

CHAPTER I: INTRODUCTION TO MODELING AND SIMULATION

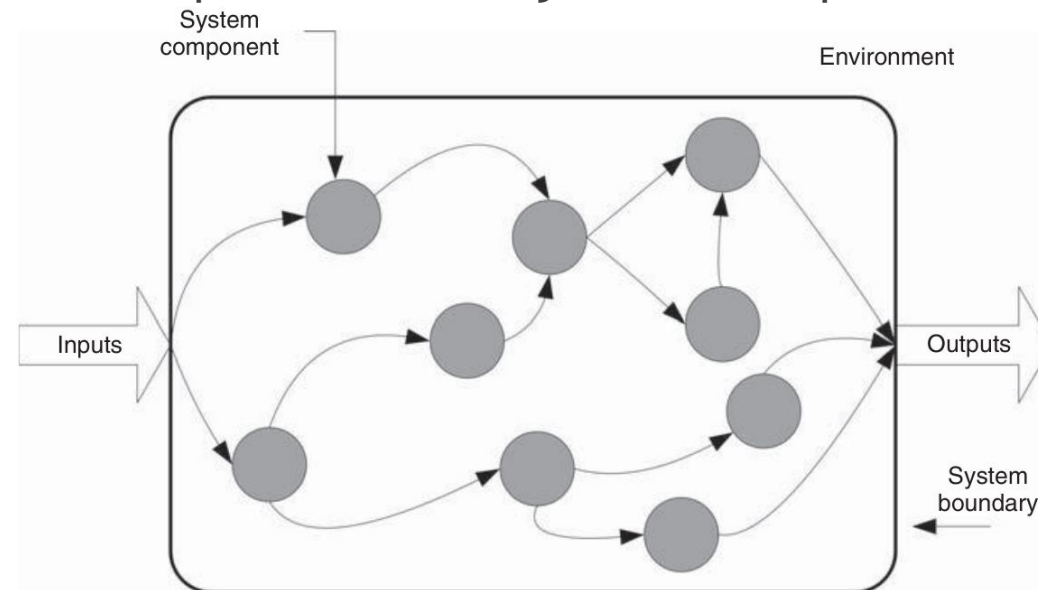
University Center of AbdElhafid Boussof, Mila
Master Artificial Intelligence and its applications
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Modeling and simulation
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1. SYSTEM

1.1. Definitions

Definition. A system is defined to be a collection of entities, e.g., people or machines, that act and interact together toward the accomplishment of some logical end.

- ▶ A system is defined by:
 - ▶ The nature of its constituent elements;
 - ▶ The interactions between these elements;
 - ▶ Its boundary, which determines whether an entity belongs to the system or not
- ▶ A system interacts with its environment: The environment acts on the behavior of the system which, in turn, reacts on this environment.
- ▶ In practice, what is meant by “the system” depends on the objectives of a particular study.



A conceptualization of a system

- ▶ In practice, what is meant by “the system” depends on the objectives of a particular study: The collection of entities that comprise a system for one study might be only a subset of the overall system for another.
- ▶ **Example 1:** If we want to study a **city's transportation network**, the entities of the system can be defined depending on the study's specific objectives:
 - ▶ **Traffic Flow Optimization:** If the primary goal of the study is to optimize traffic flow within the city, "the system" may be defined as the **road network, traffic signals**, and vehicles. The study might concentrate on improving traffic management strategies, signal timing, and road design to reduce congestion.
 - ▶ **Public Transportation Optimization :** Another research project may aim to enhance the city's public transportation system. In this case, "the system" could defined as **road network, buses, tramways, subways** (metro), and **related infrastructure** (bus stop, metro station, etc.).
- ▶ **Example 2:** If one wants to study a **bank** to determine the number of tellers needed to provide adequate service for customers who want just to cash a check or make a savings deposit: The system can be defined to be that portion of the bank consisting of the **tellers** and the **customers** waiting in line or being served.

