SE 207: Modeling and Simulation

Unit 1

Introduction to Modeling and Simulation

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Term 072

Unit Contents and Objectives

- Lesson 1: Introduction
- Lesson 2: Classification of Systems

Unit 1 Objectives:

- To give an overview of the course (Modeling & simulation).
- Define important terminologies
- Classify systems/models

SE 207: Modeling and Simulation

Unit 1

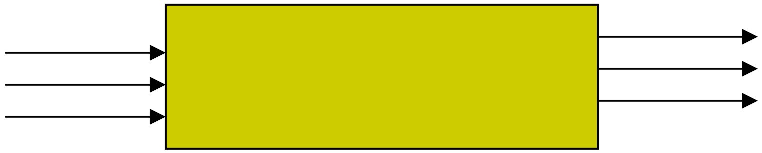
Introduction to Modeling and Simulation

Lecture 1: Introduction

Reading Assignment: Chapter 1 (Sections 1.1, 1.2)

Systems

What is a **system?**



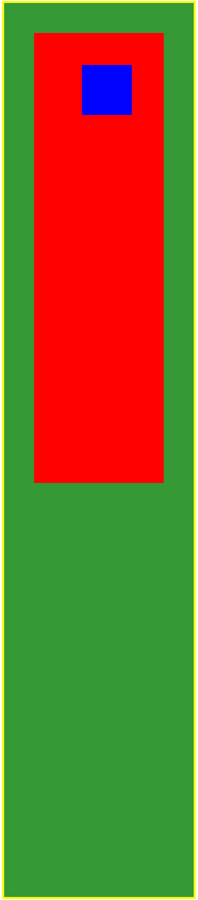
Systems

- A **system** is any set of interrelated components acting together to achieve a common objective.

  - Definition covers systems of different types
  - Systems vary in size, nature, function, complexity,…
  - Boundaries of the system is determined by the scope of the study
  - Common techniques can be used to treat them

Examples

- **Battery**
  - Consists of anode, cathode, acid and other components
  - These components act together to achieve one objective
- **Car Electrical system**
  - Consists of a battery, a generator, lamps,…
  - achieve a common objective
- **SAPTCO (transportation company)**
  - Consists of Buses, drivers, stations,…
  - Achieves a common objective

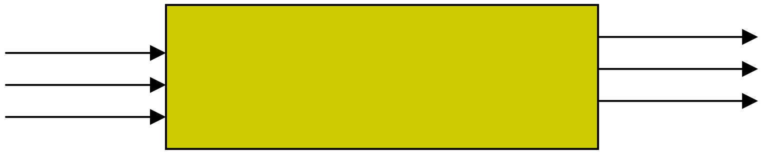


The Boundaries of the system is determined by the scope of the study

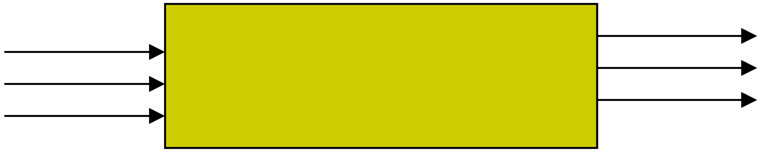
Systems

- A **system** is any set of interrelated components acting together to achieve a common objective.

