Lecture 1 Introduction

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Outline

- Preliminary

  What are the signals

  What are the systems

  Application of signals and systems

- Fundamental concepts

  Signals and systems

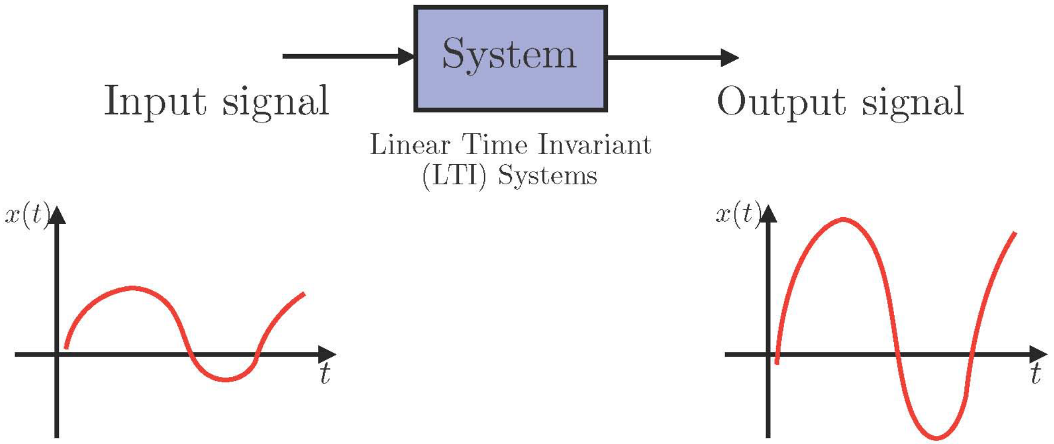
- Types of Signals

What is a Signal?

- A signal is a pattern of variation of some form
- Signals are variables that carry information
- Examples of signal include:
- Electrical signals
  – Voltages and currents in a circuit
- Acoustic signals
  – Acoustic pressure (sound) over time
- Mechanical signals
  – Velocity of a car over time
- Video signals
  – Intensity level of a pixel (camera, video) over time

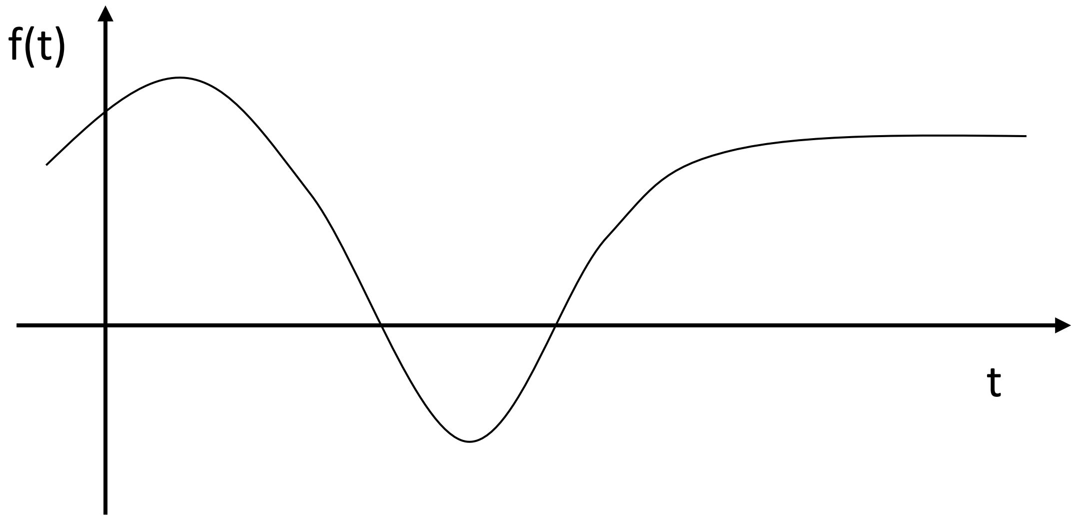
Preliminary

- A signal is a set of information of data
  - Any kind of physical variable subject to variations represents a signal
  - Both the independent variable and the physical variable can be either scalars or vectors
    - Independent variable: time (t), space (x, $\mathbf{x}=[x_1,x_2]$, $\mathbf{x}=[x_1,x_2,x_3]$)
    - Signal:
    - Electrochardiography signal (EEG) 1D, voice 1D, music 1D
    - Images (2D), video sequences (2D+time), volumetric data (3D)

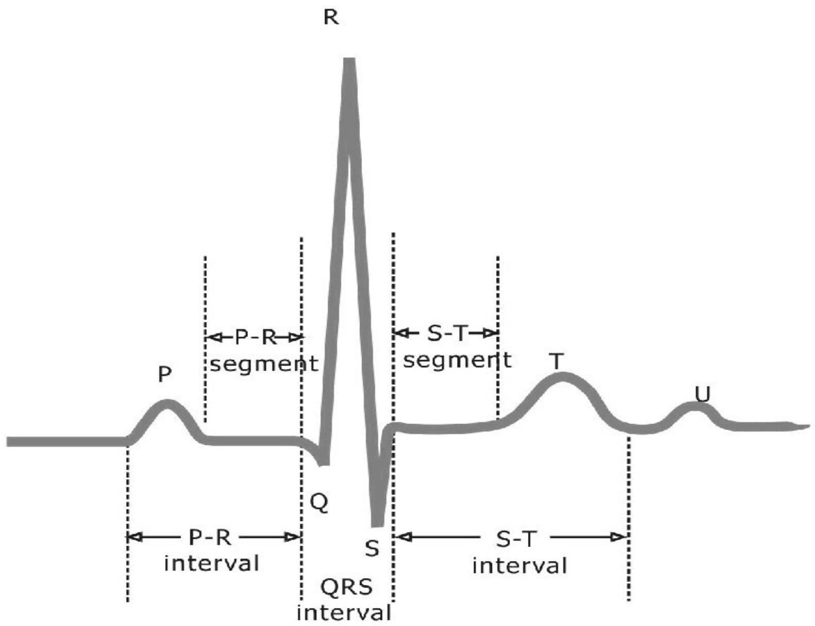


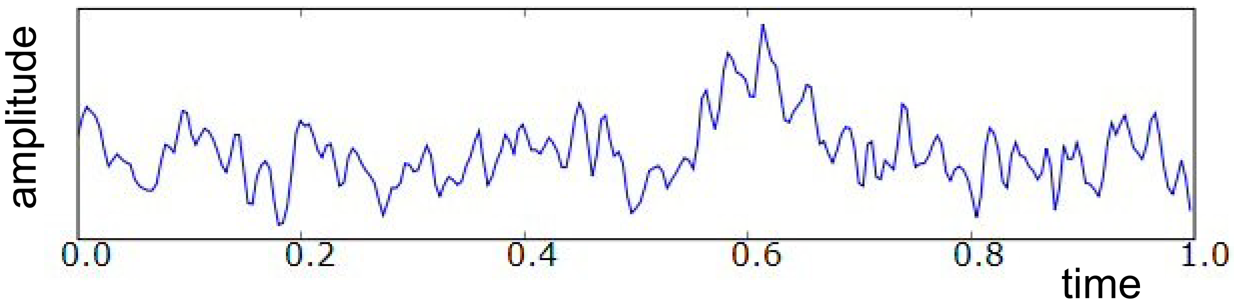
How is a Signal Represented?

