Ontario Tech
Engineering
& Applied Science

SOFE 4820U: Modelling and Simulation Winter 2024

Course Description

- Computer simulation approaches using deterministic and Monte Carlo techniques in systems modelling
- Life cycle of a simulation project
- Conceptual modelling and modelling techniques
- Validation and verification
- Design of experiments
- Simulation tools and languages
- Output data analysis
- Special topics including uncertainty modelling
- Parallel and distributed simulations
- Footprints of the computer simulation can be observed in all science and engineering fields such as transportation, manufacturing, and design engineering.

Major Topics

- Simulation Model types
- Random Number generation
- Probability distribution and random Variables
- Monte-Carlo Simulation
- Numerical Optimization
- Analysis of Simulation results
- Markov Chain Decision Processes
- Discrete Event Simulation for Queuing Models
- Simulating physical phenomena using Neural networks
- Real-world applications for Models and Simulations

Course Objective

- Understand when to Model
- Simulation method selection
- Understand fundamental / theoretical concepts with simulation
- Understand application of Monte-Carlo and Discrete Event Simulation
- Problem definition , requirement specification
- Analysis of simulation results

Grades Breakdown

- In-class Quizzes (Total 5 x 2%): 10%
- Individual Assignments (2 assignments): 20%
- Tutorials activities : 10%
- Mid-term exam: 35%
- Group Project and Presentation: 25%

Books and Reference material

- No particular textbook is required.

- Introduction to Modeling and Simulation with MATLAB® and Python. 1st Edition. Authors: Gordon, S.I. and Guilfoos, B., 2017.CRC Press.

- Stochastic simulation and Monte Carlo methods: mathematical foundations of stochastic simulation. Graham, Carl, and Denis Talay. Vol. 68. Springer Science & Business Media, 2013

- Both are Free e-books (pdf)

- Other suggested reading material may be provided.

Programming Language and Tools

- **Python**
- **Matlab Simulink**
- **Build your skills not to stress you out**

Assignments

- Assignment 1 - Model a Dynamic system using Matlab Simulink [Due **Friday, Feb. 9, 2024**]
- Assignment 2 [Due **Friday, Mar. 15, 2024**]
    - Model a Discrete Event System using Matlab Simulink
    - Model Neural Network with Python

Midterm Exam [35%]

- Friday, March 8, 2024, 12:40 pm to 2:00 pm
- Multiple Choice and short-answer questions
- Based on topics and reading material already covered thus far in the course

Group Project [25%]

Group Project [25%] Dates	
Group Project Design Guidelines discussion	**Friday, Feb. 2, 2024**
Group Project Proposal due	**Friday, Feb. 16, 2024**
Group Project Demo and Presentation	will be determined

Topics:

- Model a natural phenomena

  E.g. Population growth, a mechanical system, celestial orbits, drug effectiveness.

Let’s Start

What is a model?

- A model is a description of a system using mathematical concepts and equations. The system can represent natural phenomena, biological, mechanical, electrical, chemical systems etc.

- A Representation of an object, a system, or an idea in some form other than that of the entity itself

- The definition of a model is that it is a representation of a real-world entity but not the "real thing" itself.
- This definition, necessarily vague, encompasses just about any type of model.

Source: Wikipedia

Main Types of Models

1. Physical

It looks or feels like the real thing. It could be a toy plane or a statue or the blueprints of a house.

2. Mathematical

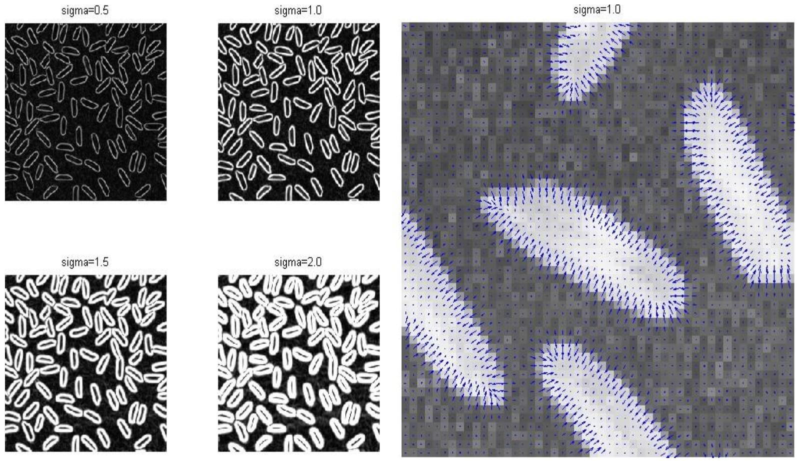
It uses mathematical symbols and relationships to describe something

$$Y_i = \beta_0 + \beta_1 X_i + \epsilon_i$$

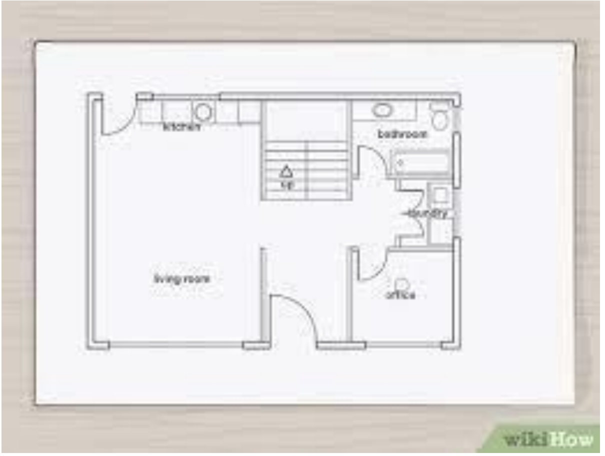
3. The Process Model

It describes the steps we to follow to get something done. For example: a to-do list, a flowchart, etc.

