Computer Simulation

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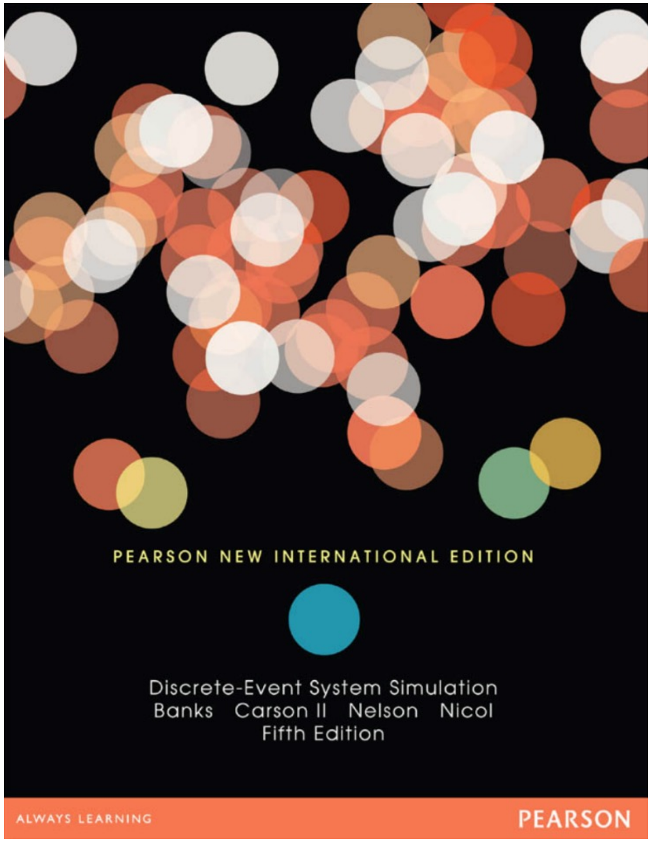
Chapter One: Introduction to Computer Simulations

Specifications of the Course (1)

- 4 Home works (4 points)
  - Theoretical problems
  - Simulation exercises
  - Every 2 weeks
- Project (3 points)
- Midterm (5 points)
- Final Exam (8 points)
- Activities (+1 points)
  - Simple home tasks
  - Class R&Q and Quiz
- Head Teacher Assistants:
  - Neda Taghizadeh and Benyamin Maleki

Specifications of the Course (2)

- 8-10 Chapters
- Main text book of the course
  - Discrete-Event System Simulation (5th edition)
    - Banks Carson
    - Nelson Nicol
  - The book will be uploaded in **CW**



Introduction

- What is Simulation?
  - A tool, which helps us to **emulate** events and functionality of systems in a time interval to **evaluate its performance**
  - It is based on:
    - Modeling a system with a number of **assumption**, and **mathematical and logical equations**
    - Conducting a set of **extensive experiments** on the model
- Goals of the simulation modeling:
  - Predicting the effect of changes to the current system
  - Evaluating the performance of the evolved versions of the system

Real-world process $\xrightarrow[\text{concerning the behavior of a system}]{\text{A set of assumptions}}$ **Modeling & Analysis**

When to Use Simulation (1)

- Studying the **interactions** between different parts of a complicated system
- Evaluating the effect of **structural** and **environmental** alterations on the behavior of the system
  - One important evaluation is to determine the **most influential input** among all the other inputs
    - This is pretty valuable when **proposing new ideas**
- Designing improved versions of the system and comparing it with the old versions
- For educational purposes and solving problems
  - Reducing the costs and possible harms during **on-the-job training**

When to Use Simulation (2)

- Simulation is a priceless tool for designing new systems, techniques, algorithms, and protocols
  - In order to test them before real-world deployment
    - Assuring correct functioning
    - Troubleshooting
    - Financial aspects
      - No need for redesigning or reproducing
    - Being prepared for what is going to happen, especially in applications such as safety/mission critical systems, where there is no room for any mistakes
- With simulation, we could add previously unthought options to the design
  - This was not possible before as the product is already produced
    - No other solution but to pay the price and produce again
- Providing animations for illustrating the functionality of the system

