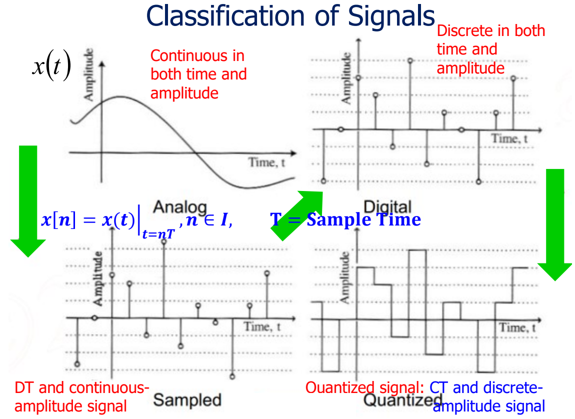
Signals

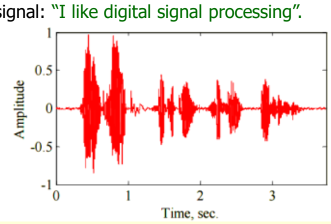
- Signal: function of one or more independent variables such as time (e.g. speech signal), position (e.g. image), temperature, and pressure etc. that carries some information or describes some physical phenomenon.
- Types of independent variable: continuous and discrete
  - Real-world signals are analog and vary continuously and take continuous values.
  - Digital signals are sampled at discrete times and are quantized to a finite number of discrete values.
- A signal can be either a real-valued function or a complex-valued function
- Signals generated naturally are called real-valued signals.
- Signals may be generated synthetically or by computer simulation

Classification of Signals



Examples: Typical Signals (1)

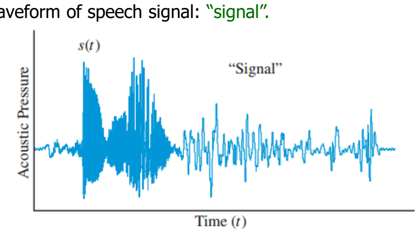
- Examples of Typical Signals: Speech, Audio, Image, and Video
  - Speech and Audio signal: represent air pressure as a function of time at a point in space
  - Waveform of speech signal: "I like digital signal processing".



- Scalar Signal or 1-D signal: signal generated by a single source
- vector signal or a multichannel signal: signal generated by multiple sources.

Characterization of Signals in Dimensionality (1)

- One-dimensional (1-D) signal:
  - Function of a single independent variable i.e. time, e.g., speech signal, s(t)
- Waveform of speech signal: "signal".



The time waveform shows the variation of acoustic pressure as a function x(t) of time for the word "signal."

Characterization of Signals in Dimensionality (2)

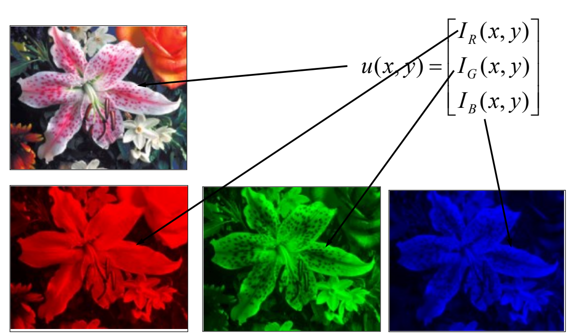
- Two-dimensional (2-D) signal:
  - Function of Two independent variables, e.g., images (x, y)
    - Black-and-white (Monochrome) picture: represents light intensity (i.e. brightness) as a function of two spatial coordinates.

(a) The brightness at each point in space is a scalar function f(x, y) of the rectangular coordinates x and y.

(b) 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.

Characterization of Signals in Dimensionality (4)

- A color image is a 3-channel signal composed of three 2-D signals representing the three primary color: red, green and blue (RGB)

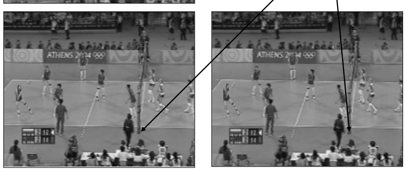


Characterization of Signals in Dimensionality (5): Video

- Multidimensional signal:
  - Black and white video signal is a 3-D signal, two spatial variables and the time variable, i.e., v(x, y, t)

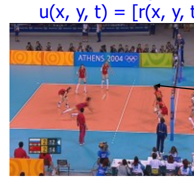
Video signals: Consists a sequence of images, called frames, and is a function of three variables – Two spatial coordinates and Time

$$I(x, y, t)$$

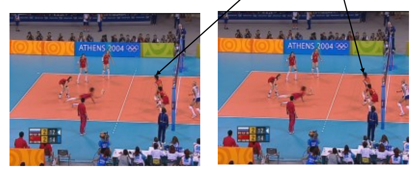


Characterization of Signals in Dimensionality (6): Video

- Multidimensional signal:
  - Color video signal has three channels of 3-D signals (RGB), i.e., u(x, y, t) = [r(x, y, t) g(x, y, t) b(x, y, t)]^T



$$u(x,y,t) = \begin{bmatrix} I_R(x,y,t) \\ I_G(x,y,t) \\ I_B(x,y,t) \end{bmatrix}$$



What is Digital Signal Processing (1) ?

