Discrete-Event Simulation: A First Course

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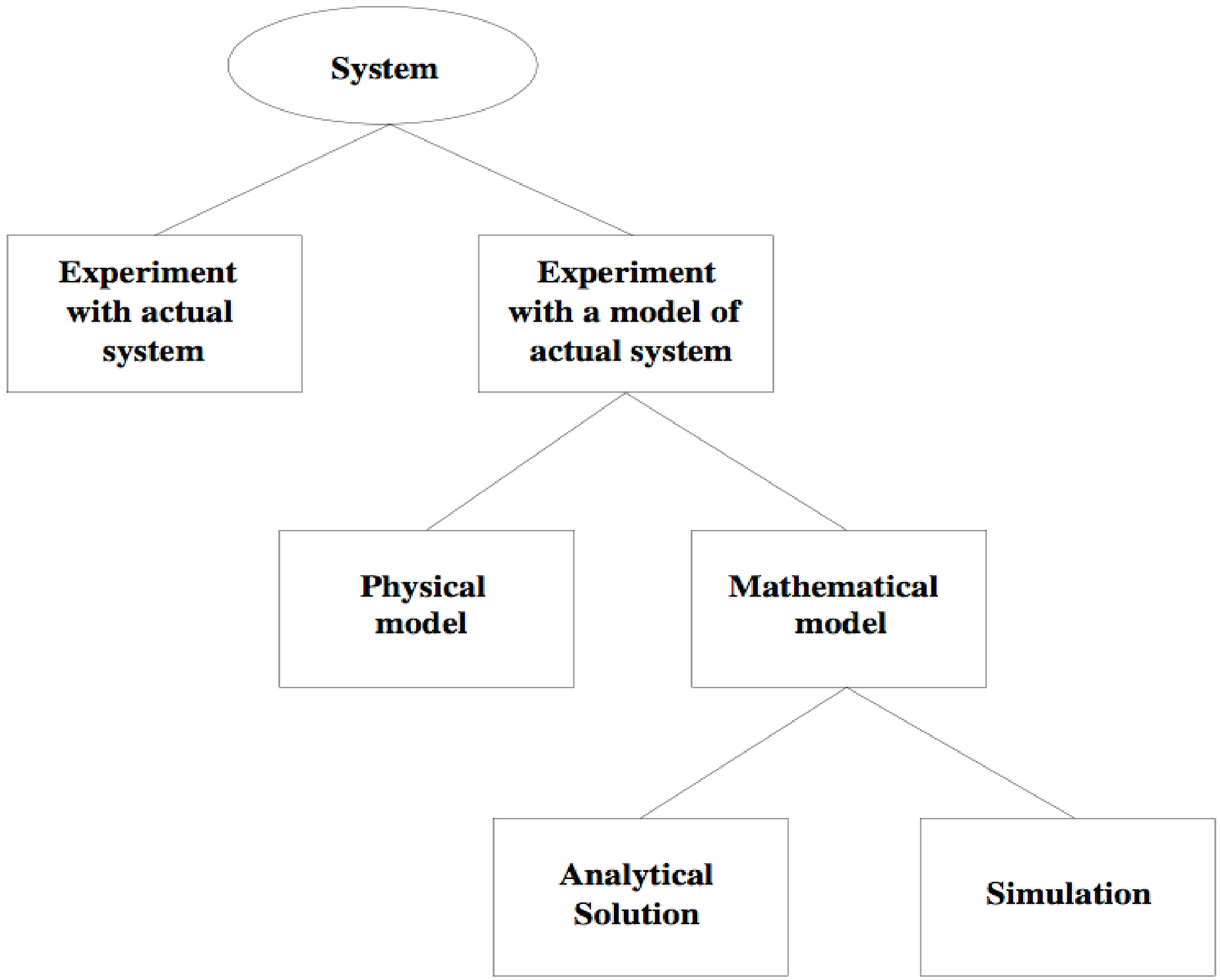
Technical Attractions of Simulation*

- Ability to compress time, expand time
- Ability to control sources of variation
- Avoids errors in measurement
- Ability to stop and review
- Ability to restore *system state*
- Facilitates *replication*
- Modeler can control level of detail