In order to understand and analyze a system, a number of terms need to be defined:

- ▶ **Entity:** an entity is an object of interest in the system.
- ▶ **Attribute:** an attribute is a property of an **entity**.
- ▶ **Activity:** an activity represents a process causing changes in a system.
- ▶ **State variable:** a state variable is a particular measurable property of an object or system.
- ▶ **State of a system:** The state of a system is defined to be that collection of variables necessary to describe the system at any time.
- ▶ **Event:** An event is an instantaneous occurrence that might change the state of the system (state variables).
 - ▶ **Endogenous** is used to describe **activities** and **events** occurring within a system,
 - ▶ **Exogenous** is used to describe **activities** and **events** in the environment that affect the system.
- ▶ **The external behavior** of a system is the relationship it imposes between its input time histories and output time histories.
- ▶ **The internal structure** of a system includes its state and state transition mechanism (dictating how inputs transform current states into successor states).
- ▶ **Knowing the system structure allows us to deduce (analyze, simulate) its behavior.**

Example 1: If a Bank is being studied system:

- Customers might be one of the **entities**,
- The balance in their accounts might be an **attribute**,
- Making deposits might be an **activity**.
- Possible **state variables** are the number of busy tellers, and the number of customers waiting in line or being served.
- The **arrival of a customer** is an **exogenous event** and the **completion of service** of a customer is an **endogenous event**.

Examples 2: systems and state variables

System	State variables
The Solar System	position, velocity, acceleration
Financial market	interest rates, stock prices, prices of goods and services, etc.
Queue	number of customers in queue, waiting time, arrival rate of customers, service rate
Weather system	air temperature, atmospheric pressure, humidity, wind speed and direction, etc.
Fluid dynamics	pressure, velocity, and density of the fluid

1. SYSTEM

Discrete-event and continuous systems

Systems can be categorized as discrete or continuous:

► Discrete-event system:

A system in which the state variables change instantaneously at discrete points in time,

Example:

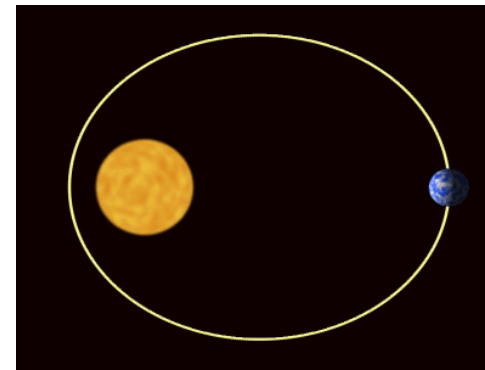
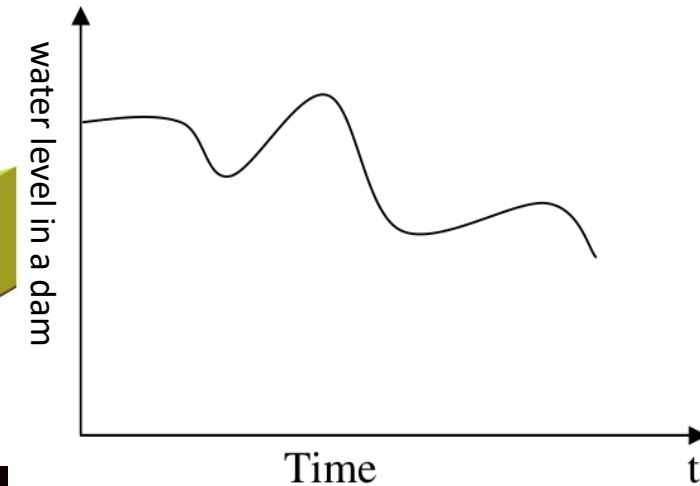
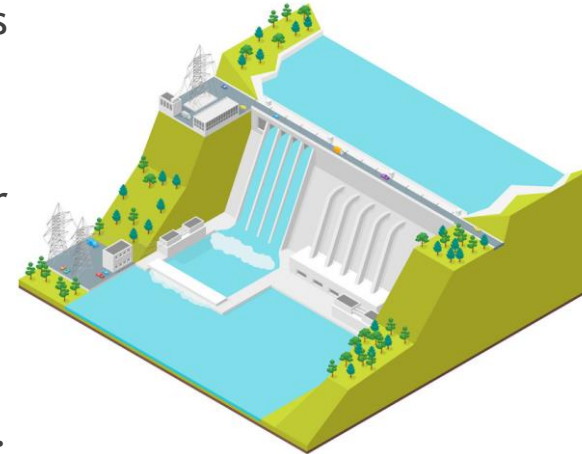
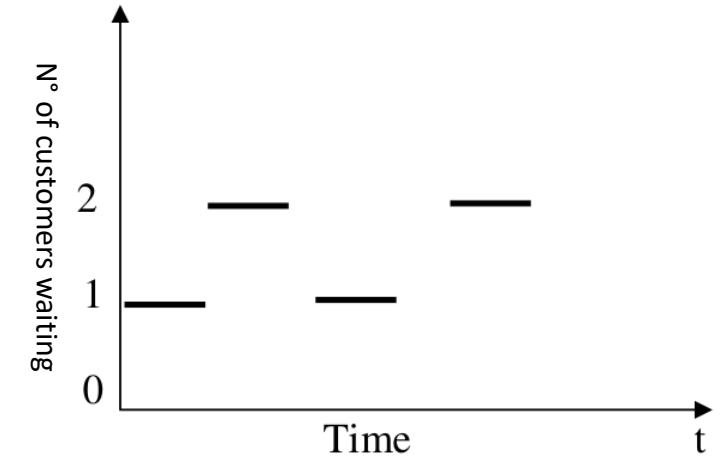
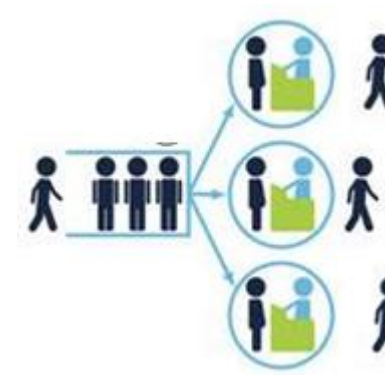
The queue of customers in a bank: The number of customers waiting in the queue changes at different points in time. It increases as new customers arrive and decreases as customers depart after receiving service.

