Introduction to Simulation

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Simulation

- **Simulation is the imitation of some real thing, state of affairs, or process, over time,** representing certain key characteristics or behaviours of the selected physical or abstract system

- **Simulation**:
  - Modeling of **natural systems or human systems** in order to gain insight into their **functioning** through **artificial systems**
  - Simulation of technology for **performance optimization**, safety engineering, testing, training and education
  - Widely used tool for **decision making** and **what-if analysis**

What is simulation?

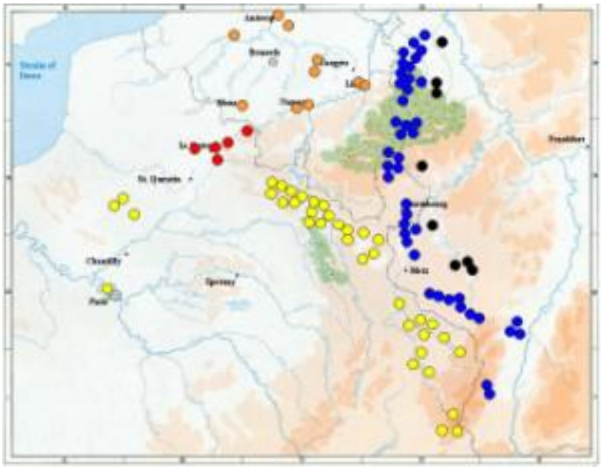
- **The imitation of the operation of a real-world process or system *over time*…**
  - Most widely used tool (along LP) for decision making
  - Usually on a computer with appropriate software
  - An analysis (descriptive) tool – can answer *what-if* questions
  - A synthesis (prescriptive) tool – if complemented by other tools

- **Applied to complex systems that are impossible to solve mathematically**

A Few Examples of Applications

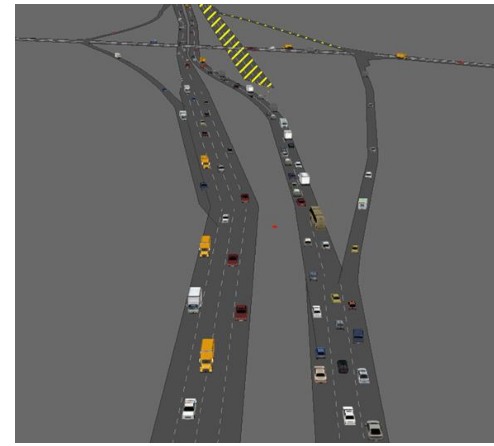
- **Games**
- Film Industry
- **Manufacturing**
- Bank operations
- **Airport and Airlines**
- Flight Simulation
- Military Operations
- **Transportation**
- Satellite Navigation
- **Robotics**
- Biomechanics
- Molecular Dynamics
- **Logistics, supply chain, distribution**
- **Hospitals: Emergency, operation, admissions...**
- Computer networks
- **Business processes**
- Chemical plants
- **Fast-food restaurants**
- Supermarkets
- Stock Exchange
- Theme parks
- **Emergency-response systems**
- **Sports**

A Few Examples of Applications



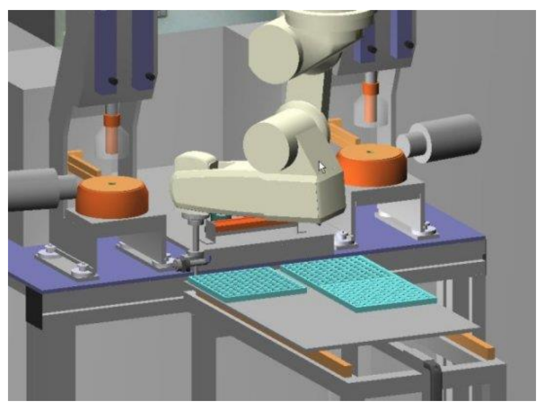
War (strategy) Games

Flight Simulators



Transportation systems

Aerodynamics: Wind Tunnel



Manufacture/Robotics

Games & Sports

System

- **A set of interacting components or entities operating together to achieve common goals or objectives**
- **Examples**
  - A manufacturing system with its machine centres, inventories, conveyor belts, production schedule, items produced.
  - A telecommunication system with its messages, communication network and infrastructure, servers.
  - A theme park with rides, workers, …