**Discrete-Event Simulation: Modeling, Programming, and Analysis* by G. Fishman, 2001, pp. 26-27

Ways To Study A System*



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

Introduction

- What is discrete-event simulation?
  - Modeling, simulating, and analyzing systems
  - Computational and mathematical techniques
- **Model**: construct a conceptual framework that describes a system
- **Simulate**: perform experiments using computer implementation of the model
- **Analyze**: draw conclusions from output that assist in decision making process
- We will first focus on the *model*

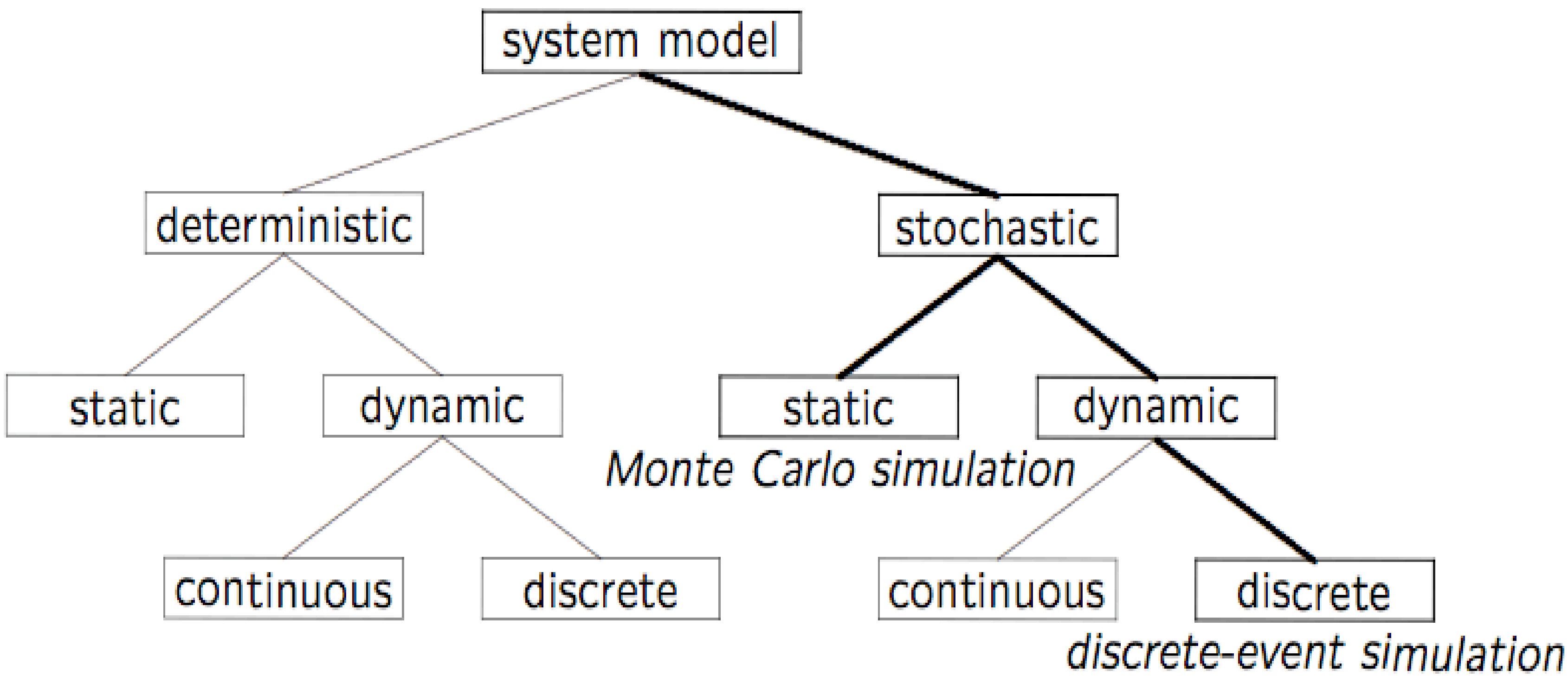
Characterizing a Model

- Deterministic or Stochastic
  - Does the model contain stochastic components?
  - Randomness is easy to add to a DES
- Static or Dynamic
  - Is time a significant variable?
- Continuous or Discrete
  - Does the system state evolve continuously or only at discrete points in time?
  - Continuous: classical mechanics
  - Discrete: queuing, inventory, machine shop models