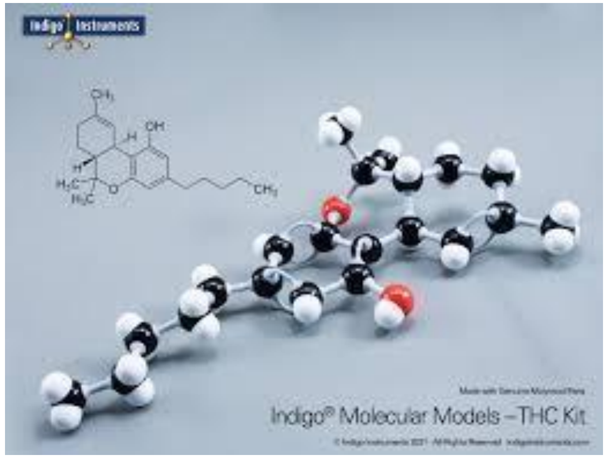
Some Models

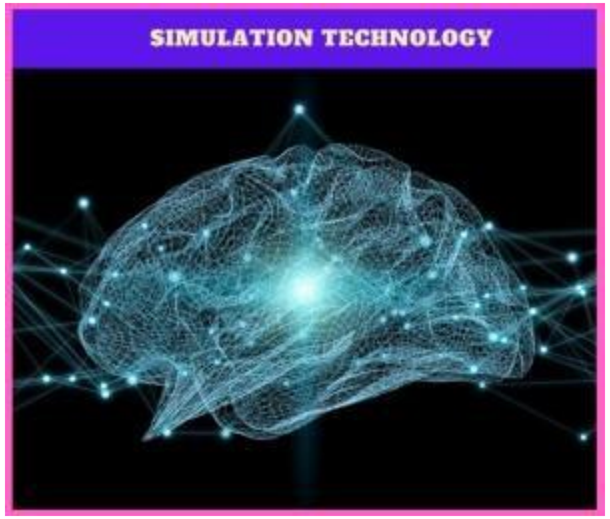


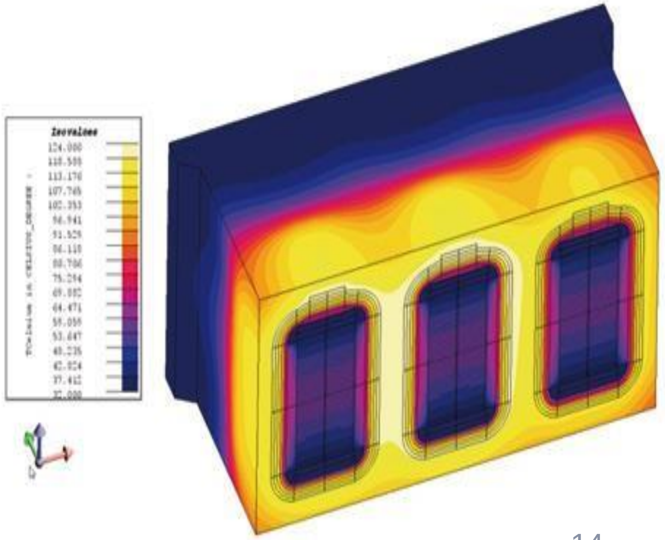
Gradient using first order derivative



Blueprint

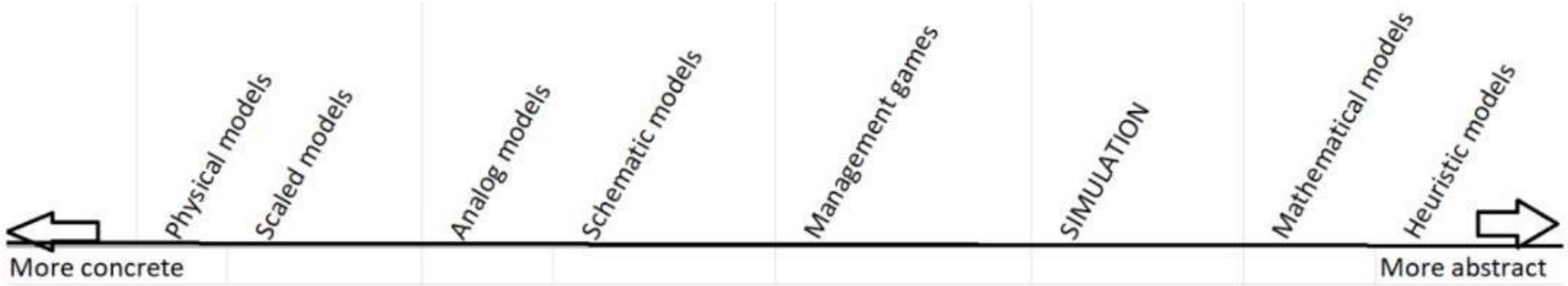






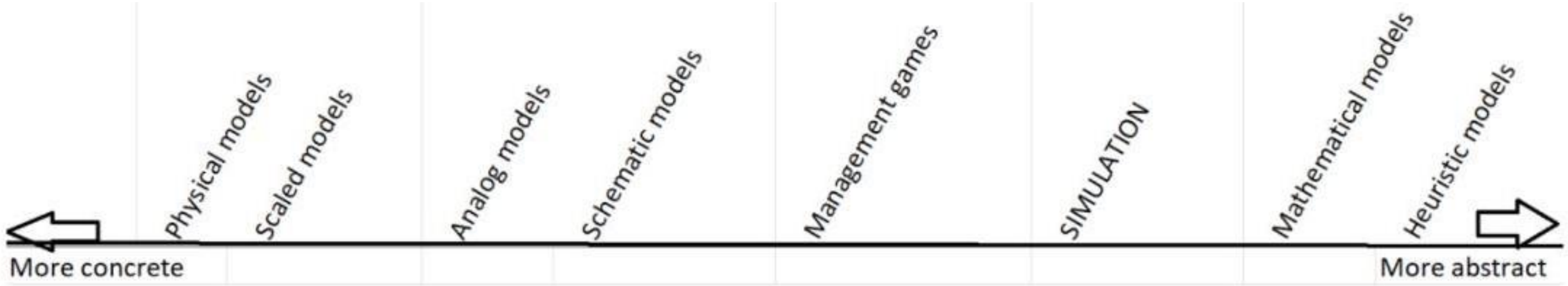
Your Turn: search of different types of models

Classifying Models – Concrete to Abstract



- Physical models resemble the system being studied, e.g., full-scale mockup for training pilots.
- Scaled models also resemble the system under study, but at a different size. e.g., scaled up model of an atom.
