Department of Industrial Engineering and Engineering Management
University of Sharjah

0405324: Stochastic System Simulation

Lecture 1: Introduction

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

- In its broadest sense, simulation is a tool to evaluate the performance of a system, existing or proposed, under different configurations of interest and over long periods of real time.

- Applied to complex systems that are impossible to solve mathematically

What is simulation?

- Simulation is used before an existing system is altered or a new system built, to reduce the chances of failure to meet specifications, to eliminate unforeseen bottlenecks, to prevent under or over-utilization of resources, and to optimize system performance.

- This course focuses on one form of simulation modelling – discrete-event simulation modelling.

Areas of Application

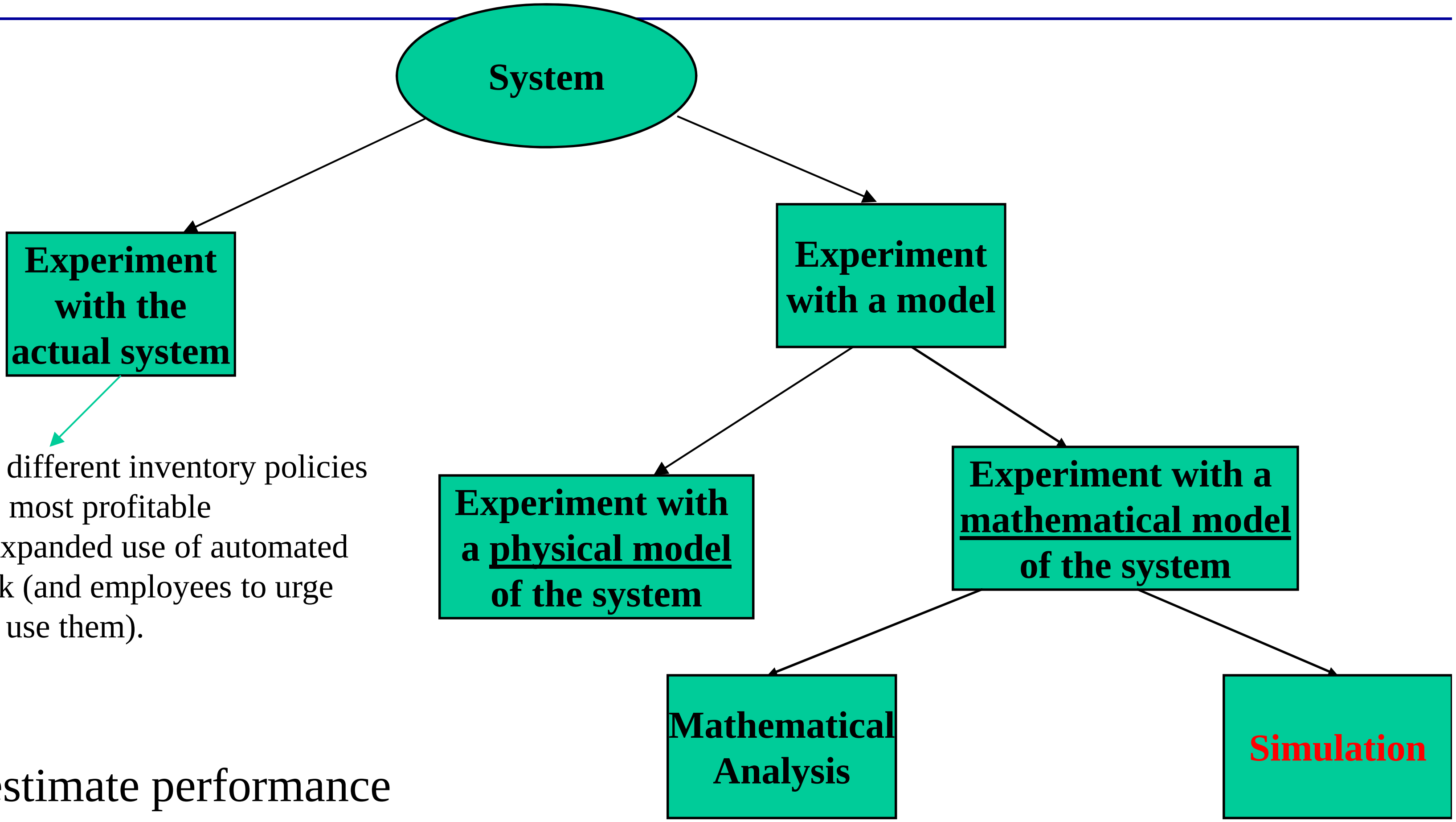
- Designing and analyzing ***manufacturing systems***
- Evaluating H/W and S/W requirements for a ***computer system***
- Evaluating a new ***military weapons system*** or tactics
- Determining ordering policies for an ***inventory system***
- Designing ***communications systems*** and message protocols for them
- Designing and operating ***transportation facilities*** such as freeways, airports, subways, or ports
- Evaluating designs for ***service facilities*** such as hospitals, post offices, or fast-food restaurants
- Analyzing ***financial or economic systems***