inputs system outputs



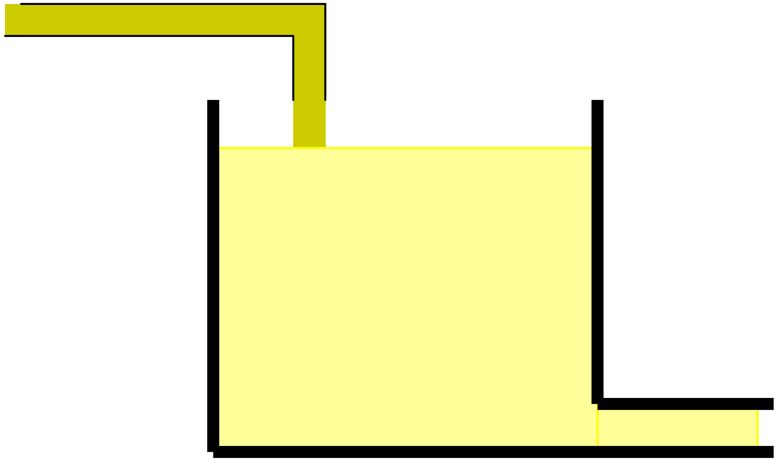
Systems



- **Inputs (excitations) :**
  - signals that cause changes in the systems variables.
  - Represented by arrows entering the system
- **Outputs (responses) :**
  - measured or calculated variables
  - Shown as arrows leaving the system
- **Systems (process)**
  - Defined the relationship between the inputs and outputs
  - Represented by a rectangular box

The choice of inputs/outputs/process depends on the purpose of the study

- Some Possible Inputs
  - Inlet flow rate
  - Temperature of entering material
  - Concentration of entering material
- Some Possible Outputs
  - Level in the tank
  - Temperature of material in tank
  - Outlet flow rate
  - Concentration of material in tank



What inputs and outputs are needed when we want to model the temperature of the water in the tank?

Modeling and Simulation

Modeling:

Obtain a set of equations (mathematical model) that describes the behavior of the system

A model describes the mathematical relationship between inputs and outputs

Simulation:

Use the mathematical model to determine the response of the system in different situations.

Falling Ball Example

A ball falling from a height of 100 meters

- We need to determine a mathematical model that describe the behavior of the falling ball.

Objectives of the model: answer these questions:

1. When does the ball reach ground?
2. What is the impact speed?

Different assumptions results in different models

Falling Ball Example

- Can you list some of the assumptions?
  -
  -
  -
  -
  -

Falling Ball Example

Assumptions for Model 1

1. Initial position = 100 $x(0) = 100$
2. Initial speed = 0 $v(0) = 0$
3. Location: near sea level
4. The only force acting on the ball is the gravitational force (no air resistance)

Model:

$$\frac{dv}{dt} = -9.8; \quad \frac{dx}{dt} = v(t)$$

$$x(0) = 100; \quad v(0) = 0$$

Solution:

