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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**
  - Simulation of technology for **performance optimization**, safety engineering, testing, training and education
  - Widely used tool for **decision making** and **what-if analysis**

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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**

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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**

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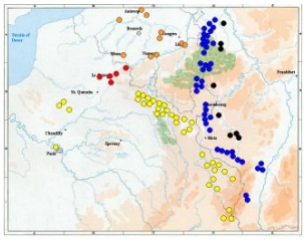
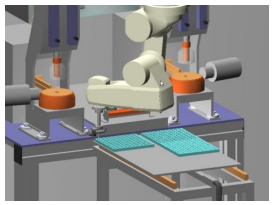
A Few Examples of Applications


War (strategy) gaming


Flight Simulators


Transportation systems


Aerodynamics: Wind Tunnel


Manufacture/Robotics


Games & Sports

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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, …

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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)

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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 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.

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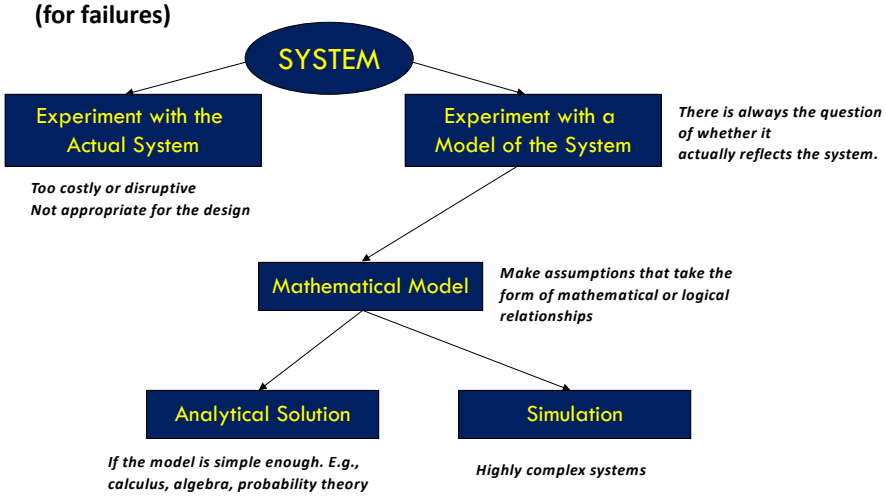
Why & How to study a system?

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



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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!**

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Systems Modelling

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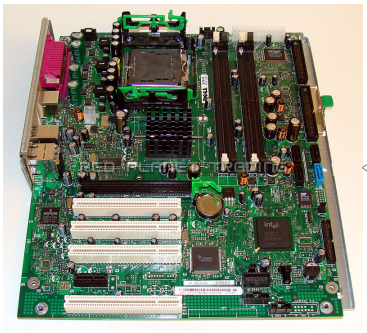
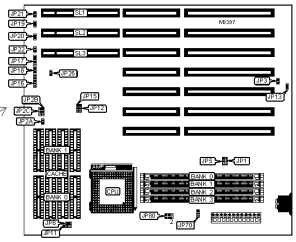
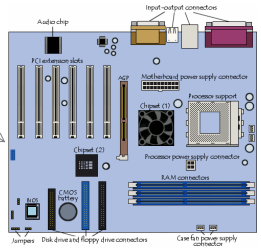


Real System (Motherboard)

Models of the System





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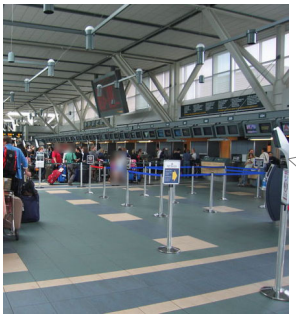
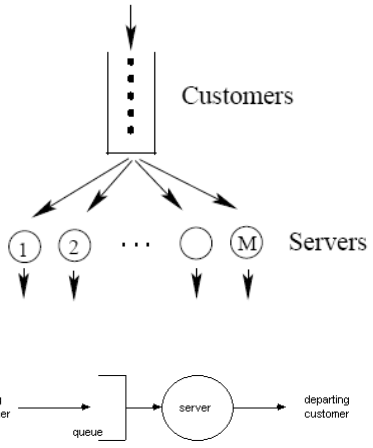
Systems Modelling