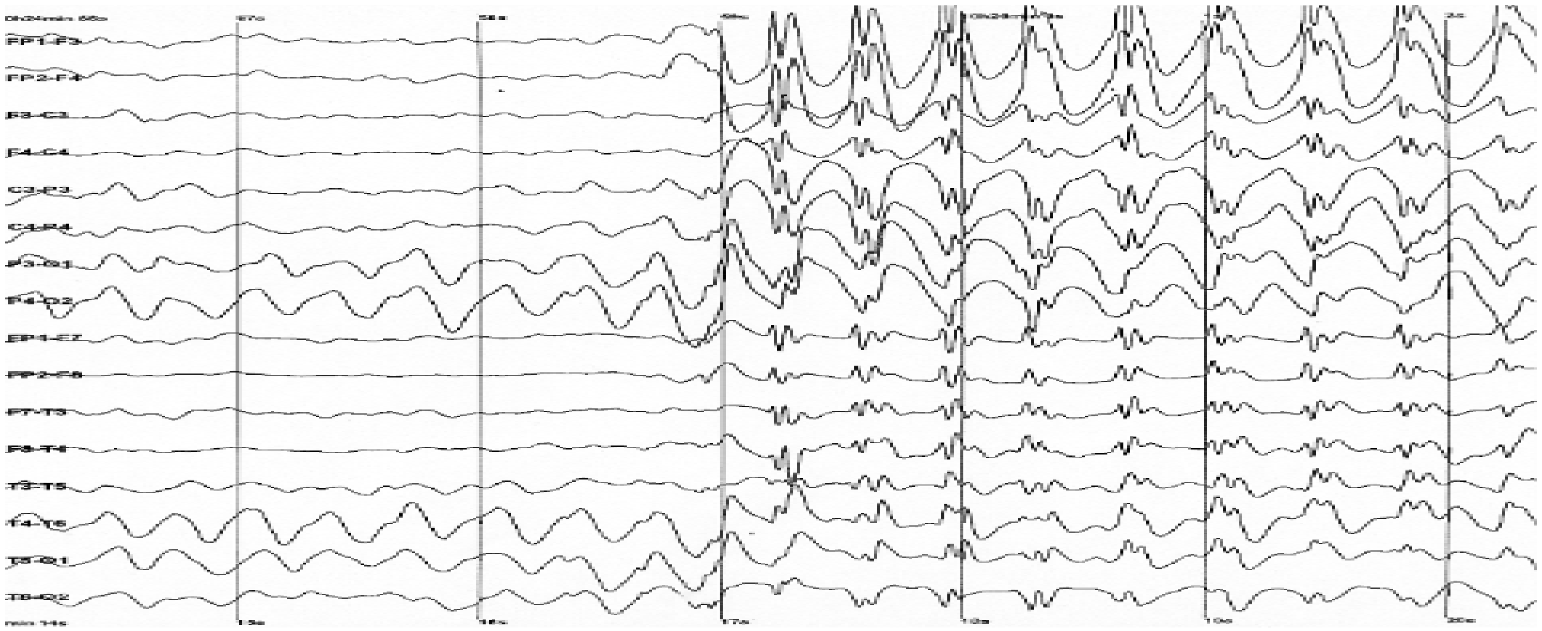
- Mathematically, signals are represented as a function of one or more **independent variables**.
- For instance a black & white video signal intensity is dependent on x, y coordinates and time t $f(x,y,t)$
- On this course, we shall be exclusively concerned with signals that are a function of a single variable: time



Example: 1D biological signals: ECG

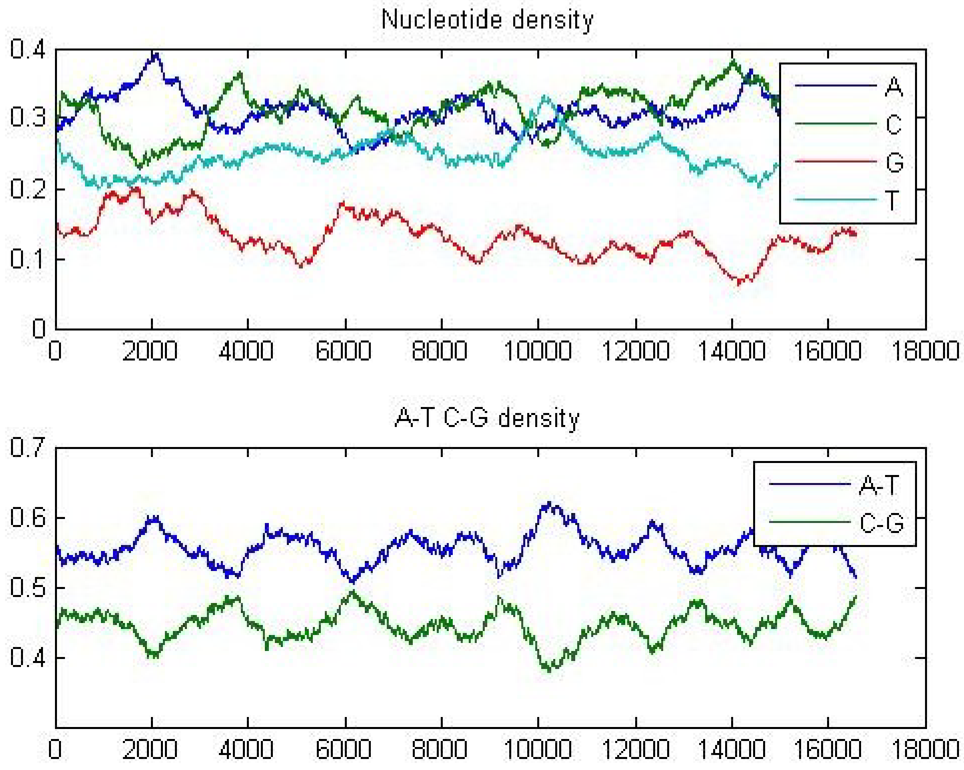






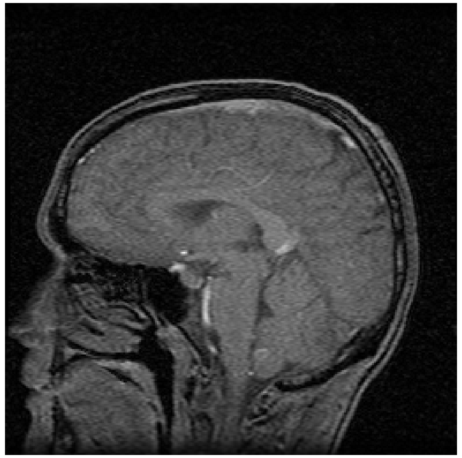
1D biological signals: DNA sequencing

GATCACAGGTCTATCACCCTATTAACCACTCACGGGAGCTCTCCATG……



Example: 2D biological signals: MI

MRI



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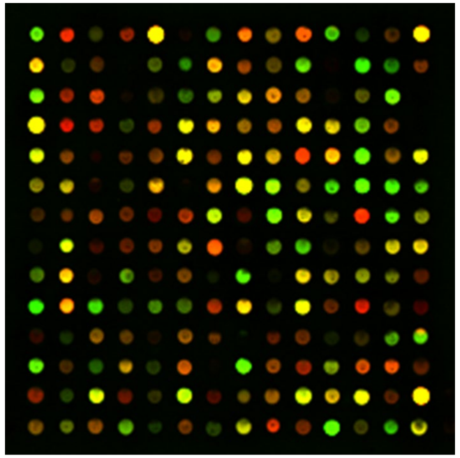

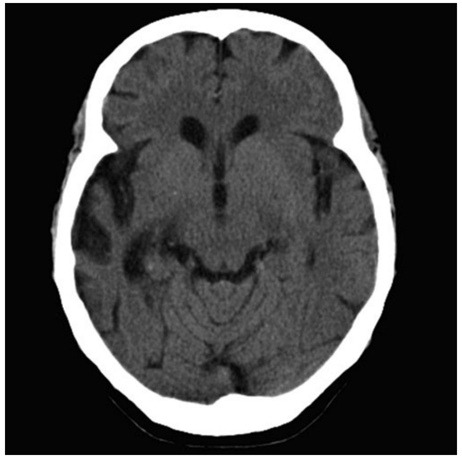

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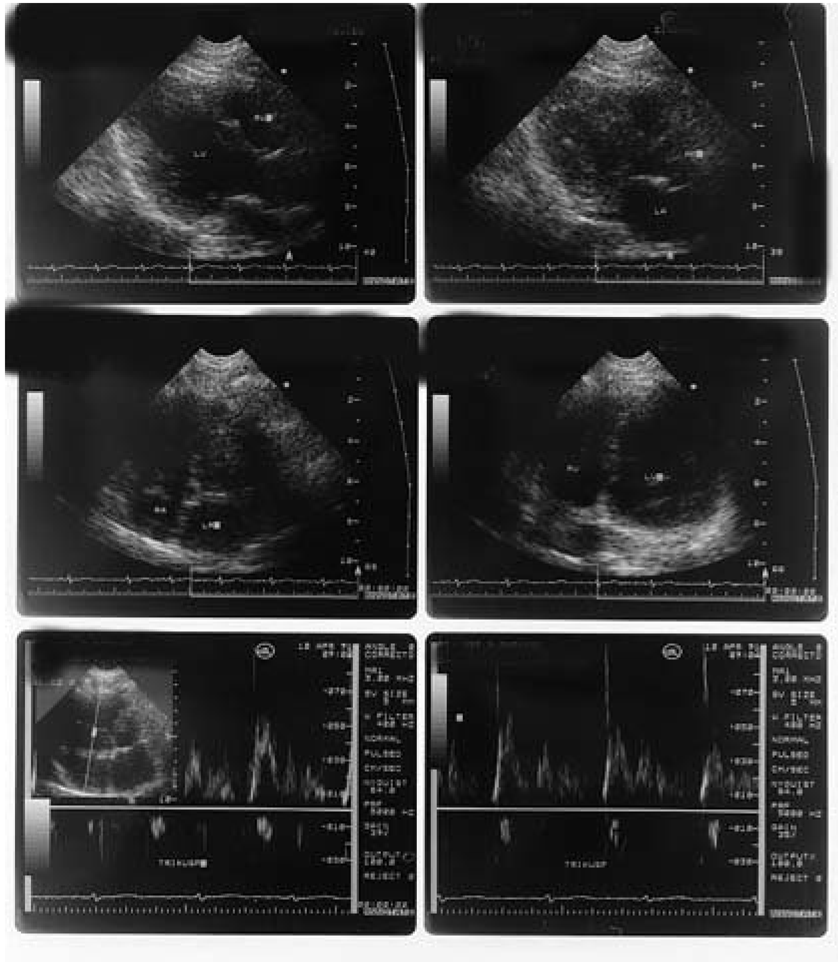