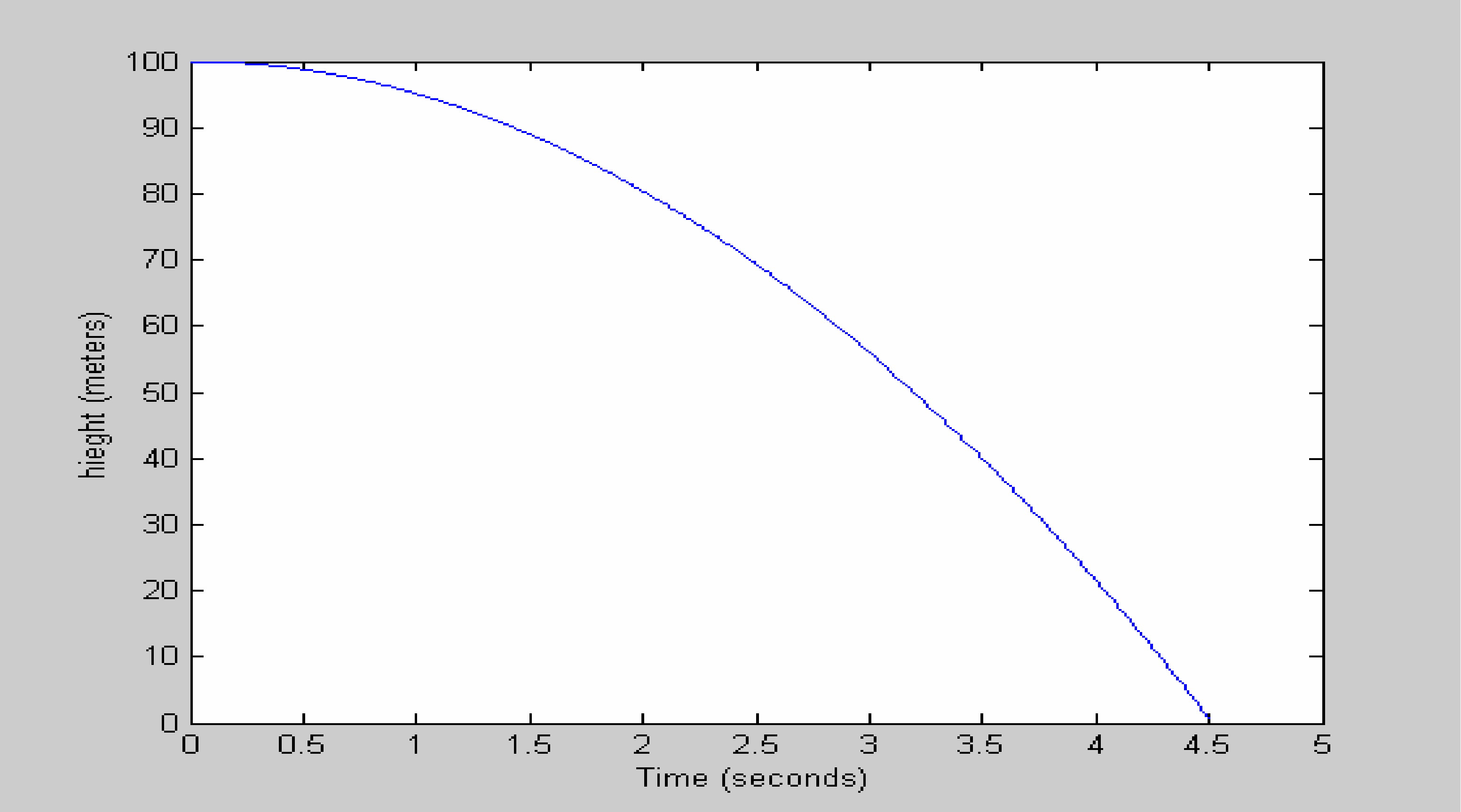
$$x(t) = 100 - 0.5\ (9.8)\ t^2$$

$$v(t) = -9.8\ t$$

Falling Ball Example

Simulation of Model 1

- The ball reaches ground at t = 4.5175 velocity = − 44.2719



Falling Ball Example

More models

- Other mathematical models are possible. One such model includes the effect of air resistance. Here the drag force is assumed to be proportional to the square of the velocity.

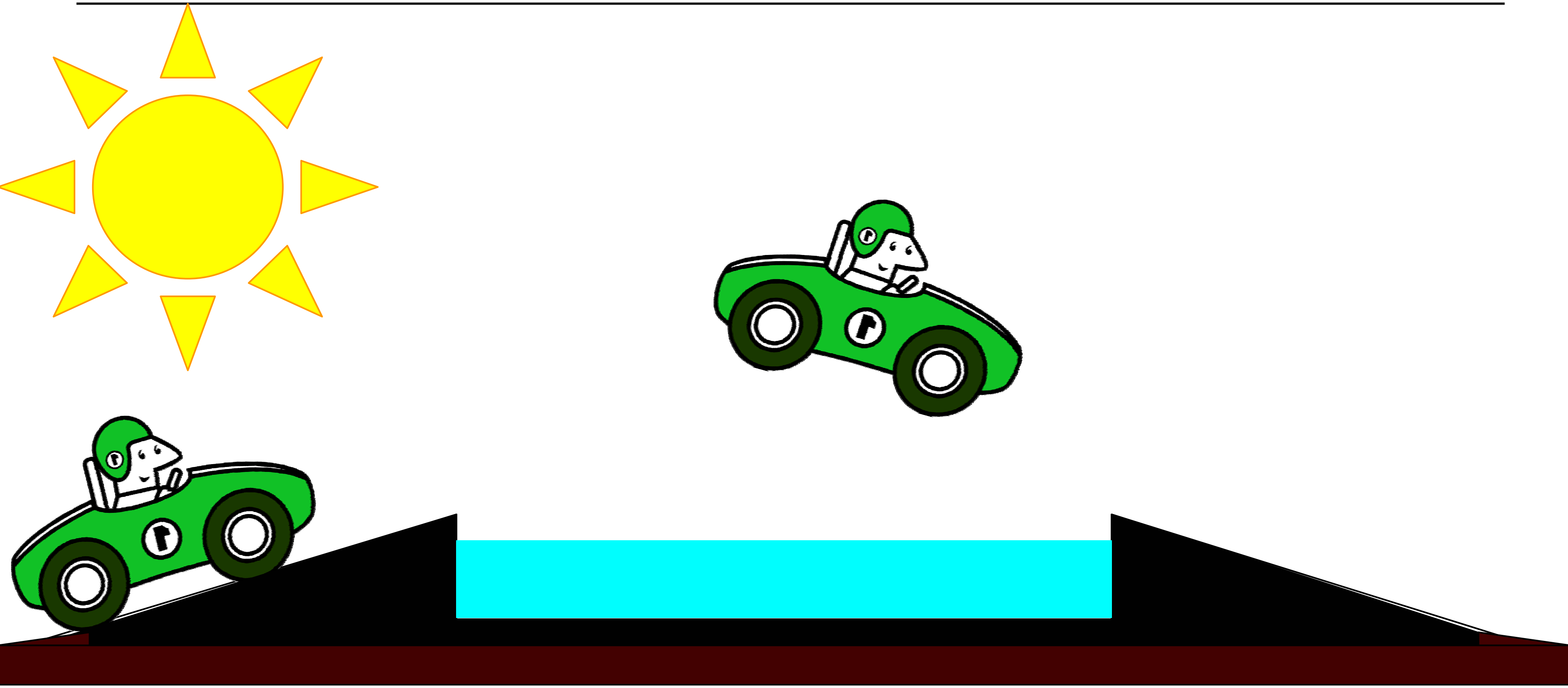
$$\text{air resistance} = cv^2, \quad \textit{where } c \text{ is the drag coeffient}$$