Metrics & Performance Indicators

- ***Metrics*** **are measurable quantities that precisely capture what we want to measure (e.g. response time, throughput, delay, etc.)**
- **For example, in computer systems, we might evaluate**
  - The response time of a processor to execute a given task
  - The execution time of two programs in a multi-processor machine
- **In Network systems, we might evaluate**
  - The (maximum/average) delay experienced by a voice packet to reach the destination
  - The throughput of the network
  - The required bandwidth to avoid congestion
- **Indicators are calculated measures of performance consisting of a set of different metrics, a.k.a Key Performance Indicators (KPIs).**
  - KPIs can provide a more accurate view of the status of a system and its historical evolution
  - E.g. Body mass index (BMI); Estimated road traffic death rate (/100K population; COVID-19 hospital admissions (/100K population /week)

Metrics & Performance Measures

- **The performance of a system is dramatically affected by the *Workload***
- **The Workload characterises the quantity and the nature of the system inputs**
  - For Web Servers, system inputs are http requests (GET or POST); The workload characterises:
    - the intensity of the requests: how many requests are received by the web server. High intensities deteriorate the system performance.
    - The nature of the requests: the request can be simple GET requests or a request that requires the access of a remote database. The performance will be different for different request types.
  - ***Benchmarks***: used to generate loads that are intended to mimic a typical user behaviour.

Why & How to study a system?

Measure/estimate performance, improve operation/training, be prepared (for failures)

SYSTEM

Experiment with the Actual (Natural) System

Too costly or disruptive
Not appropriate for the design

Experiment with a Model of the System

There is always the question of whether it actually reflects the system.

Mathematical Model

Make assumptions that take the form of mathematical or logical relationships

Analytical Solution

If the model is simple enough. E.g., calculus, algebra, probability theory

Simulation

Highly complex systems

Systems Modelling

- **An abstract and simplified representation of a system**
- **Specifies**
  - Important components
  - Assumptions/approximations about how the system works

- **Not an exact re-creation of the original system!**
- **If model is simple enough, study it with Queuing Theory, Linear Programming, Differential Equations...**
- **If model is complex, Simulation is the only way!**

Systems Modelling

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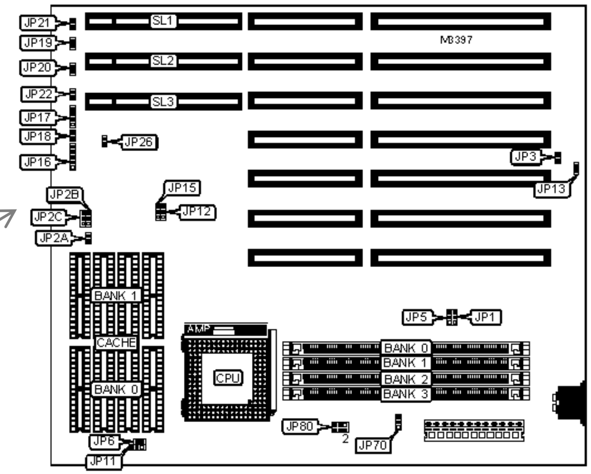
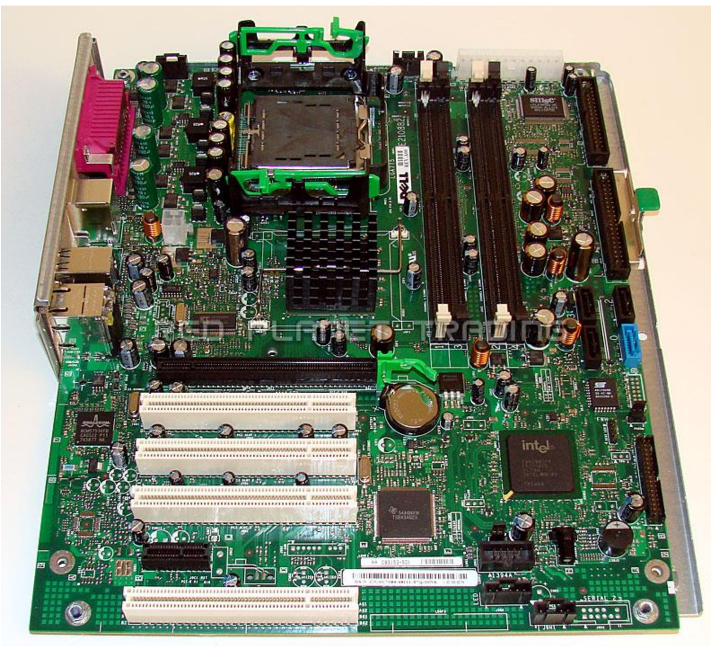
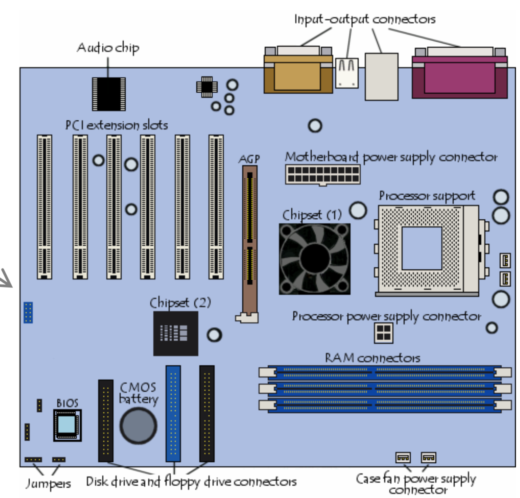