Signals as functions

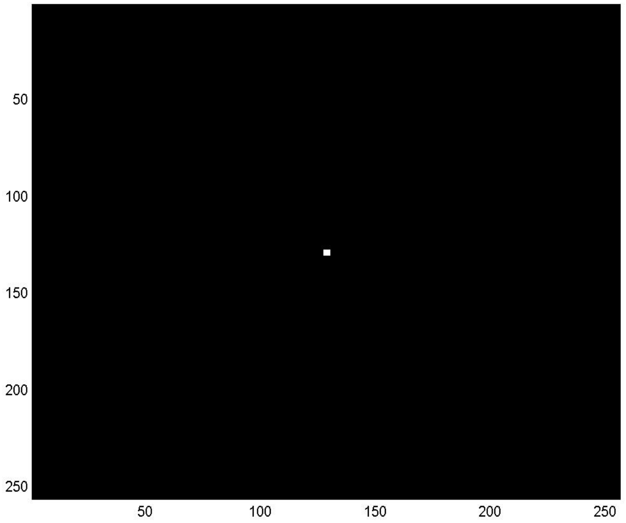
- Continuous functions of real independent variables
  - 1D: $f=f(x)$
  - 2D: $f=f(x,y)$ x,y
  - Real world signals (audio, ECG, images)
- Real valued functions of discrete variables
  - 1D: $f=f[k]$
  - 2D: $f=f[i,j]$
  - *Sampled* signals
- Discrete functions of discrete variables
  - 1D: $f^d=f^d[k]$
  - 2D: $f^d=f^d[i,j]$
  - *Sampled and quantized* signals

- Gray scale images: 2D functions
  - Domain of the functions: set of (x,y) values for which $f(x,y)$ is defined : 2D lattice $[i,j]$ defining the pixel locations
  - Set of values taken by the function : gray levels

- Digital images can be seen as functions defined over a discrete domain $\{i,j: 0<i<I, 0<j<J\}$
  - I,J: number of rows (columns) of the matrix corresponding to the image
  - $f=f[i,j]$: gray level in position $[i,j]$