$$Model\ 2:$$

$$\frac{dv}{dt} = -9.8 + \frac{c}{m}v^2; \quad \frac{dx}{dt} = v(t)$$

$$x(0) = 100; \quad v(0) = 0$$

How far can this stunt driver jump?



List some assumptions for solving this problem

Stunt driver

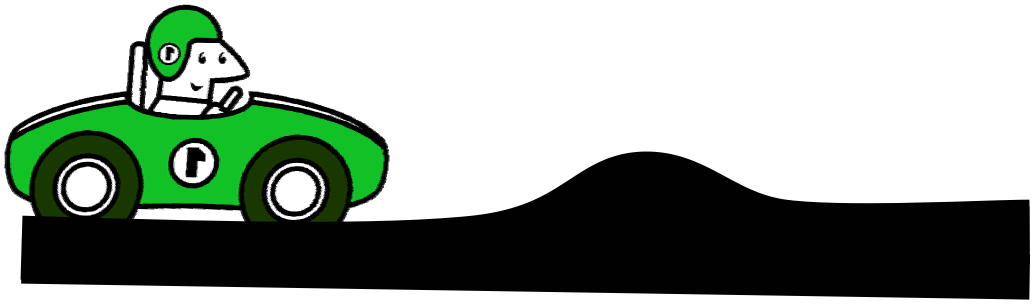
- Assumptions:
  - Point mass
  - Mass of car+driver =M
  - Initial speed = v_0
  - Angle of inclination =a
  - No drag force
  -
- Model can be obtained to give the distance covered by the jump in terms of M,a, v_0,…

How do we obtain mathematical models?

Identification (Experimental)	**Modeling** (Theoretical)
- Conduct an experiment - Collect data - Fit data to a model - Verify the model	- Construct a simplified version using idealized elements - Write element laws - Write interaction laws - Combine element laws and interaction laws to obtain the model