► Continuous system:

A system in which state variables change continuously over time,

Examples

- Water level in a dam
- Airplane moving is an example of a continuous system : state variables such as position and velocity can change continuously in time.
- Planetary motion: is an example of a continuous system : position of the planets change continuously in time.



1. SYSTEM

Discrete-event and continuous systems

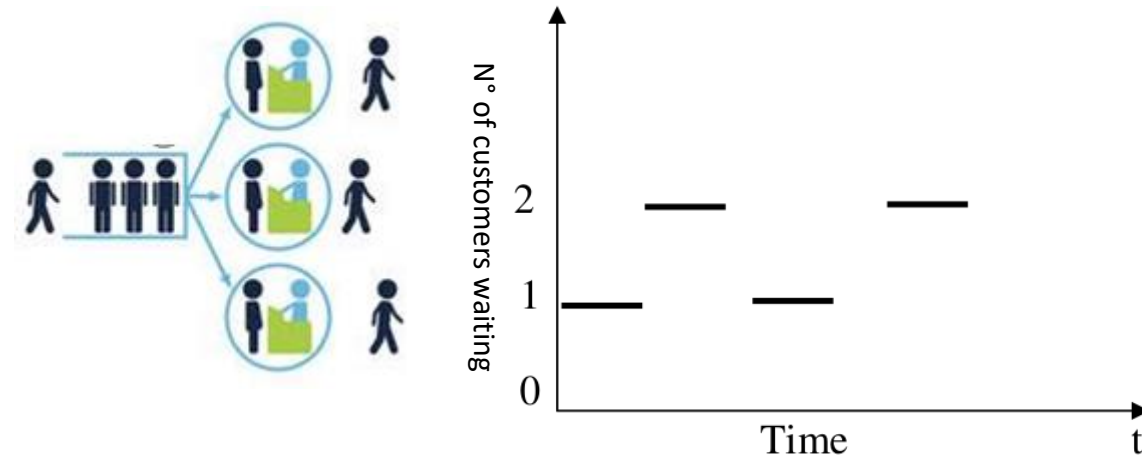
Systems can be categorized as **discrete** or **continuous**:

► Discrete-event system:

A system in which the state variables change instantaneously at discrete points in time,

Example:

The queue of customers in a bank: The number of customers waiting in the queue changes at different points in time. It increases as new customers arrive and decreases as customers depart after receiving service.



Population growth: can be viewed as a discrete system, the growth of a population is a series of discrete events, such as birth, death, and migration. Population size changes at discrete times when these events occur.