Systems – facility or process, actual or planned

What is system?

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

Why & how to study a system



Examples:

- Supermarket: different inventory policies and select the most profitable
- Airline: test expanded use of automated check-in kiosk (and employees to urge passengers to use them).

Why:

- Measure/estimate performance
- Improve operation
- Design it if it does not exist
- Prepare for failures (know what to do in case a machine breaks down)
- Control

Work With the System?

- **Study system – measure, improve, design, control**
  - Maybe just play with actual system
    - Advantage — unquestionably looking at the right thing
  - But often impossible in reality with actual system
    - System doesn't exist
    - Would be disruptive, expensive, dangerous (examples: changing a factory's layout, trying a new check-in procedure in an airport, changing emergency room staffing in a hospital)

What is Model?

- ***Model*** **– set of assumptions/approximations about how system works**
  - Study a model instead of the real system … usually much easier, faster, cheaper, safer
  - Can try wide-ranging ideas with model
    - Make your mistakes on the computer where they *don't* count, rather than for real where they *do* count
  - Often, just *building* model is instructive – regardless of results (it allows to see how the real system works)
  - Model *validity* (any kind of model … not just simulation)
    - Care in building the model to mimic reality faithfully
    - Enough level of detail→ what you will learn about the model will not differ from what you would have learned about the system
    - Get same conclusions from model as you would from system
    - More in Chapter 13

Types of Models

- ***Physical*** **(*iconic*) models**
  - Tabletop material-handling models
  - Mock-ups (is a scale or full-size model of a design or device) of fast-food restaurants
  - Flight simulators
- ***Logical*** **(*mathematical*) models**
  - Approximations, assumptions about system's operation
  - Often represented via computer program in appropriate software
  - Exercise program to try things, get results, learn about model behavior
  - Examples: traffic accident simulators, stochastic system simulators, MATLAB Simulink

Studying Logical (mathematical) Models

- **If the model is simple enough, use traditional mathematical analysis … get exact results, lots of insight into model**
  - Queueing theory
  - Differential equations
  - Linear programming
- **But complex systems can seldom be *validly* represented by simple analytic model**
  - Danger of over-simplifying assumptions … model validity?
  - Type III error – working on the wrong problem
- **Often, complex system requires complex model, analytical methods don't apply … what to do?**

Computer Simulation

- **Methods for studying wide variety of models of systems**
  - Numerically evaluate on computer
  - Use software to imitate system's operations, characteristics, often over time
- **Designing and creating a computerized model of a (real or proposed) system to conduct numerical analysis to better understand its behavior.**
- **Can be used to study simple models, but should not be used if an analytical solution is available**
- **Real power of simulation – studying complex models**

Advantages of Simulation

- Complex scenarios **can be analyzed without altering the real system**
- Alternative configurations **and options can be studied, expected performance can be analyzed prior to committing expenditure**
- Predict **expected performance measures and provides statistics**
- **Enable the** visualization **of the impact of the alternative configurations and options**
- **Allow uncertainty,** nonstationarity **in modeling**

