Overview of the Simulation Process

CS1538: Introduction to Simulations

Simulation Fundamentals

A computer simulation is 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

- Simulation program modifies state variables to model the evolution of the physical system over time

System

"A group of objects that are joined together in some regular interaction or interdependence toward the accomplishment of some purpose.“

Example: Banking

Components of a System: Entity

Entity – an object of interest in the system

- *Example:* A customer of the bank

- Attribute – a property of an entity
  - *Example:* the customer's checking account balance

- Activity – some action performed by an entity
  - Represented by a time period of specified length
  - *Example: making a deposit*

Components of a System: State

State – "that collection of *variables* necessary to describe the system at any time, relative to the objectives of the study."

Example:

- Number of busy tellers
- Number of customers waiting

Components of a System: Event

Event – "instantaneous occurrence that might change the state of the system"

- Endogenous event – occurs within the system
- Exogenous event – occurs outside in the *environment*
  - can still affect the system

Examples:

- Arrival of a new customer
- Completed service of a customer

Exercise

System	Entities	Attributes	Activities	Events	State variables
Transit					
Laundromat					
Email					
Cafeteria					

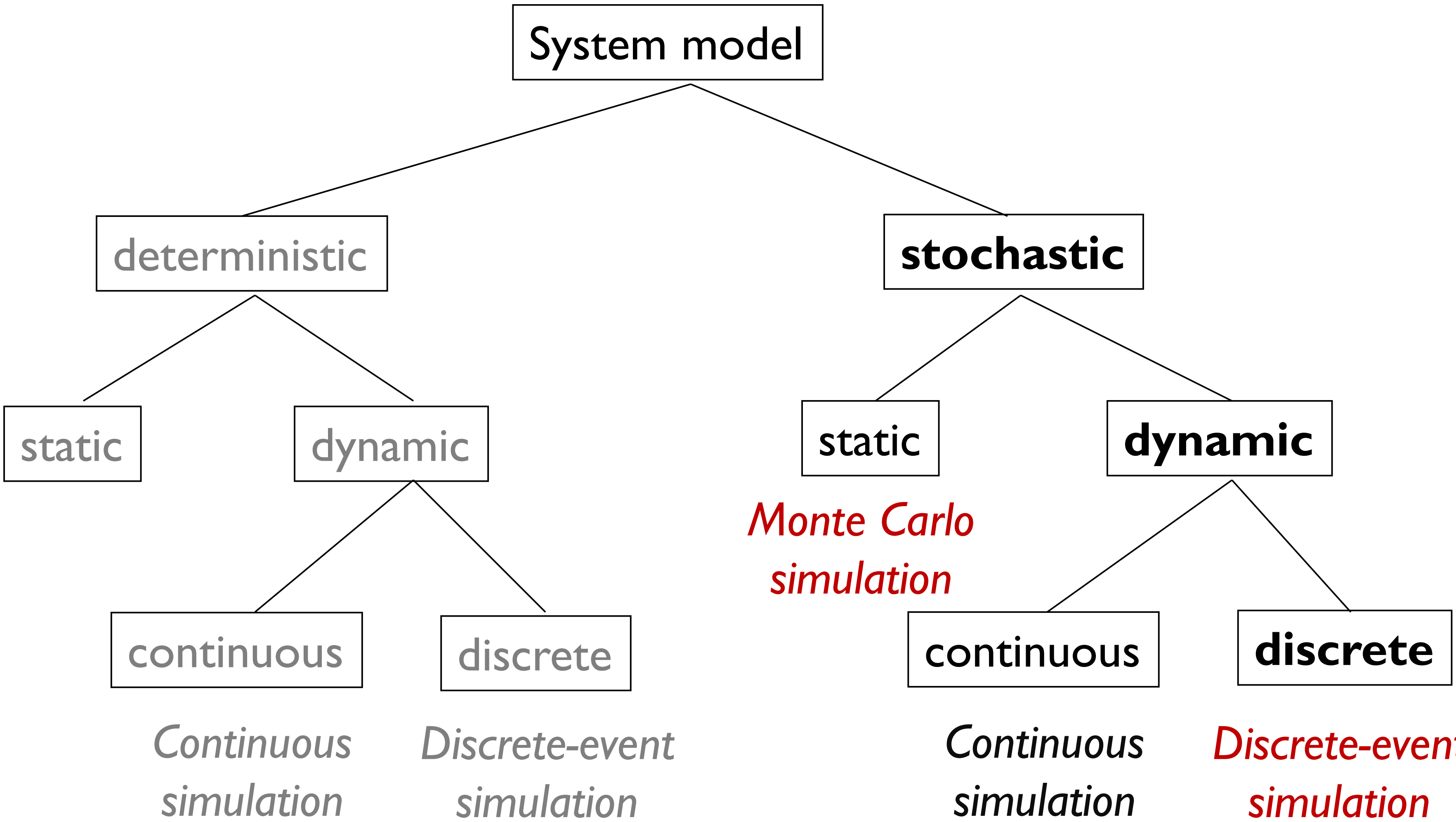
Discrete vs. Continuous Systems

- Discrete System
  - State variables change at discrete points in time
  - Event is associated with a state transition
- Continuous System
  - State variables change continuously over time
  - Can be described by differential equations (rate of change in variables)
- "*Few systems in practice are wholly discrete or continuous, but since one type of change predominates for most systems, it will usually be possible to classify a system as being either discrete or continuous.*"

Modeling

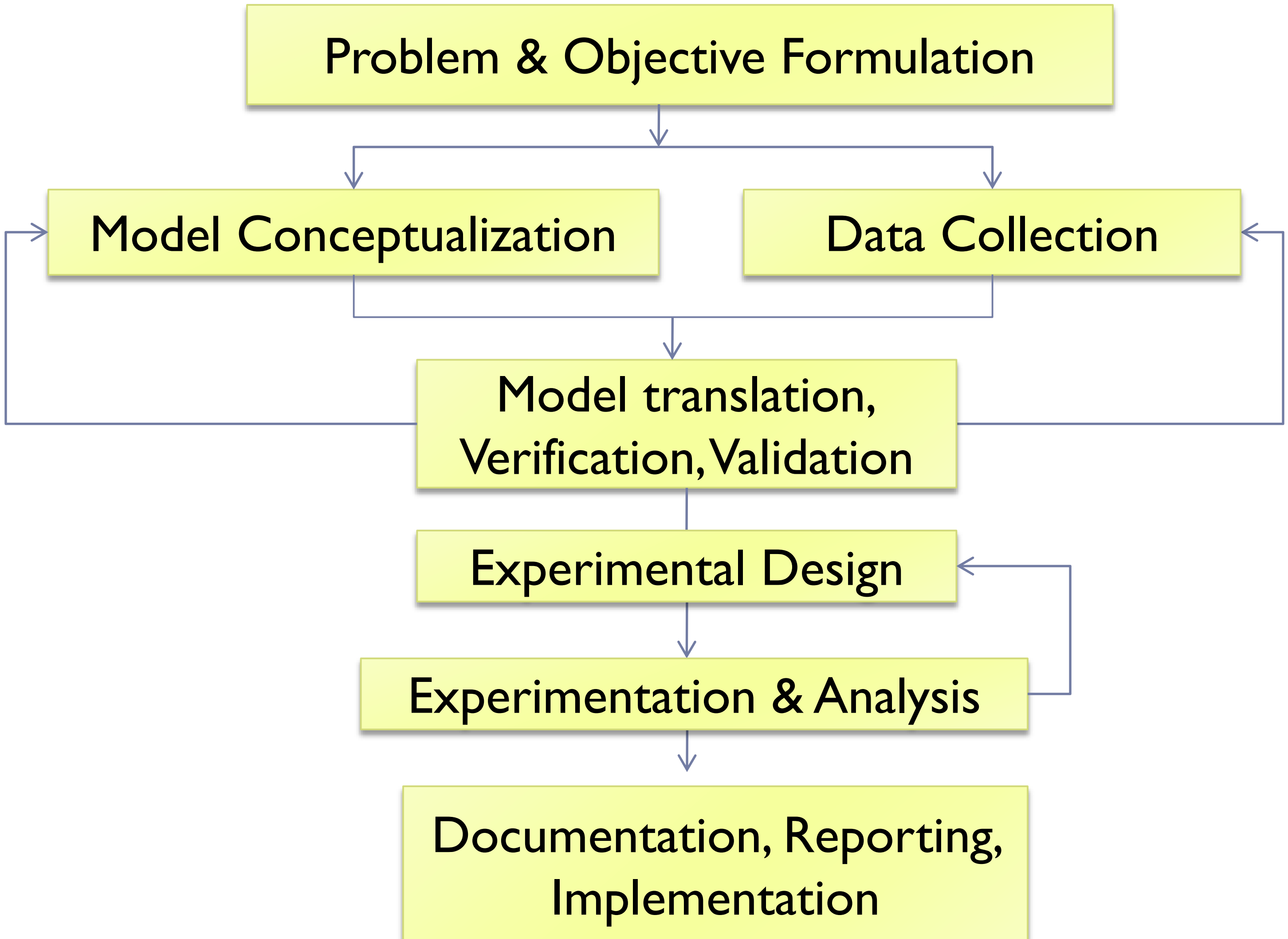
- System Model – A representation of the system to be used / studied in place of the actual system
  - Physical model – Construct a (possibly scaled-down) physical representation of the system
  - Mathematical model – Represents the system using logical and mathematical relationships
    - Deterministic vs. Stochastic
      - Does the simulation contain elements of randomness?
    - Static vs. Dynamic
      - Does the system change with time?

