Digital Signal Processing

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Textbook

- Sanjit K. Mitra, **Digital Signal Processing: A Computer-Based Approach**, 4th edition

Classical DSP Books

- Alan V. Oppenheim and Ronald W. Schafer, **Discrete-time Signal Processing**, Pearson
- Lawrence R. Rabiner and Bernard Gold, **Theory and Application of Digital Signal Processing**, Prince Hall
- J. Proakis, D. Manolakis, **Digital Signal Processing** 4th ed., Prentice-Hall, 2006

Contents

- Discrete-time signals and systems in the time domain
- Discrete-time signals and systems in the transform domain
  - Discrete-time Fourier transform
  - Discrete Fourier transform
  - z-Transform
  - Frequency response
- Digital filter structures
- IIR and FIR filter design
- DSP algorithms implementation

Assessment

- Assignments: 10%
- Two Quiz: 20%
- Laboratories: 20%
- Final Exam: 50%

Journals & Conferences in DSP

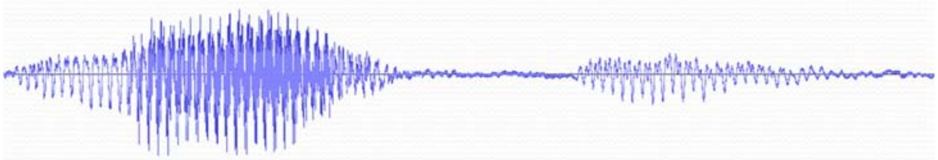
- Journals:
  - IEEE Transactions on Signal Processing (TSP)
  - IEEE Transactions on Circuits and Systems I (TCASI)
  - IEEE Transactions on Circuits and System II (TCASII)
  - IEEE Signal Processing Letter (SPL)
  - Signal Processing (Elsevier)
  - EURASIP Journal on Applied Signal Processing
  - Digital Signal Processing
  - Circuits Systems and Signal Processing (CSSP)

Journals & Conferences in DSP

- Conference:
  - IEEE International Conference on Acoustic, Speech & Signal Processing (ICASSP)
  - IEEE International Symposium on Circuits & Systems (ISCAS)
  - European Signal Processing Conference (EUSIPCO)
  - International Conference on Digital Signal Processing (DSP)

Lecture 1
Introduction

Signal



$f(t)$

$f(x, y)$

$f(t, x, y)$

Definition

- A signal can be defined simply as a mathematical function

$$y = f(x)$$

where x is the **independent variable** which specifies the domain of the signal.

- $y=\sin(\omega t)$ is a function of a variable in the **time domain** and is thus a time signal;
- An image $I(x,y)$ is in the spatial domain.

Signal Processing

- A signal carries information.
- The objective of signal processing:
  - Interpretation and information extraction. (e.g. speech recognition, machine learning, etc.)
  - Convert one signal to another. (e.g. filter, generate control command, etc.)

- Signal Processing concerns with:
  - The mathematical representation of the signal
  - The algorithmic operation carried out on the signal

Representation of Signal

- In terms of basis functions in the domain of original independent variable,
  - Time
  - Spatial, etc., or

- In terms of basis functions in a transformed domain,
  - Discrete Fourier Transform
  - z transform, etc.

Classification of Signals

- Continuous vs. Discrete
- Real-valued vs. Complex-valued
- 1-D signal vs. 2-D signal vs. M-D signal
- Stationary vs. Non-stationary
- etc.

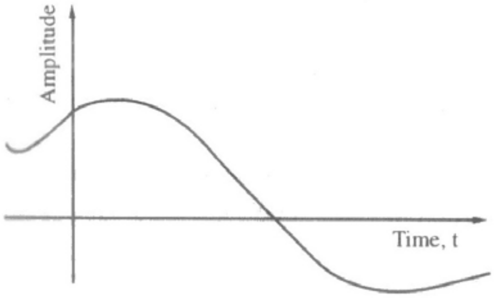
Characterization of Signals

- The value of a signal at a specific value of the independent variable is called its **amplitude**.
- The variation of the amplitude as a function of the independent variable is called its **waveform**.
- Let's consider 1-D signal
  - The independent variable is usually labeled as **time**.

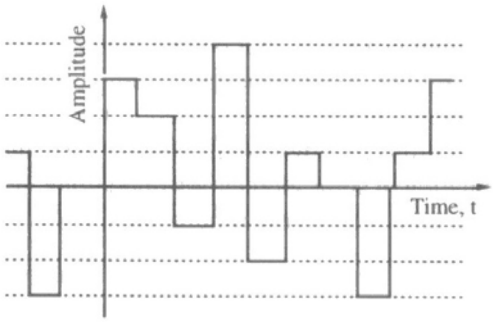
Continuous and Discrete Signals

- If the independent variable is continuous, the signal is called a **continuous-time (CT) signal**.
  - A continuous time signal is defined at every instant of time.
- If the independent variable is discrete, the signal is called a **discrete-time signal**.
  - A discrete time signal takes certain numerical values at specified discrete instants of time, and between these specified instants of time, the signal is **not defined**.
  - A discrete time signal is basically a sequence of numbers.