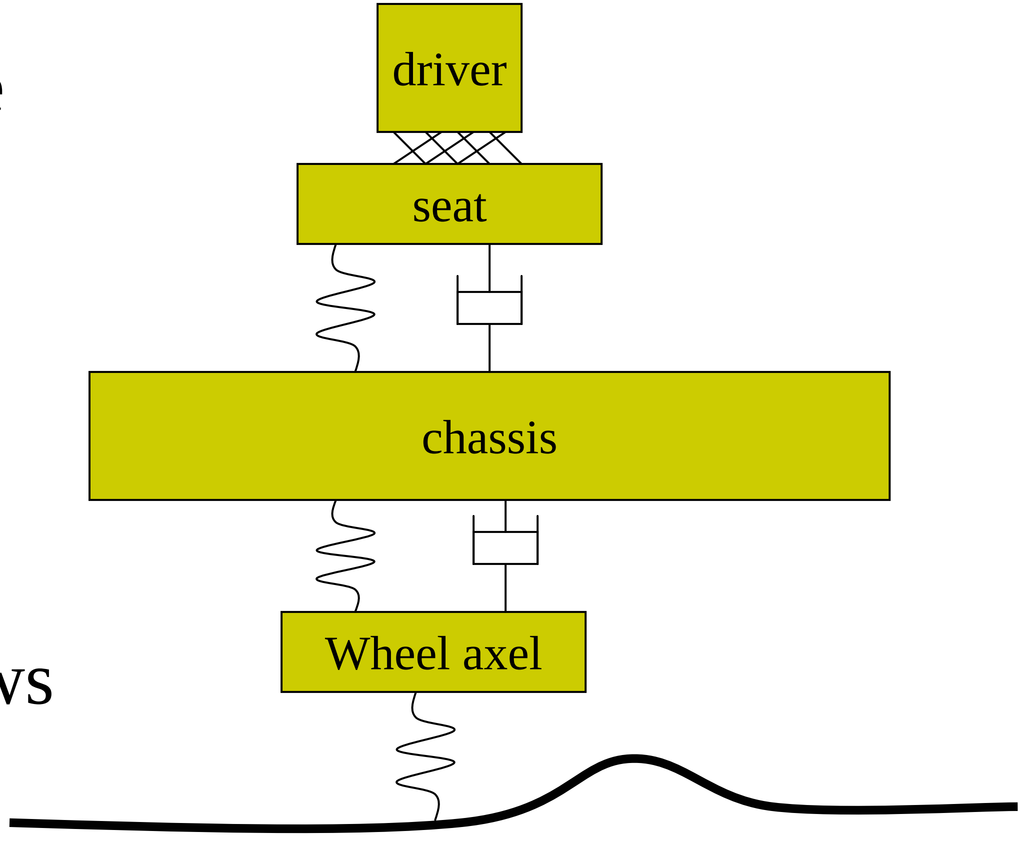
Force on the car driver

- What is the force acting on the driver when the car moves over a rough surface?
- **Input:** the shape of the road
- **Output:** force acting on the driver
- **System model:** describes the relation between input and output.



Modeling Using Idealized Elements

- A simplified representation of the car by idealized elements
- Select relevant variables
- Write element laws
- Write interaction laws
- Obtain the model



What is covered in this course

- Modeling of Systems
  - Idealized Elements (mechanical & electrical)
  - Element laws
  - Interaction laws
  - Obtaining the model
- Solution of the Model
  - Analytic solution using Laplace transform
  - Simulation using SIMULINK

Summary

- Systems: set of components, achieve common objective
  - Inputs: signals affecting the system
  - Outputs: measured or calculated variables
  - Process: relating input and output
- Modeling: Derive mathematical description of system
- Simulation: solving the mathematical model
- Examples of modeling and simulation
- Topics covered in the course

