

Simulation and Modeling

COMP 406

Prerequisites: comp 305, stat 201

Text Book: Simulation Modeling and Analysis , 4rd edition

by: Averill Law & W. Kelton

Objectives

- To encourage “system” thinking
- Provide background to systems modeling concepts
- Opportunity for a practical appreciation for discrete event simulation
- Combine theory and practice

Outline of the course

- ◆ Introduction to Simulation.
- ◆ Hand Simulation.
- ◆ Review of basic Probability Theory.
- ◆ Random Number Generation
- ◆ Generation of Random Varieties.
- ◆ Analysis of Output.
- ◆ Elementary Queuing Models

Modeling and Simulation

Model

- It is a simplification of the reality
- A (usually miniature) representation of an actual system; an example for imitation or emulation
- A description of observed behavior, simplified by ignoring certain details.
- Models allow complex systems to be understood and their behavior predicted within the scope of the model
- A model can be **Analytical** (Queuing Theory) or by Simulation.

Modeling and Simulation

Simulation

- Simulation reflects the behavior of the real world in a smaller and simpler way.
- Simulation involves the modeling of a process or system in such a way that the model mimics the response of an actual system to events that take place over time. (Schriber 1987).
- It is a program that mimics (imitate) the behaviour of the real system

Why do we use Simulation

- Provides a way to study complex, real-world systems that cannot be accurately described by a mathematical model that can be evaluated analytically.
- It may be too difficult, hazardous, or expensive to observe a real, operational system
- Parts of the system may not be observable (e.g. internals of a silicon chip or biological system)
- Allows estimation of the performance of an existing system under some projected set of operating conditions.
- Allows comparison of alternative proposed system designs to see which one best meets a specified requirement.

Why do we use Simulation

- Analyze systems **before** they are built
 - Reduce number of design mistakes
 - Improves decision making with minimal cost
 - Reasons behind specific system conditions
 - Identify system constraints and limitations
 - Training the project team
 - Specify system requirements at design stage
 - Optimize design
 - Create virtual environments for training, entertainment

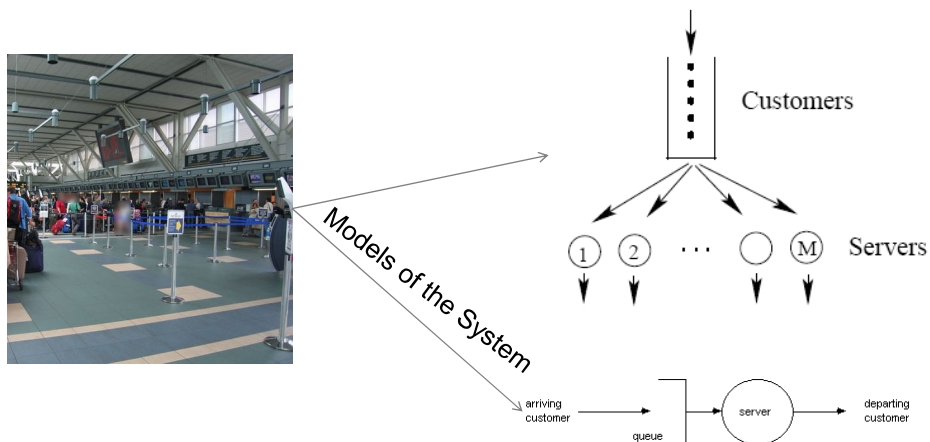
Why do we use Simulation

- Analyze **operational** systems
 - Prepare for change
 - Diagnose problems (understand the complex interactions between elements of the system)
 - Develop a general understanding of the behavior of the system
 - Explore possibilities with minimal expenses
 - Allows study of a system with a long time frame in compressed time, or alternatively, study of the detailed workings of a system in expanded time.