Definitions

- Discrete-Event Simulation Model
  - *Stochastic*: some state variables are random
  - *Dynamic*: time evolution is important
  - *Discrete-Event*: significant changes occur at discrete time instances
- Monte Carlo Simulation Model
  - *Stochastic*
  - *Static:* time evolution is not important

Model Taxonomy



DES Model Development

Algorithm 1.1 — 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
  - How comprehensive should the model be?
  - What are the *state variables*, which are dynamic, and which are important?
- Specification
  - On paper
  - May involve equations, pseudocode, etc.
  - How will the model receive input?
- Computational
  - A computer program
  - General-purpose PL or simulation language?

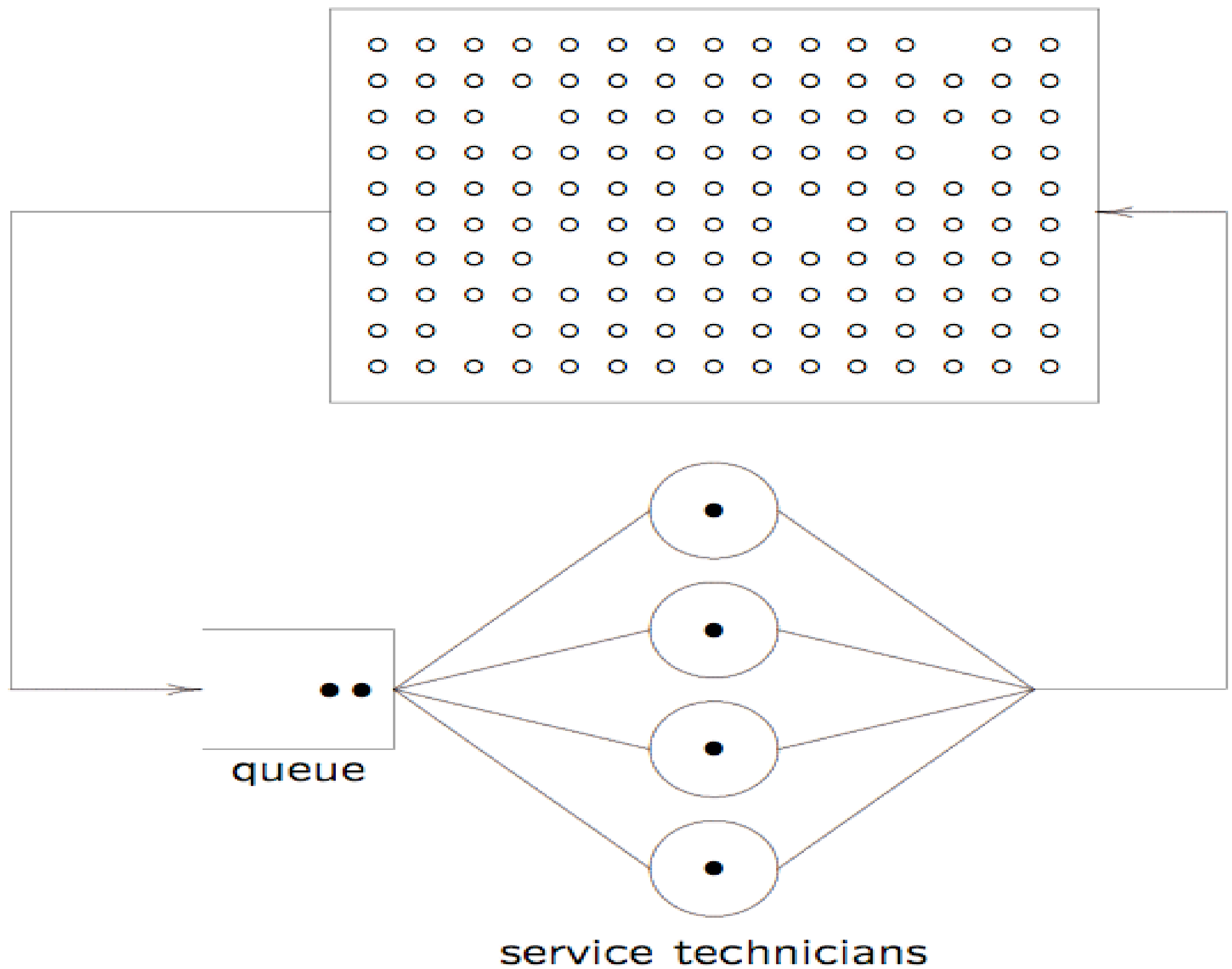
Verification vs. Validation

- *Verification*
  - Computational model should be consistent with specification model
  - Did we build the <u>model right</u>?
- *Validation*
  - Computational model should be consistent with the system being analyzed
  - Did we build the <u>right model</u>?
  - Can an expert distinguish simulation output from system output?
- Interactive graphics can prove valuable

A Machine Shop Model

- 150 identical machines:
  - Operate continuously, 8 hr/day, 250 days/yr
  - Operate independently
  - Repaired in the order of failure
  - Income: $20/hr of operation
- Service technician(s):
  - 2-year contract at $52,000/yr
  - Each works 230 8-hr days/yr
- How many service technicians should be hired?

System Diagram



Algorithm 1.1.1 Applied

1) Goals and Objectives:
   - Find number of technicians for max profit
   - Extremes: one techie, one techie per machine
2) Conceptual Model:
   - State of each machine (failed, operational)
   - State of each techie (busy, idle)
   - Provides a high-level description of the system at any time
3) Specification Model:
   - What is known about time between failures?
   - What is the distribution of the repair times?
   - How will time evolution be simulated?

Algorithm 1.1 Applied

4) Computational Model:
   - Simulation clock data structure
   - Queue of failed machines
   - Queue of available techies
5) Verify:
   - Software engineering activity
   - Usually done via extensive testing
6) Validate:
   - Is the computational model a good approximation of the actual machine shop?
   - If operational, compare against the real thing
   - Otherwise, use *consistency checks*

Observations

- Make each model as simple as possible
  - Never simpler
  - Do not ignore relevant characteristics