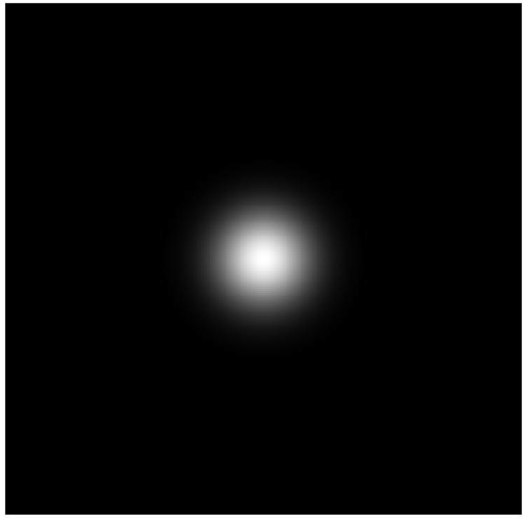
Example : function

$$\delta[i,j]=\begin{cases}1 & i=j=0\\ 0 & i,j\neq 0; i\neq j\end{cases}$$

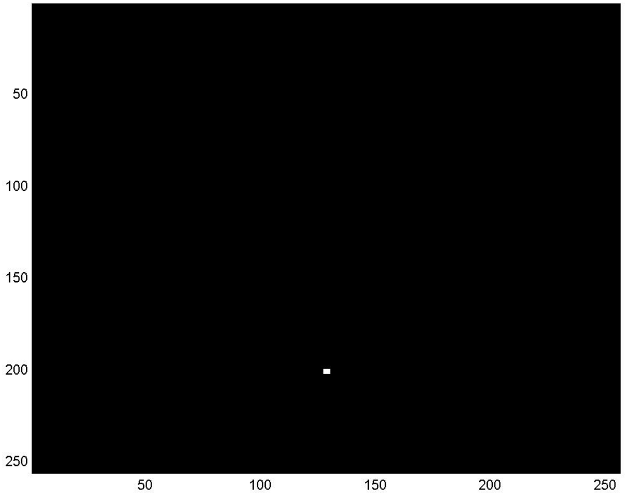


Continuous function

$$f(x,y)=\frac{1}{\sigma\sqrt{2\pi}}e^{\frac{x^2+y^2}{2\sigma^2}}$$

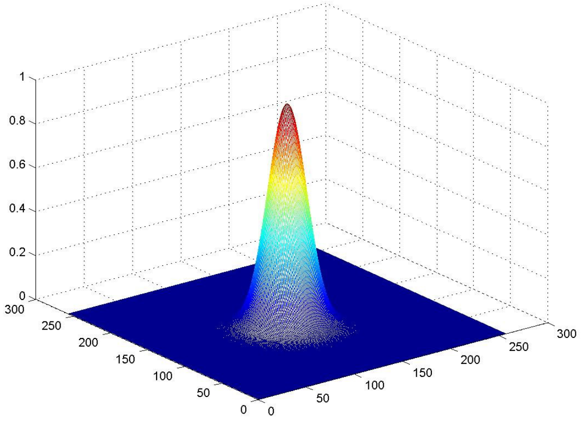


$$\delta[i,j-J]=\begin{cases}1 & i=0; j=J\\ 0 & otherwise\end{cases}$$

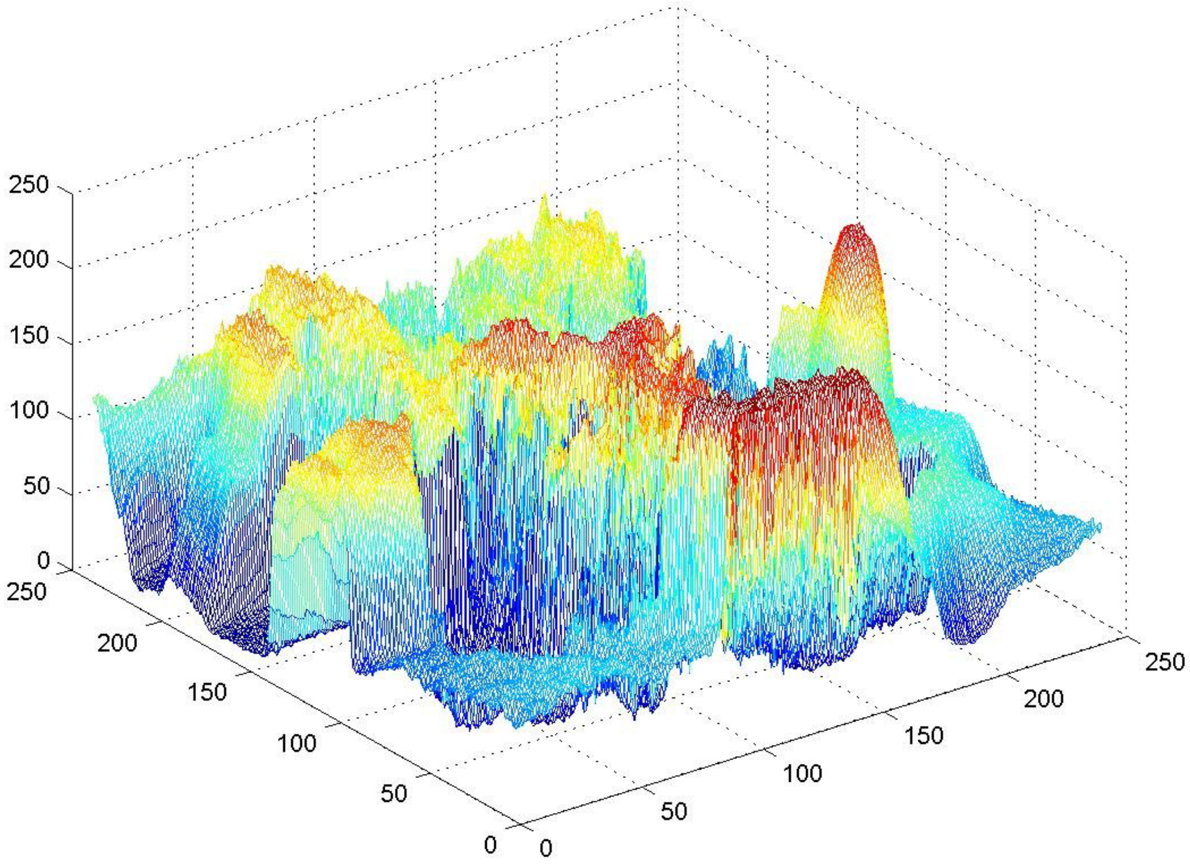


Discrete version

$$f[i,j]=\frac{1}{\sigma\sqrt{2\pi}}e^{\frac{i^2+j^2}{2\sigma^2}}$$



Example : Natural image



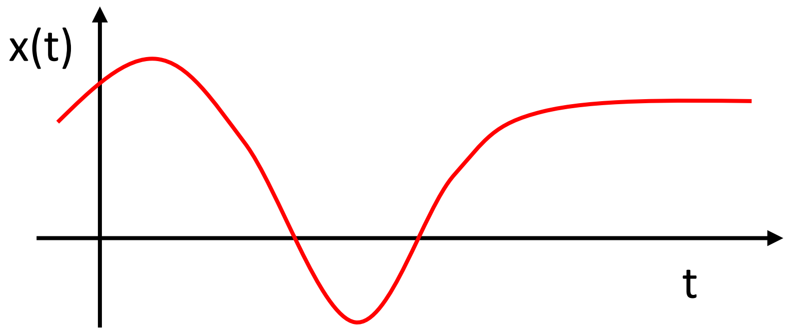
Continuous & Discrete-Time Signals

- **Continuous-Time Signals**

– Most signals in the real world are continuous time, as the scale is infinitesimally fine.

– Eg voltage, velocity,

– Denote by $x(t)$, where the time interval may be bounded (finite) or infinite

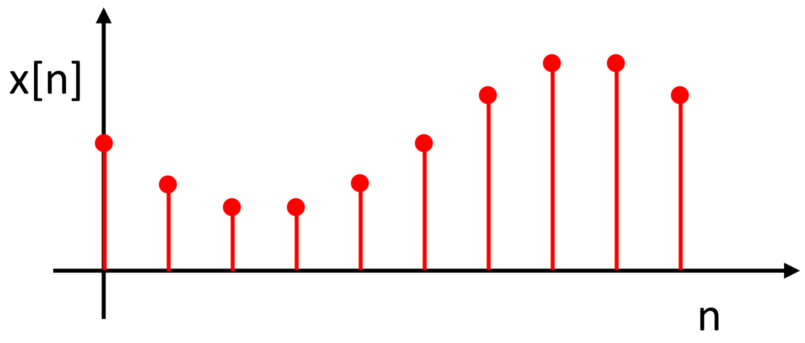


- **Discrete-Time Signals**

– Some real world and many digital signals are discrete time, as they are sampled

– E.g. pixels, daily stock price (anything that a digital computer processes)

– Denote by x[n], where n is an integer value that varies discretely



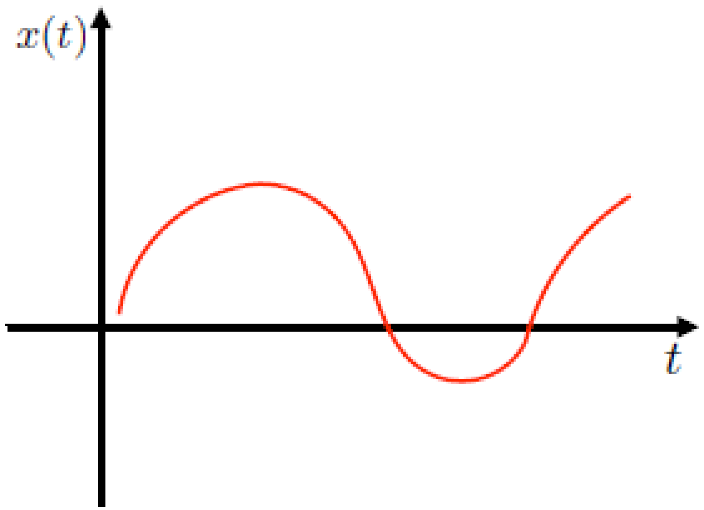
- **Sampled continuous signal**

– $x[n] = x(nk)$ – k is sample time

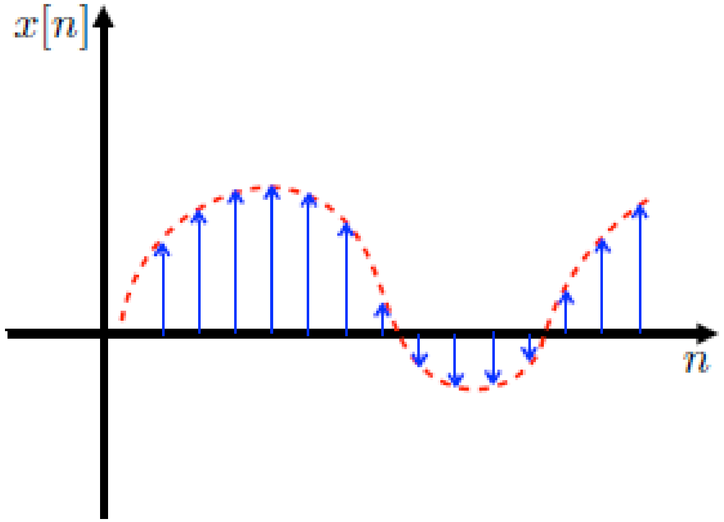
Continuous & Discrete-Time Signals

Time signals:

Continuous time signals (analog signals): for example, audio signals (FMsignals), AC voltages and currents



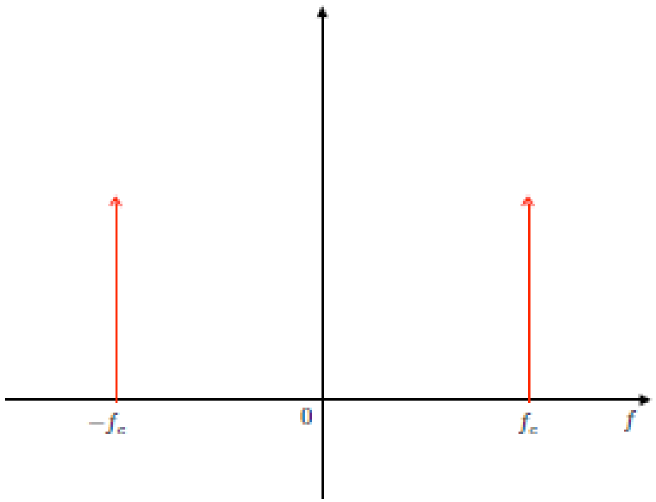
Discrete time signals (digital signals): for example, daily temperature



Note that continuous time signals and discrete time signals can be converted to each other.

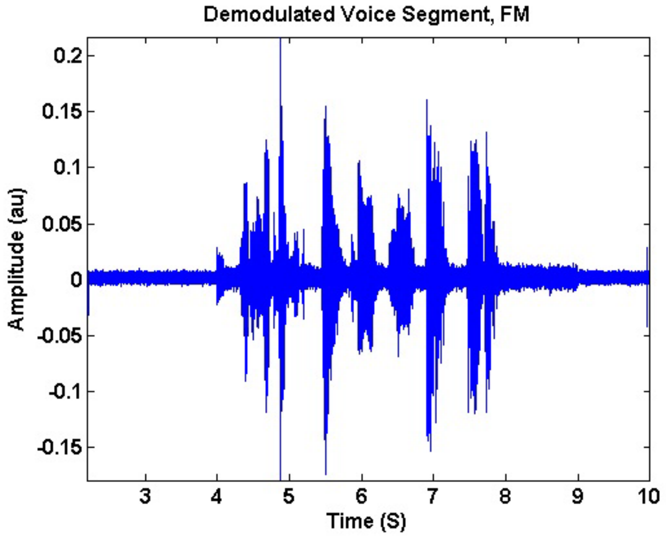
Signals in other domains

Frequency domain:



Time domain?
cos(2fct)

1D signal (e.g., voice, music): x(t) -> x[n]



2D signal (e.g., images): $x(s_1,s_2) \rightarrow x[n_1,n_2]$

3D signal (e.g., videos: 2D spatial + 1D time): $x(s_1,s_2,t) \rightarrow x[n_1,n_2,n]$

