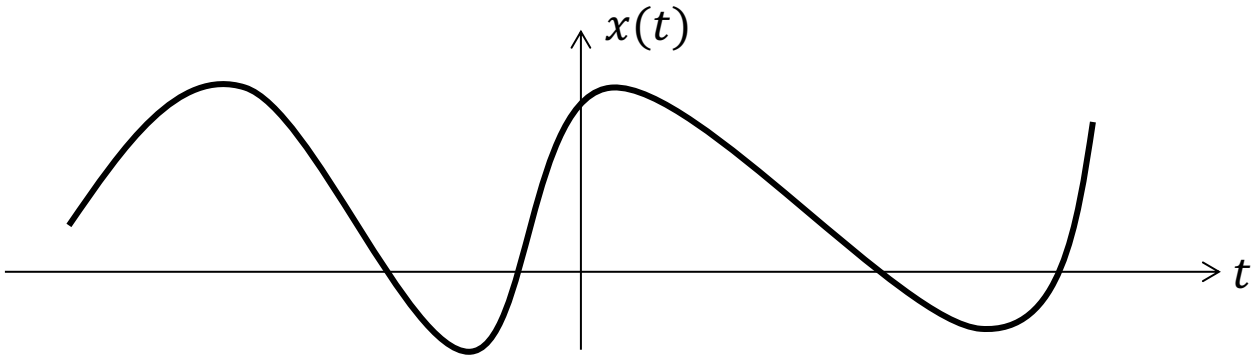
Outline

- Introduction to Signals, Systems and Transforms
  - Signal Definition
  - System definition
  - Continuous-time vs. Discrete-time
  - Analog vs. Digital

Signal Definition

- A signal is a mathematical function of one or more independent variables which conveys information on the nature of a physical phenomenon.
- For a function f, in the expression $f(t_1, t_2, \ldots, t_n)$, each of the $\{t_k\}$ is called an independent variable, while the function value itself is referred to as a dependent variable.



- Examples:
  - Temperature
  - Voltage or current in an electronic circuit
  - Position, velocity, or acceleration of an object
  - A force or torque in a mechanical system

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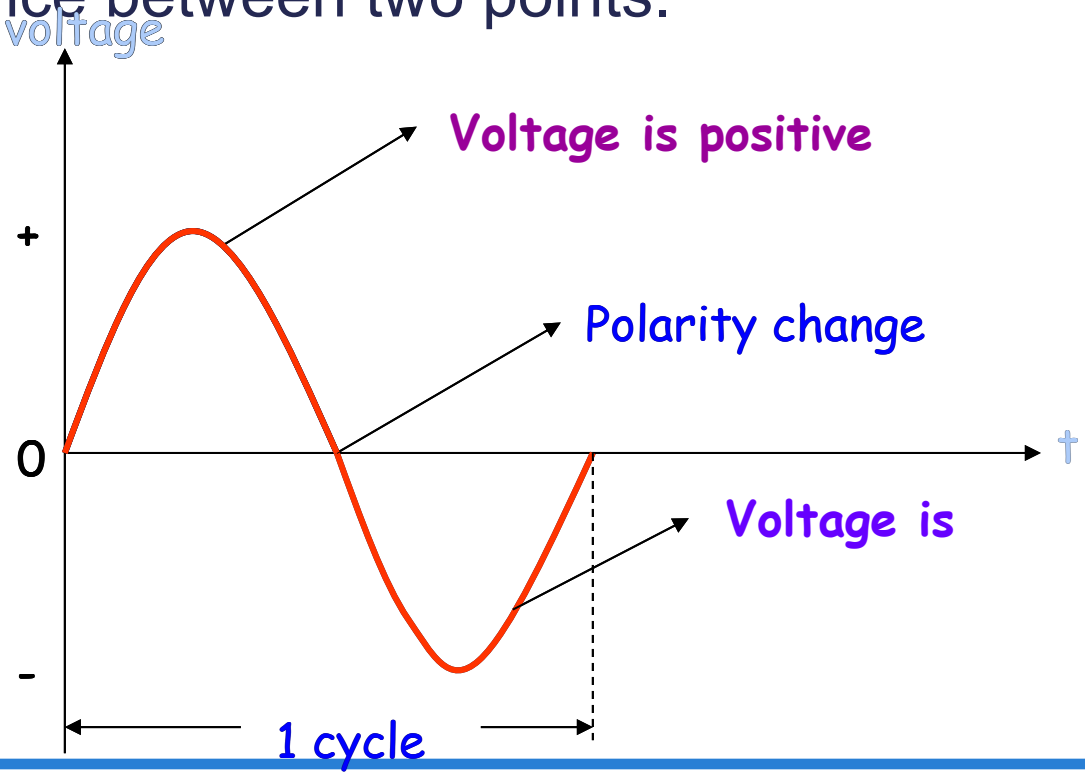
- $x(t)$: signal of one independent variable t (e.g. time), x is called dependent variable.
- A common convention is to refer to the independent variable as time, although may in fact not.
- $f(t, x, y, z)$ is a signal of four independent variables.

