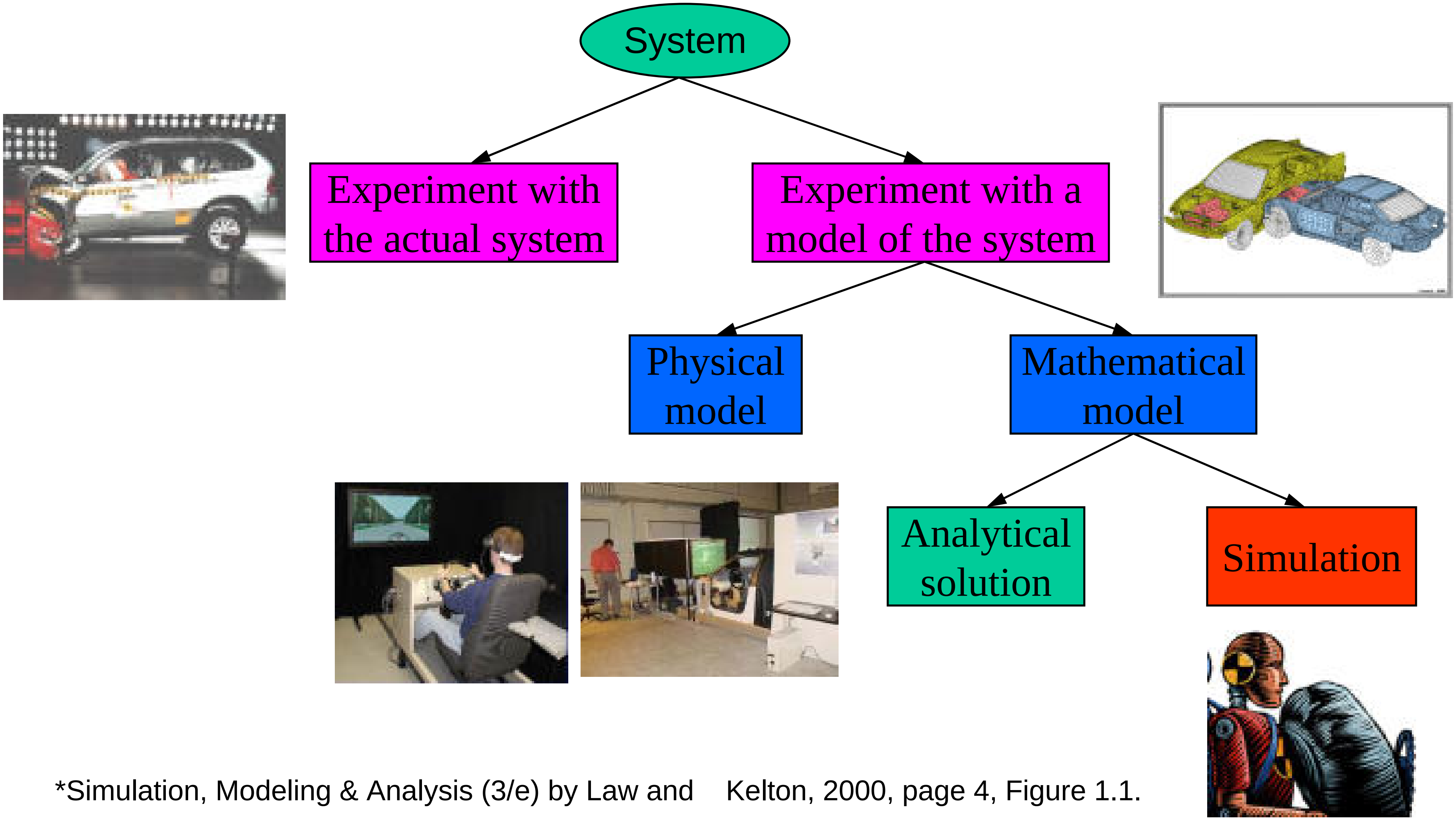
L#01: Introduction

- Ways to study a system
- What is simulation?
- Modeling and Simulation
- Simulation Model
- Discrete-event Simulation
- Example: Simulation of a Queuing System
- Summary

Ways to Study a System*



*Simulation, Modeling & Analysis (3/e) by Law and Kelton, 2000, page 4, Figure 1.1.

WHAT IS SIMULATION?

- what is a system?
- components of a system
- what is a model?
- definition of simulation

"Now, this is just a simulation of what the blocks will look like once they're assembled."

What is Simulation?

- A simulation of a system is the operation of a model which is a representation of that system.

- The model is amendable to manipulation which would be impossible, too expensive, or not practical (possible) to perform on the real system.

- The operation of the model can be studied, and, from this, properties concerning the behavior of the actual system can be inferred.

What is a System?

- A **system** is defined as a group of *objects* that are joined together in some regular *interaction* or interdependence toward the accomplishment of some purpose.

- A system that does not vary with time is **static** whereas one that varies is **dynamic**.

Components of a System

- An ***entity*** is an object of interest in the system.

- An ***attribute*** is a property of an entity. A given entity can possess many attributes.

- An ***activity*** represents a time period of specified length.

- The ***state of a system*** is defined to be that collection of variables (e.g. entities, attributes, activities) necessary to describe the system at any time, relative to the objectives of the study.