When Not to Use Simulations

- In case we had a problem with the following attributes we do not need to use simulation:
  - When the problem can be simply solved by using only **observations**
  - When the problem can be solved **analytically**
  - When it is easier to perform direct experiments on the real system
  - When the simulation costs more than our savings
  - When the resources or time are not available
    - Example: Using the patients data in a hospital
  - When system behavior is too complex or can't be defined as a model
  - When there isn't the ability to verify and validate the model
    - We will talk about this in Chapter 9

Analytical Vs. Numerical Analysis (1)

- Every system is composed of parameters, which their alteration could change the results
  - In simulation (or numerical analysis), these parameters must be previously determined
    - Results only correspond to these parameters
  - In analytical analysis, result applies to any inputs
- Simulation may provide results, which does not completely match the behavior of the real-world system
  - Also referred to as **approximated** results
  - Analytical methods provide **accurate** results
- Analytical methods require pen & paper, while simulation requires computer

Analytical Vs. Numerical Analysis (2)

- In linear systems, these two may provide the same result is specific conditions
  - But, in un-linear systems, simulation provides a new result for every set of input parameters and initial assumptions
- **Not forget**
  - **Simulation could be also used in some cases when an analytical solution is possible, or even preferable**
    - **This might be particularly true in the simulation of Queues**

Advantages of Simulation (1)

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- New policies, operating procedures, decision rules, information flows, organizational procedures, and so on can be explored without disrupting ongoing operations of the real system
- The final design, e.g., new hardware, physical layouts, etc., can be tested, and validated before production
  - Without losing financial and temporal resources
- Evaluating the hypotheses
- Understanding why certain phenomena occur
- Understanding the interaction between variables of the model

Advantages of Simulation (2)

- Detecting the most important variables on the performance of the system
- Bottleneck analysis
  - Indicating the factor(s) which imposes major delay on the response time
- Real understanding about the functionality of the system
- Research & development
  - **"What-if"** questions can be answered
  - This is particularly useful in designing new systems
    - One of the important skills in pursuing your MSc, and PhD

Disadvantages of Simulation (1)

- Model building requires special training
  - It is an art that is learned over time and through experience
  - Furthermore, if two models are constructed by two competent individuals, they may have similarities, but it is highly unlikely that they will be the same
- Simulation results may be difficult to interpret
  - Most simulation outputs are essentially random variables
    - Because they are usually based on random inputs
    - So, it may be hard to determine whether an observation is a result of system interrelationships or randomness
- Simulation modeling and analysis may be time consuming and expensive

Disadvantages of Simulation (2)

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- Precision and time are two major resources
  - Skimping on these either for **modeling** or the **analysis** may result in a simulation model or analysis that is not sufficient for your task

Simulation Applications (1)

- Manufacturing
  - Analysis of electronics assembly operations
  - Design and evaluation of assembly station for high-precision scroll compressor shells
  - Comparison of dispatching rules for semiconductor manufacturing
  - Evaluation of cluster tool throughput for thin-film head production in hard disk drives factories
  - Determining optimal lot size in semiconductor factories
    - Optimization of cycle time and utilization
  - Analysis of storage and retrieval strategies in a warehouse
  - Supply chain
  - Modeling an army chemical munitions disposal facility

Simulation Applications (2)

- Construction engineering
  - Construction of a dam embankment
  - Construction and renewal of underground urban infrastructures
  - Activity scheduling in a dynamic, multi-project setting
  - Investigating the defects and renewal process of steel constructions, e.g., bridges
  - Tunnel construction
- Military
  - Modeling leadership
  - Troops movement pattern in operation zones
  - Autonomous underwater vehicles
  - Modeling military equipment for non-war fighting operations
    - Flood, earthquake, etc.