Modeling

- Physical signal $\xrightarrow{Modeling}$ Mathematical function
- Examples:
  - Temperature of the room
  - Potential difference between two points.
  - AC voltage



Classification of Signals

- Number of independent variables (i.e., dimensionality):
  - A signal with *one* independent variable is said to be one dimensional (e.g., audio).
  - A signal with *more than one* independent variable is said to be multi-dimensional (e.g., image).
- Continuous or discrete independent variables:
  - A signal with *continuous* independent variables is said to be continuous time (CT) (e.g., voltage waveform).
  - A signal with *discrete* independent variables is said to be discrete time (DT) (e.g., stock market index).
- Continuous or discrete dependent variable:
  - A signal with a *continuous* dependent variable is said to be continuous valued (e.g., voltage waveform).
  - A signal with a *discrete* dependent variable is said to be discrete valued (e.g., digital image).
- A *continuous-valued CT* signal is said to be analog (e.g., voltage waveform).
- A *discrete-valued DT* signal is said to be digital (e.g., digital audio).

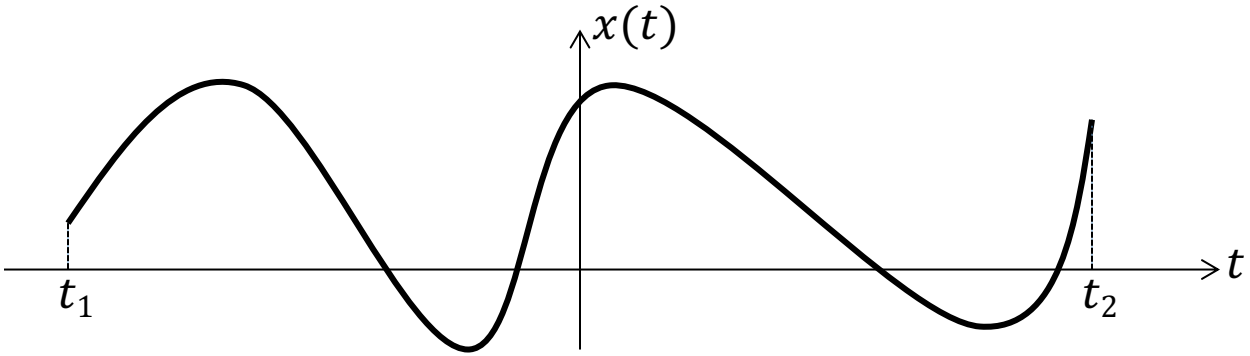
Continuous-time vs. Discrete-time

- The independent variable may be either continuous or discrete.

- Continuous-time signals:

defined at every instant of time over some time interval.

- $x(t)$ where t can take any real value.
- $x(t)$ may be 0 for a given range of values of t.