- An ***event*** is defined as an instantaneous occurrence that may change the state of the system.

- The ***progress of the system*** is studied by following the changes in the state of the system.

Examples: Components of a System

Components	Banking	Communications
entities	customers	messages
attributes	checking-account balance	length, destination
activities	making deposits	transmitting
events	arrivals, departures	arrival at destination
state of a system	number of busy tellers, number of customers waiting	number waiting to be transmitted

What is a Model?

"A **representation** of an object, a system, or an idea in some form other than that of the entity itself." - Shannon

A **model** is a description of a system intended to predict what happens if certain actions are taken.

Modeling is a way of thinking and reasoning about systems.

Types of models:

- ***physical***: scale models, prototype plants, ...
- ***mathematical*** : analytical queuing models, linear programs, simulation, etc.

Definition of Simulation

"Simulation is the process of designing a **model** of a real **system** and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system."

- R.E. Shannon

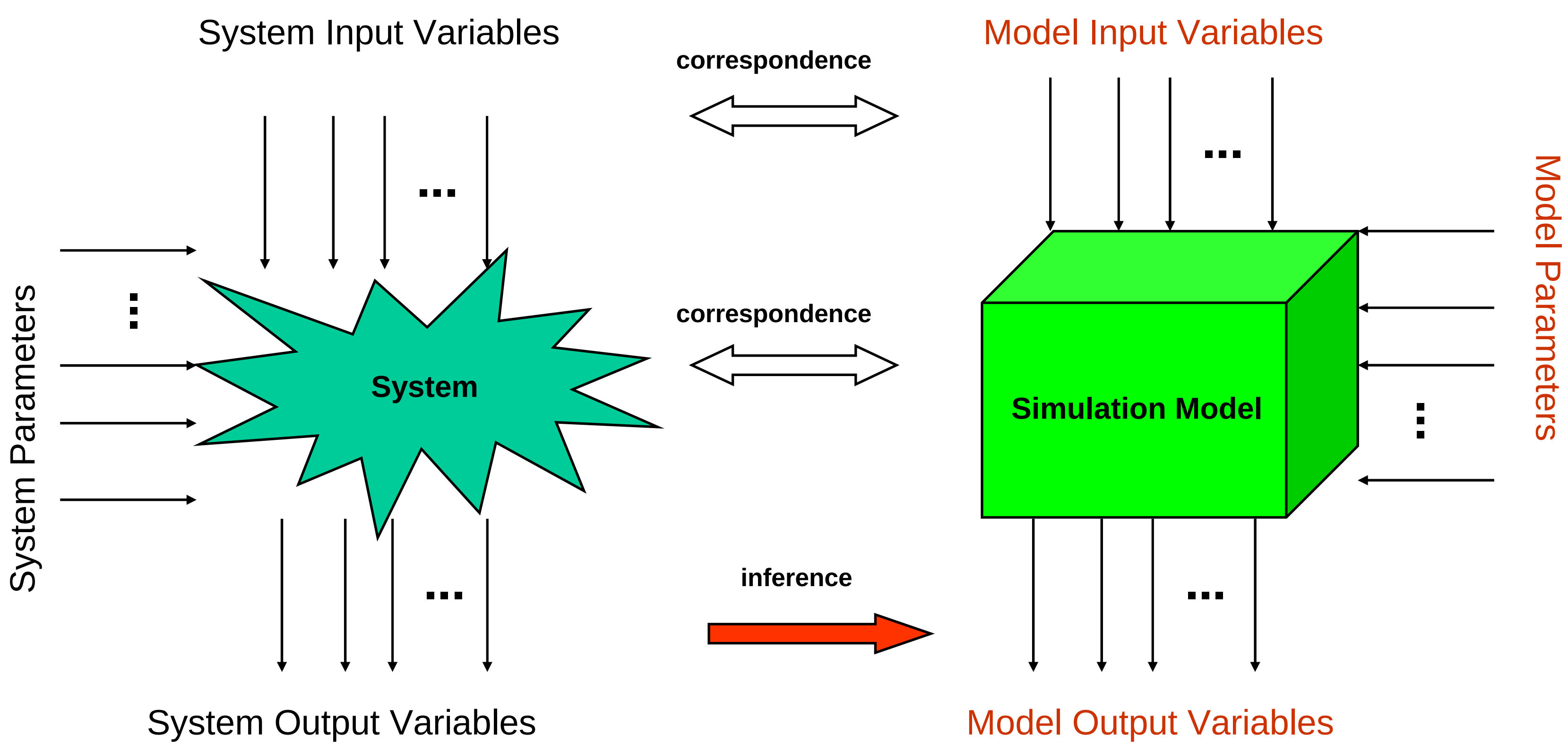
MODELING AND SIMULATION

- Use of a model
- What is a simulator?
- Why simulate?
- Advantages and Disadvantages
- Areas of Application

Use of a Model

- To study system behavior in the design stage, before such systems are built.
- To communicate a system design
- To predict the performance of new systems under varying sets of circumstances.
- “What if” questions about the real-world system.

System and Simulation Model



What is a Simulator?

