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

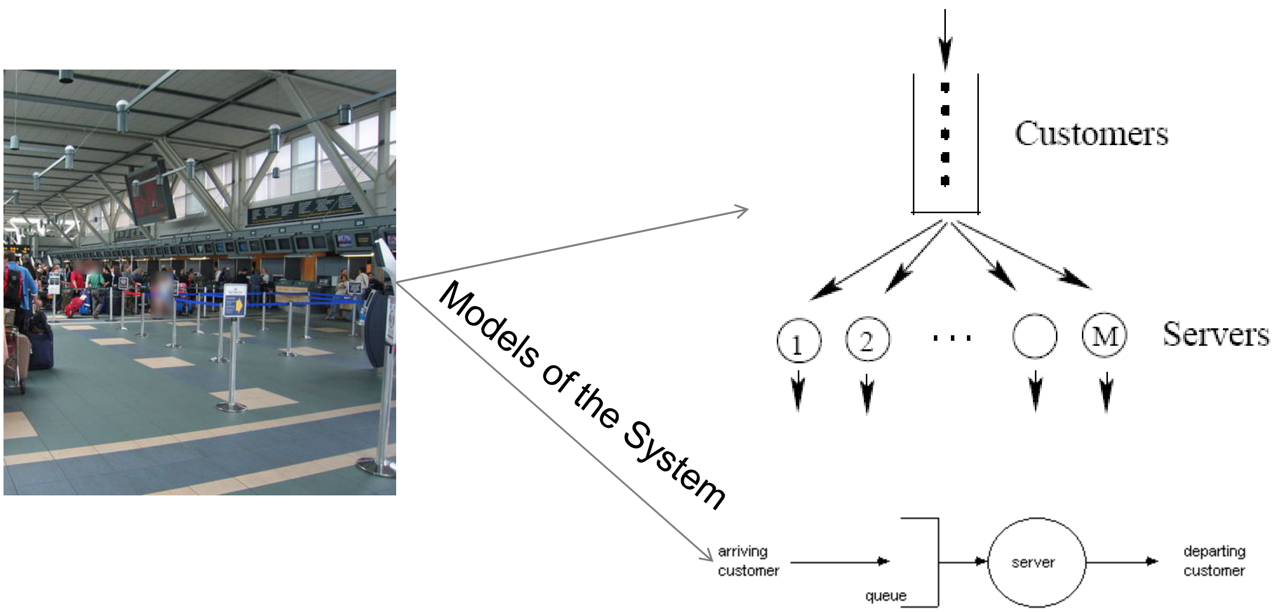
Why do we use Simulation

- 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.

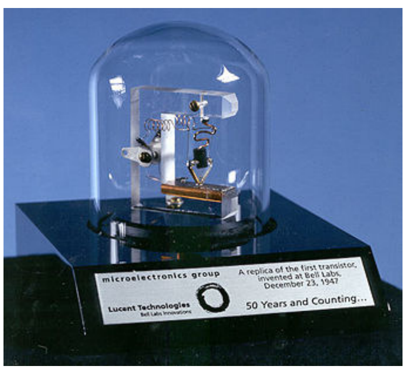
Software products

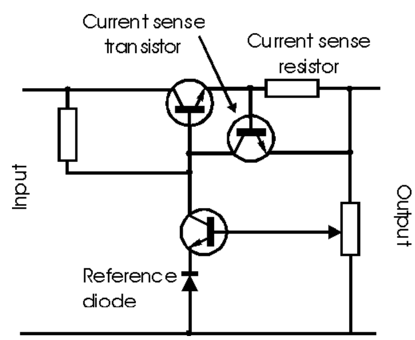
- In general models used to study large scale systems tend to be very complex
- Writing computer programs to execute them even more complex
- Now there are software products that automatically produce simulation models example: Arena

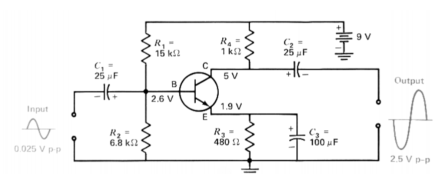
Example


Customers
1
2
M
Servers
Models of the System
arriving customer
queue
server
departing customer

Example





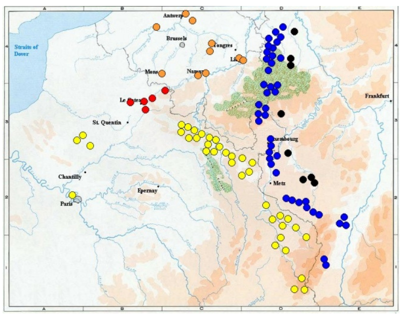


$$I = \frac{E}{R} \qquad E = IR$$

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

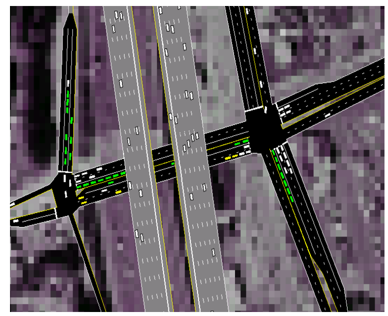
$$hfe = \frac{I_c}{I_b} \qquad I_b = \frac{I_c}{hfe}$$