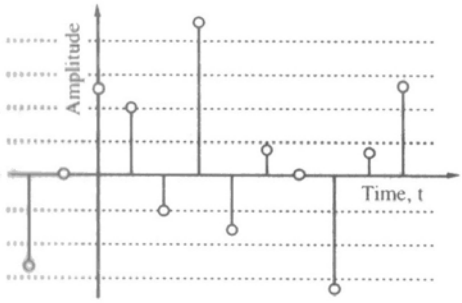
- A continuous-time signal with a continuous amplitude is usually called an **analog signal**.
  - A speech signal is an example of an analog signal.



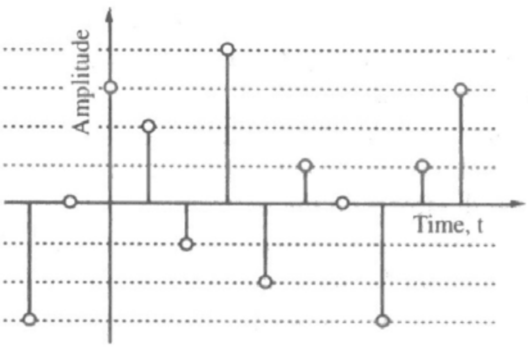
- A continuous-time signal with discrete valued amplitudes has been referred to as a **quantized boxcar signal**.
  - This type of signal occurs in digital electronic circuits where the signal is kept at fixed level (usually one of two values) between two instants of clocking.



- A discrete time signal with continuous valued amplitudes is called a **sampled-data signal**.
  - The amplitude of the signal may be any value.



- A discrete time signal with discrete valued amplitudes represented by a finite number of digits is referred to as a **digital signal**.
  - A digital signal is thus a quantized sampled-data signal.



Typical Signal Processing Operations

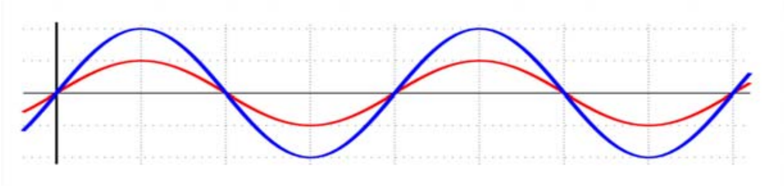
- In the case of analog signals, most signal processing operations are usually carried out in the **time domain**.
- In the case of discrete time signals, both **time domain and frequency domain** applications are employed.
- In either case, the desired operations are implemented by a combination of some **elementary operations** such as:
  - Simple time domain operations
  - Filtering
  - Amplitude modulation

Elementary Time-Domain Operations

- Three most basic time-domain signal operations
  - Scaling
  - Delay
  - Addition

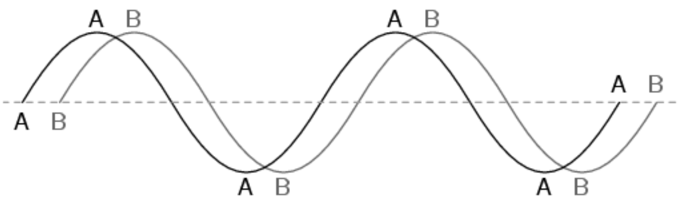
Scaling

- **Scaling** is simply the multiplication of a signal by a positive or a negative constant.
  - In the case of analog signal $x(t)$, the scaling operation generates a new signal $y(t) = \alpha x(t)$, where α is the multiplying constant.
  - The operation is called **amplification**, if $|\alpha| > 1$;
  - The operation is called **attenuation**, if $|\alpha| < 1$.



Delay

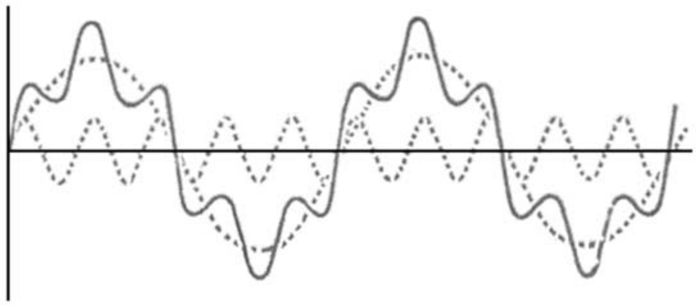
- **Delay** operation generates a signal that is delayed replica of the original signal.
  - In the case of analog signal $x(t)$, $y(t) = x(t - t_0)$ is the signal obtained by delaying $x(t)$ by the amount t_0, assuming $t_0 > 0$.



  - If $t_0 < 0$, it is an **advance** operation.