Values for x may be real or complex

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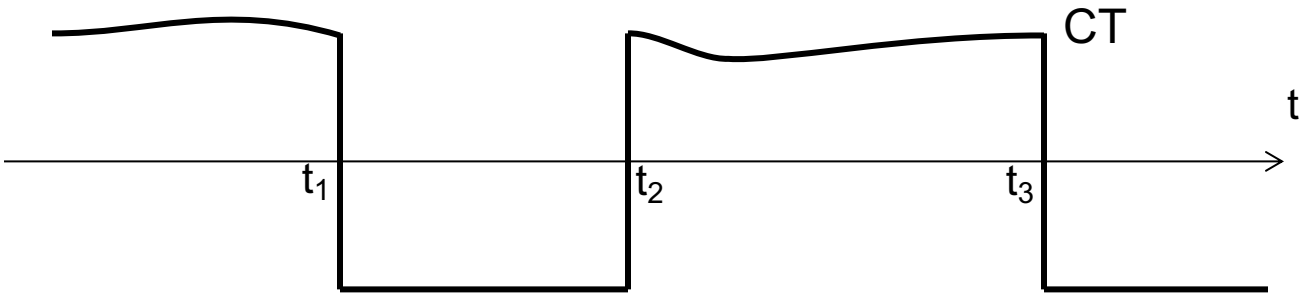
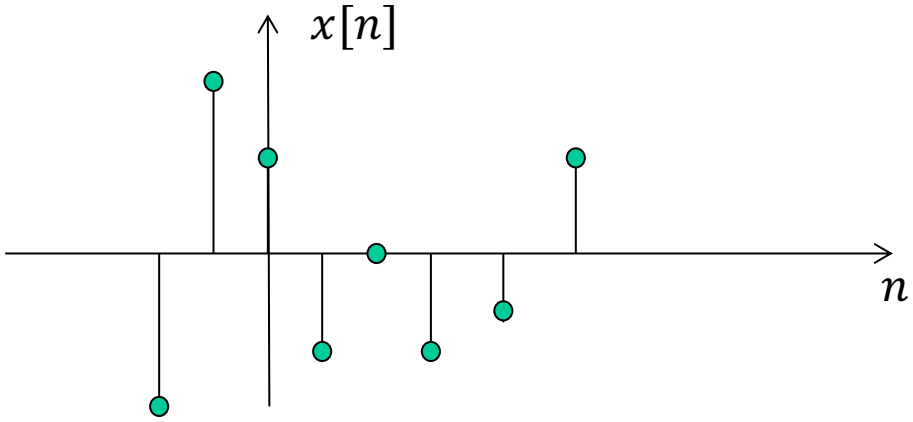


- t_1, t_2, and t_3 are points of discontinuity.
- CT is defined at a continuum points in time
  $\Rightarrow t \in \mathbb{R}, \quad \mathbb{R}: set\ of\ real\ numbers.$
- A CT signal is not necessarily to be continuous at every point in time.

Cont..

- Discrete-time signals: defined at discrete points in time and not between them.
- The independent variable takes only a discrete set of values.

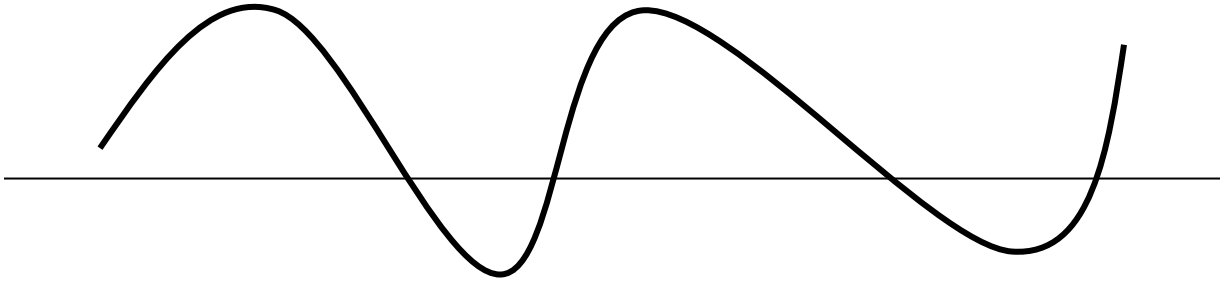
$x[n]$ where $n \in \mathbb{Z} = \{\ldots -3, -2, -1, 0, 1, 2, 3 \ldots\}$



