption, or an underground explosion
- The ground movement generates **3** types of elastic waves that propagate through the body of the earth in all directions from the source of movement

# Examples of Typical Signals - Seismic

- Typical seismograph record



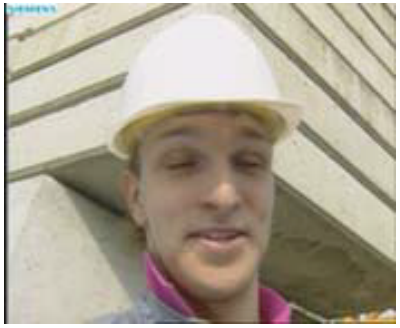



# Examples of Typical Signals - Image

- **Black-and-white picture** - Represents light intensity, $I(x, y)$ as a function of two spatial coordinates, $x$ and $y$.

# Examples of Typical Signals - Video

- **Video signals** - Consists of a sequence of images, called frames, and is a function of **3** variables, $I(x, y, t)$: two spatial coordinates, $x$ and $y$ and time, $t$



Play Movie

# Signals and Signal Processing

- Most signals we encounter are generated naturally
- However, a signal can also be generated synthetically or by a computer

# Signals and signal Processing

- A signal carries information
- **Objective of signal processing:** Extract the useful information carried by the signal
- **Method information extraction:** Depends on the type of signal and the nature of the information being carried by the signal
- This course is concerned with the discrete-time representation of signals and their discrete-time processing

# Characterization and Classification of Signals

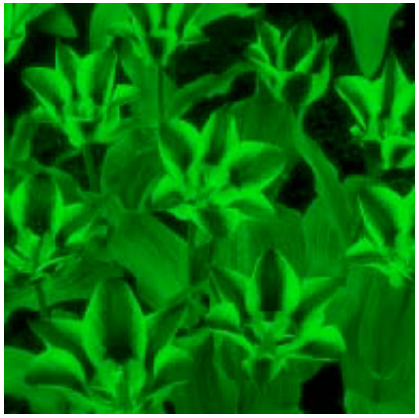
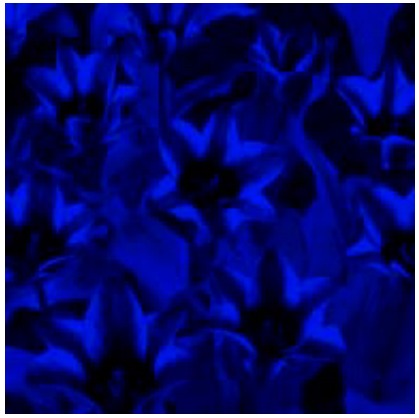
- **Types of signal:** Depends on the nature of the independent variables and the value of the function defining the signal
- For example, the independent variables can be continuous or discrete,
- Likewise, the signal can be a continuous or discrete function of the independent variables
- Moreover, the signal can be either a **real-valued** function or a **complex-valued** function
- A signal generated by a **single source** is called a **scalar signal**
- A signal generated by **multiple sources** is called a **vector signal** or a **multichannel signal**

# Characterization and Classification of Signals

- A **one-dimensional (1-D) signal** is a function of a single independent variable
- A **multidimensional (M-D) signal** is a function of more than one independent variables
- The **speech signal** is an example of a 1-D signal where the independent variable is **time**
- Moreover, the signal can be either a **real-valued** function or a **complex-valued** function
- An **image signal**, such as a photograph, is an example of a **2-D signal** where the 2 independent variables are the **2 spatial variables**
- A color image signal is composed of **three 2-D signals** representing the **three** primary colors: red, green and blue (**RGB**)

# Characterization and Classification of Signals - Image

- The 3 color components of a color image and the full color image obtained by displaying the previous 3 color components are shown below