Addition

- **Addition** operation generates a new signal by the addition of signals. For instance, $y(t)=x_1(t)+x_2(t)$ is the signal generated by the addition of the three analog signals $x_1(t)$ and $x_2(t)$.



Why Learn DSP?

- Swiss-Army-Knife of modern EE
- Impacts all aspects of modern life
  - Communications (wireless, internet, GPS...)
  - Control and monitoring (cars, machines...)
  - Multimedia (mp3, cameras, videos, restoration ...)
  - Health (medical devices, imaging....)
  - Economy (stock market, prediction)
  - More....

Advantages of DSP

- Flexibility
- System/implementation does not age
- "Easy" implementation
- Reusable hardware
- Sophisticated processing
- Process on a computer
- (Today) Computation is cheaper and better

Example I: Audio Compression

- Compress audio by 10x without perceptual loss of quality.
- Sophisticated processing based on models of human perception
- 3MB files instead of 30MB -
  - Entire industry changed in less than 10 years!

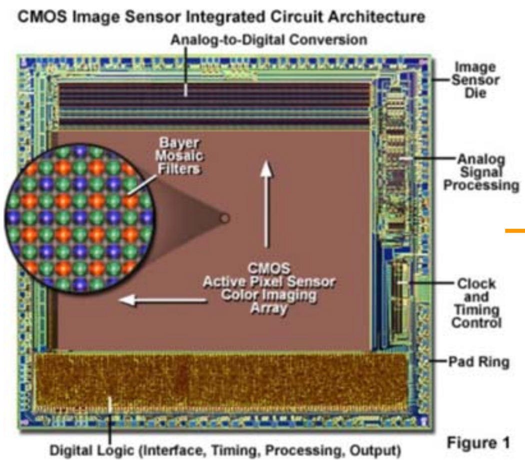
Historical Forms of Compression

- Morse code: dots (1 unit) Dashes (3 units)
  - Code Length inversely proportional to frequency
  - E (12.7%) = . (1 unit) Q (0.1%) = --.- (10 units)

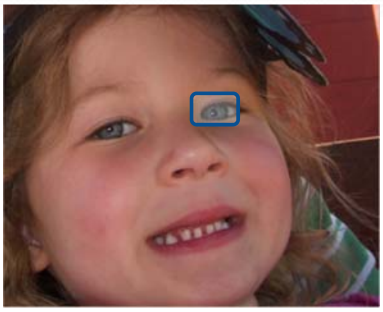
- "92 Code" - Used by Western-Union in 1859 to reduce BW on telegraph lines by numerical codes for frequently used phrases
  - 1 = wait a minute
  - 73 = Best Regards
  - 88 = Love and Kisses

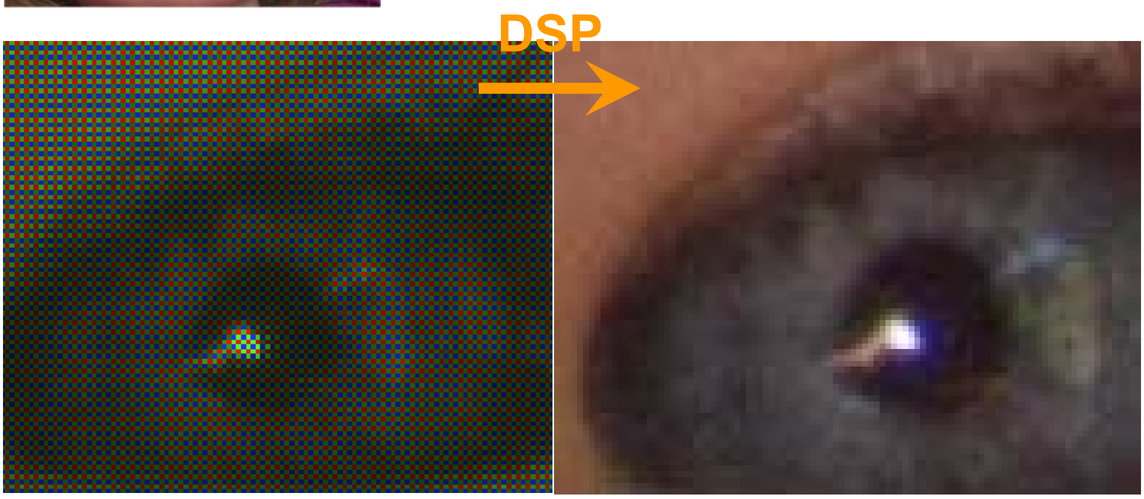
73	Best Regards
--... ...--	-... . ... - / .-. . --. .- .-. -.. ...
19 units	59 units

Example II: Digital Imaging Camera



Focus/exposure Control → Pre-processing → White Balancing → Demosaic → Color Transform → Post-processing → Compression





- Compression of 40x without perceptual loss of quality.

- Example of slight over compression:
  - difference enables x60 compression!

Computational Photography

Now implemented in smart phones (HDR)