  - Do not include extraneous characteristics
- Model development is not sequential
  - Steps are often iterated
  - In a team setting, some steps will be in parallel
  - Do not merge verification and validation
- Develop models at three levels
  - Do not jump immediately to computational level
  - Think a little, program a lot (and poorly);
    Think a lot, program a little (and well)

Simulation Studies

Algorithm 1.1.2 — Using the resulting model:

7) Design simulation experiments
   - What parameters should be varied?
   - Perhaps many combinatoric possibilities
8) Make production runs
   - Record initial conditions, input parameters
   - Record statistical output
9) Analyze the output
   - Use common statistical analysis tools (Ch. 4)
10) Make decisions
11) Document the results

Algorithm 1.1.2 Applied

7) Design Experiments
   - Vary the number of technicians
   - What are the initial conditions?
   - How many replications are required?
8) Make Production Runs
   - Manage output wisely
   - Must be able to reproduce results *exactly*
9) Analyze Output
   - Observations are often correlated (not independent)
   - Take care not to derive erroneous conclusions

Algorithm 1.1.2 Applied

10) Make Decisions
    - Graphical display gives optimal number of technicians and sensitivity
    - Implement the policy subject to external conditions
11) Document Results
    - System diagram
    - Assumptions about failure and repair rates
    - Description of specification model
    - Software
    - Tables and figures of output
    - Description of output analysis

DES can provide valuable insight about the system

Programming Languages

- General-purpose programming languages
  - Flexible and familiar
  - Well suited for learning DES principles and techniques
  - E.g.: C, C++, Java
- Special-purpose simulation languages
  - Good for building models quickly
  - Provide built-in features (e.g., queue structures)
  - Graphics and animation provided
  - E.g.: Arena, Promodel

Terminology

- Model vs. Simulation (noun)
  - *Model* can be used WRT conceptual, specification, or computational levels
  - *Simulation* is rarely used to describe the conceptual or specification model
  - *Simulation* is frequently used to refer to the computational model (program)
- Model vs. Simulate (verb)
  - *To model* can refer to development at any of the levels
  - *To simulate* refers to computational activity
- Meaning should be obvious from the context

Looking Ahead

- Begin by studying trace-driven single server queue
- Follow that with a trace-driven machine shop model