Few Application Examples



War gaming: test strategies; training

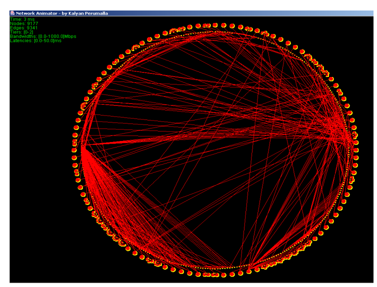
Flight Simulator



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

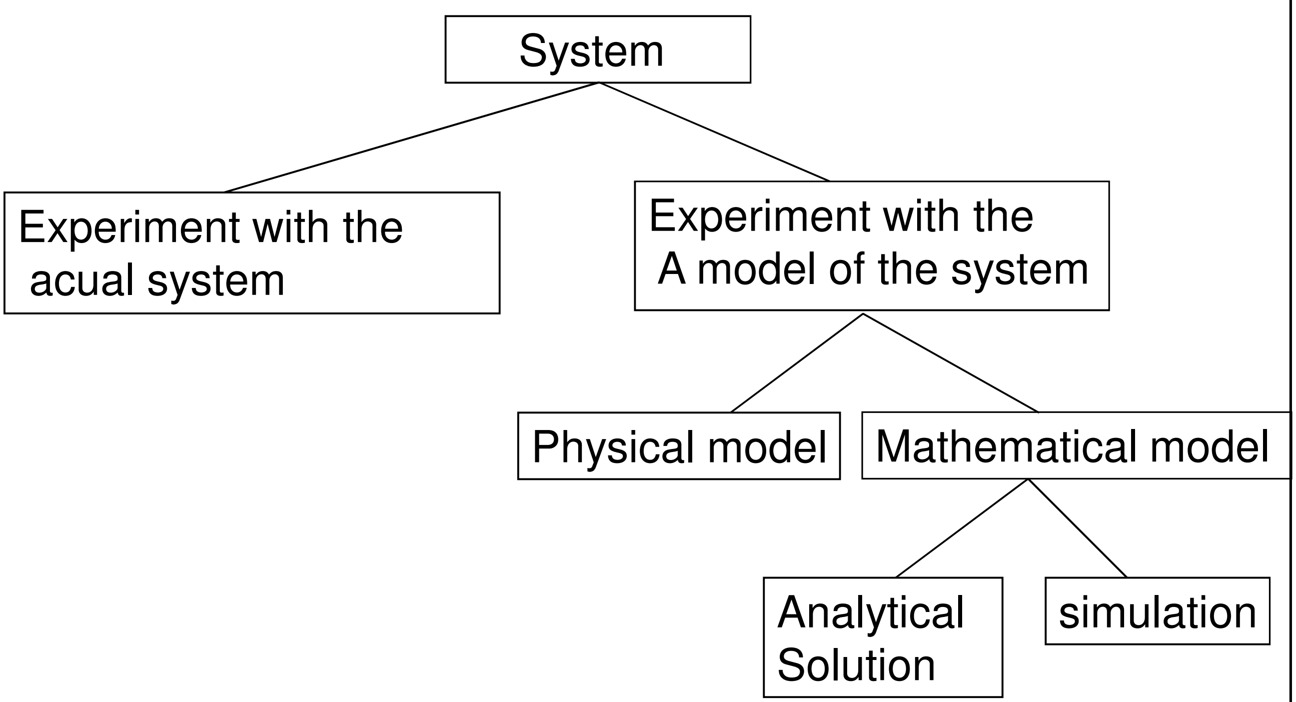
- Each run of a stochastic simulation model produces only estimates of a model's true characteristics for a particular set of input parameters. Thus several independent runs are required for each set of input parameters to be studied.
- Simulations models are often expensive and time-consuming to develop.
- 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