Simulation Applications (3)

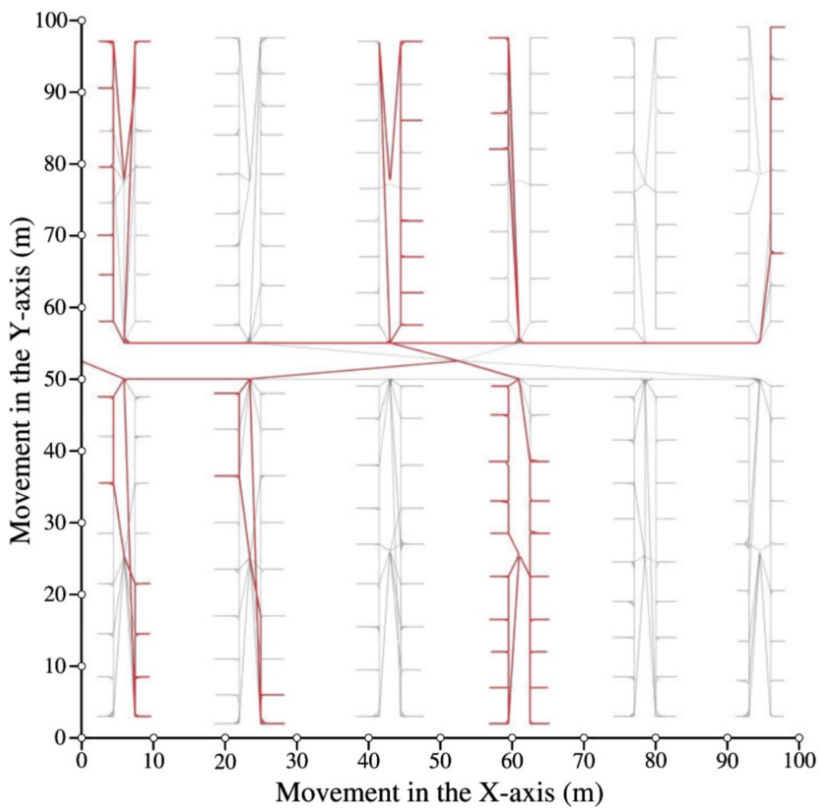
- Logistics, transportation, and distribution
  - Rail-traffic planning algorithm
  - Analysis of passenger flows in airport terminals and train stations
  - Flight-schedule evaluation
    - Evaluating the impact of connection algorithms, or gate assignment
  - Logistics issues in autonomous food production systems for extended-duration space exploration
  - Product distribution
    - Reduce gas costs, pollution
  - Design of a toll plaza

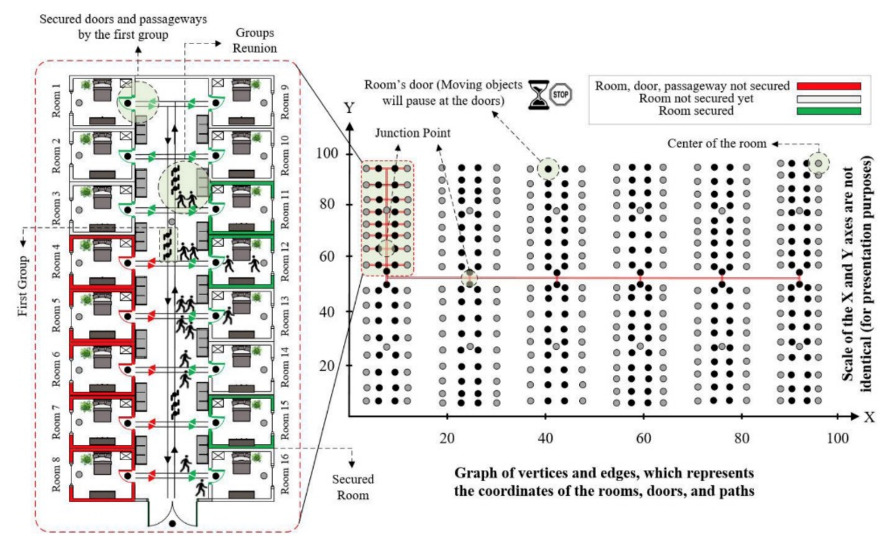
Simulation Applications (4)