Models of the System



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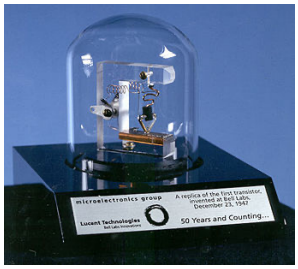
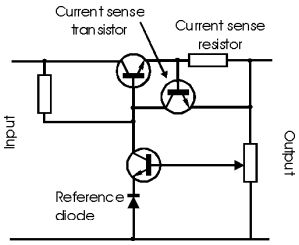
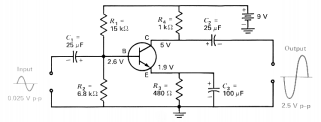
Systems Modelling



Models of the System





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

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

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

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Variables of a Model

Input parameters: uncontrollable/exogenous

Input parameters: controllable/exogenous

Model

Output parameters: endogenous

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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**

$Y = f(X)$

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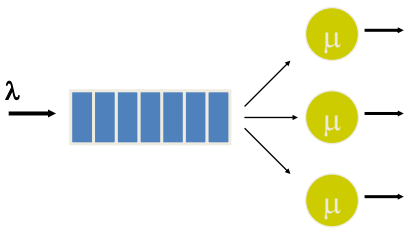
Stochastic Models

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



Actual System Queuing Model

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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)

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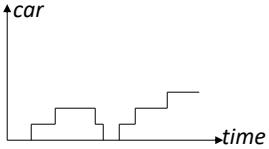
Classification of simulation models

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

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Simulation Approaches

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

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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

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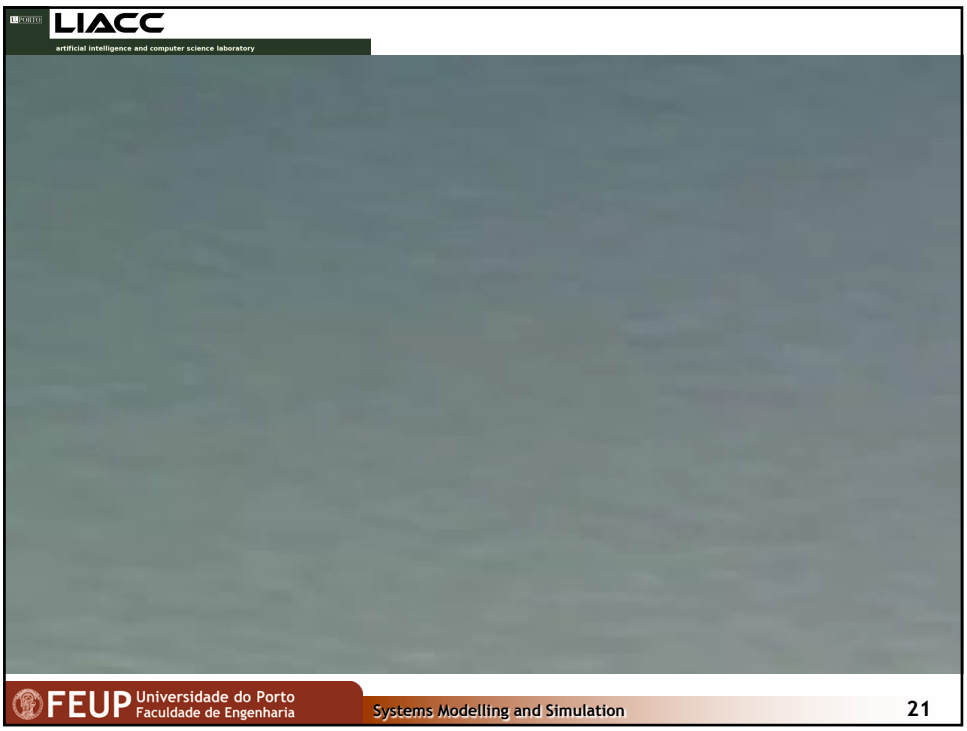

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Simulation Advantages

- **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**

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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)**

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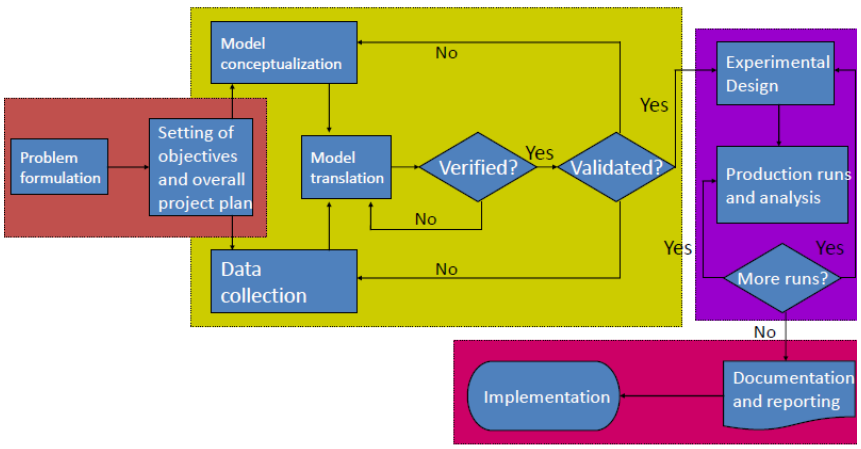
Life-cycle of a Simulation Project