Disadvantages of Simulation

- **Don't get** exact answers**, only approximations, estimates**
- **Get** random output **from stochastic simulations**
- **Large scale study can be** complex
- Data **is required for most studies and should be accurate, relatively comprehensive and consistent**
- Specialist staff **with knowledge and skill are required to perform the simulation study**
- Cost **of license for many simulation tools tend to be expensive**

Classification of simulation models

Static (Monte Carlo)

Represents the system at a particular point in time

IID (Indep. Ident. Dist.) observations

- Estimation of π
- Risk Analysis in Business

Dynamic Systems

Represents the system behaviour over time

<u>Continuous Simulation:</u>

(Stochastic) Differential Equations (state changes continuously)

- Water Level in a Dam

<u>Discrete Event Simulation:</u>

System quantities (state variables) change with events (only at discrete points in time)

- Queuing Systems
- Inventory Systems

Using Computers to Simulate

- **General-purpose languages (C, C++, C#, Java, Matlab, FORTRAN, others)**
  - Tedious, low-level, error-prone
  - But, almost complete flexibility
- **Support packages for general-purpose languages**
  - Subroutines for list processing, bookkeeping, time advance
  - Widely distributed, widely modified
- **Spreadsheets**
  - Usually static models (only *very* simple dynamic models)
  - Financial scenarios, distribution sampling, SQC
  - Examples in Chapter 2 (one static, one dynamic)
  - Add-ins are available (@RISK, Crystal Ball)

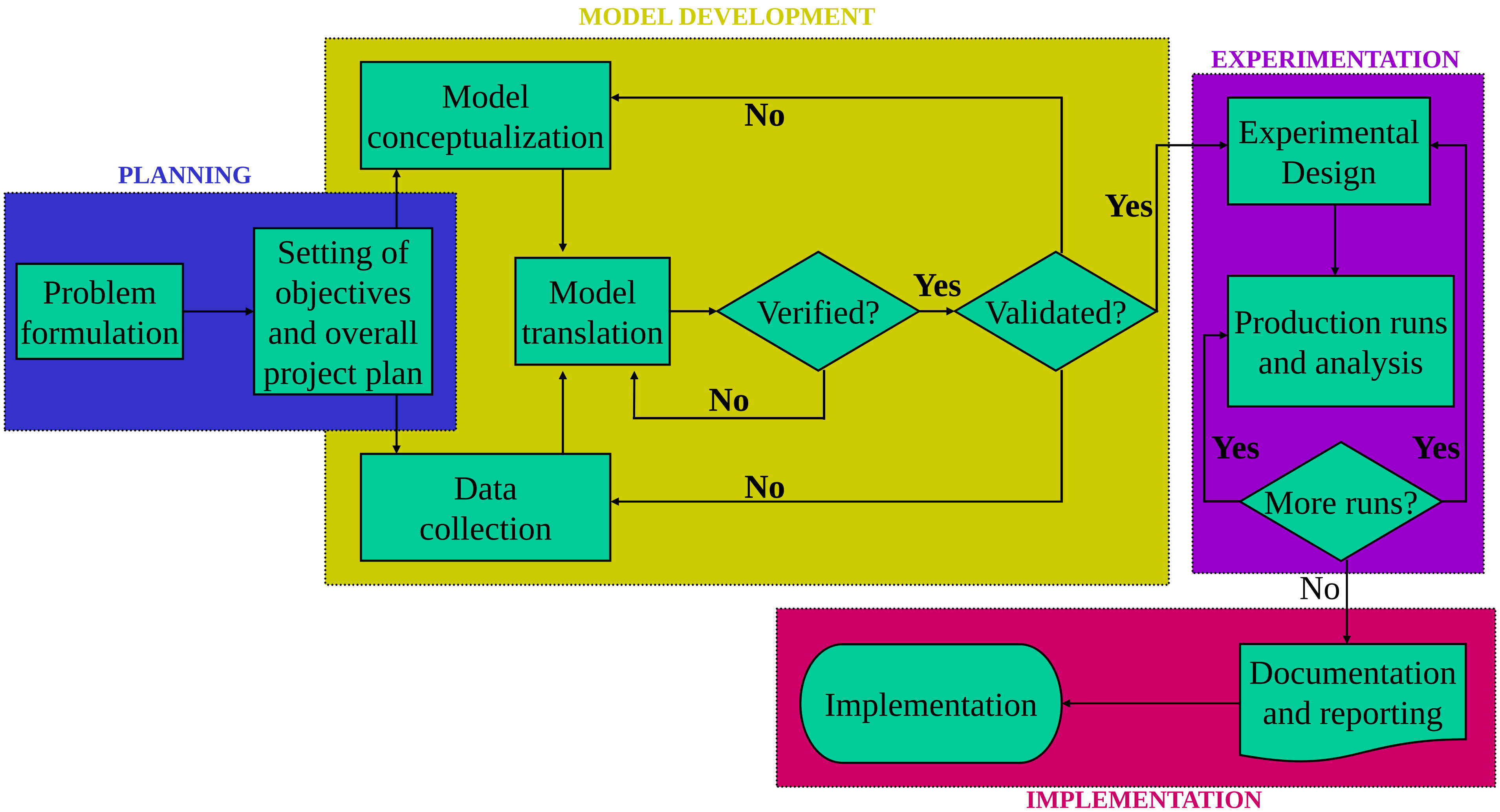
Using Computers to Simulate (cont'd.)