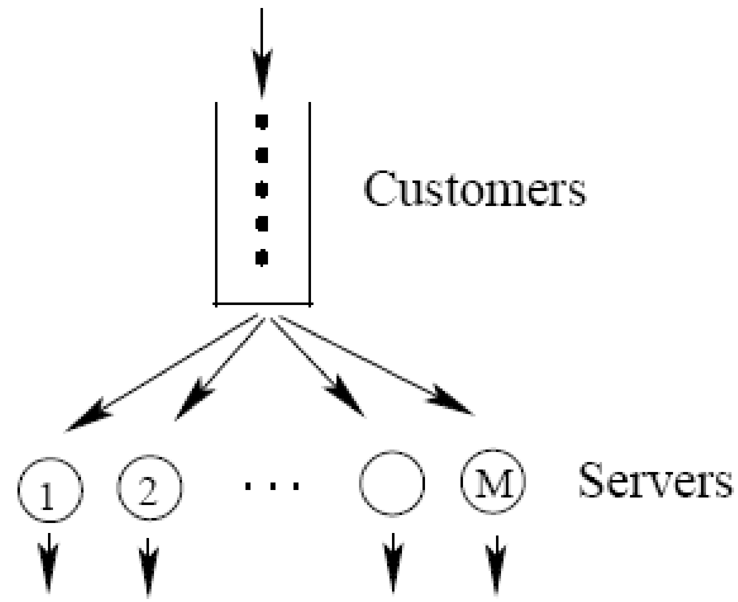
Models of the System

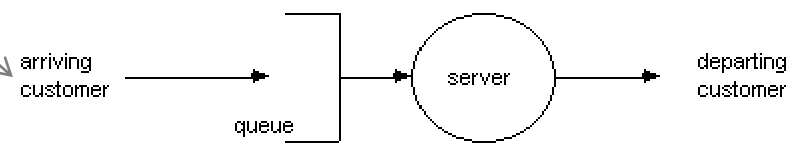


Real System (Motherboard)