1. SYSTEM

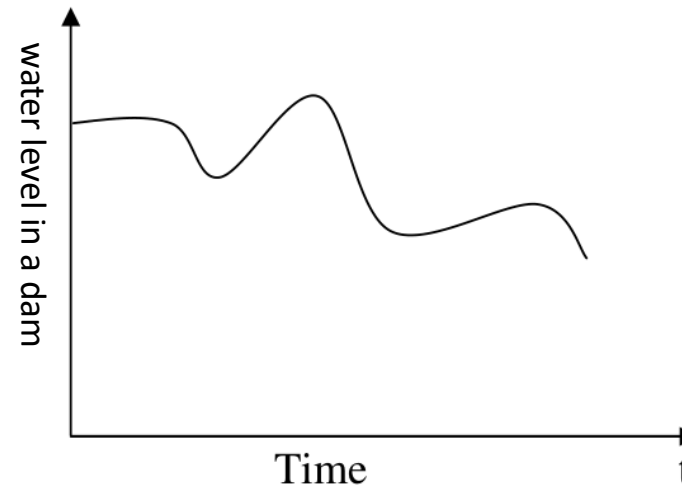
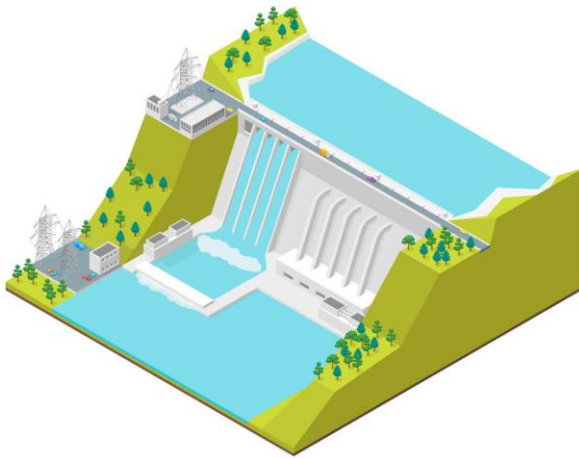
Discrete-event and continuous systems

Continuous system:

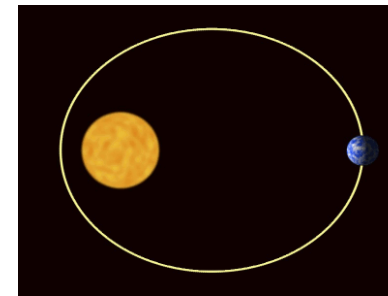
A system in which state variables change continuously over time,

Examples

- ▶ Water level in a dam is an example of a continuous system: a level of water change continuously in time.



- ▶ Airplane moving is an example of a continuous system : state variables such as position and velocity can change continuously in time.
- ▶ Planetary motion: is an example of a continuous system : position of the planets change continuously in time.



- ▶ Studying a system consists of understanding the relationships between its components and predicting system behavior ;
- ▶ To study a system, it is sometimes possible to experiment with the system itself.

Definition. An experiment is a process by which we collect data on a system by acting on its inputs

- ▶ However, it is not always practical or possible to perform experiments on the system.

Examples:

- It is impossible to conduct experiments on celestial objects like stars or planets.
 - Conducting large-scale experiments on the Earth's environment, such as deliberately polluting a natural ecosystem, is both impractical and harmful.
 - In the case of a bank, reducing the number of tellers to study the effect on the length of waiting lines, can lead them to switch banks.
 - Etc.
- ▶ Hence, system studies often use **models**.

2. Model of a System

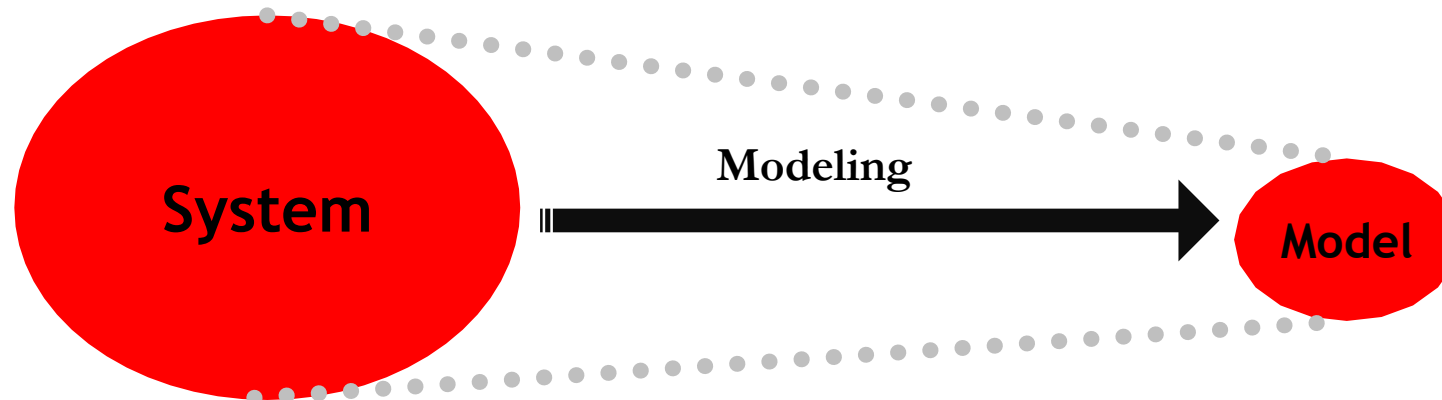
2.1. Definitions

Definition 1. A model is a representation of a system for the purpose of studying the system.