- Analog models. A property of the real (studied) object is represented by a substituted property that often behaves in a similar manner. e.g., voltage through an electronic analog computer network may represent flow of goods through a system. A graph is an analog model: distance represents time, temperature, sales, etc. Another example is an organizational chart.
- Schematic model is a pictorial representation of a system, e.g., blueprint, graph.

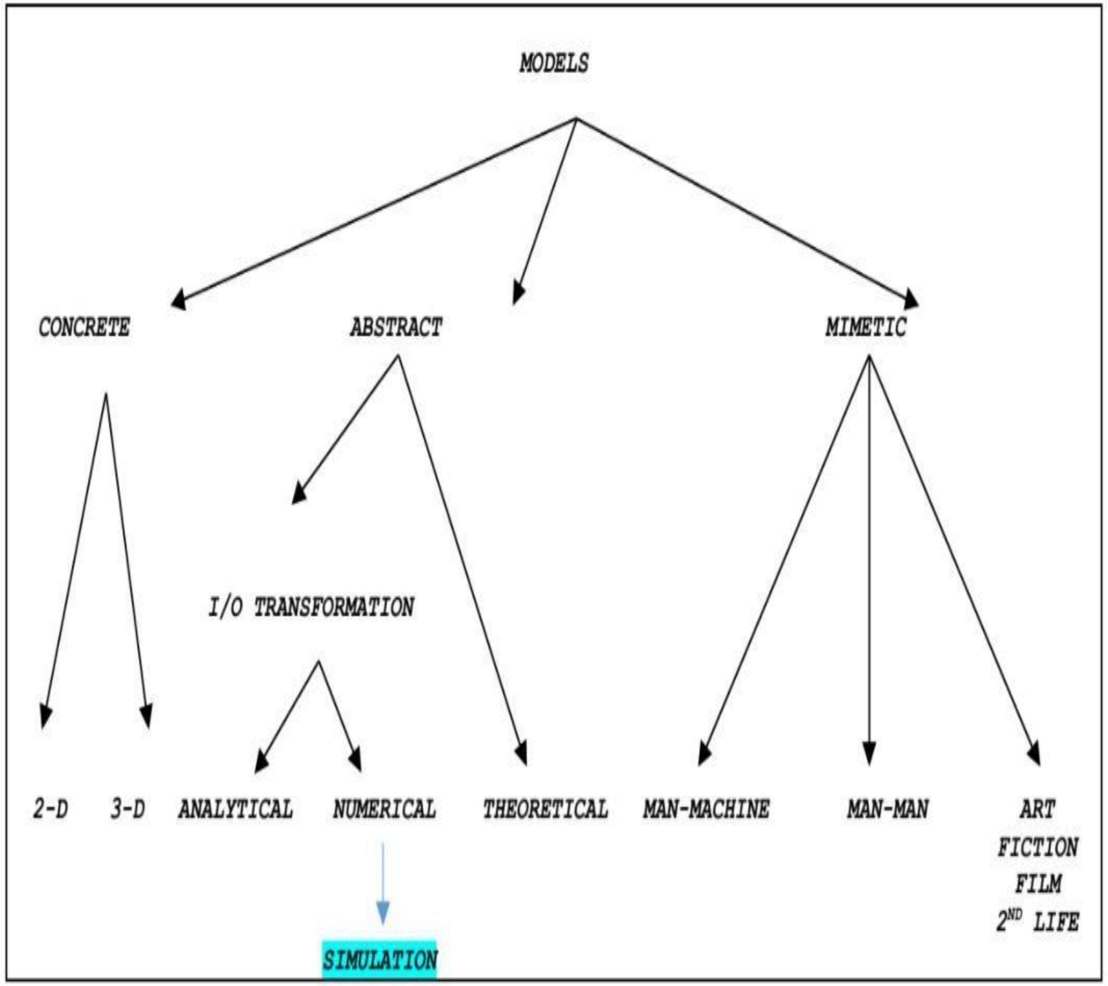
Classifying Models – Concrete to Abstract