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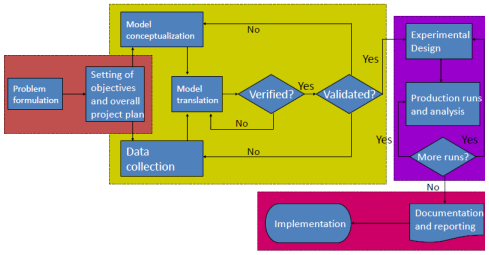
Life-cycle of a Simulation Project

1. **Problem Formulation**
   - Statement of the problem
2. **Set Objectives & Project Plan**
   - Questions to be answered
   - Is simulation appropriate?
   - Methods, alternatives
   - Allocation of resources
3. **Model Conceptualization**
   - Requires experience
   - Begins simple and adds complexity
   - Captures essence of system
   - Involves the user
4. **Data Collection**
   - Time consuming, begin early
   - Determine what is to be collected



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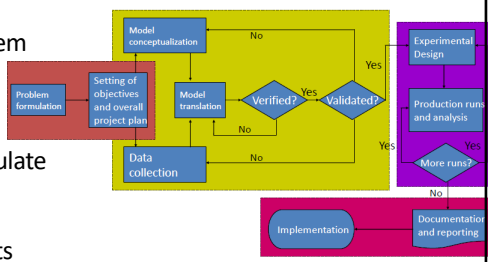
Life-cycle of a Simulation Project

5. **Model translation**
   - Computer form
   - general purpose vs. special purpose lang.
6. **Verification**
   - Does the program represent the model and run properly? Common sense
7. **Validation and Calibration**
   - Compare model to actual system
   - Does model replicate system?
   - How to calibrate the model?
8. **Experimental Design**
   - Determine alternatives to simulate
   - Time, initializations, etc.
9. **Production & Analysis**
   - Actual runs + Analysis of results
   - Determine performance measures
10. **More Runs?**



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Problem formulation

- **A statement of the problem**
  - the problem is clearly understood by the simulation analyst
  - the formulation is clearly understood by the client
  - All involved elements and their characteristics, as well as behaviours and interactions are well identified

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Setting of objectives & project plan

- **Project proposal**
  - Determine the questions that are to be answered
  - Identify scenarios to be investigated
  - Decision criteria
  - Determine the end-user
  - Determine data requirements
  - Determine hardware, software, & personnel requirements
  - Prepare a time plan
  - Cost plan and billing procedure

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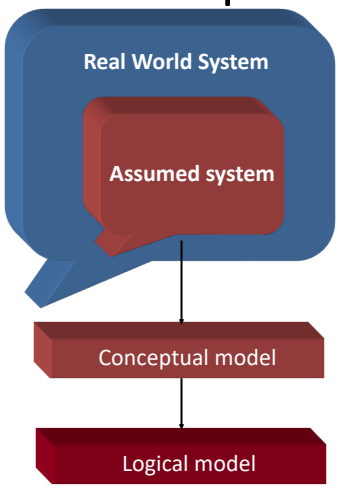
Model Conceptualisation



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Conceptual Model

- **Abstract essential features**
  - Events, activities, entities, attributes, resources, variables, and their relationships
  - Performance measures
  - Data requirements
- **Select correct level of details (assumptions)**

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Level of Details

- **Low levels of detail may result in loosing information and goals cannot be accomplished**
- **High levels of detail require:**
  - more time and effort
  - longer simulation runs
  - more likely to contain errors
  - More available data for validation and verification