- Business
  - Modeling the effect of various parameters on the stock price
  - Personnel forecasting and strategic workforce planning
- Human Systems
  - Modeling human performance in complex systems
  - Human behavior
- Computer science
  - Mobile Ad-hoc Networks
    - VANET
    - FANET
  - IoT
  - Edge/Fog/Cloud computing
  - Embedded Systems

Simulation Applications (5)

- Example for simulating movement pattern of objects in mobile IoT applications





- Tactical Indoor Mobility Model
  - Simulated with BonnMotion

System and its Environment

- System
  - A group of objects that are joined together in some regular interaction or interdependence for accomplishing a purpose
- Environment
  - Changes occurring outside the system (outsiders)
  - Out of our control
  - Could affect the performance of the system
- The decision about the **boundary** between the system and its environment depends on the purpose of the study
  - If outsiders are **partially** affecting the system, there are 3 options:
    - Simply consider the outsiders as your inputs
    - Expand the definition of the system to include them in the system
    - Neglect the outsiders ☹

Elements of a Simulation Model

- A simulation model is often made up of two objects:
  - Entity
    - Individual elements of the system that are being simulated and whose behavior is being explicitly tracked
  - Resource
    - Also individual elements of the system but they are not modelled individually
    - They are treated as countable items whose behavior is not tracked
- The modeler must decide about whether an element should be treated as an entity or as a resource
  - This depends on the purpose of the simulation
  - Example: Consider a donut shop
    - Employees may either be considered as entities or resources

Organization of Entities and Resources

- Attributes
  - Properties of entities or resources
  - Often used to control the behavior of the object
    - Example: In our donut shop, an employee maybe busy or available
- State
  - Collection of variables necessary to describe the system at any point of time
    - Example: In our donut shop, in the simplest case, the necessary variables are number of customers queuing and number of busy employees
- List
  - Collection of entities or resources ordered in some logical fashion
    - Example: The customers waiting in our shop may be ordered in the so-called fist-come, first-served

Operations of the Objects (1)

- During a simulation study, entities and resources will cooperate and therefore change state
- The following terminologies emerge while an object changes its state
  - Event
    - The instant of time where the state of the system changes
    - Example: In the donut shop, suppose there are currently two customers being served
      - An event is when a customer has finished being served
      - Accordingly, the number of busy employees decreases by one and there is one less customer in the queue

Operations of the Objects (2)

- Activity
  - A time period of **specified** length which is known when it begins
  - Example: The time an employee takes to serve a customer
  - Its length may be completely random
- Delay
  - Duration of time of **unspecified** length, which is not known until it ends
  - This is not specified by the modeler ahead of time, and depends on the conditions of the system
  - Typically, delay is one of the desired outputs of a simulation
    - Example: The waiting time of a customer in the queue of our donut shop

- Note: **endogenous**, and **exogenous** adjectives are used to describe activities and events occurring within a system or the environment that affects the system

Examples for System Components

System	Entities	Attributes	Activities	Events	State Variables
Banking	Customers	Account balance	Making deposits	Arrival, Departure	Number of busy tellers, number of customers waiting
Rapid Rail	Riders	Origination, Destination	Traveling	Arrival at station, Arrival at destination	Number of riders waiting at each station, number of riders in transit
Production	Machines	Speed, Capacity, Breakdown Rate	Welding, Stamping	Breakdown	Status of Machines (busy, idle, or down)
Communications	Massages	Length, Destination	Transmitting	Arrival at destination	Number waiting to be transmitted
Inventory	Warehouse	Capacity	Withdrawing	Demand	Level of inventory