- Games, or man-machine models, include management games, war games, planning, competition
- Simulation models, such as discrete-event system simulation models, have no human interaction. an abstract model, e.g., an algorithm or a step-by-step computation or computer program.
- Mathematical models. Symbols represent entities. These are the most generalized models, with the risk of oversimplification.
- The heuristic model is an approach to problem-solving in which the objective is to produce a working solution within a reasonable time frame. Instead of looking for a perfect solution, heuristic strategies look for a quick solution that falls within an acceptable range of accuracy

Classifying Models

- The following is an attempt to classify the universe of models as used in various scientific and non-scientific disciplines. The taxonomy is multi-level. At the first level, models are grouped into :
- concrete (e.g., a physical scale model such as a model airplane),
- abstract (e.g., an analytical formula or numerical approximation), and
- mimetic (e.g., a work of art or a virtual reality environment).



What makes a model?

- What do the models in the above classification have in common?
- Do they even belong on the same tree? An examination of the various models represented in the classification tree reveals that there is indeed some commonality in the way these very different fields process information.
- Each model : is a view of reality;

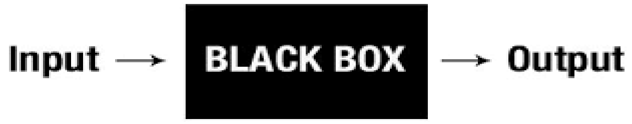
  has a purpose; and employs abstraction, structure,

  and information hiding.

- In addition, each model alters reality to some degree. Even physical models, which we may expect to be fairly good representations, may be faster, slower, flatter, larger, or smaller than the reality they purport to represent.
- Abstraction models reality or, at the very least, a chosen view of reality in which irrelevant objects or properties are ignored ... making the model simpler conceptually and easier to study, manipulate, and implement.

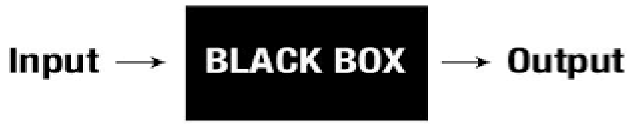
What Makes a Model? Abstraction & Information Hiding

- In the Black Box Model, the general model governing abstraction is the so-called black box model, adopted from the engineering disciplines to many diverse areas.
- In that model, a set of inputs is mapped to a set of outputs or results using a transform.
- To use the transform, once it has been built, one need not know how it works; only that it does work. For example, we do not need to understand much about electricity to know that when we flip the light switch (input), the bulb will light up (output).



What Makes a Model? Abstraction & Information Hiding Cont'd

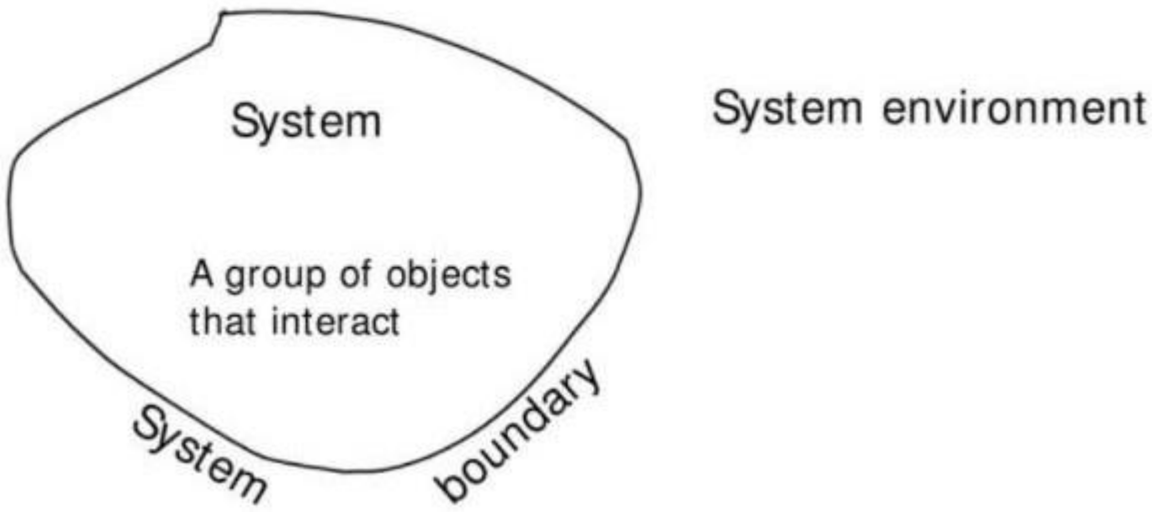
- All abstraction uses the concept of information hiding.
- When models are well-designed, they are relatively independent. They communicate with each other only through well-defined interfaces.
- A "user" system does not require access to all the implementation details of the "used." This unnecessary information may be hidden from the user, protecting the integrity of individual systems and reducing the confusion that comes along with too much information.
- Abstraction also allows one to ignore the tedious and possibly irrelevant details (at least temporarily) and concentrate on the larger picture.