- Values of x may be real or complex

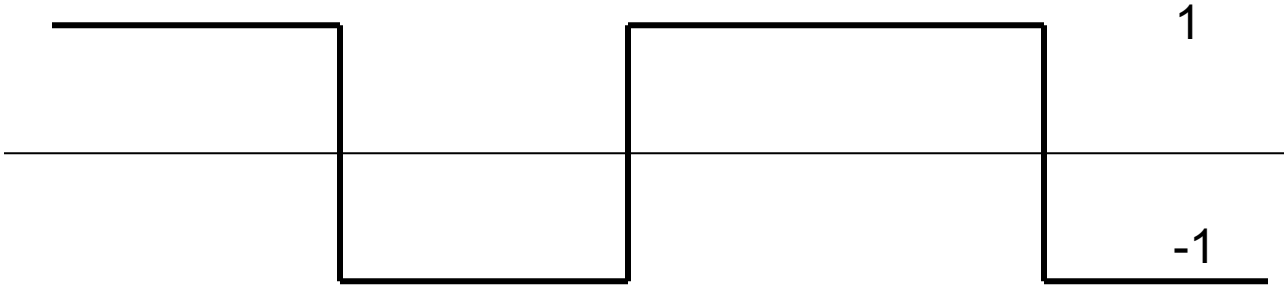
Analog vs. Digital

- The signal amplitude may be either continuous or discrete
- At each time value, analog signal amplitude takes real or complex value (a.k.a. continuous-valued)



Analog continuous-time signal

- Digital signal amplitude takes values from a discrete set "finite number of values" (a.k.a. discrete-valued)



Digital continuous-time signal

Reminder:

- Finite set: has a beginning and end and the number of elements is countable.
  - Every finite set is countable
  - e.g., {-1,0,1,2}, $\{x \in \mathbb{Z}: -2 < x \leq 2\}$
- Infinite set: does not has start or end or has both start and end but is uncountable.
  - e.g., infinite and countable: {…,2,4,6,8}, {-1,1,3,5,7,…}, {…,2,5,8,11,14,…}.
  - e.g., infinite and uncountable: $\{x \in \mathbb{R}: -2 < x \leq 2\}$
- If the signal's amplitude (A) is a finite set $\Longrightarrow$ the signal is Digital, otherwise it is Analog.

