Lecture 1
Basic notions and classifications

4 October 2022

System as a subject of scientific research

A system is an isolated part of reality or a construction of mind that we wish to study through scientific inquiry([H]).

Science and engineering deal with studying systems (natural or man-made) in order to

- understand them
- predict their behavior
- design new systems
- improve existing ones

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A system is a collection of entities which are logically related and which are of interest to a particular application.

- blood flow in aorta
- architecture of the internet
- Golden Gate Bridge
- the solar system
- city
- car
- computer
- population
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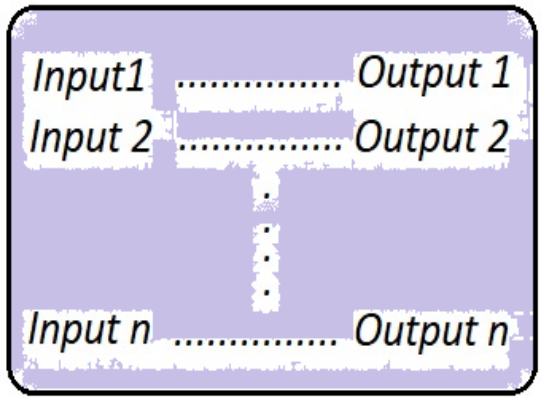
Input-output systems

Most of the systems can communicate with external world



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”An experiment on a system is a process of extracting data from a system by acting through its inputs.”

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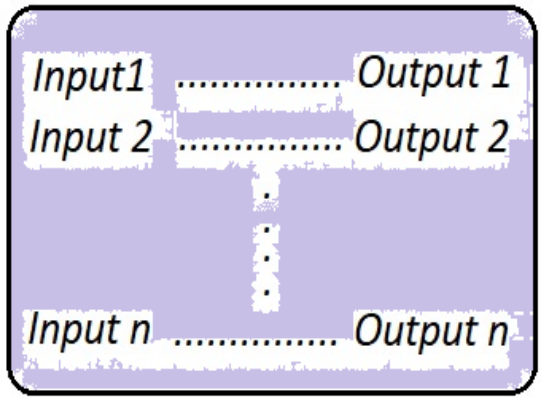

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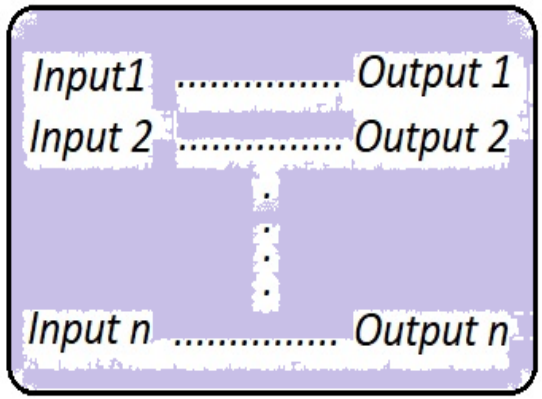

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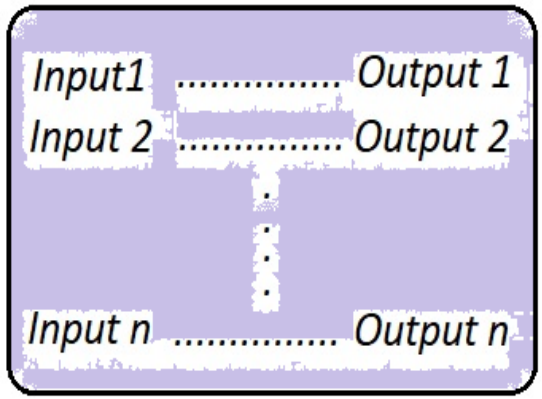

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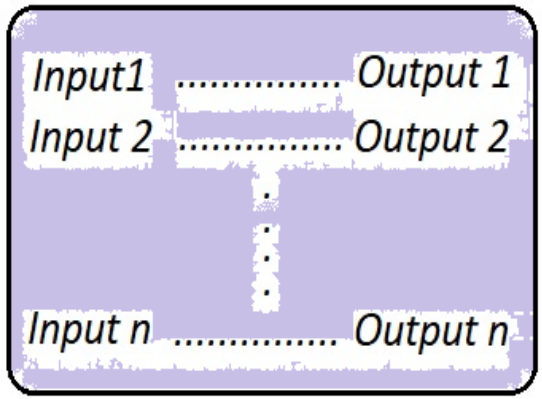

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How do we study systems

In many cases it is easier, safer, and less expensive to experiment on a representation of the system than on the system itself.