- ▶ The model, by definition, is a simplification of the system.
- ▶ It is necessary to consider only those aspects of the system that affect the problem under investigation.

Definition 2. In the context of Modeling and simulation:
A model **M** of a system **S** for an experiment **E** is anything to which we can apply **E** to answer questions concerning **S**.

Definition 3. Modeling is the activity of building models



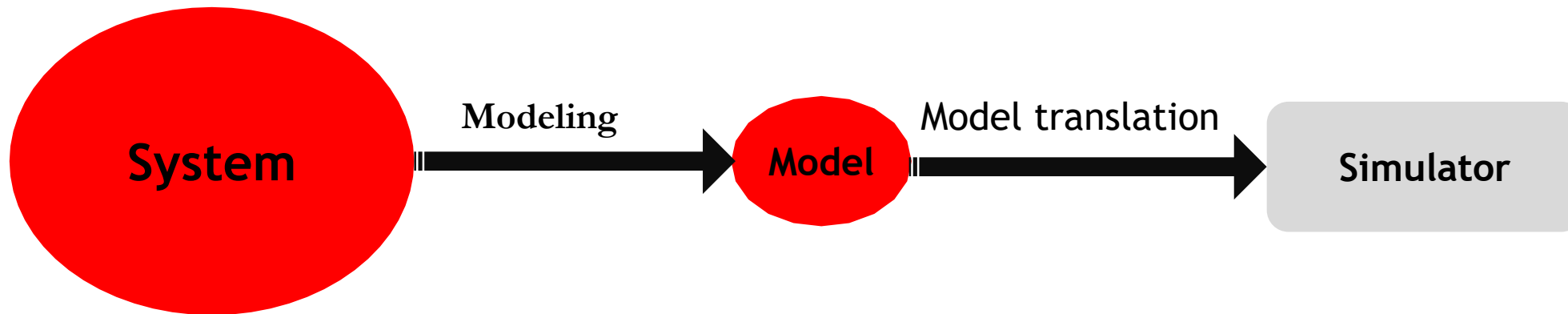
2. Model of a System

2.1. Definitions

Definition 1. Simulation is the reproduction of the dynamic behavior of a real system based on a model