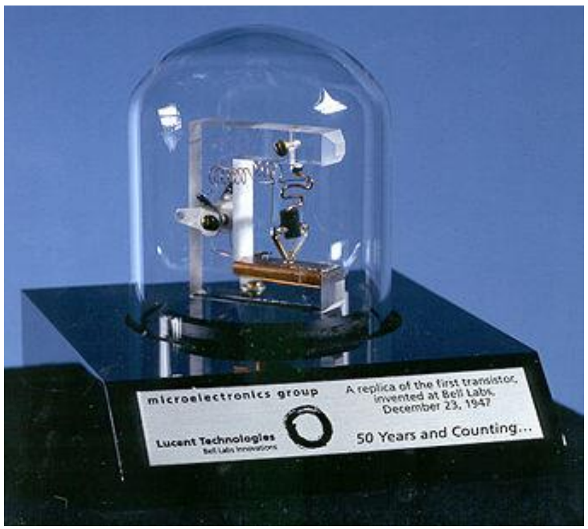
Systems Modelling

Models of the System

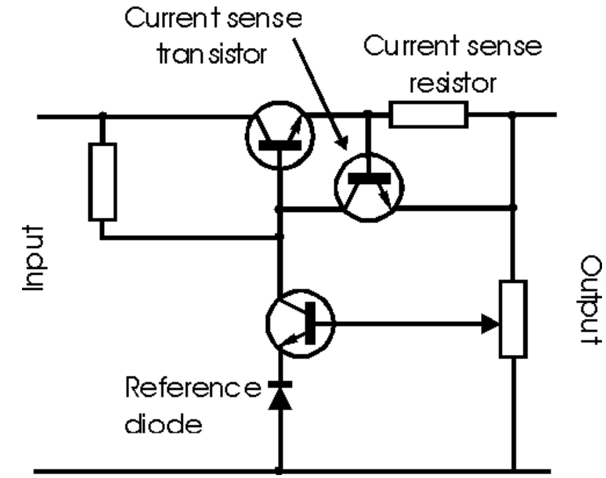




Systems Modelling



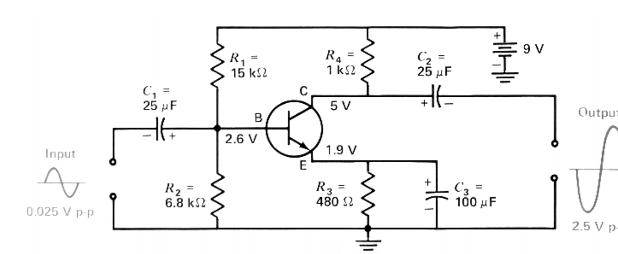
Models of the System



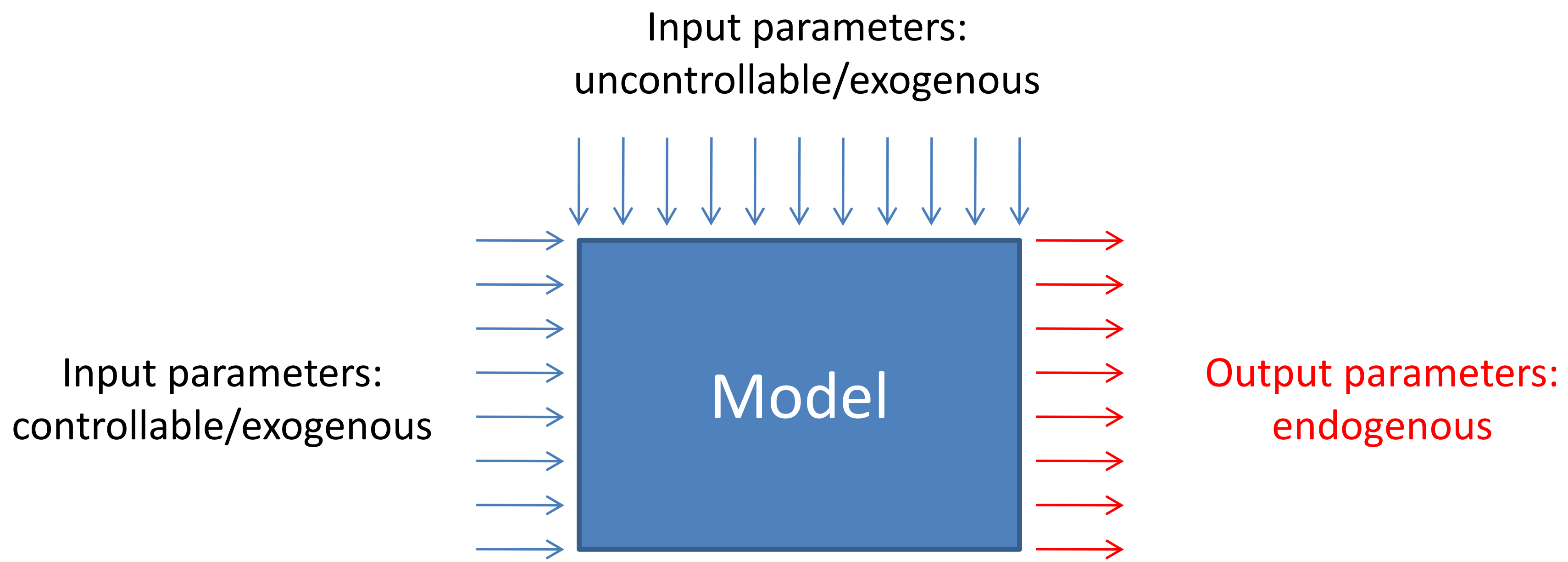
$$I = \frac{E}{R} \qquad E = IR$$

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

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



Variables of a Model



Getting answers from models

ACTUAL SYSTEM

Operating Policies

- **Single queue, parallel servers**
- **FIFO**

Input Parameters

- **Nº of servers**
- **Inter-arrival Time Distribution**
- **Service Time Distributions**

(X)

MODEL

(Y)