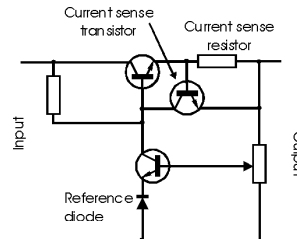
Software products

- In general models used to study large scale systems tend to be very complex
- Writing computer programs to execute them even more complex
- Now there are software products that automatically produce simulation models example: Arena

Example



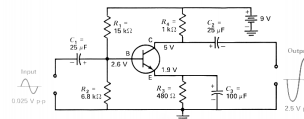
Example



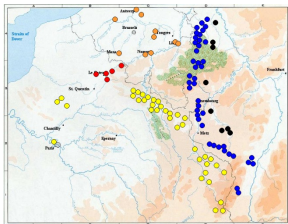
$$I = \frac{E}{R} \quad E = IR$$

$$R = \frac{E}{I} \quad P = EI$$

$$hfe = \frac{I_c}{I_b} \quad I_b = \frac{I_c}{hfe} \quad 1$$



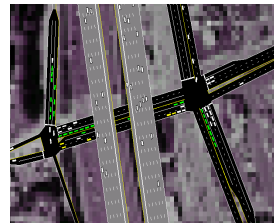
A Few Example Applications



War gaming: test strategies; training



Flight Simulator



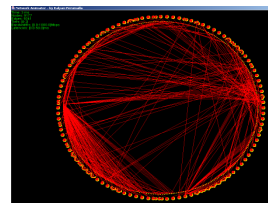
Transportation systems: improved operations



Parallel computer systems: developing scalable software



Games



Computer communication network: protocol design

Applications

System Analysis

- planning, flight simulation) Telecommunication Networks (ATM, IP, TCP, UDP, WiFi ...)
- Transportation systems (Traffic, Urban planning, Metro Planning, ...)
- Electronic systems (e.g., microelectronics, computer systems)
- Battlefield simulations (blue army vs. red army)
- Ecological systems, Manufacturing systems, Logistics ...

Virtual Environments

- Physical phenomena
- training and entertainment (e.g., military, medicine, emergency)

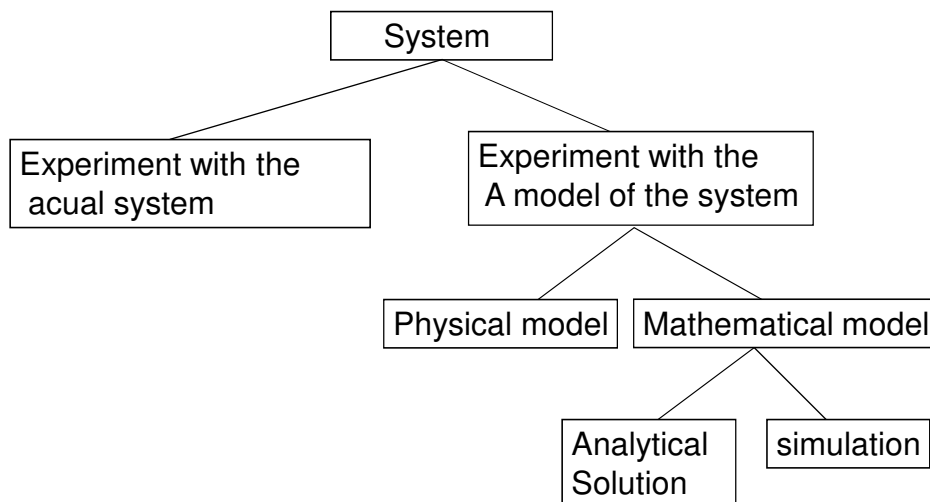
Disadvantages of Simulation

- Each run of a stochastic simulation model produces only estimates of a model's true characteristics for a particular set of input parameters. Thus several independent runs are required for each set of input parameters to be studied.
- Simulations models are often expensive and time-consuming to develop.
- The large volume of numbers produced by a simulation study often creates a tendency to place greater confidence in a study's results than is justified.

System

- **System:** Collection of entities (People / machines) that act and interact together to some goal (solve a problem/ produce an output)
- **Example:** When you go to a bank , a system here may consist of customer, teller, and computers
- **The state of a system:** Collection of variables necessary to describe a system at a certain time.
- **Example:** the number of customers at 12:00
- **Performance Evaluation** of a **System** means quantifying the service delivered by the System
Experimental, Analytical, or by simulation

Ways to study a system



Simulation versus Analytical Modeling

- Simulation is not used when a suitable mathematical model exists
- Simulations are often complex pieces of software
- Simulation only produce approximate answers
- Simulation can take a LONG time to execute
- Mathematical models are less flexible, but they are exact and efficient

Examples

- Consider a system when a given object move
- This system can be modelled by the equation

$$S = V * t$$

Where S is the distance run through, V is the speed of the object, t is the time that has been observed.