- **Simulation languages**
  - GPSS, SLX, SIMAN (on which Arena is based, included in Arena)
  - Popular, some still in use
  - Learning curve for features, effective use, syntax
- **High-level simulators**
  - Very easy, graphical interface
  - Domain-restricted (manufacturing, communications)
  - Limited flexibility — model validity?

Discrete Event Simulation

- **The state variable changes only at a discrete set of points in time.**
- **The simulation models are analyzed by numerical rather than analytical methods.**
- **Numerical methods employ computational procedures to "solve" mathematical models.**
- **In simulation, models are "run" rather than "solved".**
- **An artificial history of the system is generated from the model and observations are collected to be analyzed and to estimate the system performance measures**

Steps in a simulation study



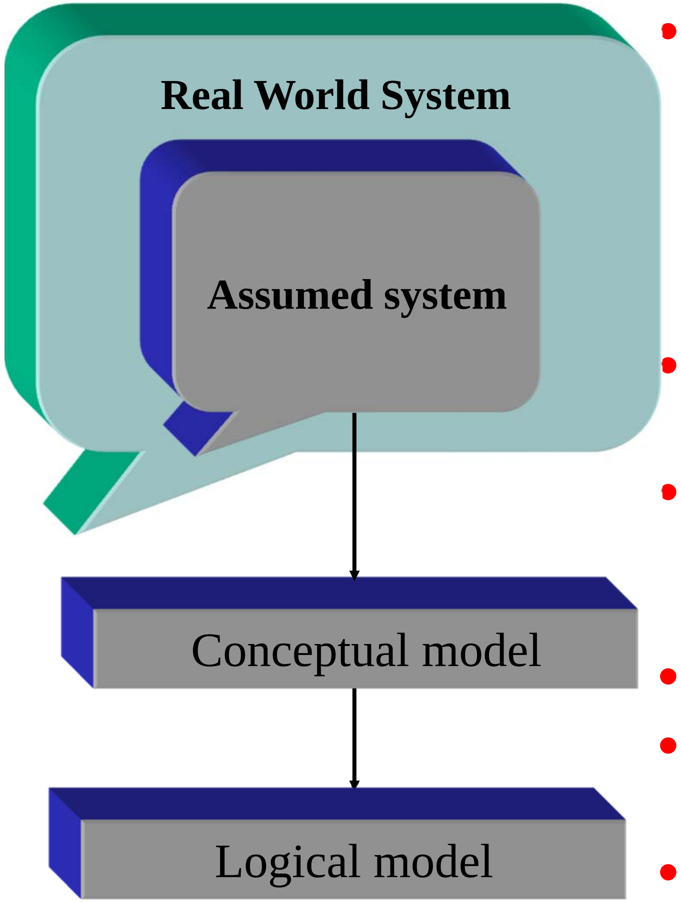
Steps in a simulation study: problem formulation