Output Parameters

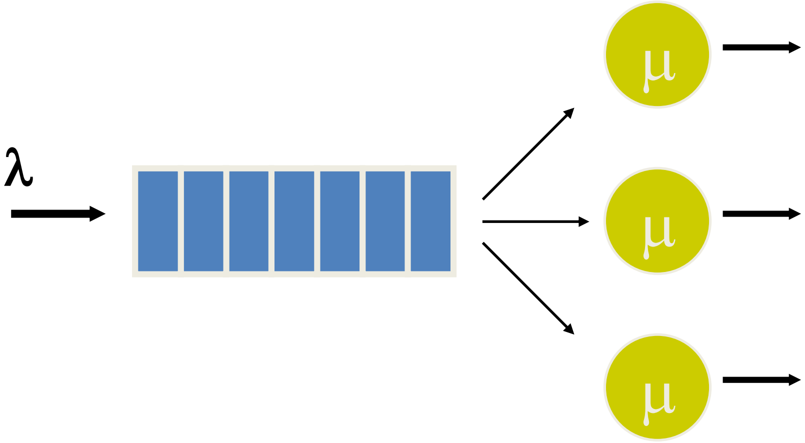
- **Waiting Times**
- **System Size**
- **Utilizations**

Y = f (X)

Stochastic Models

- **Uncertainty (randomness) is an inherent characteristic**
- **Example: bank with costumers and tellers**

Actual System



Queuing Model

Classification of simulation models

1. **Static** vs. **Dynamic** Models:

Represents a system as it evolves over time
(e.g., a conveyor system in a factory)

Time plays no role; represents a system at a particular point in time
(e.g., Monte-Carlo methods)

2. **Deterministic** vs. **Stochastic** Models:

Involves random variables, probabilities
(e.g., most queueing and inventory systems)

No probabilistic components
(e.g., worst-case analysis of a system)

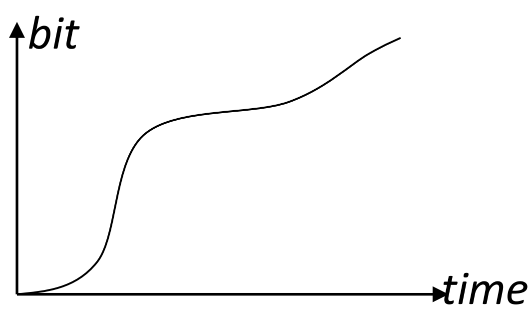
Classification of simulation models

3. Continuous vs. Discrete Models:

The state of the system changes only at discrete points in time.

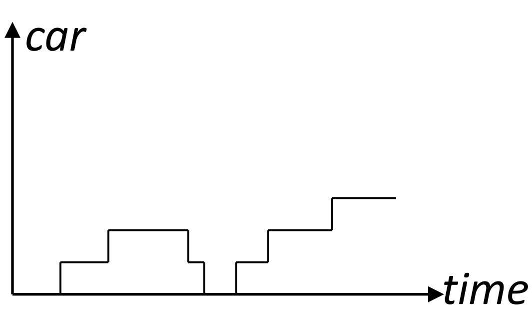
The state of the system changes continuously (e.g., chemical processes)

Bit Arrival in a Queue



Continuous Model

# of cars in a parking lot



Discrete Model

Simulation Approaches

- **Types of discrete models**
  - Event-oriented
  - Process-oriented
  - Activity-oriented
  - Object-oriented
  - Agent-based

How to simulate

- **By hand**
  - Buffon's needles and cross experiments
    http://www.ms.uky.edu/~mai/java/stat/buff.html
- **Spreadsheets**
- **Programming in a general purpose language**
  - C++, Java, C#
- **Simulation languages**
  - SIMAN, Simscript, and SIMULA (first OO language)
- **Simulation packages**
  - Arena, Simulink, SeSam (agent-based), NetLogo, etc.

Issue: modelling flexibility vs. ease of use

Simulation Advantages

- **Advantages of Simulation:**
  - When mathematical analysis methods are not available, simulation may be the only investigation tool
  - When mathematical analysis methods are available, but are so complex that simulation may provide a simpler solution
  - Provides practical feedback when designing real-world systems
  - **Time compression or expansion**
  - Higher Control
  - Lower costs
  - Comparison of alternative designs or alternative operating policies
  - Sensitivity Analysis
  - **Training tool**
  - **It doesn't disturb the real system**

Simulation is not Appropriate if?

- **Problem can be solved by:**
  - Common sense
  - simple calculations
  - Analytical methods
  - Direct experiments
- **Simulation costs exceed savings**
- **Resources & time are not available**
- **Data is not available**
- **Verification & validation are not practical due to limited resources**
- **System behavior is too complex (essential model is not easy to capture)**