SE 207: Modeling and Simulation

Unit 1

Introduction to Modeling and Simulation

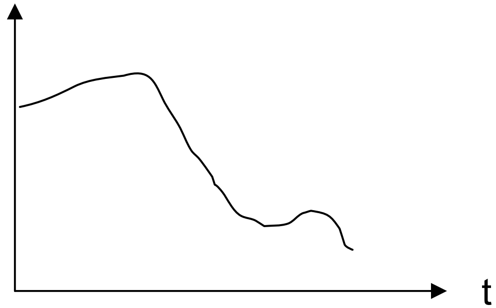
Lecture 2: Classification of systems

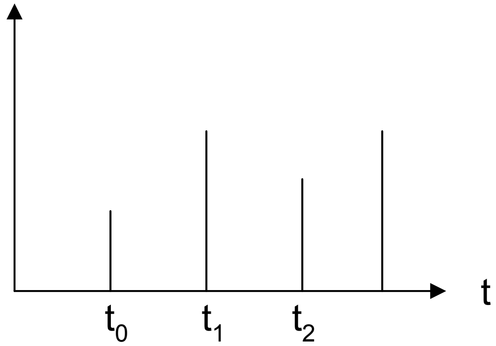
Reading Assignment: Chapter 1

Classification of Systems

- Systems can be classified based on different criteria
  - Spatial characteristics: lumped & distributed
  - Continuity of the time variable: continuous & discrete-time & hybrid
  - Quantization of dependent variable: Quantized & Non-quantized
  - Parameter variation: time varying & fixed (time-invariant)
  - Superposition principle: linear & nonlinear

Continuity of time variable





Continuous-time Signal

The signal is defined for all t in an interval $[t_i, t_f]$

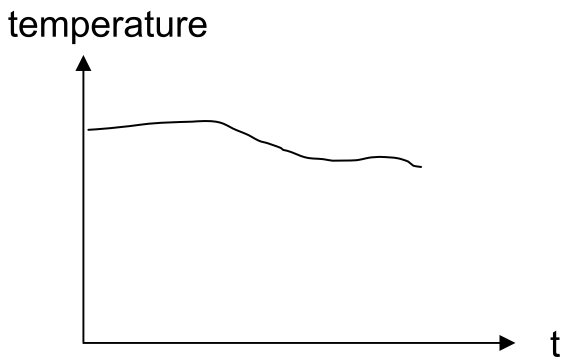
Discrete-time Signal

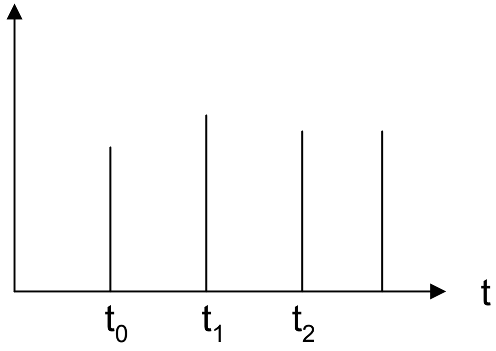
The signal is defined for a finite number of time points $\{t_0, t_1, \ldots\}$

Give Examples

- Give examples of
  - continuous time signal
    -
    -
    -
  - Discrete time signal
    -
    -
    -

Examples of signals

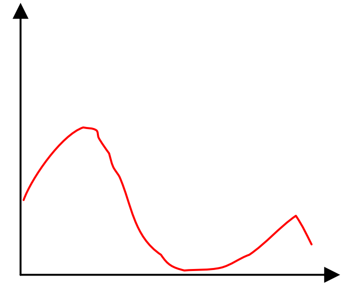




Temperature Sensor that provides Continuous reading of the temperature

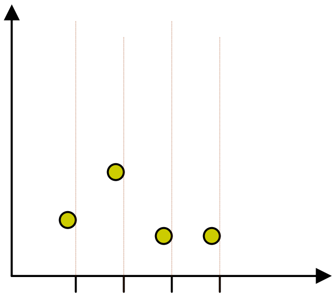
Digital Temperature Sensor that provides reading of the temperature every 30 Seconds

Classification of Signals

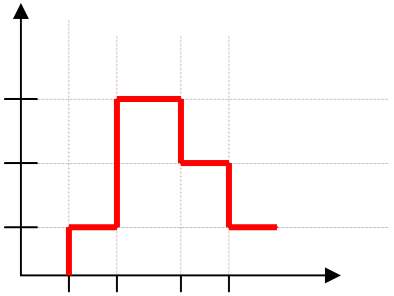


Continuous-time,nonquantized

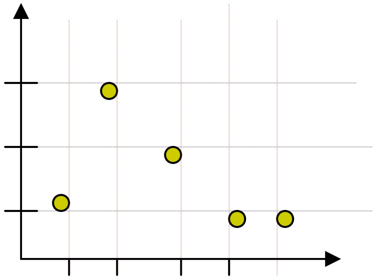
(Analog signal)



Discrete-time,nonquantized



Continuous-time,quantized



Discrete-time,quantized

(Digital Signal)

Classification of Signals and Systems

Classification of Signals

Classification of Systems

Classification of Systems

Systems are classified based on

- Spatial Characteristics (physical dimension,size)
- Continuity of time
- Linearity
- Time variation
- Quantization of variables

Spatial Characteristics

Lumped Models:

Lumped models are obtained by ignoring the physical dimensions of the system.