- **A statement of the problem**
  - the problem is clearly understood by the simulation analyst (if it is described by the policy maker)
  - the formulation is clearly understood and agreed upon by the client (policymaker) (if it is developed by the analyst)

Steps in a simulation study: Setting of objectives and project plan

- **Project Proposal**
  - Is simulation the appropriate approach?
  - Determine the questions that are to be answered (by the simulation)
  - 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

Steps in a simulation study: Model conceptualization



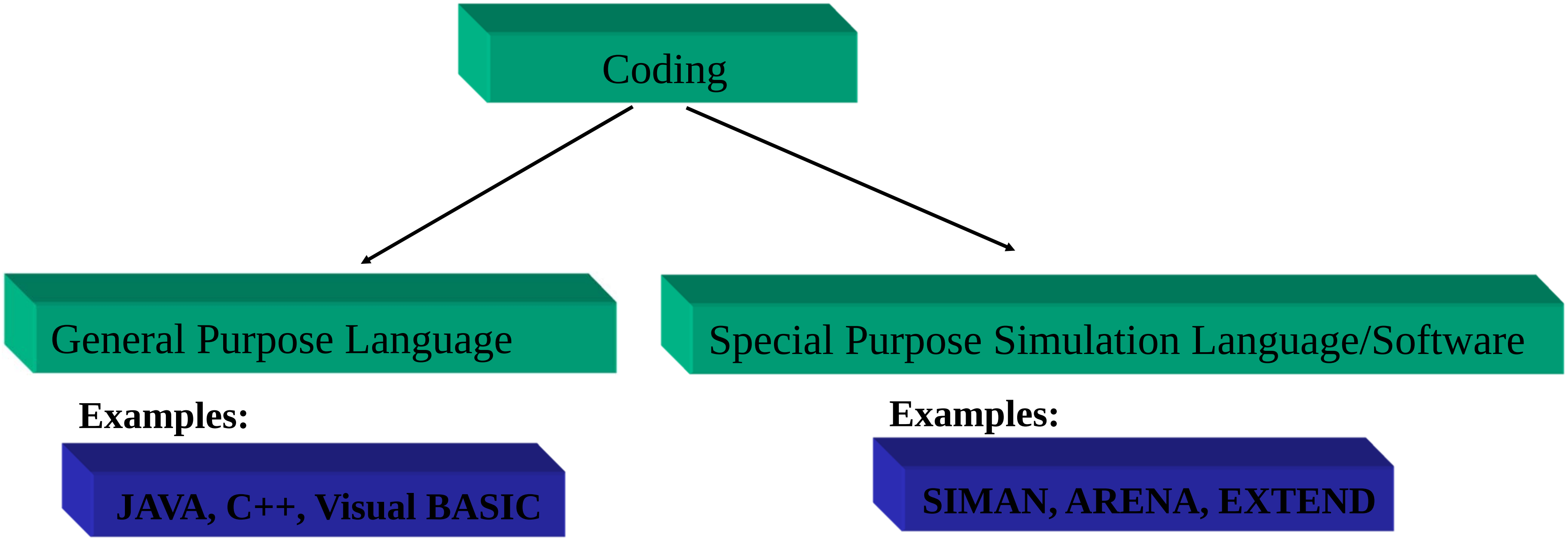
- **Abstract essential features**
  - *Events, activities, entities, attributes, resources, variables*, and their relationships
  - Performance measures
  - Data requirements
- **Conceptual model can be a graphical representation (flow chart) with some information**
- **A logical model contains the logical structure and more details (information) than the conceptual model**
- **Select correct level of details (assumptions)**
- **Low levels of detail may result in loss of information and goals cannot be accomplished**
- **High levels of detail require:**
  - more time and effort
  - longer simulation runs
  - more likely to contain errors