# Characterization and Classification of Signals - Video

- Each **frame** of a black-and-white digital **video signal** is a **2-D image signal** that is a function of **2 discrete spatial variables**, with each **frame** occurring at discrete instants of **time**
- Hence, black-and-white digital video signal can be considered as an example of a **3-D signal** where the 3 independent variables are the **2 spatial variables** and **time**
- A color video signal is a **3-channel signal** composed of three **3-D signals** representing the three primary colors: red, green and blue (**RGB**)
- For transmission purposes, the **RGB television signal** is transformed into another type of **3-channel signal** composed of a **luminance** component and **2 chrominance** components

# Characterization and Classification of Signals

- For a **1-D signal**, the independent variable is usually labeled as **time**
- If the independent variable is **continuous**, the signal is called a **continuous-time signal**
- If the independent variable is **discrete**, the signal is called a **discrete-time signal**

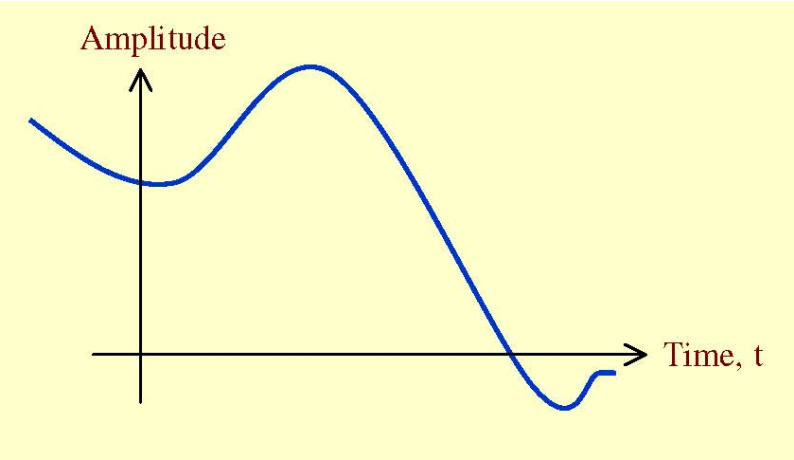
# Characterization and Classification of Signals

- 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**
  - A speech signal is an example of an analog signal
- A discrete-time signal with discrete-valued amplitudes represented by a finite number of digits is referred to as the **digital signal**
  - An example of a digital signal is the digitized music signal stored in a CD-ROM disk
- A discrete-time signal with continuous valued amplitudes is called a **sampled-data signal**

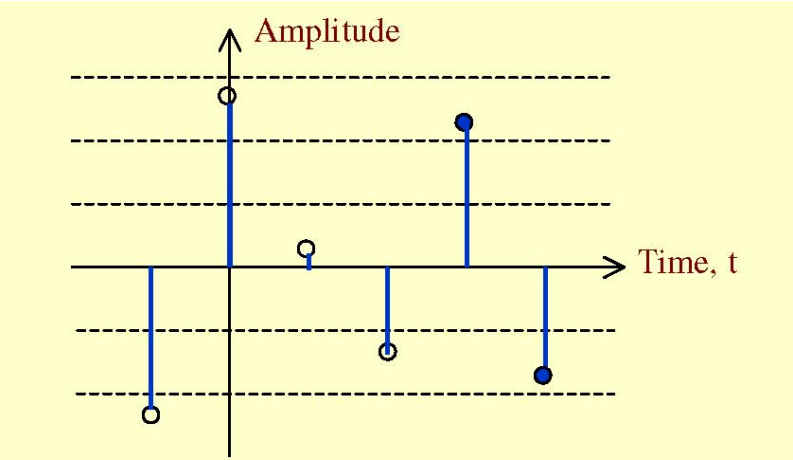
# Characterization and Classification of Signals

- A digital signal is thus a **quantized sampled-data signal**
- A continuous-time signal with discrete-value amplitudes is usually called a **quantized boxcar signal**
- The figure in the next slide illustrates the 4 types of signals