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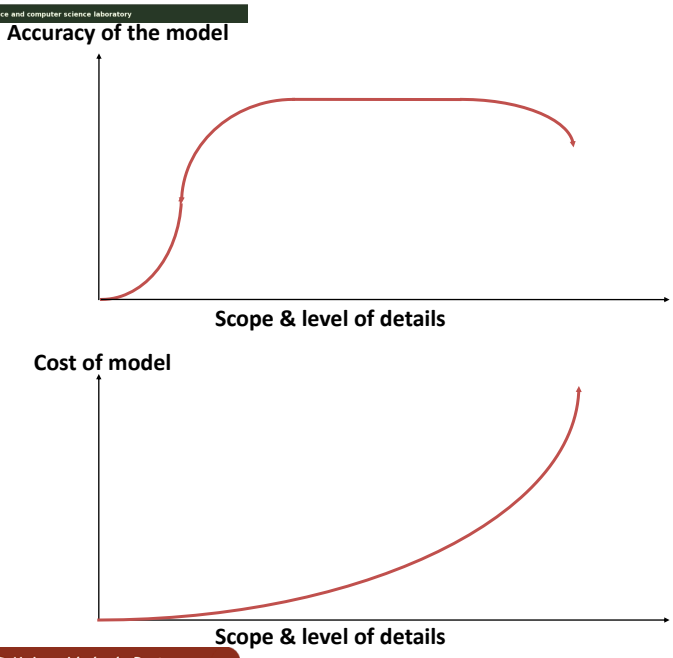

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Components of a System

- ***Entity*: is an object of interest in the system**
  - *Dynamic objects* – get created, move around, change status, affect and are affected by other entities, leave (maybe)
  - Usually have multiple *realizations* floating around
  - Can have different types of entities concurrently

Example: Health Centre

Physicians?

Patients

Visitors

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Components of a System

- ***Attribute*: is a characteristic of all entities, but with a specific value "local" to the entity that can differ from one entity to another**

Example: Patient

Type of illness,

Age,

Gender,

Temperature,

Blood Pressure

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Components of a System

- ***Resources*: ...what entities compete for!**
  - Entity *seizes* a resource, *uses* it, *releases* it
  - Think of a *resource being assigned to an entity*, rather than an entity "belonging to" a resource
  - "A" resource can have several *units* of capacity which can be changed during the simulation

Example: Health Centre

Doctors, Nurses

X-Ray Equipment

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Components of a System

- ***Variable*: A piece of information that reflects some characteristic of the whole system, not of specific entities**
  - Entities may access and change some variables
  - Other variables are changed as a result of the system dynamics

Example: Health Centre

Number of patients in the system,

Number of idle doctors,

Current time

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Components of a System

- ***State*: A collection of variables that contains all the information necessary to describe the system at any time**

Example: Health Center

{Number of patients in the system,

Status of doctors (busy or idle),

Number of idle doctors,

Status of Lab equipment, etc...}

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Components of a System

- ***Event*: An instantaneous occurrence that changes the state of the system**

Example: Health Centre

Arrival of a new patient,

Completion of service (i.e., examination)

Failure of medical equipment, etc...

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Components of a System

- ***Activity*: represents a time period of specified length**

Example: Health Centre

Surgery,

Checking temperature,

X-Ray.

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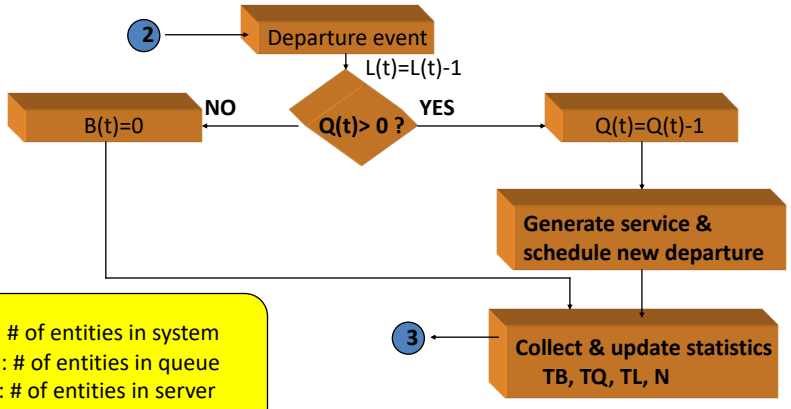
Logical Model

- **Shows the logical relationships among the elements of the model (flowchart)**



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Data Collection & Analysis

- **Collect data for input analysis and validation**
- **May require the help of subjects (e.g. Measures, survey forms such as SP)**
- **Analysis of the data**
  - Determine the random variables
  - Fit distribution functions