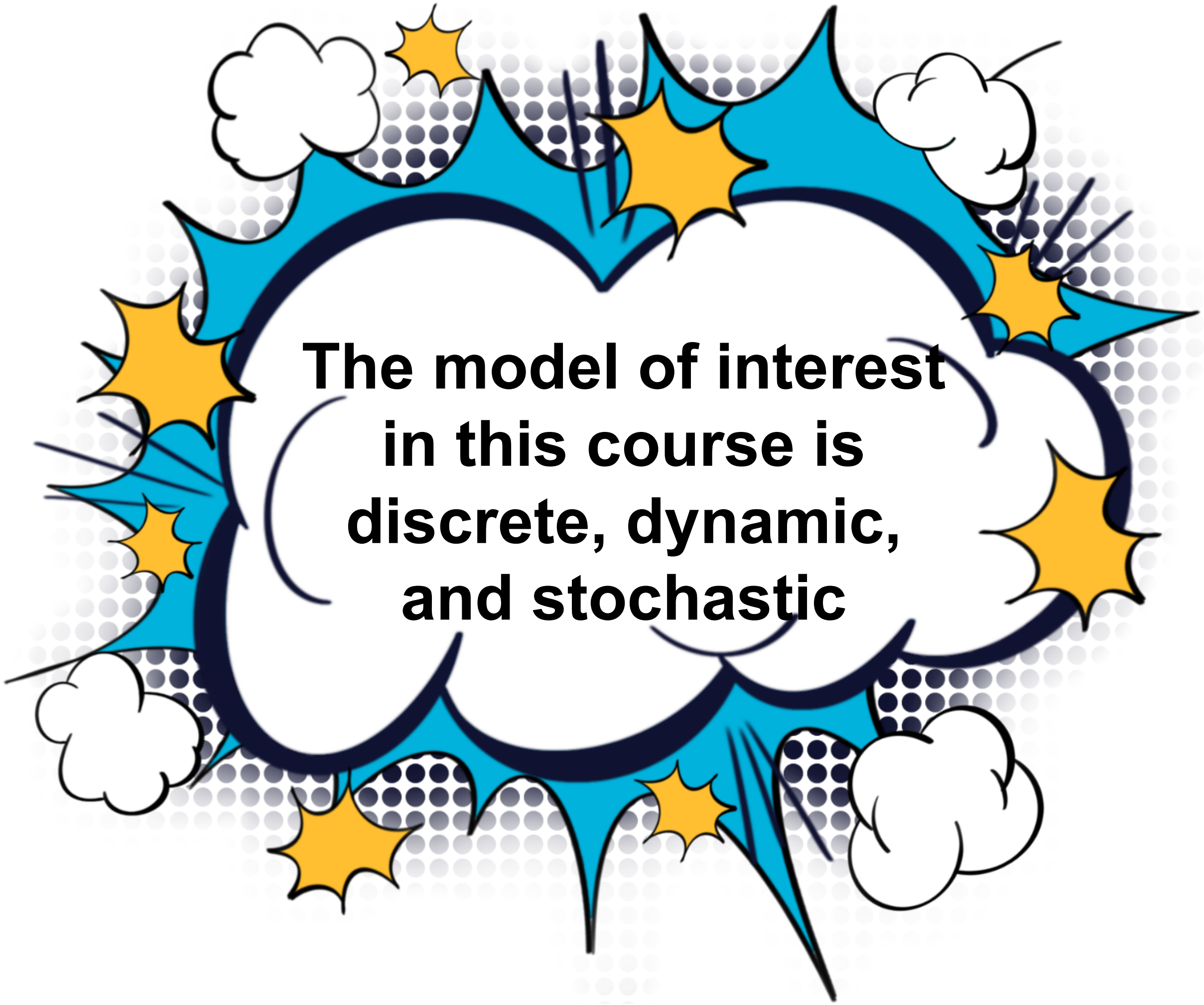
Types of State Variables and Systems

- Systems and state variables can be categorized as continuous or discrete
  - Examples for discrete states:
    - Banking: Account balance
    - Data communication: Number of packets
    - Transportation: Number of idle riders
  - Examples for continuous states:
    - Dam: Volume of water
    - Vehicle: Length of movement