System and System Environment

- A system is defined as a group of objects that are joined together in some regular interaction toward the accomplishment of some purpose.
  - An automobile factory: machines, components parts and workers operate jointly along an assembly line.

- A system is often affected by changes occurring outside the system: the system environment
  - Factory: Arrival orders
    - Effect of supply on demand: relationship between factory output and arrival (activity of the system)
  - Banks: arrival of customers



Component of the System

- Entity: An entity is an object of interest in a system.
  - Ex: in the factory system, departments, orders and products are the entities.

- Attributes: An attribute denotes the property of the entity.
  - Ex: quantities of each order, type of parts, or number of machines as a department are attributes of the factory system.

- Activity: any process causing changes in the system is called activity.
  - Ex: Manufacturing process of the department,

- State of the system: the state of a system is defined as the collection of variables necessary to describe a system at any time, relative to the objective of the study.

- In other words, the state of the system means a description of all entities, attributes and activities as they exist at one point in time.

Component of the System

- Event: an event is defined as an instantaneous occurrence that may change the state of the system.

- Endogenous System: the term is used to describe activities and events occurring within the system
  - Example: Drawing cash in a back

- Exogenous System: the term is used to describe activities and events in the environment that affect the system.
  - Ex: arrival of customer

- Closed System: A system for which there is no exogenous activity and event is said to be closed.
  - Ex: Water in an insulated flask

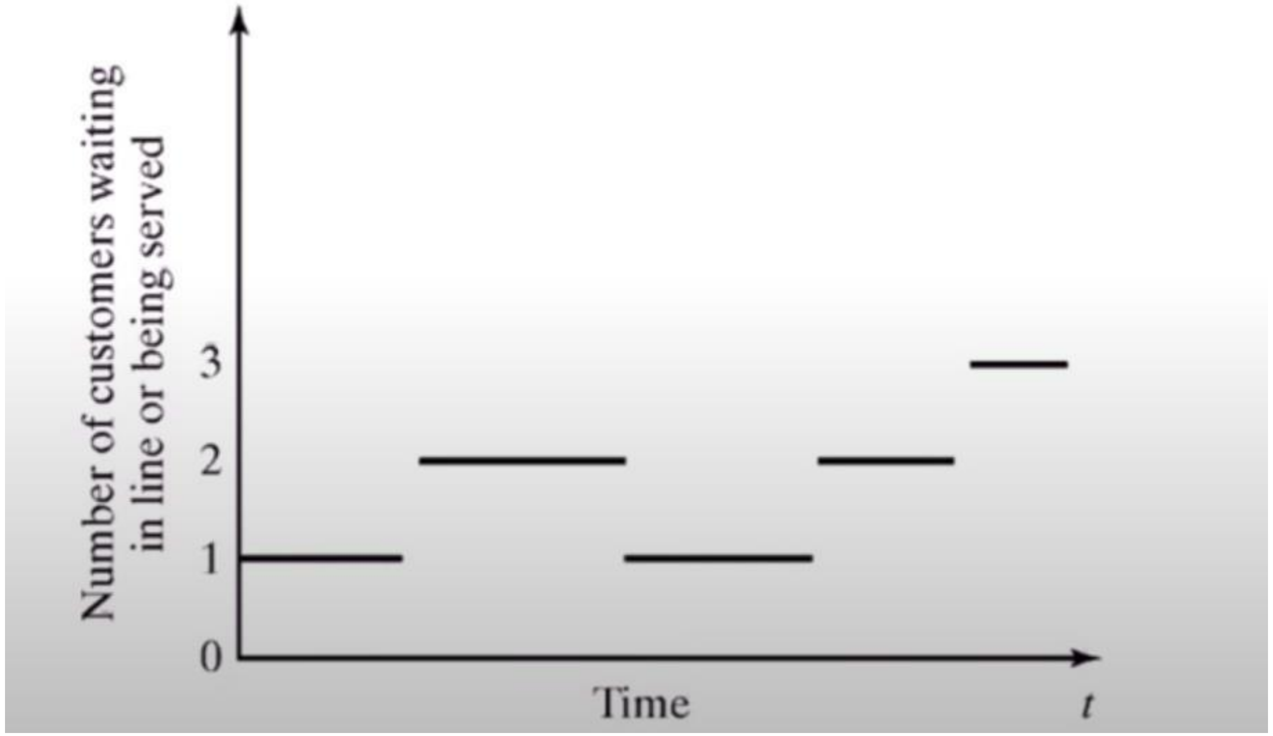
- Open System: A system for which there is exogenous activity and event is said to be open.
  - Ex: Bank system

Example of system and it's components

System	Entities	Attributes	Activities	Events	State variables
Banking	Customers	Account balance	Making deposit	Arrival, Departure	Number of customers waiting