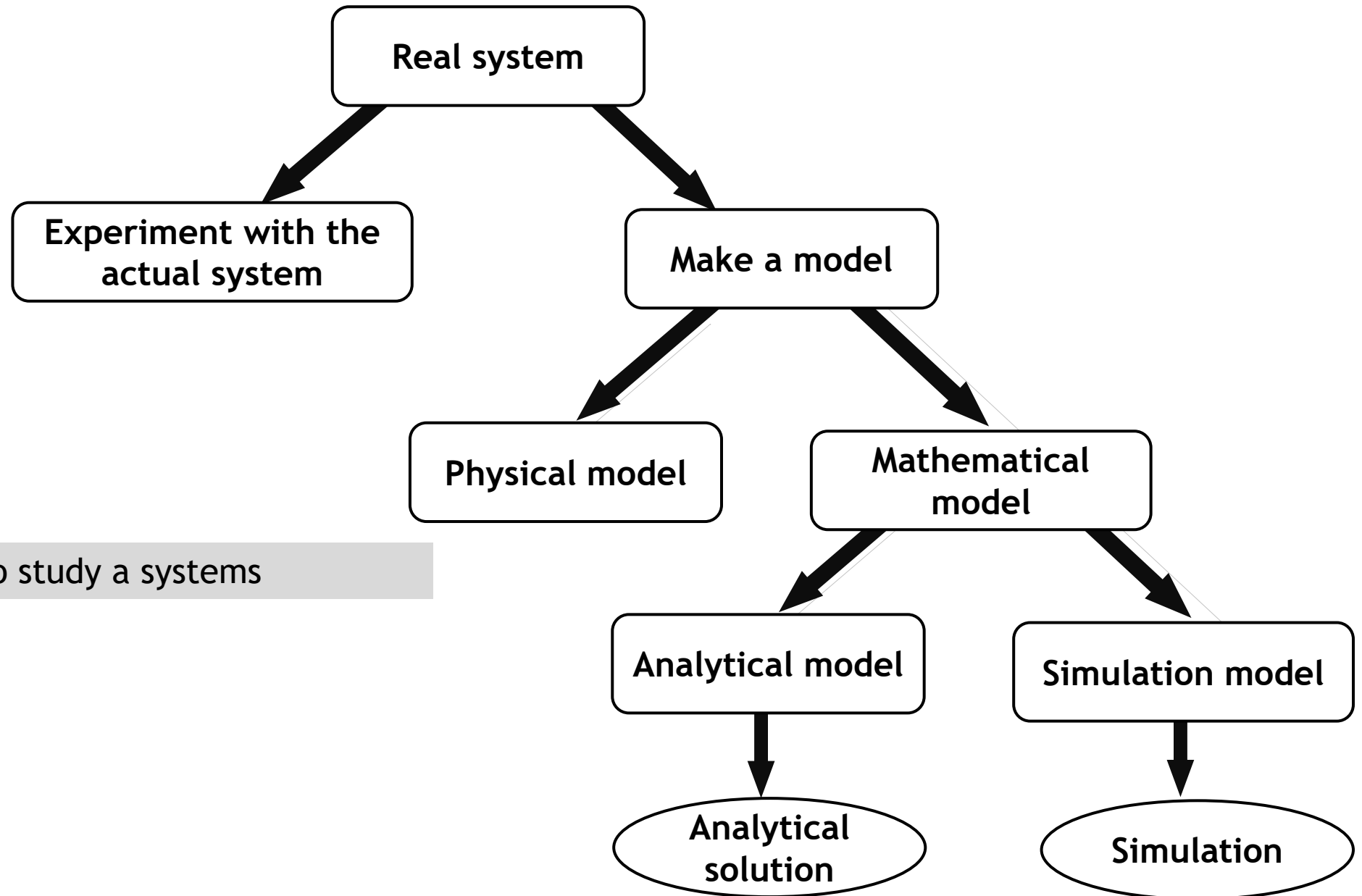
Definition 2. A simulator is the translation into computer programs (algorithms) of the dynamic behavior of a model

Definition 3. Computer simulation is the reproduction of the dynamic behavior of a real system based on a model



2. Model of a System

2.1. Definitions



2. Model of a System

2.2. Types of Models

2.2.1. Physical and mathematical models

- **Physical models** are physical scaled-down representations of systems, or phenomena that are used for various purposes, including experimentation, education, etc.

Examples:

Wind Tunnel Models: Engineers use scale models of aircraft, cars, and buildings in wind tunnels to study aerodynamics, airflow, and structural integrity. These models help in optimizing designs.

Hydraulic Models: Physical hydraulic models to simulate the behavior of water flow in rivers, reservoirs, etc. These models help in designing flood control systems.



- **Mathematical models** are a representation of a real systems using mathematical equations, expressions, symbols, and relationships.

Example: The equation $d = r * t$ represents a simple relationship between distance (d), rate or speed (r), and time (t).

2.2.2. Analytical and simulation models

► Analytical models

- Are mathematical representations of a system or a problem (e.g. differential equations) derived from physical laws or well-established theoretical relationships
- They often can be solved explicitly using mathematical methods to predict the behavior of the system
- Analytical models are generally limited to simple or idealized systems due to the complexity of the equations and the difficulty in solving them for complex systems.

Example: $d = r \times t$ is a mathematical formula that relates distance, rate, and time. It can be used to calculate any of the three variables if the other two are known. Where d is the distance traveled, r is the rate of speed, and t is the time spent traveling. This equation is:

- A valid model in some instances (For example: a space probe after it has attained its flight velocity)
- A very poor model for other purposes. For example: the arrival time of a bus on congested urban freeways

► Simulation models.

- Most real-world systems are too complex for which analytical models are not feasible
- Simulation models are computational approximations of real systems created through mathematical modeling using a computer program.
- In a simulation we use a computer to evaluate a mathematical model numerically, and data are gathered in order to estimate the desired
- Simulation models make it possible to study the behavior of a system under different conditions, explore hypothetical scenarios and observe results that cannot be obtained by direct analytical approaches.