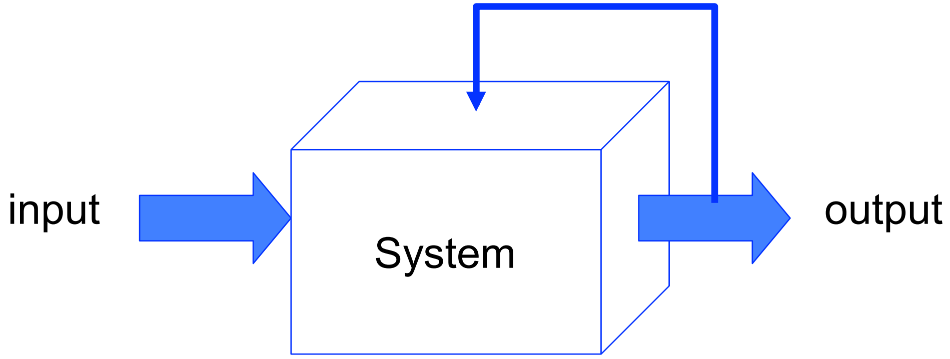
http://www.acasper.org/wp-content/uploads/2011/10/demodulatedVoiceFM.png

Signal Properties

- On this course, we shall be particularly interested in signals with certain properties:
- **Periodic signals**: a signal is periodic if it repeats itself after a fixed period T, i.e. $x(t) = x(t+T)$ for all t. A sin(t) signal is periodic.
- **Even and odd signals**: a signal is even if $x(-t) = x(t)$ (i.e. it can be reflected in the axis at zero). A signal is odd if $x(-t) = -x(t)$. Examples are cos(t) and sin(t) signals, respectively.
- **Exponential and sinusoidal signals**: a signal is (real) exponential if it can be represented as $x(t) = Ce^{at}$. A signal is (complex) exponential if it can be represented in the same form but C and a are complex numbers.
- **Step and pulse signals**: A pulse signal is one which is nearly completely zero, apart from a short spike, $d(t)$. A step signal is zero up to a certain time, and then a constant value after that time, $u(t)$.
- These properties define a large class of tractable, useful signals and will be further considered in the coming lectures

What is a System?

- **Systems process input signals to produce output signals**
- **Examples:**
  - –A circuit involving a capacitor can be viewed as a system that transforms the source voltage (signal) to the voltage (signal) across the capacitor
  - –A CD player takes the signal on the CD and transforms it into a signal sent to the loud speaker
  - –A communication system is generally composed of three sub-systems, the transmitter, the channel and the receiver. The channel typically attenuates and adds noise to the transmitted signal which must be processed by the receiver

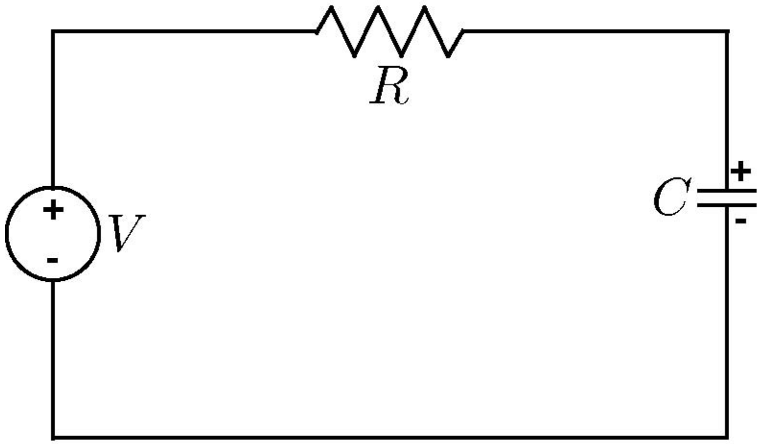


The function linking the output of the system with the input signal is called transfer function and it is typically indicated with the symbol *h(•)*

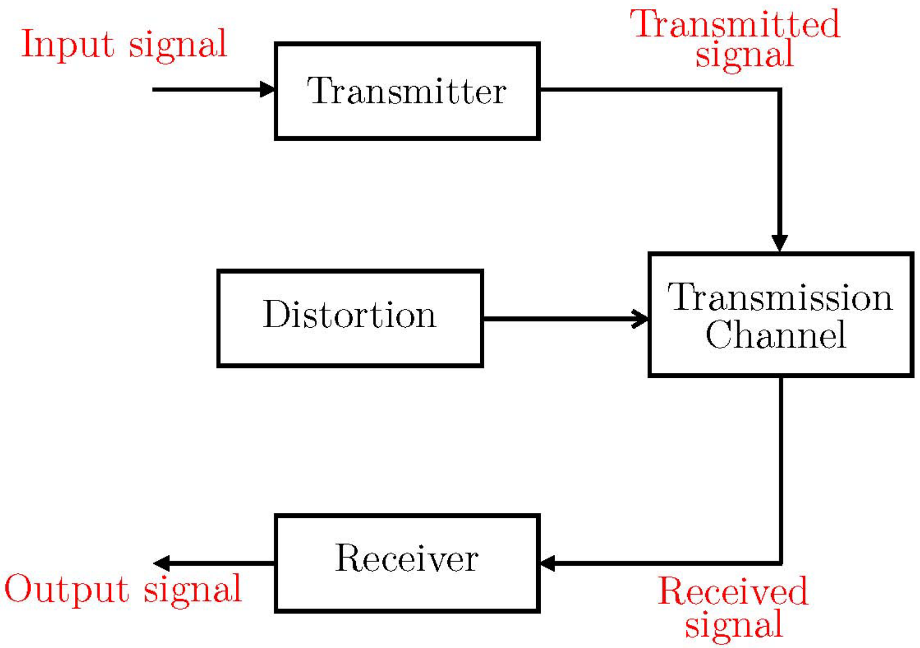
Signals and systems

- What is a system
- An entity that manipulates one or more signals to accomplish some function, including yielding some new signals.

Circuit:

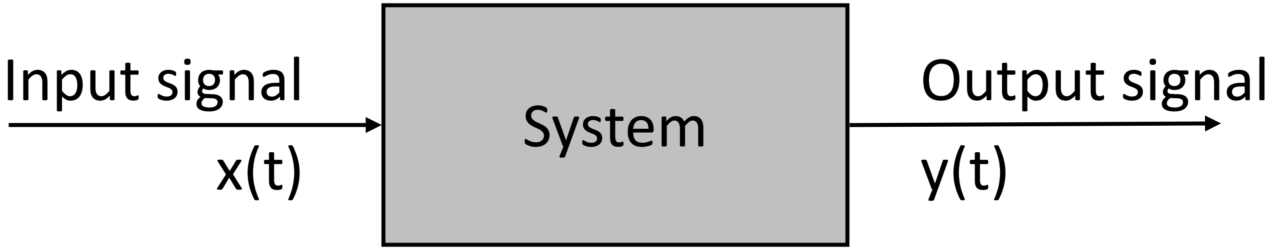


Communication systems:



How is a system Represented?

- A system takes a signal as an input and transforms it into another signal



- In a very broad sense, a system can be represented as the ratio of the output signal over the input signal
  - That way, when we “multiply” the system by the input signal, we get the output signal
  - This concept will be firmed up in the coming weeks

Continuous & Discrete-Time Mathematical Models of Systems

- **Continuous-Time Systems**

– Most continuous time systems represent how continuous signals are transformed via **differential equations**.

– E.g. circuit, car velocity

$$\frac{dv_c(t)}{dt} + \frac{1}{RC} v_c(t) = \frac{1}{RC} v_s(t)$$

$$m\frac{dv(t)}{dt} + \rho v(t) = f(t)$$

First order differential equations

- **Discrete-Time Systems**

– Most discrete time systems represent how discrete signals are transformed via **difference equations**