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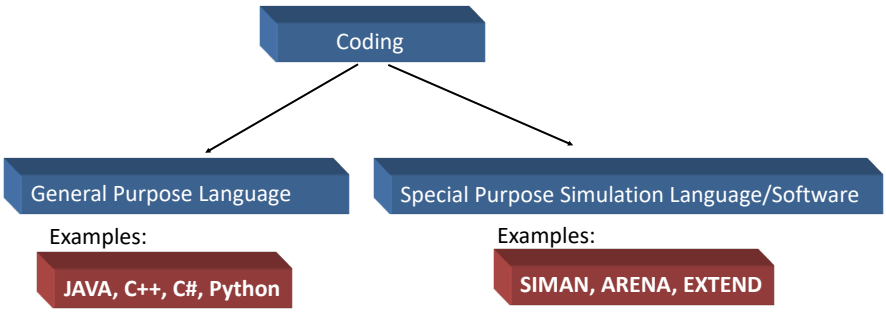
Model Translation

- **Simulation model executes the logic contained in the flow-chart model**



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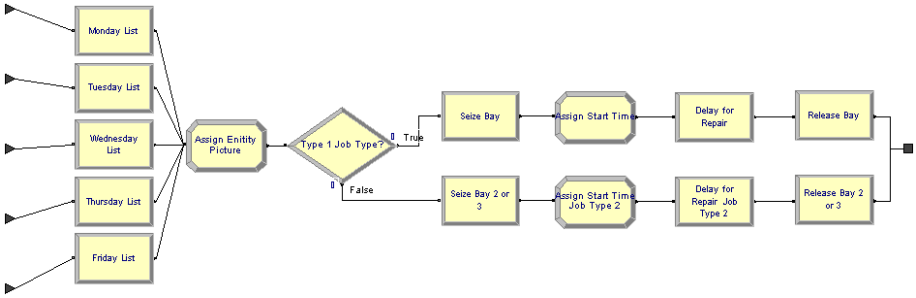
Model Translation

- **Visual Interactive Modelling & Simulation**
- **IDE example: Arena**



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Model Translation

- **General purpose languages**
- **Example: Java**

```
public static void main(String argv[])
{
        Initialization();

        //Loop until first "TotalCustomers" have departed
        while (NumberofDepartures < TotalCustomers)
        {
                Event evt = FutureEventList[0]; //get imminent event
                removefromFEL(); //be rid of it
                Clock = evt.get_time(); //advance in time
                if (evt.get_type() == arrival) ProcessArrival();
                else ProcessDeparture();
        }

        ReportGeneration();
}
```


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Verification & Validation

- ***Verification*: the process of determining if the operational logic is correct.**
  - Debugging the simulation software
- ***Validation*: the process of determining if the model accurately represents the system.**
  - Comparison of model results with collected data from the real system

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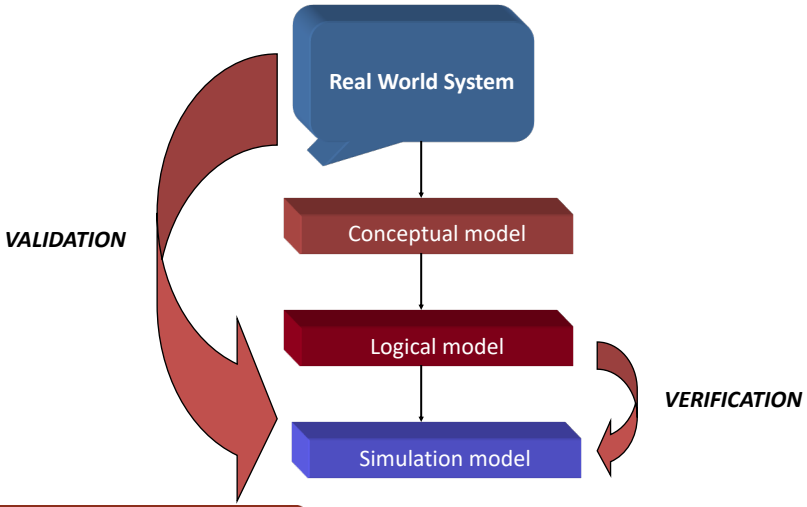
Verification & Validation



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Experimental Design

- **Alternative scenarios to be simulated**
  - ***Calibration*** is necessary to guarantee the scenario is accurate
- **Type of output data analysis (steady-state vs. terminating simulation analysis)**
- **Number of simulation runs**
- **Length of each run**
- **The manner of initialization (warm-ups)**
- **Variance reduction**

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Result Analysis

- **Statistical tests for significance and ranking**
  - Point Estimation
  - Confidence-Interval Estimation
- **Interpretation of results**
- **More runs?**

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Documentation & Reporting

- **Program Documentation**
  - Allows future modifications
  - Creates confidence
- **Progress Reports**
  - Frequent reports (e.g. monthly) are suggested
  - Alternative scenarios
  - Performance measures or criteria used
  - Results of experiments
  - Recommendations

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Implementation

- **Deployment of results…**

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