2.2.3. Static and Dynamic models

- ▶ **Static simulation models** : A static simulation model is a representation of a system at a particular time or one that may be used to represent a system in which time simply plays no role.
- ▶ **Examples** of static simulations include **Monte Carlo simulations** applied to financial risk analysis, system reliability analysis, etc.
- ▶ **Dynamic simulation models**: represent systems as they change over time.
- ▶ **Example** of a dynamic simulation: The simulation a queue in a bank from 9H:00 to 16H:00 ,

2.2.4. Deterministic and Stochastic

- ▶ **Deterministic simulation models** contain no random variables. Deterministic models have a known set of inputs that will result in a unique set of outputs.
- ▶ **Stochastic simulation models** have one or more random variables as inputs. Random inputs lead to random outputs.

2.2.5. Discrete and continuous models

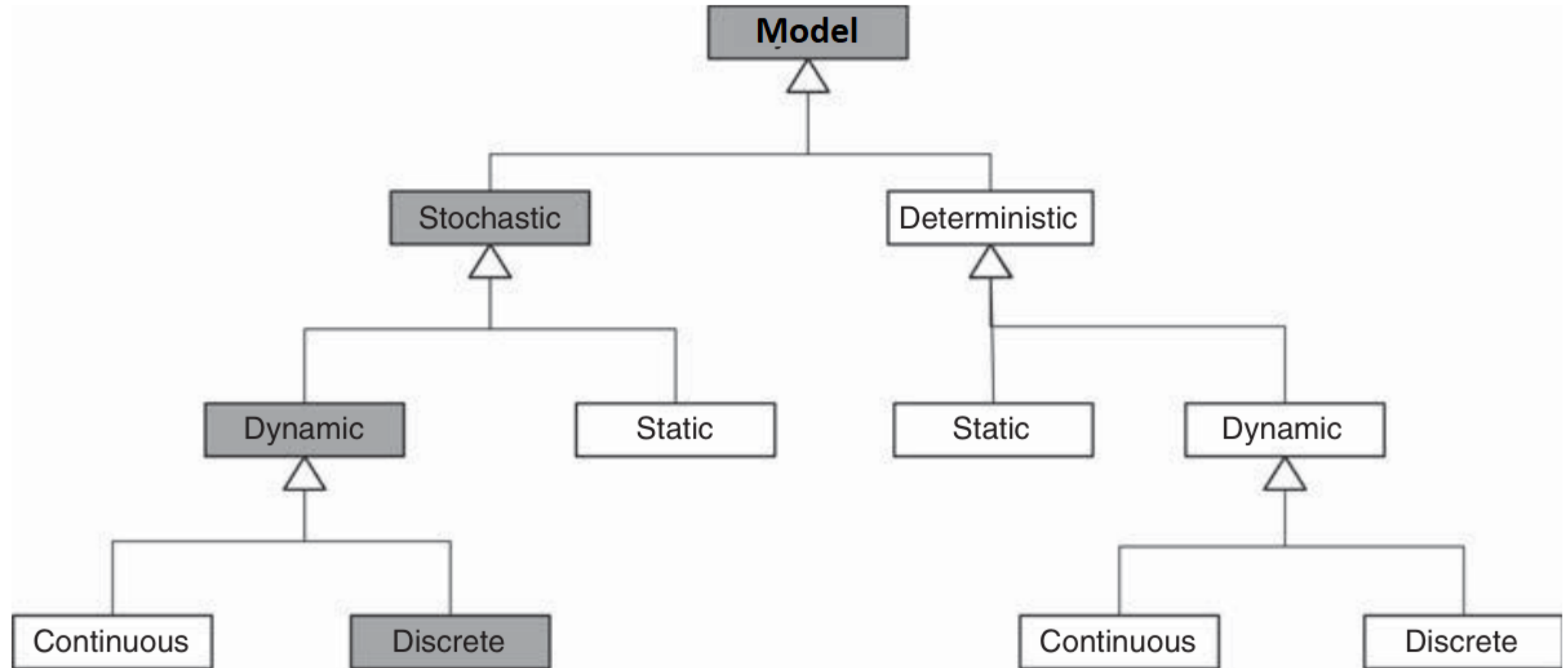
- ▶ **Discrete model**: in which the state variables change instantaneously at discrete points in time,
- ▶ **Continuous models**: in which state variables change continuously over time.

Note: Discrete model can be used to model a continuous system, and continuous model can be used to model a discrete system.

2. Model of a System

2.2. Types of Models

This course primarily examines stochastic, dynamic, and discrete modeling.



Definition. A modeling paradigm is a set of concepts, laws and means aimed at defining models.

► Examples of modeling paradigms:

- Differential equations ;
- Markov chains and queuing theory;
- Discrete-Event Simulation
- Petri net
- Cellular automata;
- Multi-agent systems
- etc.