- A simulator is a computer program which mimics both:
  - the internal behavior of a real-world system
  - the input processes which drive or control the simulated system

- The simulator output is a set of **measurements** concerning the observable reactions and performance of the system.

Measurements are only **estimates** of what the real-world measurements actually are / would be.

Why?

Because an abstraction of the real-world system is simulated!

Why Simulate?

- Appropriate
  - gain knowledge about improvement of system
  - the system as yet does not exist
  - experimentation with the system is expensive, too time consuming, too dangerous
  - experimentation with the system is inappropriate, e.g. disaster planning

- Not appropriate
  - problem can be solved by common sense
  - Problem can be solved analytically
  - Easier to perform direct experiments
  - cost exceed savings
  - Resource and time are not available

Advantages of Simulation

- time can be compressed or expanded to allow for speedup or slow-down of the phenomenon
- pperating performance of new hardware designs, physical layouts, etc. can be tested prior to full-scale implementation
- new policies, operating procedures, information flow, etc. can be explored without disrupting ongoing operation of the real system
- answer “what if” questions

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Disadvantages of Simulation

- Model building requires special training
- Simulation modeling, execution and analysis can be time consuming and expensive
- Hidden critical assumptions may cause the model to diverge from reality
- Model parameters may be difficult to initialize

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Areas of Applications

- Computer systems – microprocessor (CPU, memory), internet-backbone, wireless networks, ….
- Manufacturing systems – material handling system design for semiconductor manufacturing, aircraft assembly operations, inventory cost model for "just-in-time" production, …..
- Transportation systems – container port operations, traffic flow analysis, ERP, ..

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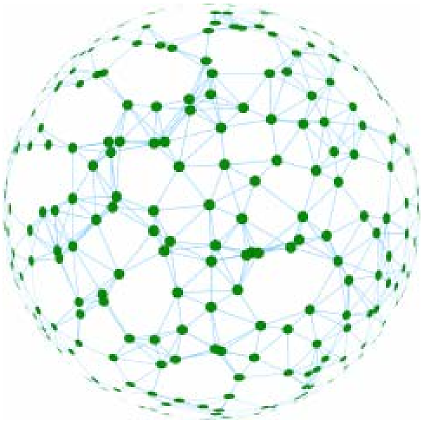
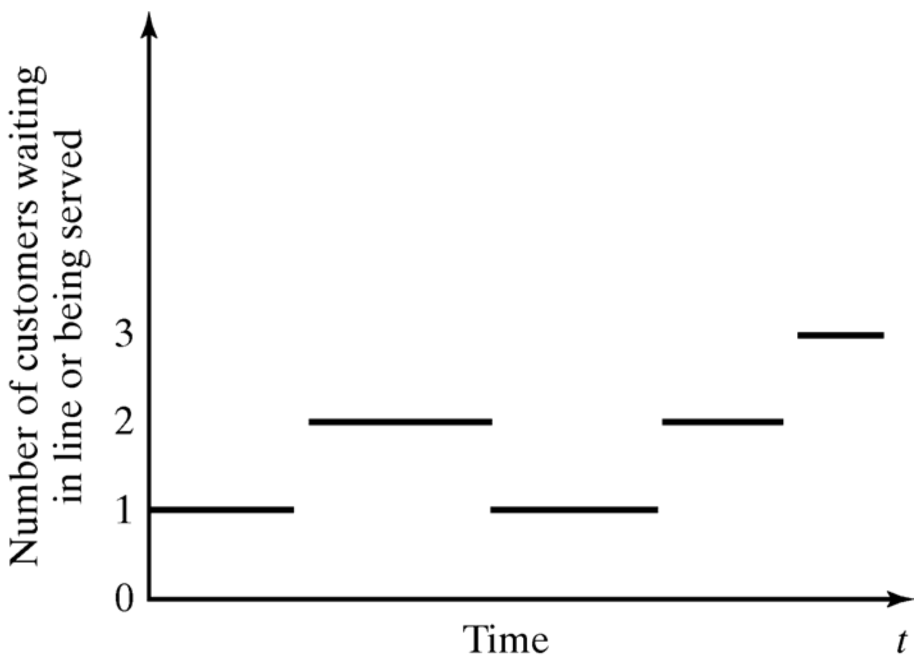