Types of Simulation Models



Slide adapted from: R. Fujimoto

Steps in a Simulation Study



Simple Simulation: Single Server Queue

- Scenario: A fast-food restaurant with just a single server/cook and a single stove.
  - Customers arrive and wait in line for their turn.
  - The customer orders, then wait for the food to be prepared (service time may vary).
  - Customer picks up the food and leaves.

The Single Server Restaurant

- A few simplifying assumptions (for now)
  - Ignore: customer's party size, order complexity, money spent
  - Customers will patiently wait for their turns indefinitely
  - The restaurant never closes, never runs out of supplies, the server is never tired
  - Customer arrival is independent and identically distributed (iid)
  - Service time is also iid.
- Simulations objectives:
  - How often is the server idle?
  - What's the chance that a customer has to wait?
  - On average, how long is a customer's wait time?
    - How long is a customer's wait time *given that there already is a line*?

Modeling the Single Server Restaurant

- Need to model:
  - Randomized customer arrivals
  - Waiting in line
  - Randomized customer service times
- How to generate a random event?
- How to simulate the passage of time?

Generating Random Events

- Customer arrival time:
  - Suppose a new customer always arrives 6-10 minutes after the previous customer arrives (discretized by minutes)
  - We'll assume the random gap length is generated from a uniform distribution

  How do we implement this?

  Assume we have `rand()` a function that returns a random number between [0,1]
- How about customer service (cooking) time with the following distribution:

Cook time	3 min	4 min	5 min	7 min	8 min	9 min
Probability	0.1	0.2	0.3	0.25	0.1	0.05

Time Advance Mechanisms

Next-event time advance

- Simulation clock initialized to zero
- Determine the times of occurrences of future events
- Advance clock to the most imminent of the future event
- Update system variables
- Update knowledge of the times for future events

Fixed-increment time advance

- Simulation clock initialized to zero
- Increment clock by a fixed amount (Δt)
- Check to see if one or more events should have occurred during the previous interval of length Δt.
- If so, consider them to occur at the end of the interval; update system state variables

Why (When) is simulation useful?

- Direct experimentation is not possible
  - Internal interactions of a complex system
  - Many informational, organizational, environmental changes
- Diagnostics for the real system
  - Suggestions for improvements
  - Insights about how variables within the system interact
- Preview of a real system before building it
  - Experiment with new designs or policies
- Learning and verification
  - Complements analytic solutions
  - In conjunction with animation, help to visualize the work flow of the overall system

When not to use simulations?

- Don't use a simulation to solve a problem when it’s not necessary
  - Problem can be solved with common sense
  - Problem can be solved easily and exactly with an analytic solution
- Don't use a simulation if it’s easier or cheaper to experiment directly on a real system
- Don't use a simulation if the system is too complex to model accurately, or if there isn’t enough resources/time to perform a proper simulations study.