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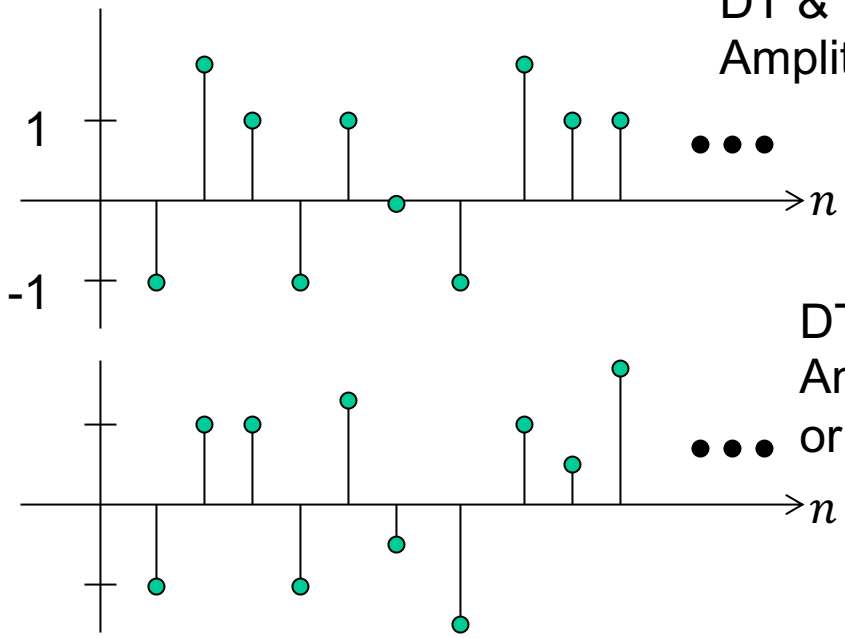
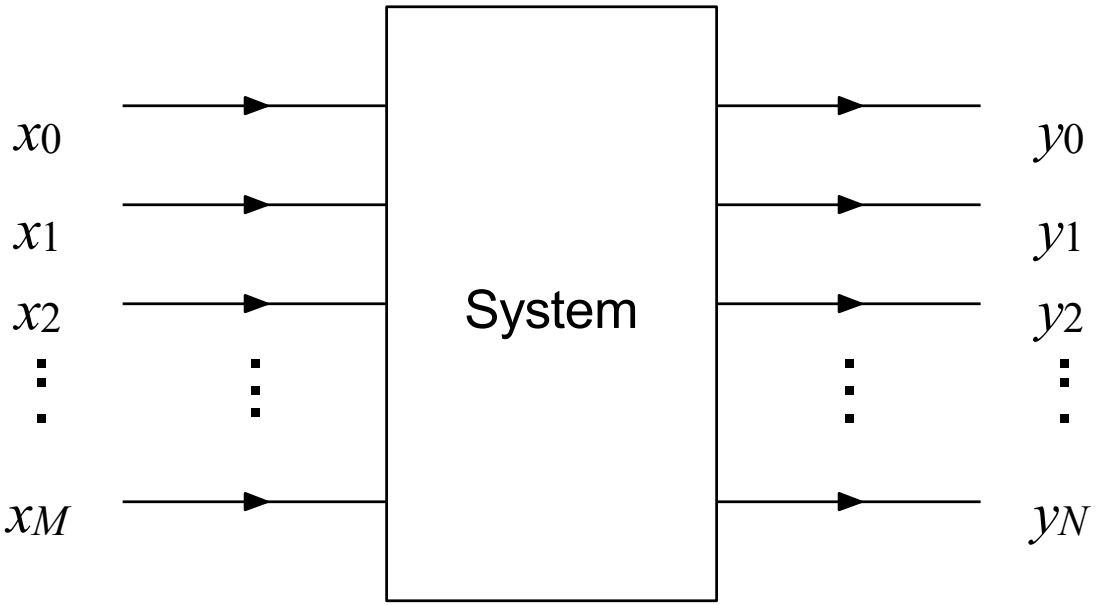
- Example:



- CT & DT: qualify the nature of the signal along the time (horizontal) axis.
- Analog & Digital: qualify the nature of the signal along the amplitude (vertical) axis.

System definition

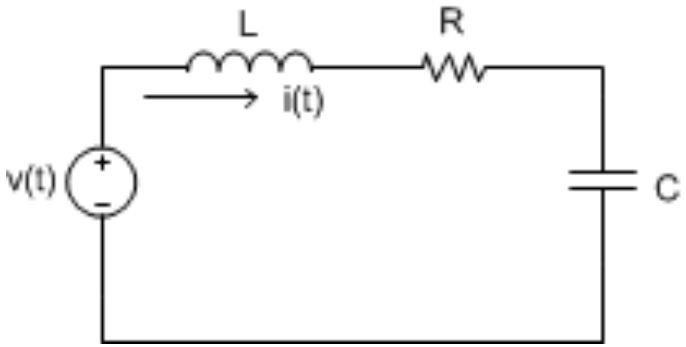
- An entity that manipulates one ore more signals to accomplish a function (job), thereby yielding new signals.
- Any *process* or *interaction of operations* that transforms an input signal into an output signal with properties different from those of the input.
- Examples:
  - Air-turbine
  - Car motor
  - Kettle
  - Radio receiver



System Modeling

Physical System $\xrightarrow{Modeling}$ Mathematical Equations

- Example:



$$R\,i(t) + L\frac{di(t)}{dt} + \frac{1}{C}\int_{-\infty}^{t} i(\tau)d\tau = v(t)$$