SIMULATION MODEL

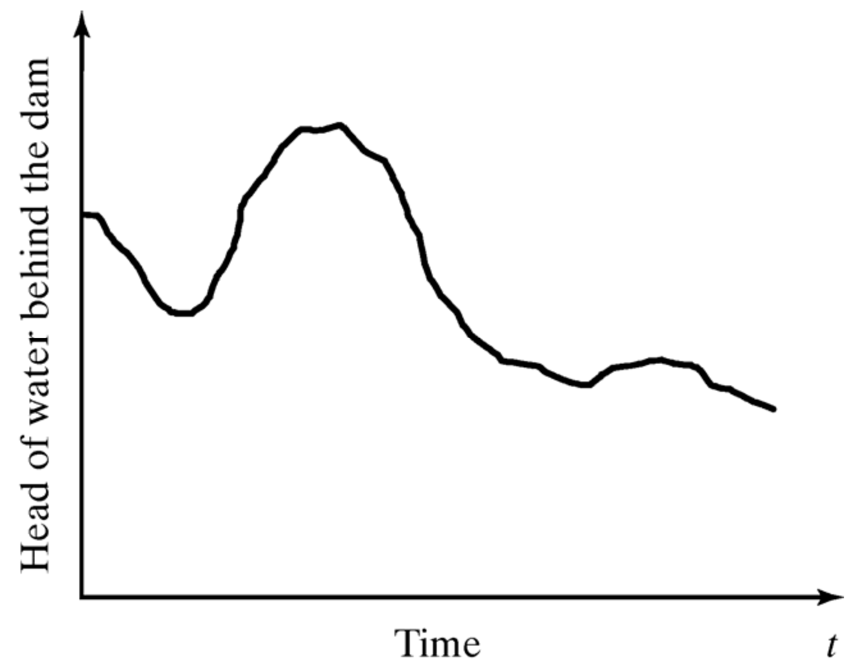
- Discrete and continuous systems
- Deterministic and stochastic models
- Characterizing a simulation model
- Model taxonomy

Discrete and Continuous Systems

A **discrete system** is one in which the state variables change only at discrete set of points in time.



A **continuous system** is one in which the state variables change continuously over time.



Deterministic and Stochastic Models

- **DETERMINISTIC**
  - no random variable in the model
  - have a known set of inputs which will result in a unique set of outputs
  - *e.g.* patients arriving at a clinic at scheduled appointment time (deterministic arrivals)

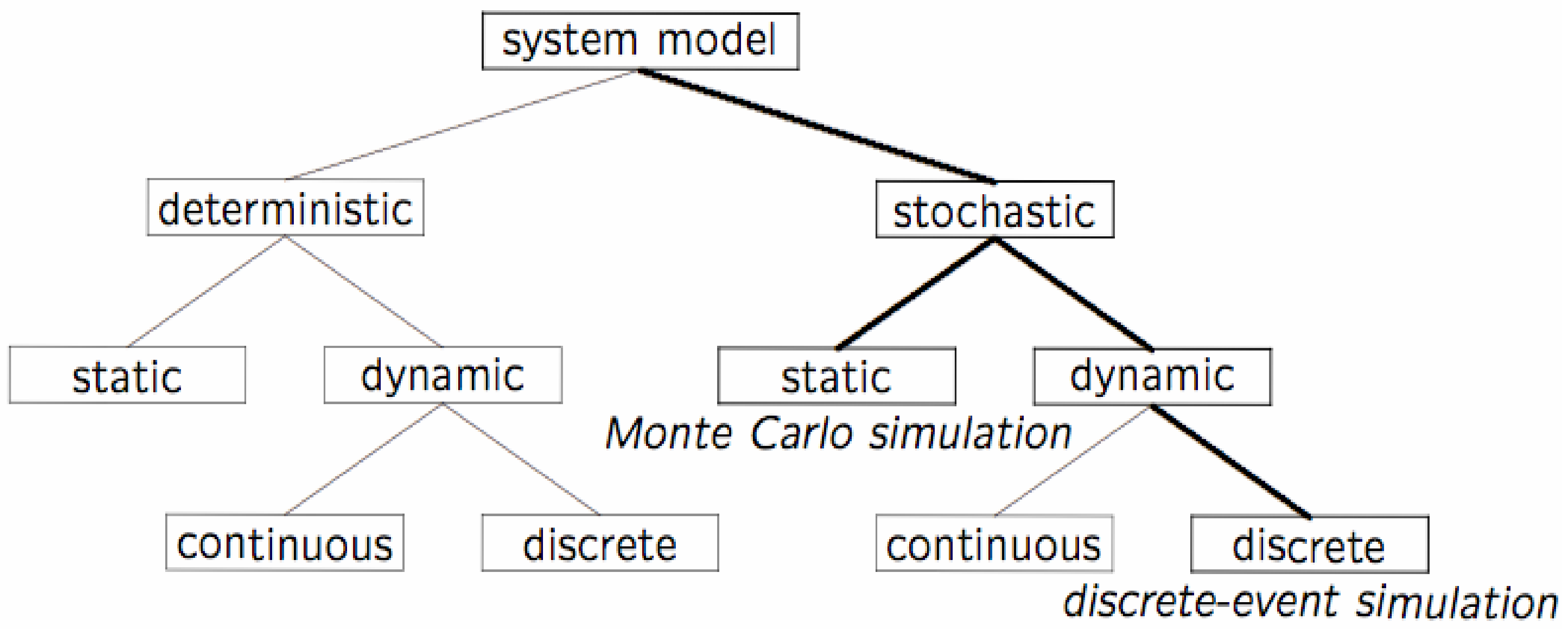
- **STOCHASTIC (NON-DETERMINISTIC or PROBABILISTIC)**
  - model has one or more random variables as inputs
  - *e.g.* Bank - random customer inter-arrival and service times

Characterizing a Simulation Model

- **Monte Carlo Simulation**
  - describe systems which are both stochastic and static
- **Continuous Simulation**
  - used to model systems which vary continually with time
  - the systems modeled are dynamic but may be either deterministic or stochastic
- **Discrete(-Event) Simulation**
  - used to model systems which are assumed to change only at discrete set of points in time (correspond to state changes)
  - the systems modeled are dynamic and almost invariably, stochastic
- **Combined Discrete/Continuous Simulation (Hybrid)**
  - combination of discrete and continuous variables

Choice of simulation model is a function of the characteristics of the system and the objectives of the study.