- This is a **simplification** of the real world
- **Another model** can take into account the direction of movement, or the three dimension coordinate ...
- It is therefore to study the behaviour of the system based on a specific model

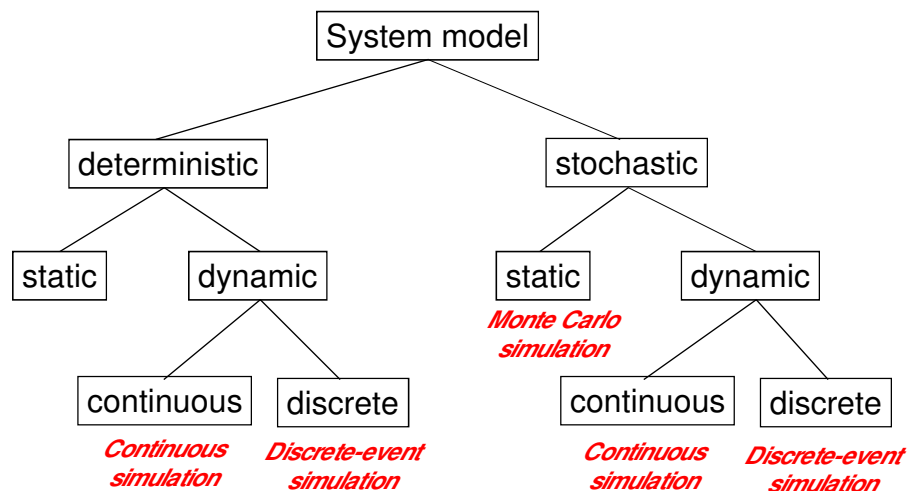
Computer Simulation

- a computer program that models the behavior of a **physical system** over time.
- Program variables (state variables) represent the current state of the physical system

How it works?

- The behavior of the system is described by **state variables**
- The simulation program modifies the states variables to emulate the evolution

Types of Simulation Models



Deterministic vs. Stochastic

- Stochastic simulation: a simulation that contains **random** (probabilistic) elements, e.g.,
 - Examples
 - Inter-arrival time or service time of customers at a restaurant or store
 - Amount of time required to service a customer
 - Output is a random quantity (multiple runs required to analyze output)
- Deterministic simulation: a simulation containing **no random** elements
 - Examples
 - Simulation of a digital circuit
 - Simulation of a chemical reaction based on differential equations
 - Output is deterministic for a given set of inputs

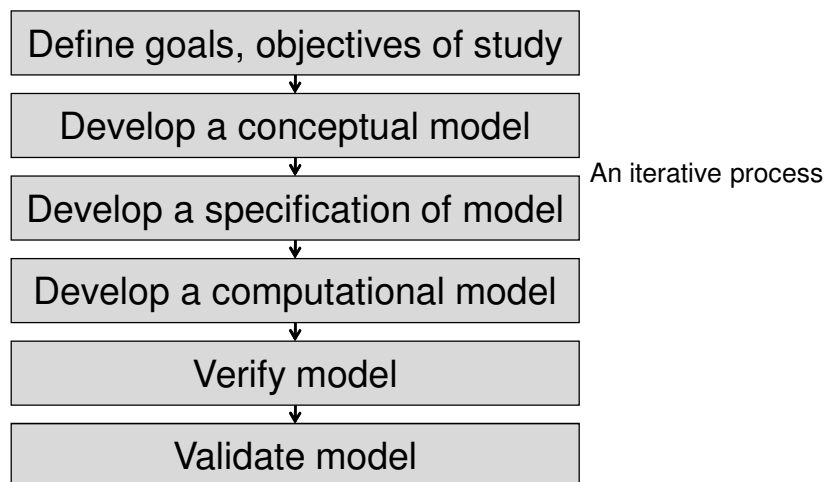
Static vs. Dynamic Models

- Static models
 - Model where time is not a significant variable
 - Examples
 - Determine the probability of a winning solitaire hand
 - Static + stochastic = Monte Carlo simulation
 - Statistical sampling to develop approximate solutions to numerical problems
- Dynamic models
 - Model focusing on the evolution of the system under investigation over time