- A signal carries information
- Objective of signal processing: extract useful information from the signal, i.e.,

  Signal processing is concerned with the mathematical representation of the signal and the algorithmic operation carried out to extract the information present

Digital signal processing of analog signals

Analog signal → ADC → Digital signal → Digital signal processor → Digital signal → DAC → Analog signal

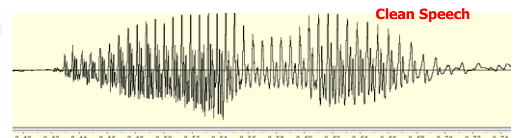
- DSP: signal processing in the digital domain

Applications of DSP (1)

- Noise removal from speech.

Noisy Speech

Clean Speech

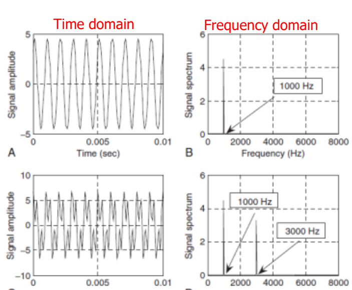


Applications of DSP (2)

- Signal spectral analysis

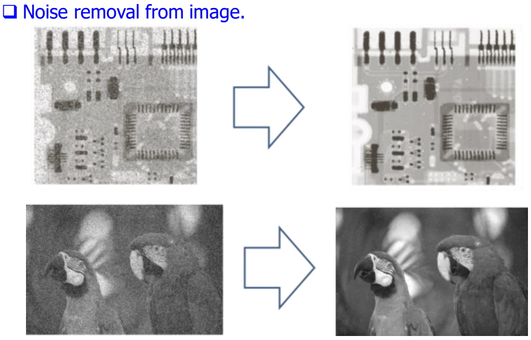
Single tone: 1000 Hz

Double tone: 1000 Hz and 3000 Hz



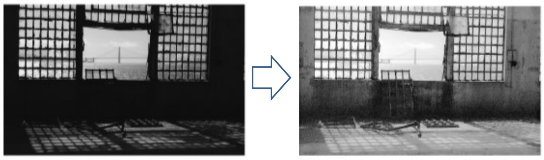
Some Applications of DSP (3)

- Noise removal from image.



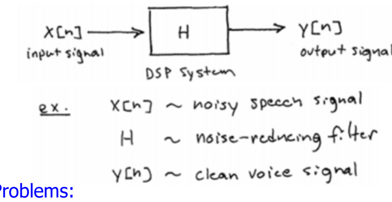
Applications of DSP (4)

- Image enhancement.



What is Digital Signal Processing (2) ?

- Basic Idea:
  - Process signals and images by performing operations on samples of continuous-time signals



- DSP Problems:
  - Given x[n], y[n], design or determine H
  - Given x[n], H, compute y[n]
  - Given H, y[n], find input x[n]

Signal Processing Operation (1): Time Domain Operation

- Scaling: $y[n] = ax[n]$
  - If a is +ve i.e. a>1, called Amplification
  - If a is -ve i.e. a<1, called Attenuation
- Delay: $y[n] = x[n - n_0]$
  - If n_0 is +ve i.e. n_0 >1, called Delay
  - If n_0 is -ve i.e. n_0 <1, called Advance
- Addition: $y[n] = ax_1[n] + bx_2[n] - cx_3[n]$
- Multiplication: $y[n] = x_1[n]x_2[n]$

Complex signal processing operations are implemented by combining two or more elementary operations

Signal Processing Operation (2): Filtering

- Filtering: operation performed by a filter
- Filter is a frequency selective device i.e. it is used to pass certain frequency components in a signal through the system without any distortion and to block other frequency components
- Passband: Range of the signal frequency component allowed to pass through the filter.
- Stop band: Range of the signal frequency component blocked by the filter.
- Filter can be designed depending upon the nature of Filtering operations
- The filtering operation of analog signal is performed by a linear, time invariant (LTI) filter i.e. convolution operation

$$y[n] = \sum_{k=-\infty}^{\infty} x[k]h[n-k] = x[n] * h[n]$$

where x[n] is the input signal, y[n] is the output of the filter, and h[n] is the impulse response of the filter

Example: Filtering of a Signal

- Frequency-selective filters can be classified according to their passbands and stopbands: **low-pass**, **high-pass**, **bandpass**, and **bandstop** filters
- **Notch filter**: blocks a single frequency component
- Consider an input signal consisting of three sinusoidal components of frequencies 50 Hz, 110 Hz, and 210 Hz