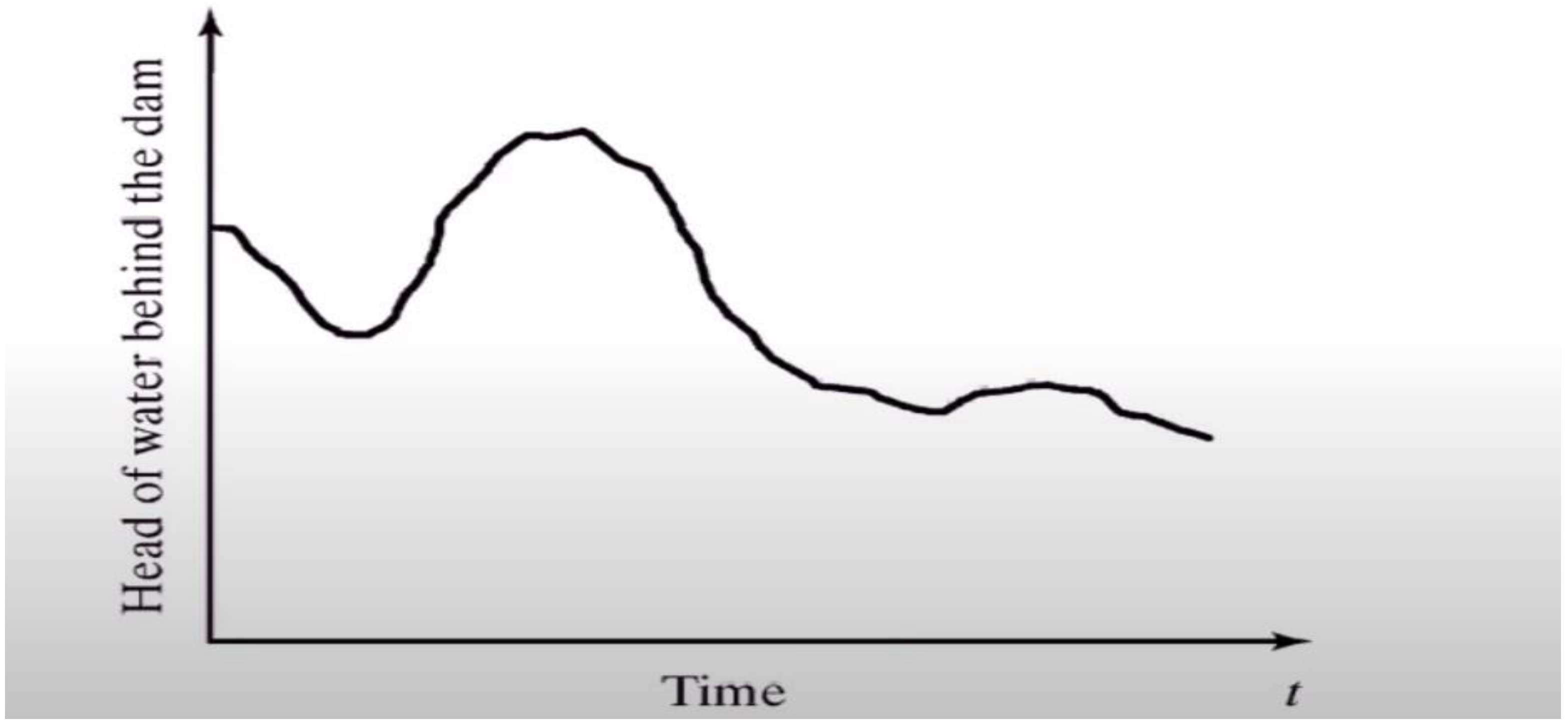
Discrete system

- A discrete system is one in which that the state variables change only at a discrete set of points on time.
  - Ex: (Bank): the number of customer’s changes only when a customer arrives or when the service provided a customer is completed.



Continuous system

- A continuous system is one in which the state variables change continuously over time
  - Ex: the level of water behind a dam



Model of a System- Further Characteristics of Models

A model is defined as a representation of a system to study that system.

The various types of models are:

- Mathematical or Physical Model
- Static Model
- Dynamic Model
- Deterministic Model
- Stochastic model
- Discrete Model