Steps in a simulation study: Data collection and analysis

- **Collect data for input analysis and validation**
- **Analysis of the data**
  - Determine the random variables
  - *Fit distribution functions*

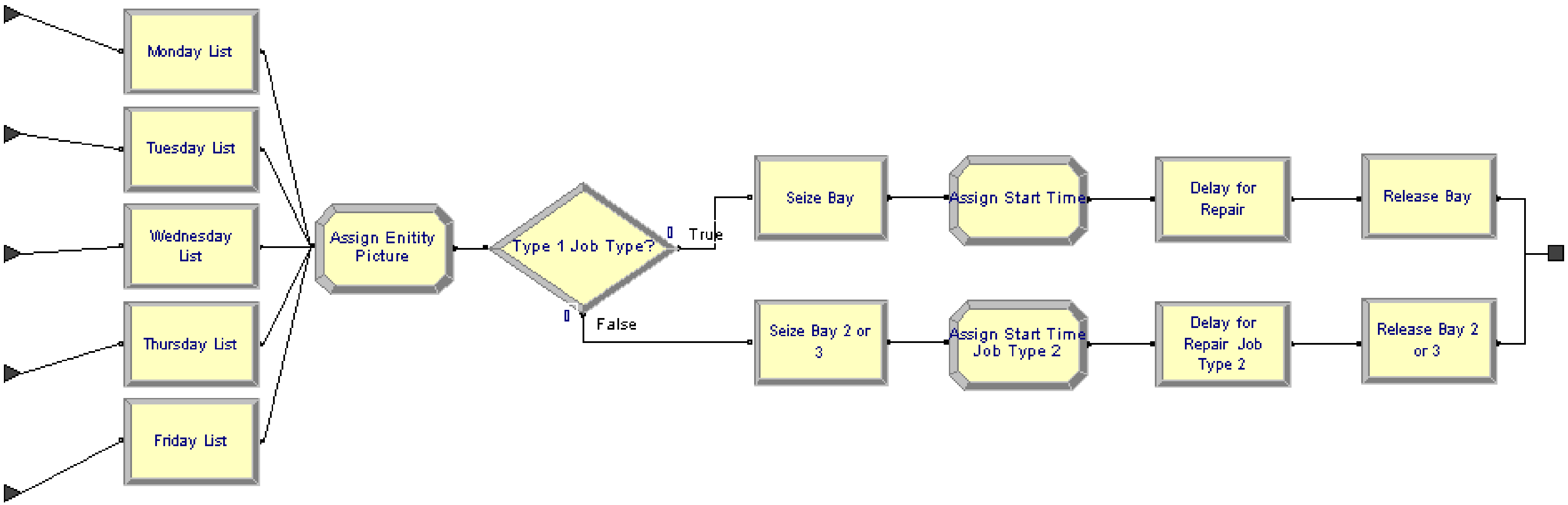
Steps in a simulation study: Model translation

- **Simulation model executes the *logical relationships among the elements of the model* (*flow chart*)**



Steps in a simulation study: Model translation

ARENA Example:



Steps in a simulation study: Model translation

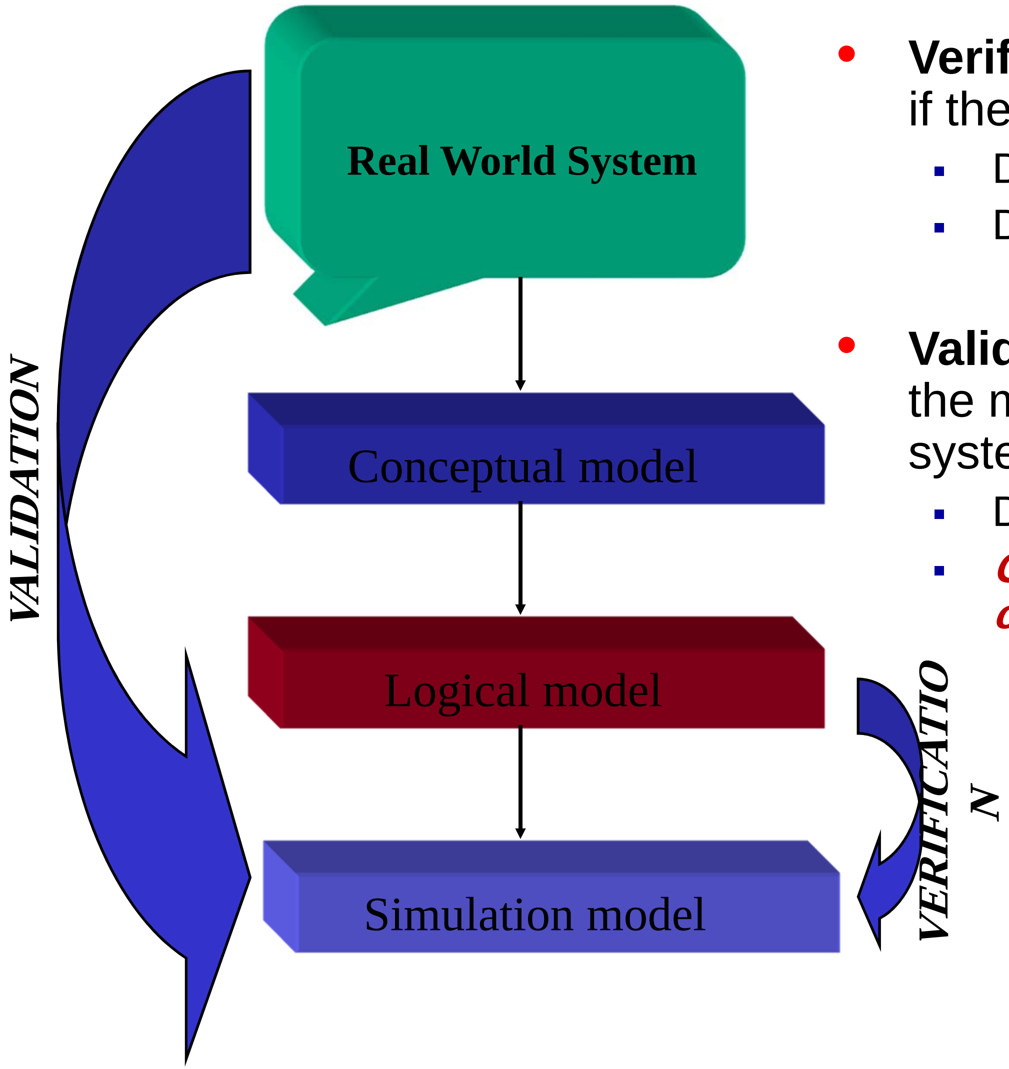
JAVA Example:

```
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();
}
```

Steps in a simulation study: Model verification and validation



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

Steps in a simulation study: Experimental design

- **Alternative scenarios to be simulated**
- **Type of output data analysis (*steady-state* vs. *terminating simulation* analysis)**
- **Number of simulation runs**
- **Length of each run**
- **The manner of initialization**
- **Variance reduction**

Steps in a simulation study: Analysis of results

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

Steps in a simulation study: Documentation and reporting

- **Program Documentation**
  - Allows future use/modifications (if the program is to be used again by the same/other users, it should be understood how it works)
  - Creates confidence in the simulation program
- **Progress Reports**
  - Of the simulation projecct
  - Frequent reports (e.g. monthly) are suggested
  - Alternative scenarios
  - Performance measures or criteria used
  - Results of experiments
  - Recommendations

Steps in a simulation study: Implementation

Continued in lecture 2