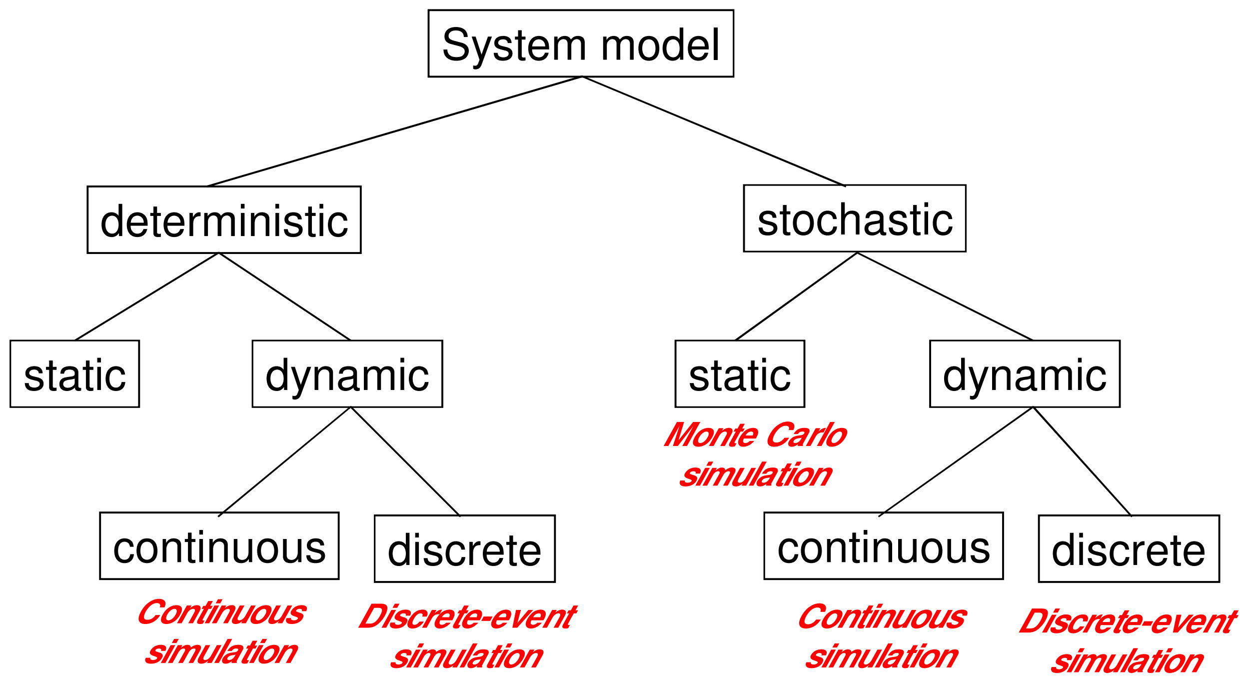
Computer Simulation

- 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 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

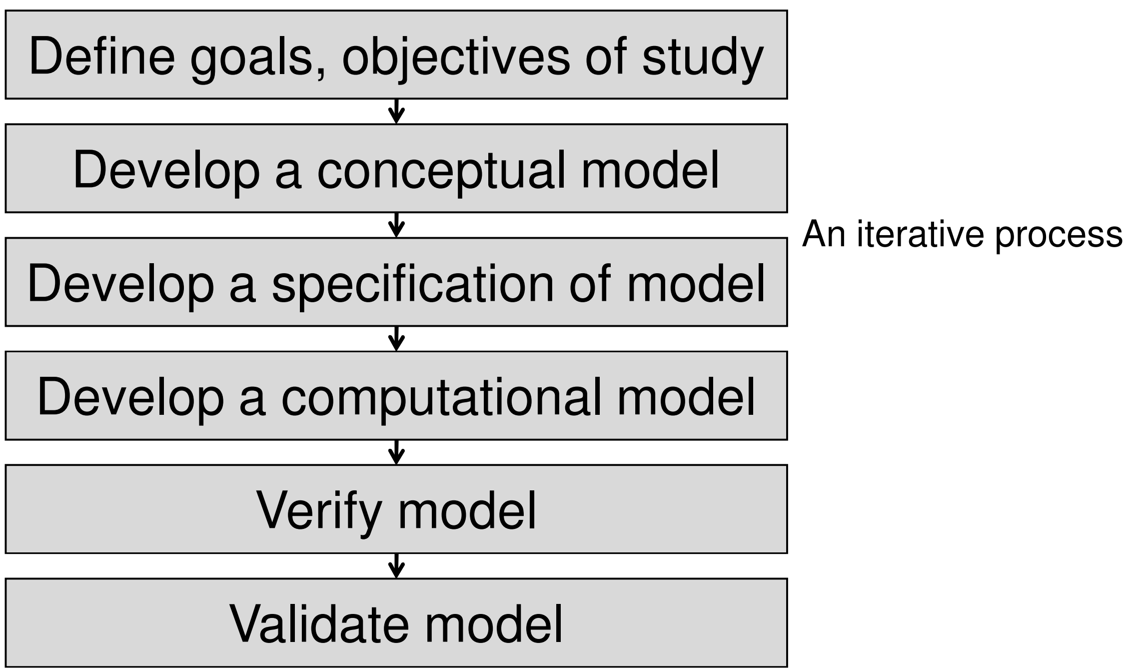
Static vs. Dynamic Models

- 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 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