A model is a task-driven representation of a system that we study.

- **conceptual models** are mind-concepts
- **physical models** are material

We can say that

a **Model(M)** for a **System (S)** is is anything that can be applied to answer a **Question (Q)** about **(S)**.

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- globe (the Earth)
- calendar (period of time)
- toy-car (car)
- differential equation (e.g. physical phenomenon)
- stochastic equation (e.g. stock price)
- graph representing a formal language (formal language)

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Model

Since a model is task-driven,

- it will refer only to some aspects of the system under study
  By building a model we simplify things!

  "The best model is the simplest model that still serves its purpose, that is, which is still complex enough to help us understand a system and to solve a given problem". ([V]).

- two models of the same system may be essentially different.

  Suppose that **S** - some mechanical system. Then the appropriate **M** model depends on **Q** .

  - if **Q** is asking about the behavior of S at **moderate velocities**, then **M =** { **equations of Newtonian mechanics**}
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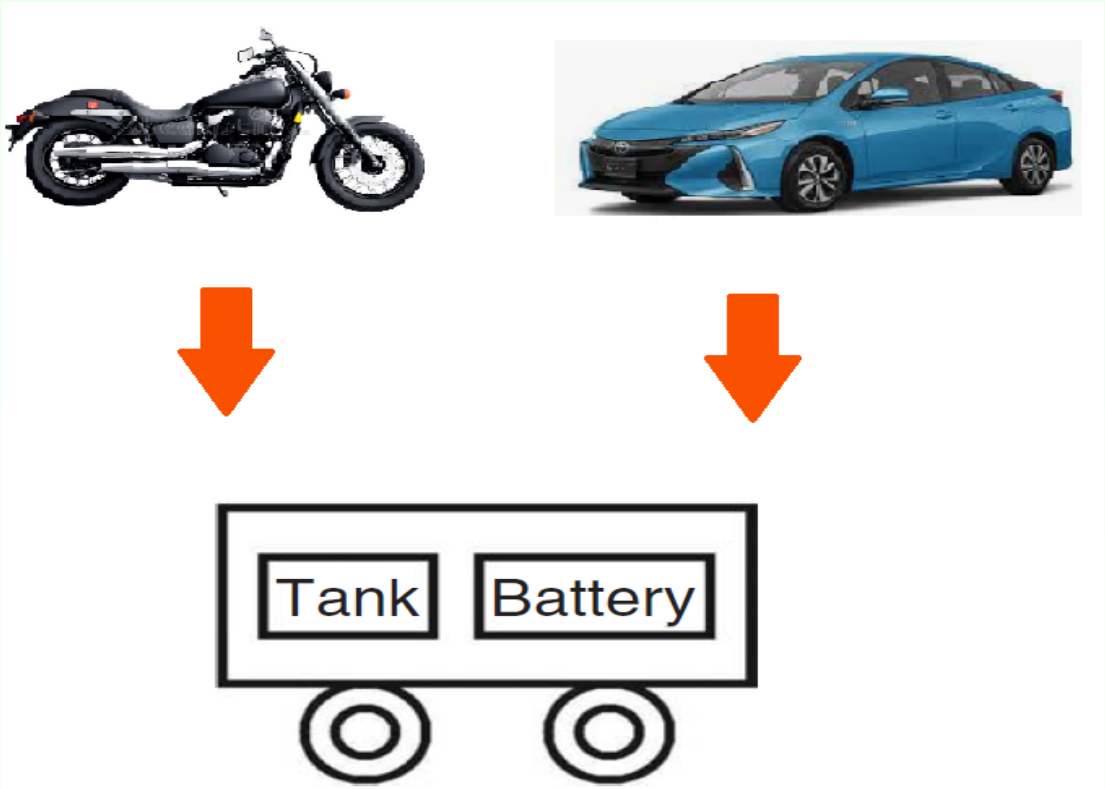
- one model can represent different systems.