- A mass is replaced by its center of mass (a point of zero radius)
- The temperature of a room is measured at a finite number of points.
- Lumped models can be described by a finite set of state variables.

Distributed Models:

- Dimensions of the system is considered
- Can not be described by a finite set of state variables.

Spatial Characteristics

Lumped Models:

- Only one independent variable (t)
- No dependence on the spatial coordinates
- Modeled by ordinary differential equations
- Needs a finite number of state variables

Distributed Models:

- More than one independent variable
- Depends on on the spatial coordinates or some of them.
- Modeled by partial differential equations
- Needs an infinite number of state variables

Questions

- Give examples of
  - Distributed models
  - Lumped models

Continuity of time

Continuous Systems:

The input, the output and state variables are defined over a range of time.

Discrete Systems:

The input, the output and state variables are defined for $t=\{t_0,t_1,t_2,\ldots\}$. For other values of t, they are either undefined or they are of no interest.

Hybrid Systems:

Contains both continuous-time and discrete time subsystems

Quantization of the Dependant Variable

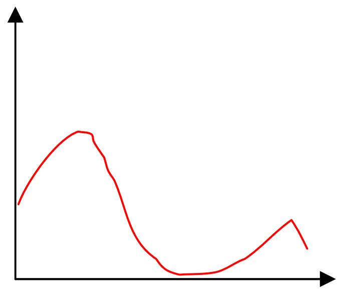
Quantized variable:

The variable is restricted to a finite or countable number of distinct values

Non-Quantized variable:

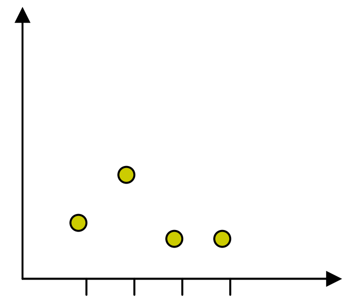
The variable can assume any value within a continuous range.

Classification of Signals

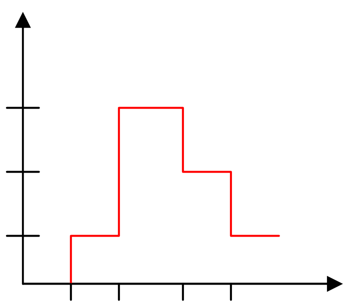


Continuous-time,nonquantized

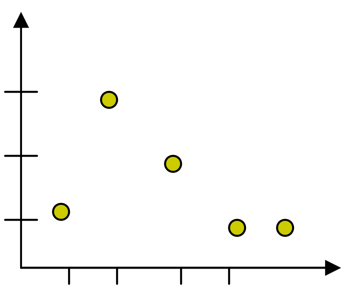
(Analog signal)



Discrete-time,nonquantized



Continuous-time,quantized



Discrete-time,quantized

(Digital Signal)

Questions

- Give examples of
  - Continuous signal
  - Continuous system
  - Discrete signal
  - Discrete system

Parameter Variations

Systems can be classified based on the properties of their parameters

Time-Varying Systems

Characteristics changes with time. Some of the coefficients of the model change with time

Time-Invariant Systems

Characteristics do not change with time.

The coefficients are constants

Linearity

A system is linear if it satisfies the **super position principle**. A system satisfies the superposition principle if the following conditions are satisfied:

1. Multiplying the input by any constant, multiplies the output by the same constant.

2. The response to several inputs applied simultaneously is the sum of individual response to each input applied separately.