Model Taxonomy



DISCRETE-EVENT SIMULATION

- Discrete-event simulation model
- DES model development
- Three model levels
- Verification and validation
- Steps in simulation study

Discrete-Event Simulation Model

- **Stochastic**: some state variables are random
- **Dynamic**: time evolution is important
- **Discrete-event**: significant changes occur at discrete time instances

DES Model Development

How to develop a model?

1. Determine the goals and objectives
2. Build a **conceptual** model
3. Convert into a **specification** model
4. Convert into a **computational** model
5. Verify
6. Validate

Typically an iterative process!

Three Model Levels

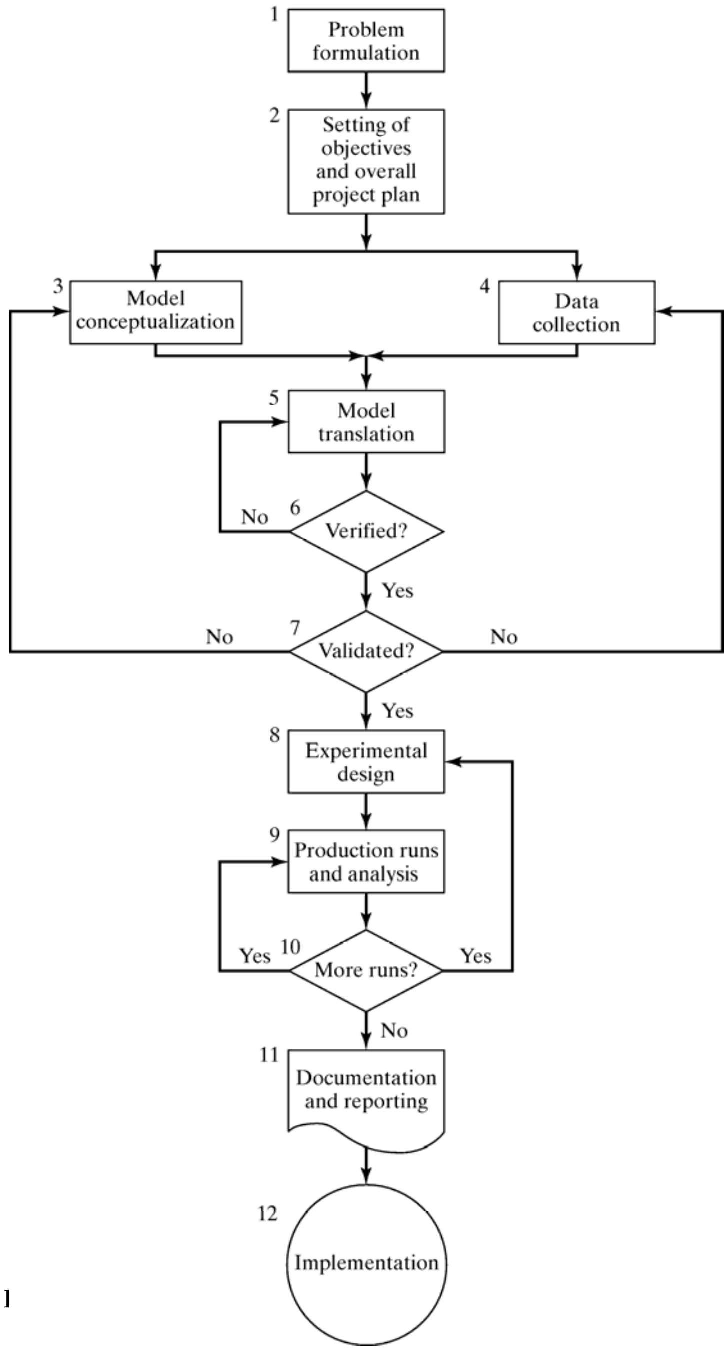
- *Conceptual*
  - Very high level
  - What are the state variables, which are dynamic, and which are important?
  - How comprehensive should the model be?
- *Specification*
  - On paper
  - May involve equations, pseudocode, etc.
  - How will the model receive input?
- *Computational*
  - A computer program
  - General-purpose programming language or simulation language?

Verification and Validation

- *Verification*
  - Computational model should be consistent with specification model
  - Did we build the model right?

- *Validation*
  - Computational model should be consistent with the system being analyzed
  - Did we build the right model?
  - Can an expert distinguish simulation output from system output?