System Model (1)

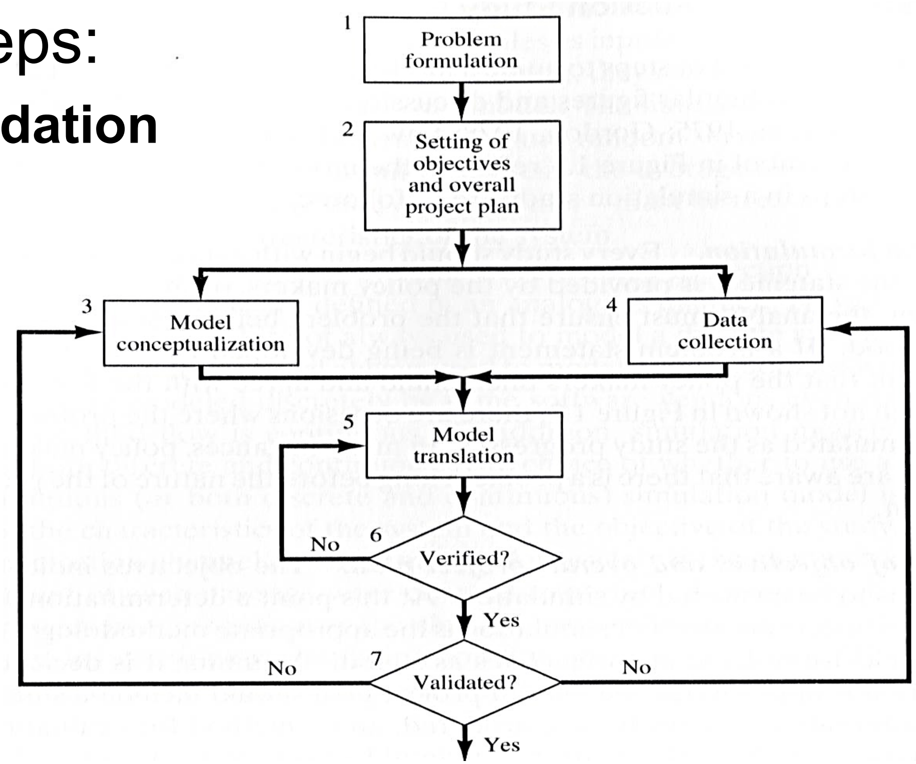
- Model is a representation of the system for the purpose of studying it
  - Is a simplification of the system
  - sufficiently detailed to permit valid conclusions to be drawn about the real system
- A system model may be **static** or **dynamic**
  - Static simulation model represents a system at a particular point in time
    - Steady state
  - Dynamic simulation model represents systems as they change over time
- A system model may be **deterministic** or **stochastic**
  - Deterministic simulation models contain no random variables and have a known set of inputs which will result in a unique set of outputs
  - Stochastic simulation model has one or more random variables as inputs
    - Random inputs lead into random outputs

System Model (2)



Simulation Process (1)

- The process of simulation could be divided in to 2 major steps:
  - **Model verification and validation**
  - Simulation run



- Model conceptualization includes:
  - Extracting the specifications of the problem
  - Selection and modification of assumptions
  - Iterative model modification to reach dependable results

- Data collection mechanism could be changed model by model based on the complexity, volume and required precision

Simulation Process (2)

- The process of simulation could be divided in to 2 major steps:
  - Model verification and validation
  - **Simulation run**
- Experimental design includes:
  - Preparing the system setup
  - Determining the simulation period
  - Determining the number of replications to achieve the desired error
- After evaluating the quality of results in (9), if the results did not meet our expectations
  - There may be a mistake in our system setup or analysis
- Documentation: reporting the accomplished tasks, the relation between inputs and outputs, and future prospects