Linearity

Examples of Linear Systems

$$y(t) = \int_0^2 u(t)\, dt$$

$$y(t) = 2t\, u(t)$$

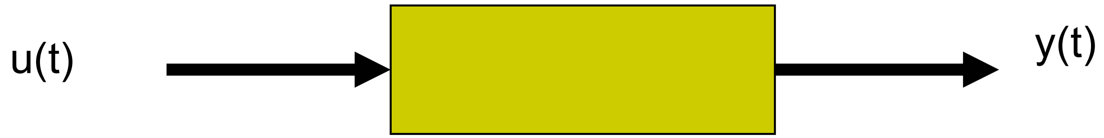
$$\frac{dy(t)}{dt} + 3t^2 y(t) = u(t)$$

Examples of Nonlinear Systems

$$y(t) = \int_0^2 u^2(t)\, dt$$

$$y(t) = 2t\, |u(t)|$$

$$\frac{dy(t)}{dt} + u(t)\, y(t) = u(t)$$



Linearity

Example of linear systems

$$y_1(t) = \int_0^2 u_1(t)\,dt, \qquad y_2(t) = \int_0^2 u_2(t)\,dt$$

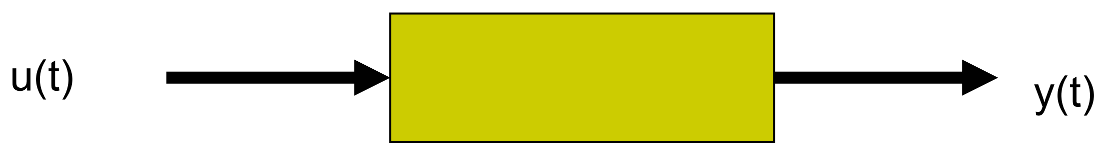
$$u(t) = u_1(t) + u_2(t)$$

$$y(t) = \int_0^2 u(t)\,dt = \int_0^2 [u_1(t) + u_2(t)\,]dt$$

$$= \int_0^2 u_1(t)dt + \int_0^2 u_2(t)\,dt = y_1(t) + y_2(t)$$

$$u(t) = k\,u_1(t) \Rightarrow y(t) = \int_0^2 k\,u_1(t)dt = k\int_0^2 u_1(t)dt$$

Both conditions are satisfied



Linearity

Example of non-linear systems

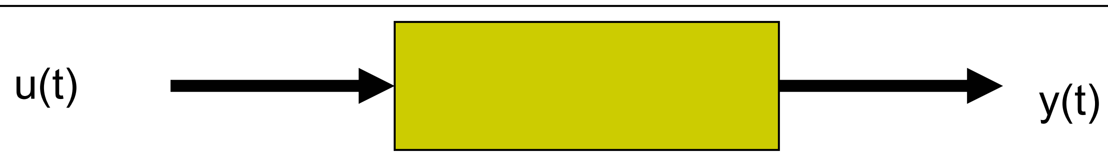
$$y_1(t) = 2t\left|u_1(t)\right|,$$

$$u(t) = -u_1(t)$$

$$u(t) = 2t\left|-u_1(t)\right| = 2t\left|u_1(t)\right| = y_1(t)$$

$$\textit{In}\ \text{general} \qquad y_1(t) \neq -y_1(t)$$

If the input is multiplied by (-1) the output remains unchanged. This system is nonlinear



Classification of Systems

Spatial characteristics	lumped	distributed	
Continuity of the time variable	continuous	discrete-time	hybrid
Parameter variation	Fixed (time-invariant)	time varying	
Quantization of dependent variable	Quantized	Non-Quantized	
Superposition principle	linear	nonlinear	

Keywords

- Linear model
- Nonlinear model
- Continuous
- Discrete
- Hybrid
- Fixed
- Time-invariant
- Time-varying
- Lumped
- Distributed
- Input
- Output
- Static model
- Dynamic model
- Quantized variable
- Non-Quantized
- Super position principle
- Spatial characteristics
- Analog signal
- Digital signal
- Idealized element
- System
- Process

Summary

- Classification of signals
  - Continuous, discrete, quantized, non-quantized
- Classification of Systems
  - Continuous-time systems, discrete-time systems
  - Hybrid systems
  - Linear systems, nonlinear systems
  - Time-varying, time-invariant,