Continuous vs. Discrete

- **Discrete**
 - State of the system is viewed as changing at discrete points in time
 - An event is associated with each state transition
- **Continuous**
 - State of the system is viewed as changing continuously across time
 - System typically described by a set of differential equations

Model Development Life Cycle



Define Goals and Objectives

- What do you (or the customer) hope to accomplish with the model
 - May be an end
 - Predict the weather
 - Train personnel for some skills (e.g., driving)
 - More often a means to an end
 - Optimize a manufacturing process or develop the most cost effective means to reduce traffic congestion in some part of a city
- Often requires developing a business case to justify the cost
- Goals may not be known when you start the project!

Develop Conceptual Model

- An abstract (i.e., not directly executable) representation of the system
- What should be included in the model? What can be left out?
- we start identifying our system in its three main dimensions:
 - Spatial,
 - Temporal and
 - Structural

Goals and Objectives

The Space Dimension

- What is the specific size of the object that we need to analyze?
- How far spatially does that system extend (scalability)?
- How does the system evolve in space?
 - Is it static, or dynamic?

Goals and Objectives

The Structural Dimension

- What are the elements and processes in our system?
- How much detail about them we need and can afford?
- Do we have enough information about all of them or some of them are entirely unknown?
- Which are the limiting ones, where are the gaps in our knowledge?
- What are the interactions between the elements?

Goals and Objectives

The Time Dimension

- What is the time duration we should observe the system?
 - Are we looking at it over years, days, hours, or seconds?
- Which processes are so slow that they may be considered constant during the observed time?
- Do we need to see how does the system evolve in time, like in a movie, or we just need a snapshot of the reality, like on a photo?
 - Static or Dynamic ?
- If the system is evolving, how does it change from one state to another?
- Is it a **continuous** process or a **discrete** process?
- Is the transition from one state of the system to another **stochastic** or **deterministic**?

The Conceptual Model

- A **conceptual model** may be a mental model, a flow diagram.
- Building the right conceptual model is half the way to success.
- In the conceptual model, you should clearly identify the following components of the system:
 - **Boundaries**
 - **Variables**
 - **Parameters**
 - **Forcing functions**
 - **Control functions**

The Conceptual Model

- **Boundaries:** specify what elements are included in the system and those not.
 - They distinguish the system from the outside world.
 - What material and information flows into and out of the system?
 - What processes are internal and which ones are external.
- **State Variables:** They characterize the elements in the system. These quantities represent the evolution of the system, that you analyze and report as a result of the modeling exercise.
- **Parameters:** They also characterize the elements of the system, but they are **constant** throughout the modeling process. Parameters can either be measured by direct experiments or may be borrowed from analyses of similar systems performed previously.

The Conceptual Model

- **Forcing functions:** They describe the effect of the outside world upon your system.
 - The forcing functions may change in time, but they do not respond to changes within the system.
- **Control functions:** They are actually *parameters*, except that you allow them to change to see how their change affects your system dynamics.
 - It is like the tuning button on your radio set. At every time it is dialed to a certain position, but you know that it may vary and result in different performance of the system.

Develop Specification Model

- A more detailed specification of the model including more specifics
- Collect data to populate model
 - Traffic example: Road geometry, signal timing, expected traffic demand, driver behavior
- Development of algorithms necessary to include in the model
 - Example: Path planning for vehicles

Develop Computational Model

- Executable simulation model
- Software approach
 - General purpose programming language
 - Special purpose simulation language
 - Simulation package (Arena)
 - Approach often depends on need for customization and economics

Verification

- Did I build the model right?
- Does the computational model match the specification model?
- The process of checking the consistency of a simulation program
- Debugging: checking if the program contains any programming errors.
- Not to be confused with correctness (see model validation)!

Validation

- Did I build the right model?
- Does the computational model match the actual (or envisioned) system?
- Typically, compare against
 - Measurements of actual system
 - An analytic (mathematical) model of the system
 - Another simulation model