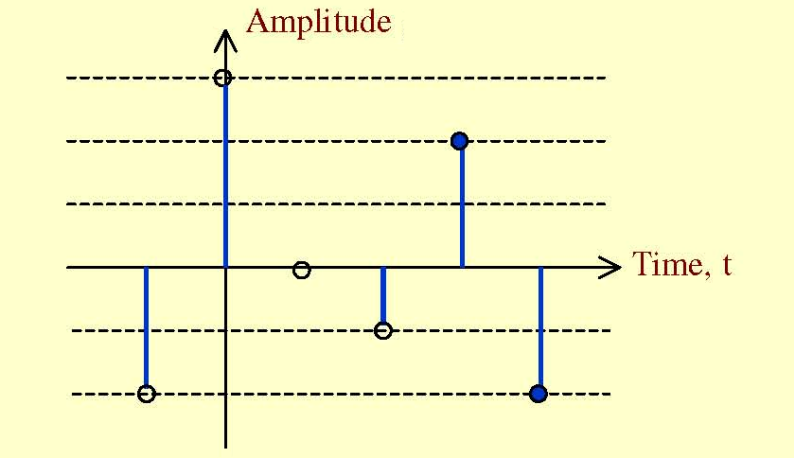
# Characterization and Classification of Signals



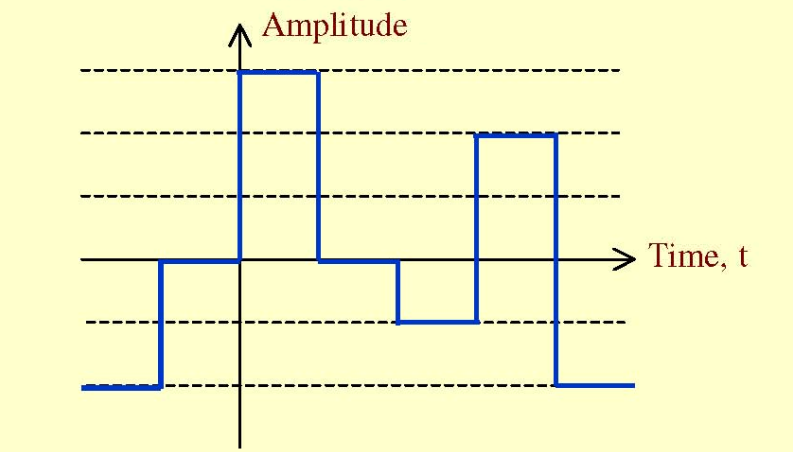

(a) a continuous-time signal




(b) a sampled-data signal




(c) a digital signal




(d) a quantized boxcar signal

# Characterization and Classification of Signals

- The functional dependence of a signal in its mathematical representation is often explicitly shown
- For a **continuous-time 1-D signal**, the continuous independent variable is usually denoted by $t$
  - For example, $u(t)$ represents a continuous-time 1-D signal
- For a **discrete-time 1-D signal**, the discrete independent variable is usually denoted by $n$
  - For example, $\{v[n]\}$ represents a discrete-time 1-D signal
  - Each member, $v[n]$, of a discrete-time signal is called a **sample**

# Characterization and Classification of Signals

- In many applications, a discrete-time signal is generated by **sampling** a parent continuous-time signal at **uniform intervals** of time
- If the discrete instants of time at which a discrete-time signal is defined are **uniformly spaced**, the independent discrete variable $n$ can be normalized to assume **integer values**

# Characterization and Classification of Signals

- In the case of a continuous-time **2-D** signal, the 2 independent variables are the **spatial coordinates**, usually denoted by $x$ and $y$
  - For example, the **intensity** of a black-and white image at location $(x, y)$ can be expressed as $u(x, y)$
- On the other hand, a digitized image is a **2-D** discrete-time signal, and its 2 independent variables are **discretized spatial variables**, often denoted by $m$ and $n$
  - Thus, a digitized image can be represented as $v[m, n]$

# Characterization and Classification of Signals

- A continuous-time black-and-white video signal is a **3-D** signal and can be represented as $u(x, y, t)$
- A **color video signal** is a vector signal composed of 3 signals representing the 3 primary colors: red, green and blue

$$\mathbf{u}(x, y, t) = \begin{bmatrix} r(x, y, t) \\ g(x, y, t) \\ b(x, y, t) \end{bmatrix}$$