Integro-differential Equation

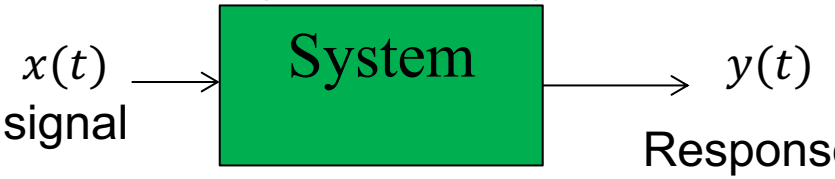
Classification of Systems

- Number of inputs:
  - A system with *one* input is said to be single input (SI).
  - A system with *more than one* input is said to be multiple input (MI).
- Number of outputs:
  - A system with *one* output is said to be single output (SO).
  - A system with *more than one* output is said to be multiple output (MO).
- Types of signals processed:
  - A system can be classified in terms of the *types of signals* that it processes. Consequently, terms such as the following (which describe signals) can also be used to describe systems:
    - one-dimensional and multi-dimensional, continuous-time (CT) and discrete-time (DT), and analog and digital.
  - For example, a continuous-time (CT) system processes CT signals and a discrete-time (DT) system processes DT signals.

Types of Systems

- Systems are classified according to the number of inputs and outputs to:

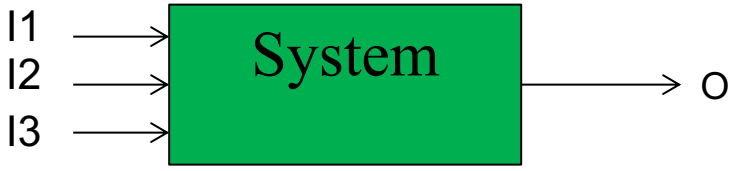
SISO: Single-Input Single-Output



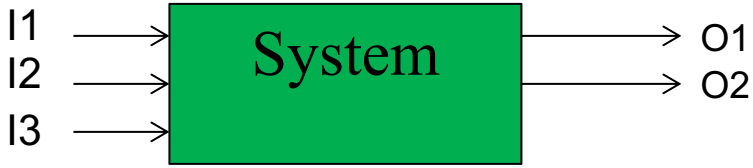
Excitation signal
Input: I

Response signal Output: O

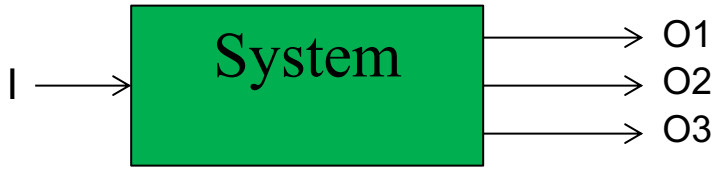
MISO: Multi-Input Single-Output



MIMO: Multi-Input Multi-Output

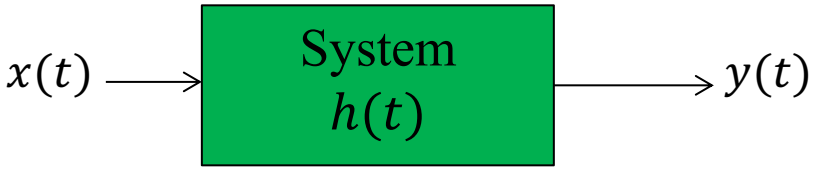


SIMO: Single-Input Multi-Output

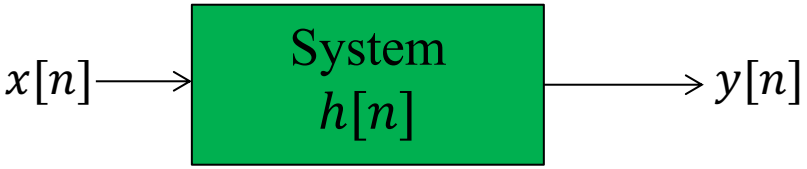


Continuous-time vs. Discrete-time system

- Systems are classified according to the type of input signals and output signals.
- Continuous-time system: all the signals are CT signals.



- Discrete-time system: all the signals are DT signals.



Example: CT Signal and System

- The following RLC circuit is a straight example of a CT system
- The system can be described using the following differential equation

$$L\frac{di(t)}{dt} + Ri(t) + \frac{1}{C}\int_{-\infty}^{t} i(\tau)d\tau = v(t).$$

- The sinusoidal input voltage V_s is an example of a CT signal
- The output current *I* is another example of a CT signal