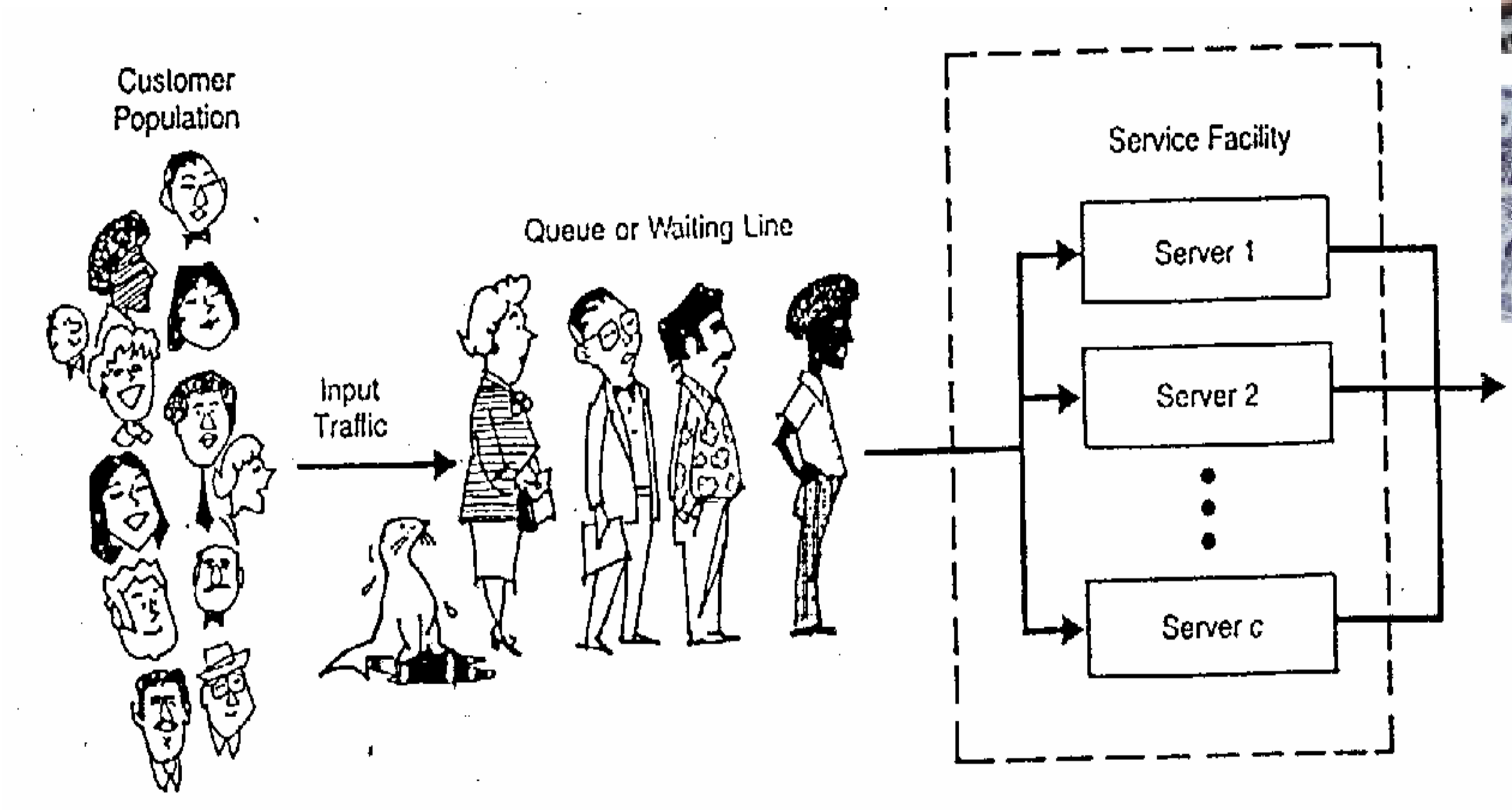
Steps in Simulation Study



Steps in a Simulation Study

1. Problem formulation
2. Setting objectives and overall project plan
3. *Model conceptualization*
4. *Data collection*
5. *Model translation*
6. *Verified?*
7. *Validated?*
8. Experimental design
9. Production runs and analysis
10. More runs
11. *Documentation and reporting*
12. *implementation*