– E.g. bank account, discrete car velocity system

$$y[n] = 1.01y[n-1] + x[n]$$

$$v[n] - \frac{m}{m+\rho\Delta} v[n-1] = \frac{\Delta}{m+\rho\Delta} f[n]$$

$$\frac{dv(n\Delta)}{dt} = \frac{v(n\Delta) - v((n-1)\Delta)}{\Delta}$$

First order difference equations

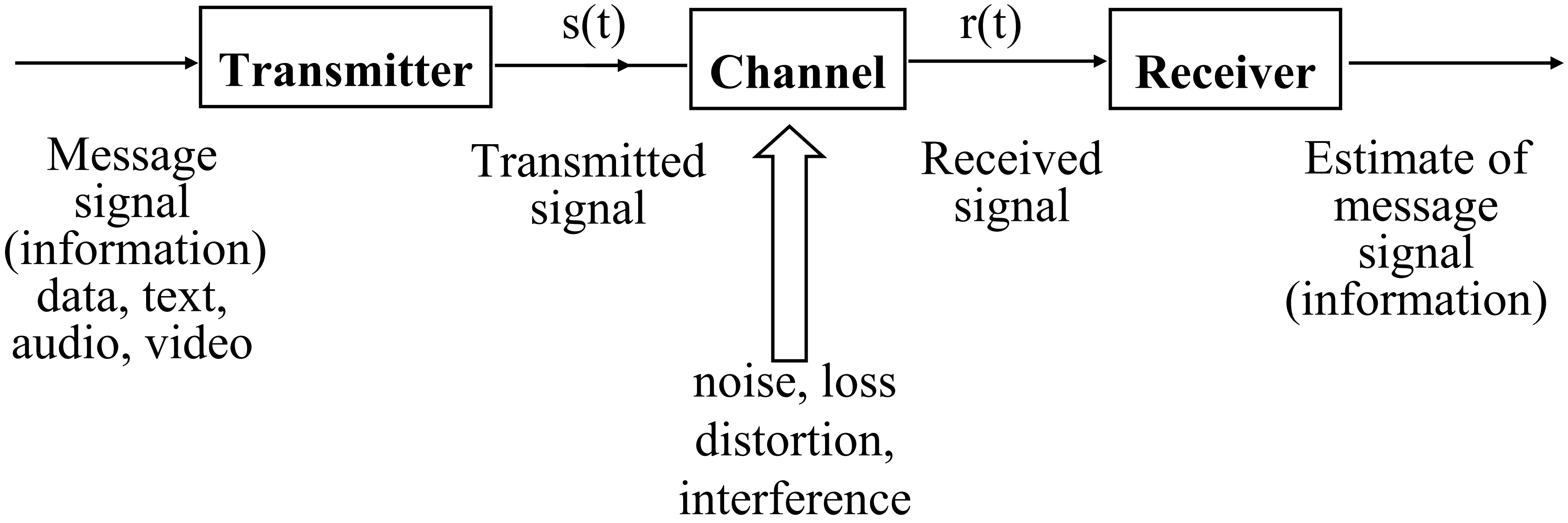
Properties of a System

- On this course, we shall be particularly interested in signals with certain properties:
- **Causal**: a system is causal if the output at a time, only depends on input values up to that time.
- **Linear**: a system is linear if the output of the scaled sum of two input signals is the equivalent scaled sum of outputs
- **Time-invariance**: a system is time invariant if the system's output is the same, given the same input signal, regardless of time.

- These properties define a large class of tractable, useful systems and will be further considered in the coming lectures

Typical Examples of Signals/Systems Concerned

- **Communication Systems**

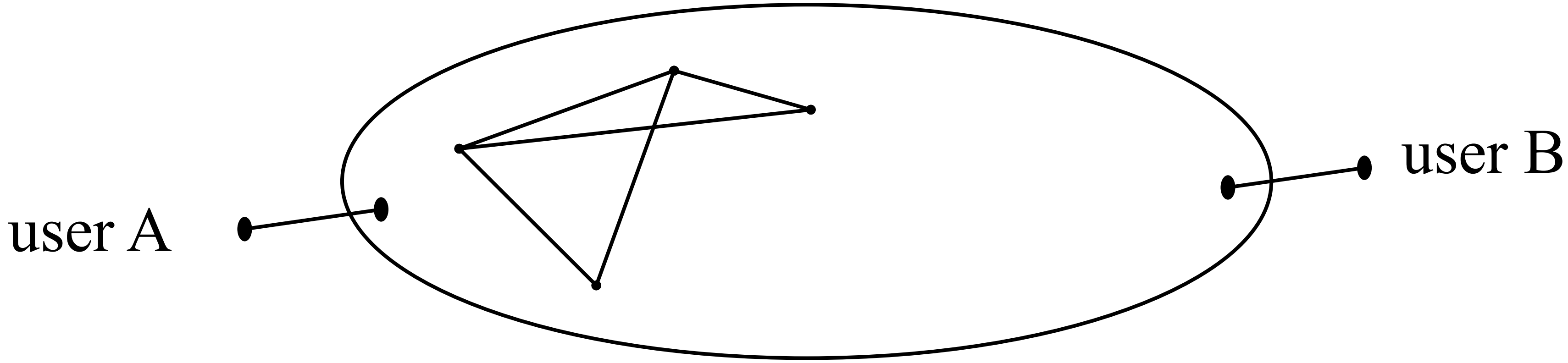


Typical Examples of Signals/Systems Concerned

- Computers
- Signal Processing Systems
  - software systems processing the signal by computation/ memory
  - examples : audio enhancement systems, picture processing systems, video compression systems, voice recognition/ synthesis systems, array signal processors, equalizers, etc.

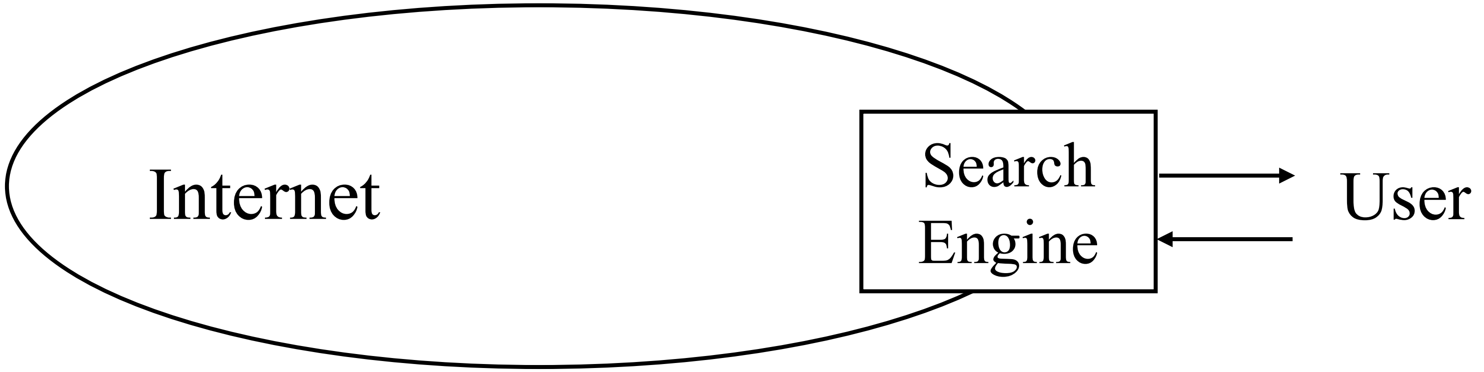
Typical Examples of Signals/Systems Concerned

- Networks



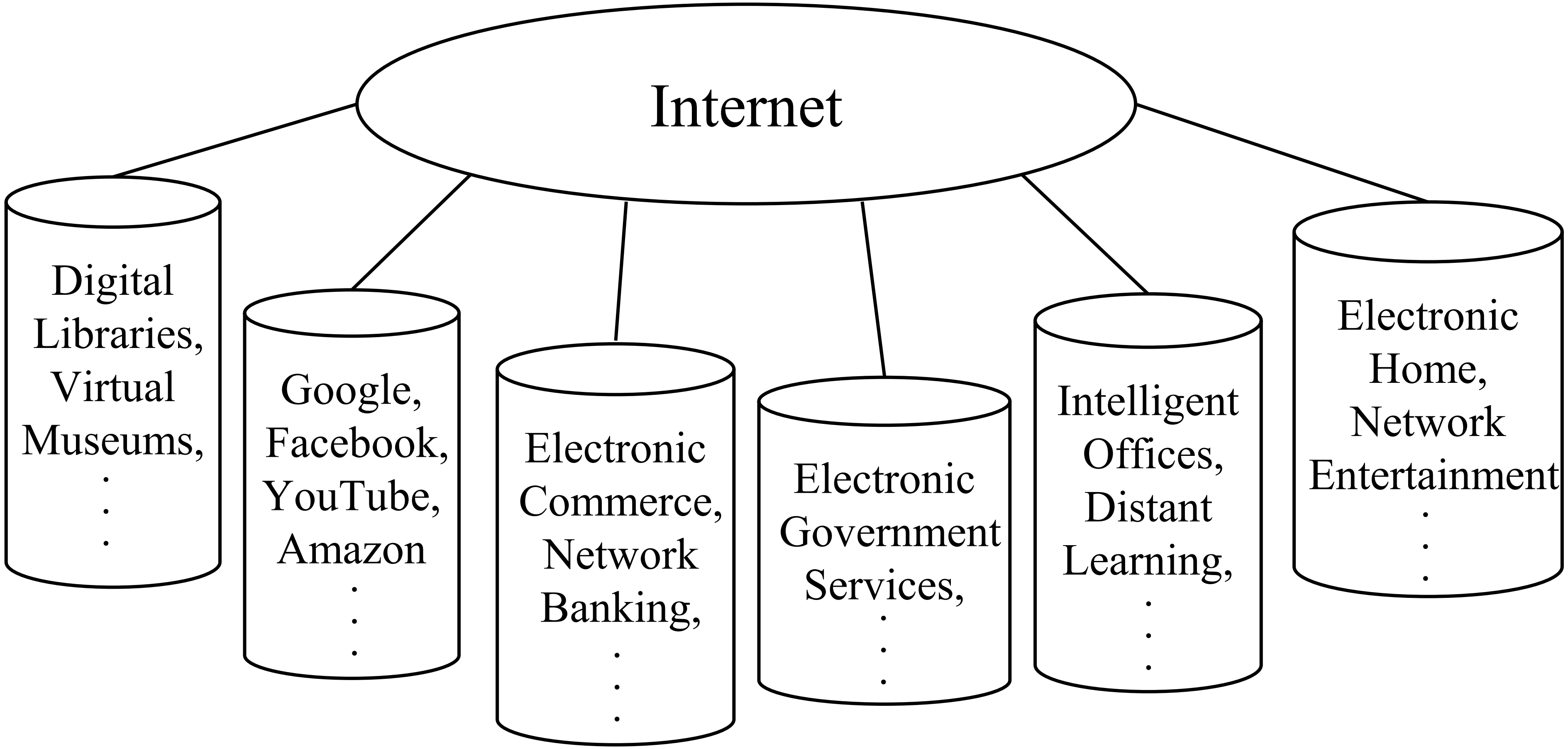
Typical Examples of Signals/Systems Concerned