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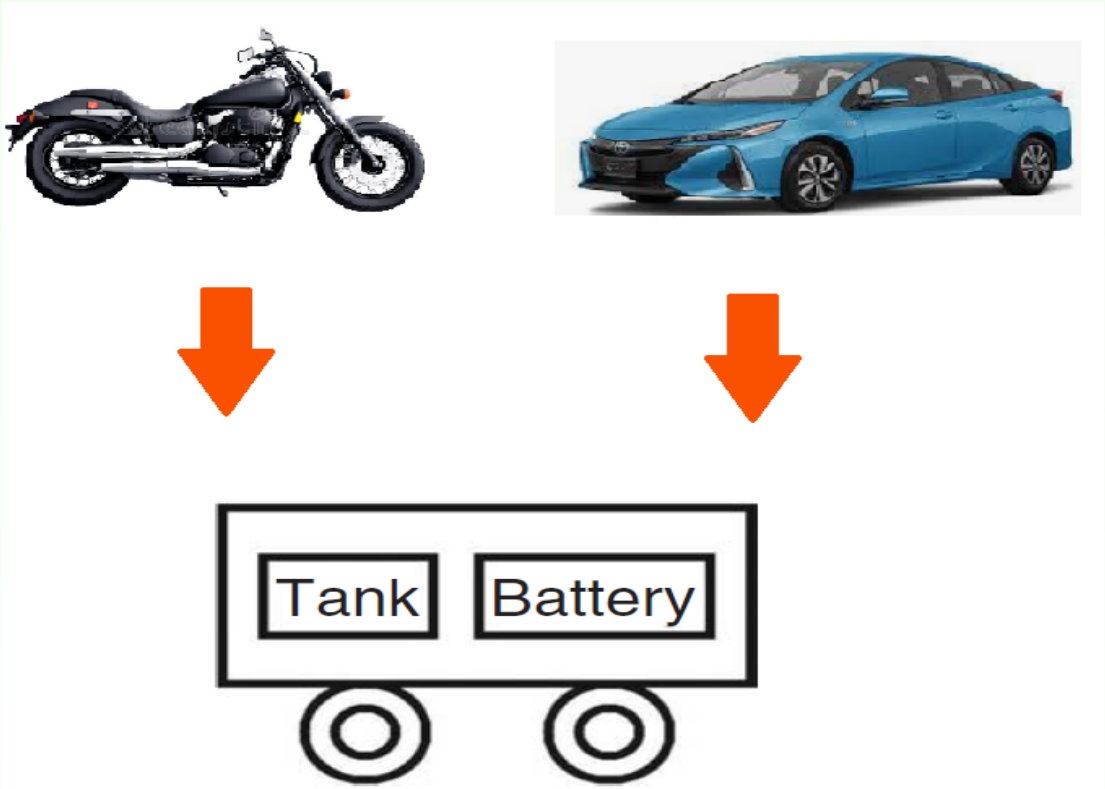

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*The term **simulation** originates from the Latin word **simulare**, which means **to pretend**.*

A simulation is an experiment done on the model.

A simulation is the application of a model with the objective to derive strategies that help to solve a given problem or answer a given question

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Computer simulations and new technologies

Some breakthrough computer simulations

- **simulations run to help development of hydrogen bomb** (Stanislaw Ulam and John von Neumann) (Monte Carlo method applied)
- **simulations for weather prediction** - take into account enormous number of data (collected from ground observation stations, radars and satellites)
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Computer simulations can be

- expensive
- time consuming
- complicated

But also can be highly useful - especially when:

- **a system does not exist yet** and building a prototype would be extremely expensive, time-consuming or dangerous (aircraft, nuclear reactor)
- a system exists but **experimentation would be too expensive or dangerous** (military unit, transportation system, airport baggage handling system)
- **it is required to analyze long time periods in a compressed format** (population growth, urbanization studies, pandemic flu spread)
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Modelling and simulation scheme([V])

1. **Definitions**
   - Definition of a problem that is to be solved or of a question that is to be answered
   - Definition of a system, that is, a part of reality that pertains to this problem or question
2. **System Analysis**
   - Identification of parts of the system that are relevant for the problem or question
3. **Modelling**
   - Development of a model of the system based on the results of the system analysis step
4. **Simulation**
   - Application of the model to the problem or question
   - Derivation of a strategy to solve the problem or answer the question
5. **Validation**
   - Does the derived strategy solve the problem for the real system?

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Mathematical model

A mathematical model - a conceptual model that is created with the use of mathematical formulas.

It is an abstract, simplified, mathematical construct related to a part of reality and created for a particular purpose.