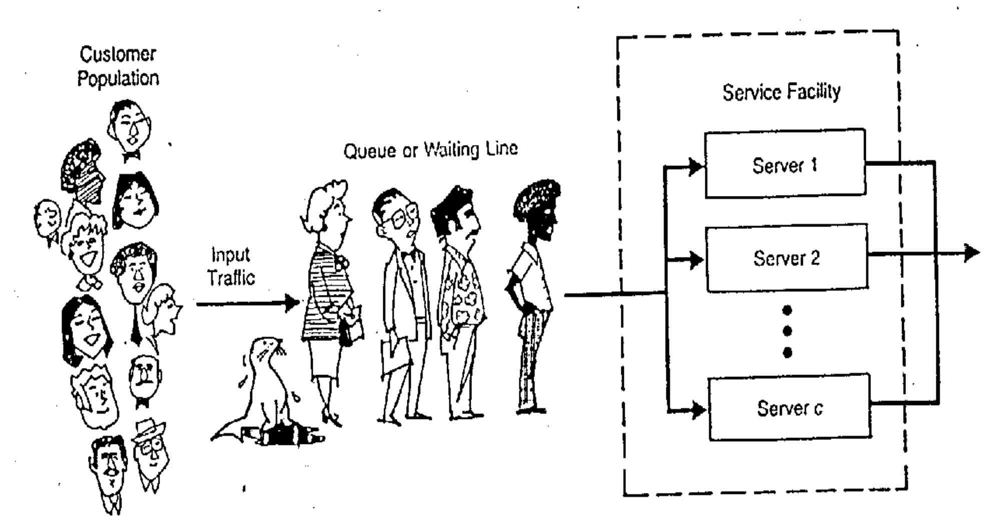
Example: Simulation of Queuing Systems

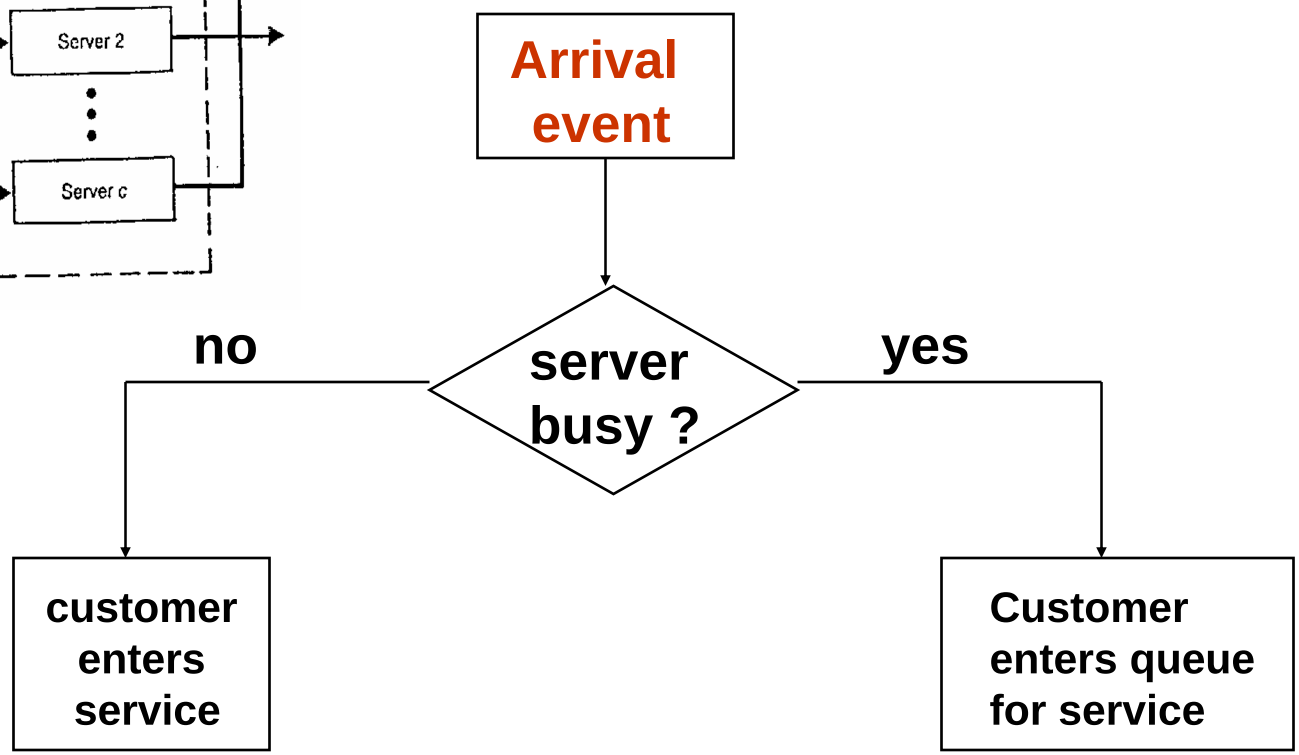


Example: Simulation of a Queuing System

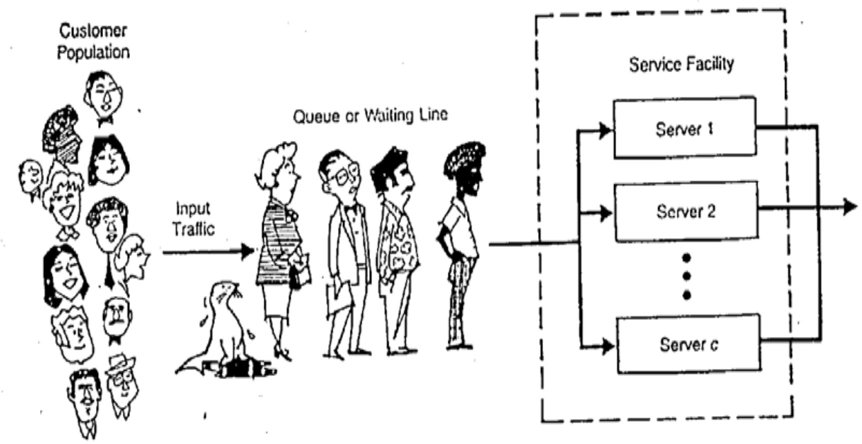
- Calling population (finite, infinite) – customers
- Nature of arrival – arrival times
- Pattern of service – service time
- System capacity
- Queuing discipline: FIFO, LIFO, etc.
- States of system: number of customers in the queue, server (idle, busy)
- An event cause an instantaneous change in system state
  - Arrival of a customer (the **arrival event**)
  - Completion of service (the **departure event**)