- Information Retrieval Systems



- Internet
- Other Information Systems
  – examples : remote sensing systems, biomedical signal processing systems, etc.

Internet



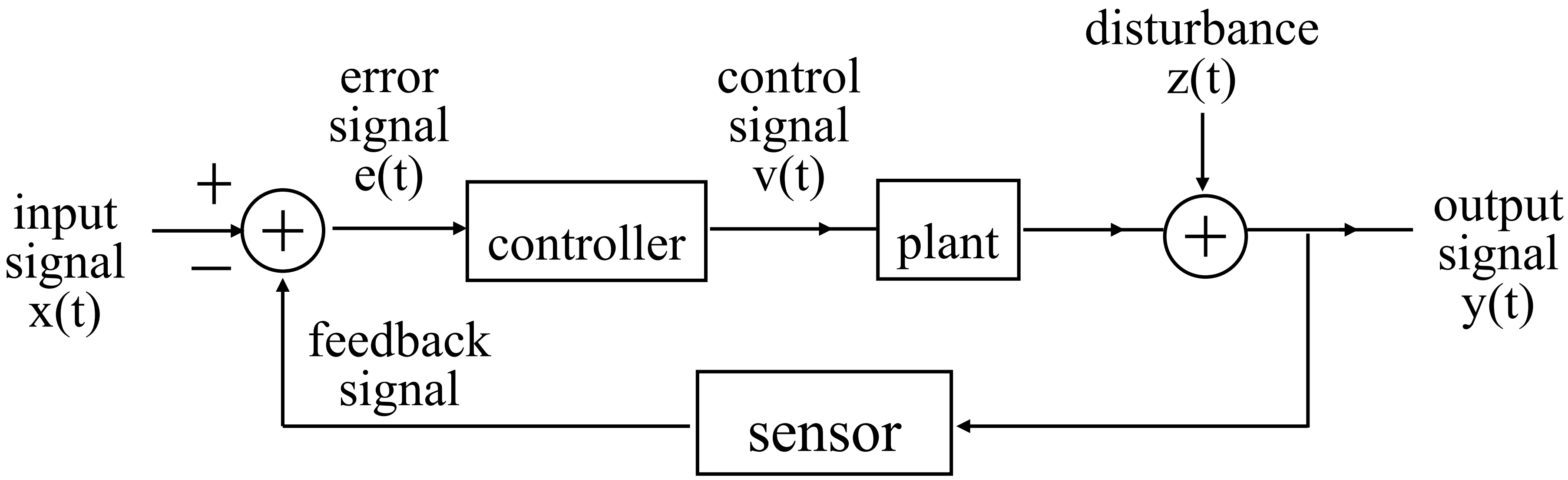
Internet
Digital Libraries, Virtual Museums, . . .
Google, Facebook, YouTube, Amazon . . .
Electronic Commerce, Network Banking, . . .
Electronic Government Services, . . .
Intelligent Offices, Distant Learning, . . .
Electronic Home, Network Entertainment . . .

Internet

- Network Technology Connects Everywhere Globally
- Huge Volume of Information Disseminated across the Globe in Microseconds
- Multi-media, Multi-lingual, Multi-functionality
- Cross-cultures, Cross-domains, Cross-regions
- Integrating All Knowledge Systems and Information related Activities Globally

Typical Examples of Signals/Systems Concerned

- Control Systems
  - close-loop/feedback control systems



  - example: aircraft landing systems, satellite stabilization systems, robot arm control systems, etc.

Typical Examples of Signals/Systems Concerned

- Other Systems
  - manufacturing systems, computer-aided-design systems, mechanical systems, chemical process systems, etc.

Outline

- **Preliminary**
  - What are the signals
  - What are the systems
  - Application of signals and systems
- **Fundamental concepts**
  - Signals and systems
- **Types of Signals**

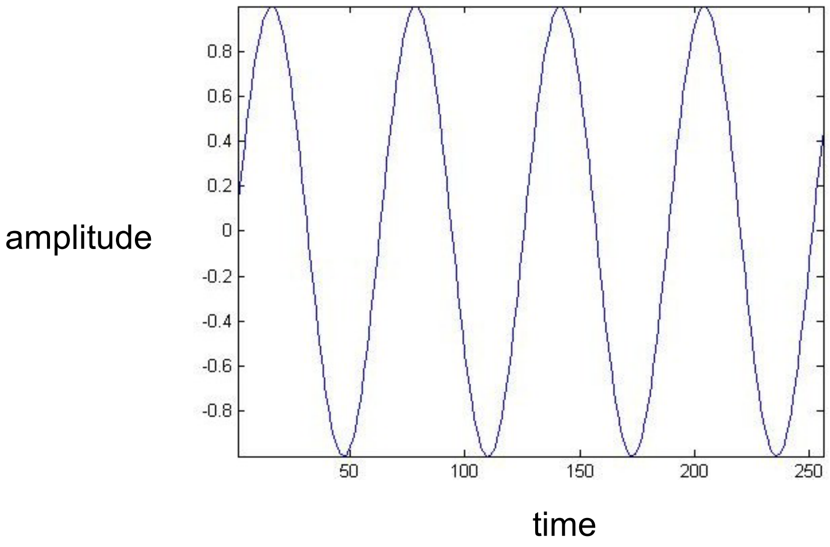
Classification of signals

- **Continuous time – Discrete time**
- **Analog – Digital (numerical)**
- **Periodic – Aperiodic**
- **Energy – Power**
- **Deterministic – Random (probabilistic)**
- **Note**
  - Such classes are not disjoint, so there are digital signals that are periodic of power type and others that are aperiodic of power type etc.
  - Any combination of single features from the different classes is possible

Continuous time – discrete time

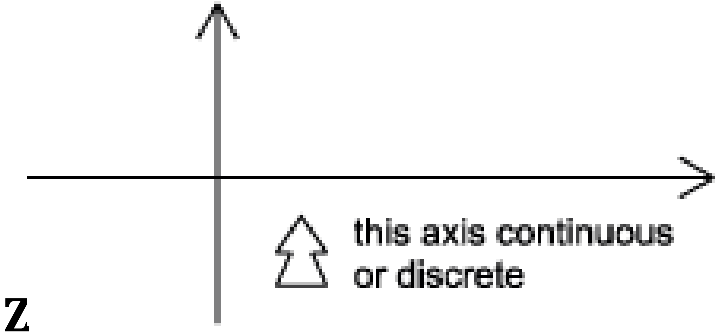
- **Continuous time signal: a signal that is specified for every real value of the independent variable**
  - The independent variable is continuous, that is it takes any value on the real axis
  - The domain of the function representing the signal has the cardinality of real numbers
    - Signal $\leftrightarrow$ f=f(t)
    - Independent variable $\leftrightarrow$ time (t), position (x)
    - For continuous-time signals:

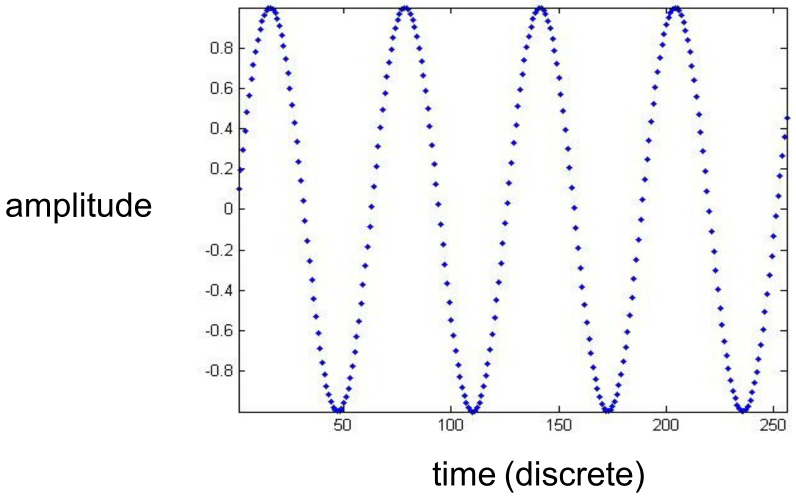
$$t \in \mathbb{R}$$



Continuous time – discrete time

- Discrete time signal: a signal that is specified only for *discrete values* of the independent variable
  - It is usually generated by *sampling* so it will only have values at *equally spaced*
    intervals along the time axis
  - The domain of the function representing the signal has the cardinality of integer numbers

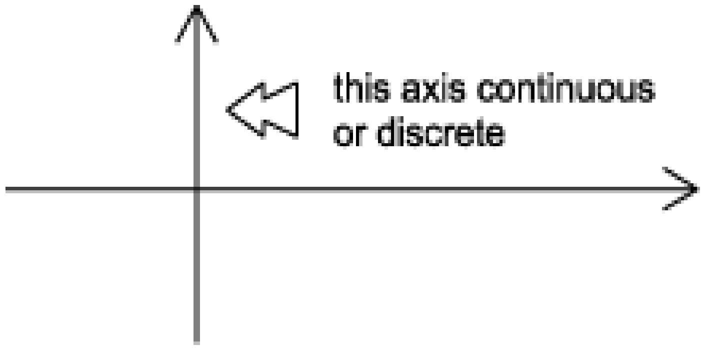




- Signal ↔ f=f[n], also called “sequence”
- Independent variable ↔ n
- For discrete-time functions: $t \in \mathbf{Z}$

Analog - Digital

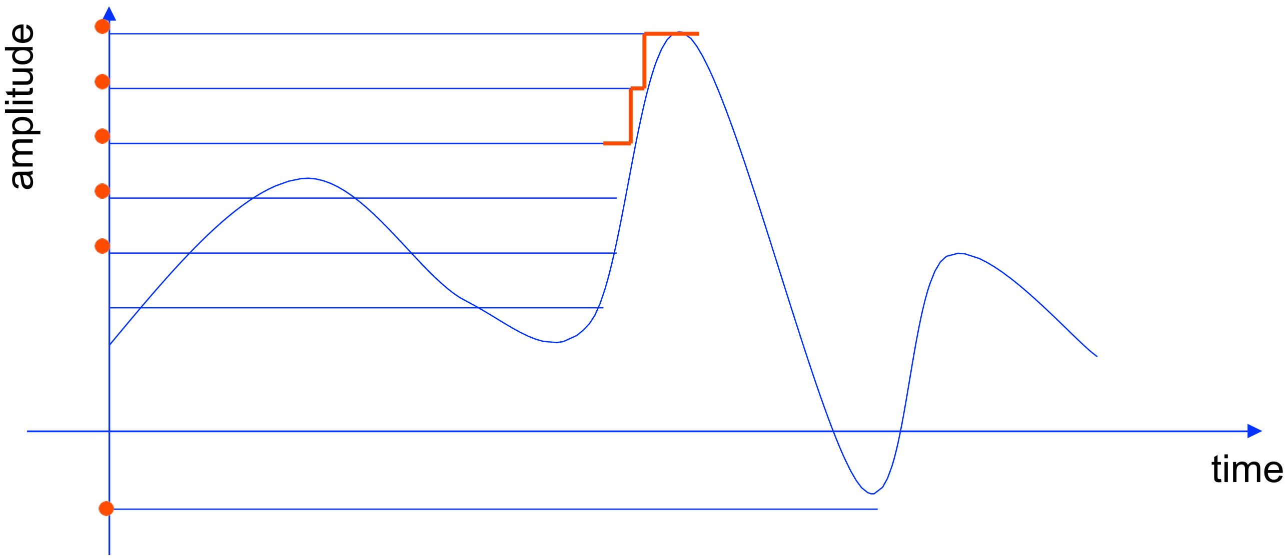
- **Analog signal**: signal whose amplitude can take on any value in a continuous range
  - The amplitude of the function f(t) (or f(x)) has the cardinality of real numbers
    - The difference between analog and digital is similar to the difference between continuous-time and discrete-time. In this case, however, the difference is with respect to the value of the function (y-axis)
  - Analog corresponds to a continuous y-axis, while digital corresponds to a discrete y-axis



- *Here we call digital what we have called quantized in the EI class*
- An analog signal can be both continuous time and discrete time

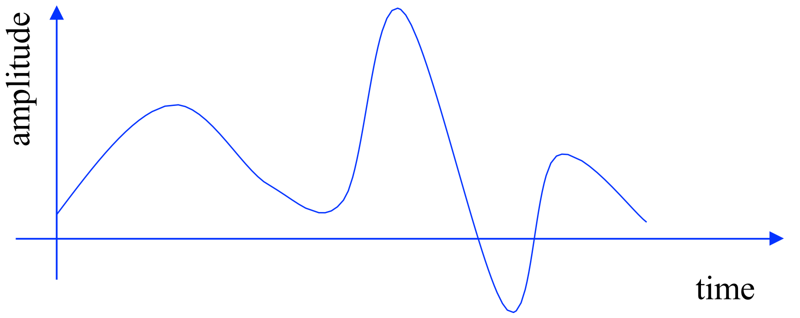
Analog - Digital

- **Digital signal**: a signal is one whose amplitude can take on only a finite number of values (thus it is quantized)
  - The amplitude of the function f() can take only a finite number of values
  - A digital signal whose amplitude can take only M different values is said to be Mary
    - Binary signals are a special case for M=2

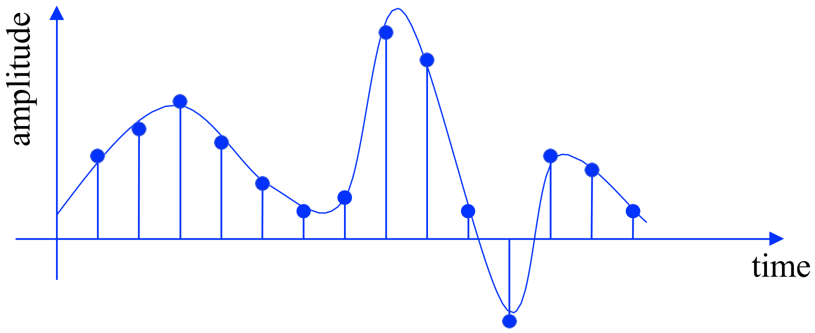


Example

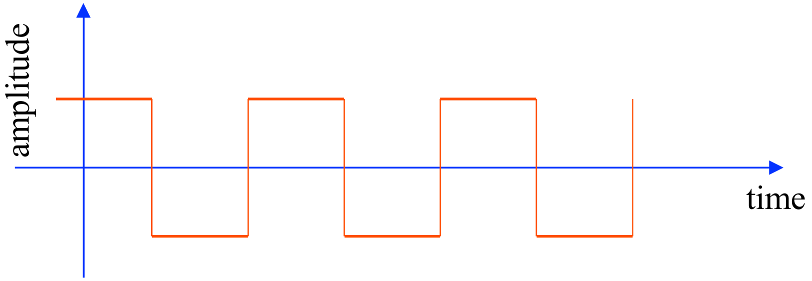
- Continuous time analog



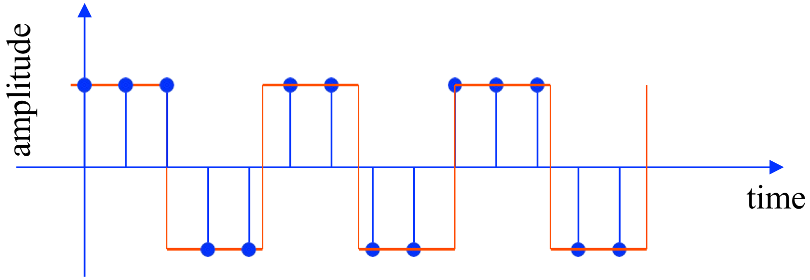
- Discrete time analog



- Continuous time digital (or quantized)
  - binary sequence, where the values of the function can only be one or zero.



- Discrete time digital
  - binary sequence, where the values of the function can only be one or zero.



Summary

Signal amplitude/ Time or space	Real	Integer
Real	Analog Continuous-time	Digital Continuous-time
Integer	Analog Discrete-time	Digital Discrete time