Some citations regarding modeling and simulation

- ▶ Mathematical models are caricatures of real systems that aim to capture the fundamental mechanisms of some process in order to explain observations or predict outcomes.

—*István Z. Kiss, Joel C. Miller, Péter L. Simon*

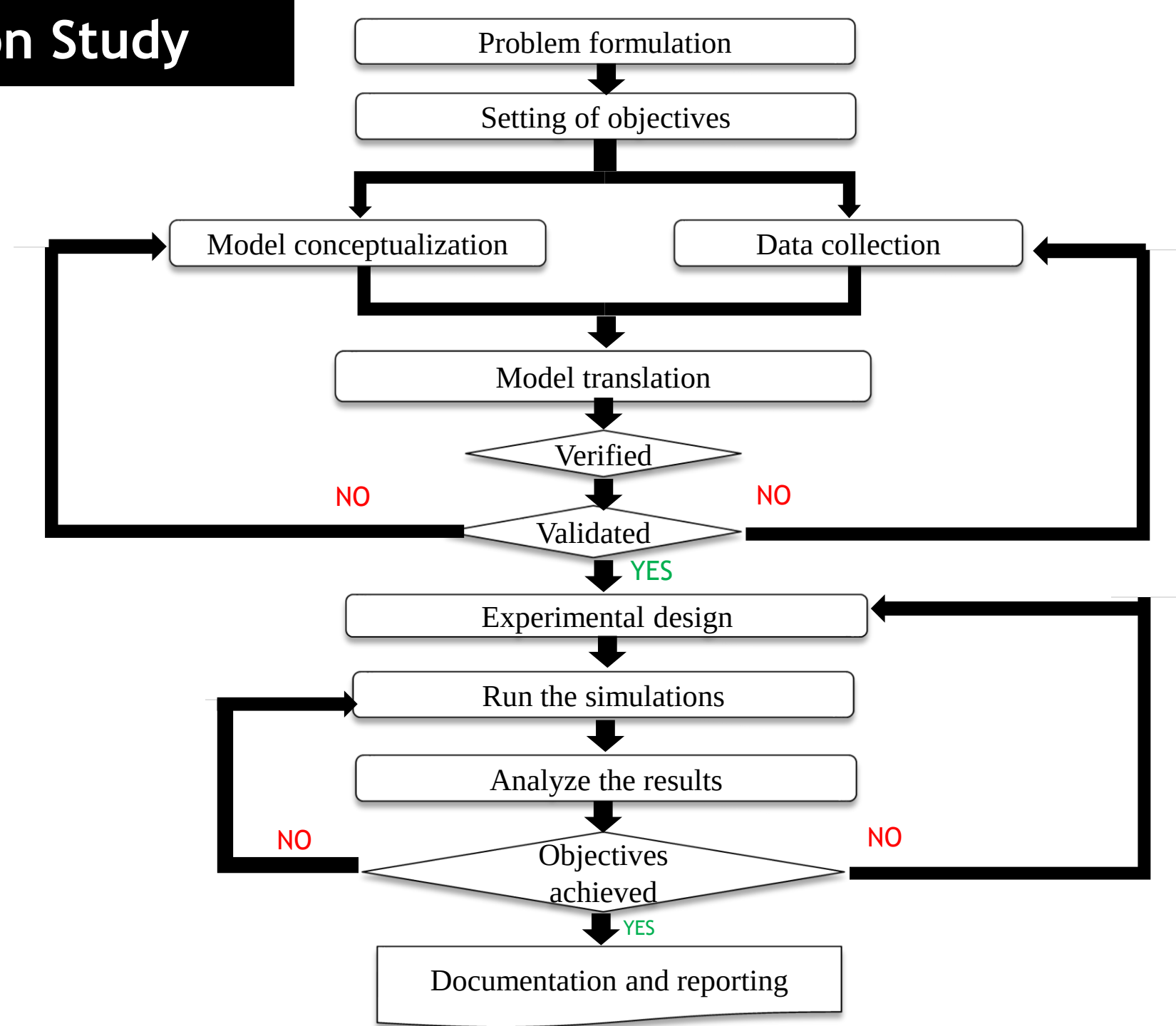
- ▶ All models are wrong, some are useful.

—*George E.P. Box*

- ▶ As far as the laws of mathematics refer to reality, they are not certain, and as far as they are certain, they do not refer to reality.

—*Albert Einstein*

4. Steps in a Simulation Study



Steps in a Simulation Study