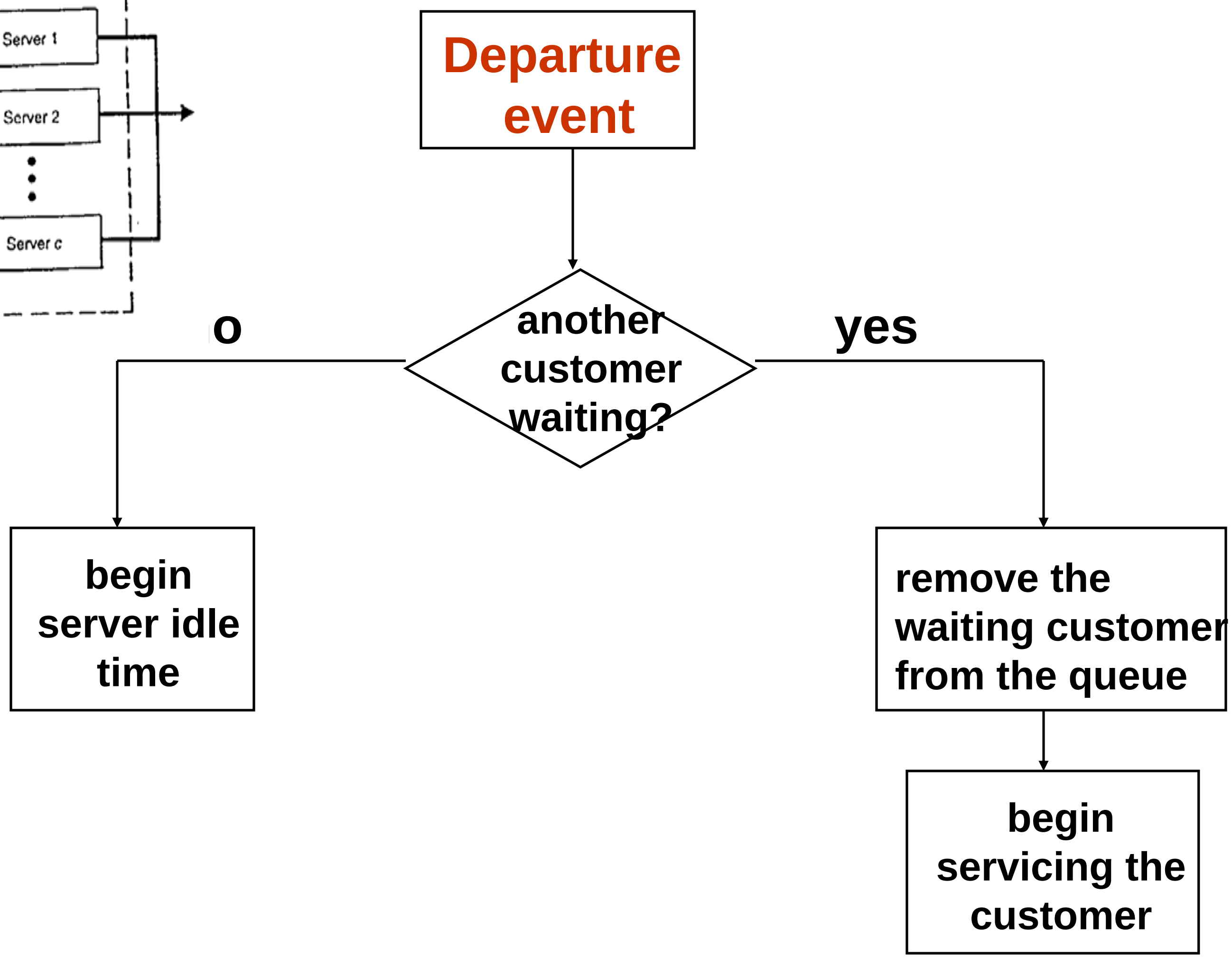
Arrival Event





Departure Event





Events

- Occurs at random (initiates real life)

- The times that mark the occurrence of events are usually randomly generated.

- Inter-arrival (or arrival) times and service times are determined (generated) from the distributions of these random variables

How to model events in simulated time?

1. Maintain an **event list** to determine what happened next. The event list indicates the times at which the different types of events occur at each unit.
2. A (simulation) **clock** to mark the occurrences of events in time.

Customer Arrival and Completion of Service

		Queue status	
		Not empty	Empty
Server status	Busy	Enter queue	Enter queue
	Idle	Impossible	Enter service

Actions upon Customer Arrival

		Queue status	
		Not empty	Empty
Server outcomes	Busy		Impossible
	Idle	Impossible	

Server Outcomes after Completion of Service

Example - Simulation of Queuing Systems (one server only)

Customer	Inter-arrival Time	Arrival Time	Service Time
1	-	0	2
2	2	2	1
3	4	6	3
4	1	7	2
5	2	9	1
6	6	15	4

% server is idle = total idle time / total simulation time = 6/19 x 100 = 32%

Average waiting time = total waiting time / number of customers
= 4/6 = 2/3 minute

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Summary

- System, model, simulation, simulator
- System evolves over time
- Concepts – system states, events, simulation clock

Read Banks and Carson chapters 1 and 2