Model of a System- Further Characteristics of Models

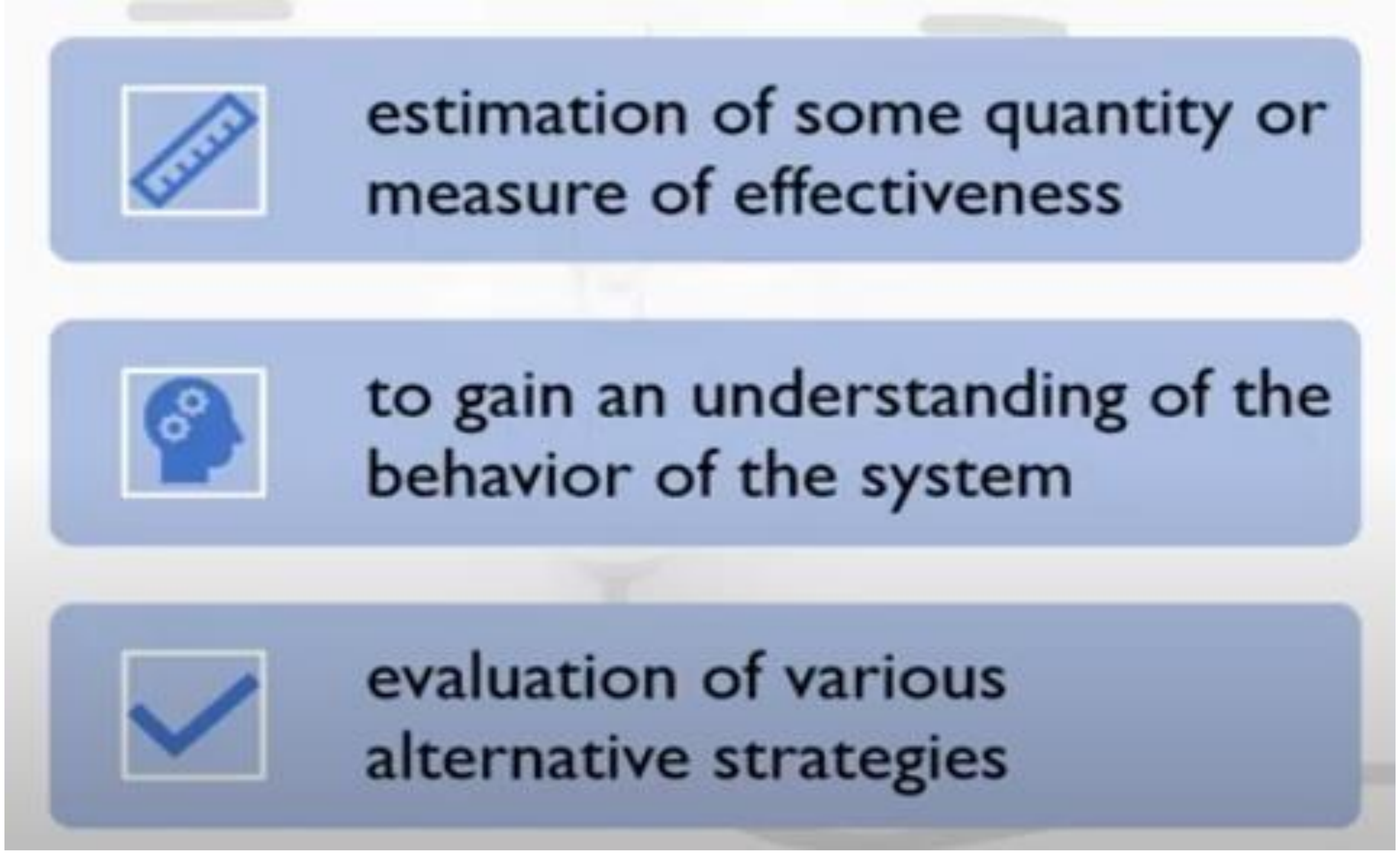
- Mathematical
  - Uses symbolic notation and mathematical equations to represent a system
- Static Model
  - Represent a system at a particular point in time and also known as the Monte-Carlo simulation
- Dynamic Model
  - Represent systems as they change over time.
  - Ex: Bank Simulation
- Deterministic Model
  - Contains no random variables. It has a known set of inputs which will result in a unique set of outputs.
  - Ex: Arrival of patients to the dentist at the scheduled appointment time.
- Stochastic Mode
  - Has one or more random variables as inputs. Random inputs lead to random outputs.
  - Ex: Simulation of a bank involves random interval and service times
- Discrete-Event System Simulation
  - Modeling of systems in which state variables change only at a discrete set of points in time.
  - The simulation models are analyzed by numerical rather than by analytical methods.

What is Simulation?

- Simulation is the process of:
  - Design a model of a real system, and
  - Conducting experiments with this model.
- Consists of methods and applications to imitate or mimic real systems, usually via computers
- Simulation applies in many fields and industries
- Very popular and powerful method

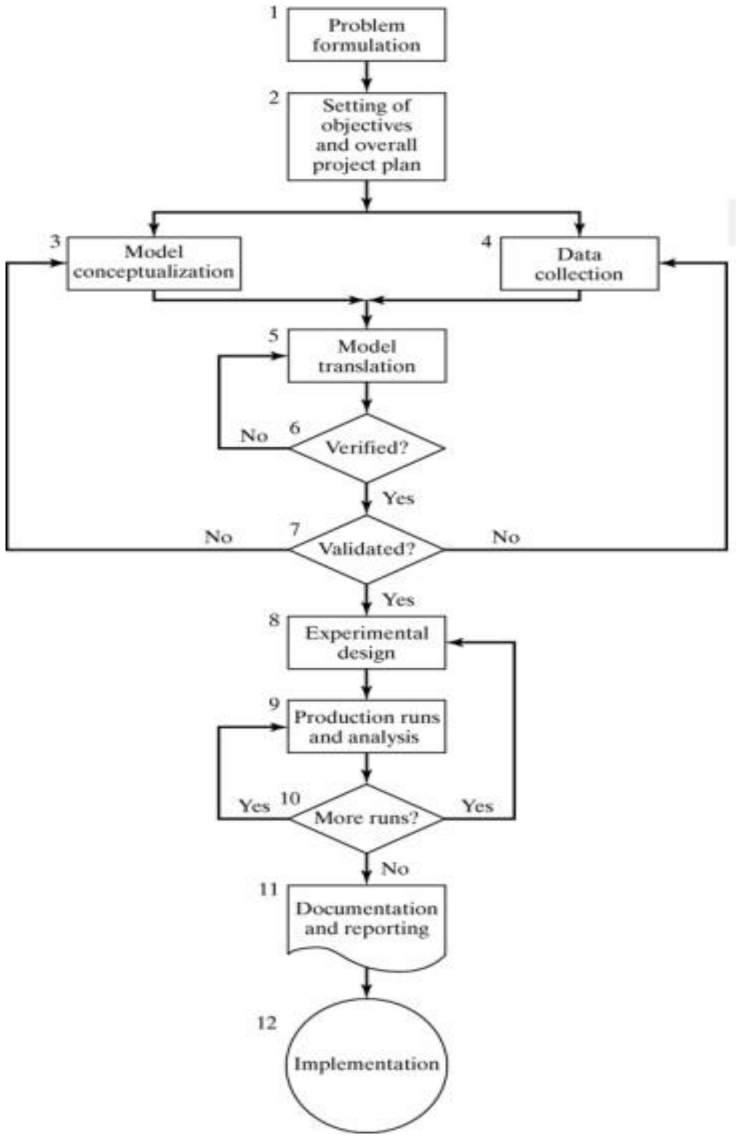
Why Simulate?