Some examples:

- differential or stochastic equation
- matrix of a game (in Game Theory - correspond to natural, social, economic, military or other phenomena
- neural network - a model of a brain: it has a learning capacity (that serves to solve practical problems)
- genetic algorithm - models mechanisms of the evolution; used to solve optimization problems
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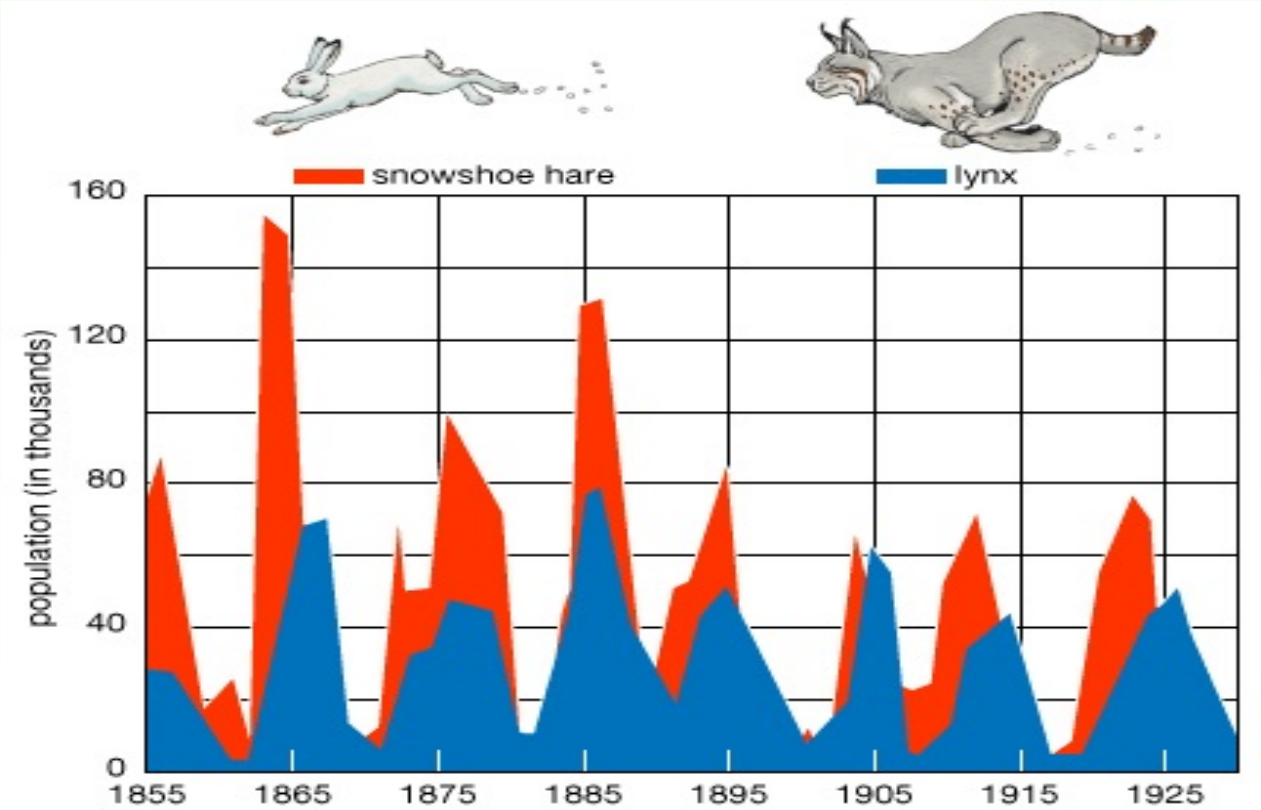
Lynx-hare cycle

Fluctuations of populations of the **snowshoe hare** and the **Canada lynx** were observed more than two hundred years ago by trappers involved in the fur trade.



Lotka-Volterra's equations

Lotka-Volterra's equations model the interactions between a predator and its prey

$$\begin{cases} \frac{dx}{dt} = \alpha\, x(t) - \beta\, x(t)y(t) \\ \frac{dy}{dt} = \delta\, x(t)y(t) - \gamma\, y(t), \end{cases} \tag{1}$$

t - time
x - number of hares y - number of lynxes

$\alpha, \beta, \gamma, \delta$ - positive constants
αx - represents growth rate of hare's population
βxy - represents the rate of predation
δxy - represents growth rate of predator's population
γy - represents loss rate of predators.

Simplifying assumptions in lynx-hare model

The above equations make a number of simplifying assumptions:

- prey's population finds enough food at all times
- food supply of the predator's population depends entirely on the size of the prey's population
- predators have limitless appetite
- the rate of change of a population is proportional to its size
- during the process environment does not change in favour of any species

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