The objective if a simulation experimentation may be:



Steps in Simulation

1. Problem Definition
2. Project Planning
3. System Definition
4. Model Formulation
5. Input Data Collection & Analysis
6. Model Translation
7. Verification & Validation
8. Experimentation & Analysis
9. Documentation & Implementation



Types of Simulations

1. Discrete Event Simulation

Modelling a system as it progresses through time, for example;

- factory operations (stamping, turning, milling)
- traffic analysis (roads, networks, queues)

2. Dynamic Simulation

Modelling a system as it progresses through space, for example;

- machine kinematics
- human ergonomics
- aerodynamic testing
- virtual prototyping

3. Process Simulation

Modelling physical interactions between two or more systems, for example;

- in-service product modelling
- in-manufacture product modelling
- weather forecasting. Weather forecasting uses simulations based on past data to predict extreme weather conditions such as hurricanes or cyclones.

Simulation

Pros: Concrete advantages that can be obtained from the use of simulation models:

- It reproduces the behaviour of a system about situations that cannot be directly experienced.
- It represents real systems, even complex ones, while also considering the sources of uncertainty.
- It requires limited resources in terms of data.
- It allows experimentation in limited time frames.
- The models that are obtained are easily demonstrable.

CONS: technique capable of reproducing complex scenarios have some limitations:

- The simulation provides indications of the behaviour of the system, but not exact results.
- The analysis of the output of a simulation could be complex and it could be difficult to identify which may be the best configuration.
- The implementation of a simulation model could be laborious and it may take a long calculation time to carry out a significant simulation.
- The results that are returned by the simulation depend on the quality of the input data: it cannot provide accurate results in the case of inaccurate input data.
- The complexity of the simulation model depends on the complexity of the system it intends to reproduce.

Example. Checkout stand

- We want to simulate the checkout in a small store (say, a small gift shop). One cashier, one line of customers waiting for service. We are interested in determining the average time a customer spends in the system (both waiting and being serviced) and the percentage of time that the checkout clerk is not occupied with work.

- To simulate the system, we need to generate an artificial experience that would be characteristic of the situation as described.

- In other words, we need an artificial way to generate customer interarrival times and service times based on the distribution assumptions above.

Example. Checkout stand Cont'd

- One way to do this – if we are simulating *by hand* – is to obtain ten poker chips and a single die.
- Number the poker chips from 1 to 10, put them in a hat, and mix them up.
- By drawing a poker chip out of the hat and reading off the number, we represent the time between the arrival of the present customer and the next one.
- Roll the die and read off the number on its face to represent how long it takes to service the customer currently at the checkout.
- By repeating this process, we can generate a stream of customer arrivals and service times.
- Our problem then reduces to being simply one of bookkeeping

Checkout stand run the simulation

- What might a sample of 20 customers look like?
- *(We start the simulation when the first customer arrives and enters the system.)*

DIE

CHIPS

	TIME (minutes)		CLOCK TIME			MOEs (minutes)	
Customer	Since last arrival	Service	Arrival	Service begins	Service ends	Customer in system	Clerk idle
1	-	1	0:00	0:00	0:01	1	0
2	3	4	0:03	0:03	0:07	4	2
3	7	4	0:10	0:10	0:14	4	3
4	3	2	0:13	0:14	0:16	3	0
5	9	1	0:22	0:22	0:23	1	6
6	10	5	0:32	0:32	0:37	5	9
7	6	4	0:38	0:38	0:42	4	1
8	8	6	0:46	0:46	0:52	6	4
9	8	1	0:54	0:54	0:55	1	2
10	8	3	1:02	1:02	1:05	3	7
11	7	5	1:09	1:09	1:14	5	4
12	3	5	1:12	1:14	1:19	7	0
13	8	3	1:20	1:20	1:23	3	1
14	4	6	1:24	1:24	1:30	6	1
15	4	1	1:28	1:30	1:31	3	0
16	7	1	1:35	1:35	1:36	1	4
17	1	6	1:36	1:36	1:42	6	0
18	6	1	1:42	1:42	1:43	1	0
19	7	2	1:49	1:49	1:51	2	6
20	7	2	1:56	1:56	1:58	2	5
					TOTALS	68	55

Checkout stand. analysis

- Average customer time in system = $\frac{68}{20}$ = 3.40 minutes
- Percent of time cashier is idle = $\frac{55}{118}$ x 100% = 46%
- Obviously, to obtain statistical significance, we would have to use a much larger sample, and we have ignored several important system simulation considerations, such as starting conditions (e.g., how many customers might be waiting when the doors open in the morning).

References

- Bossel, H., 2013. *Modeling and simulation*. Springer-Verlag.
- Carson, John S. "Introduction to modeling and simulation." *Proceedings of the Winter Simulation Conference, 2005.*. IEEE, 2005.