CPSC 531: System Modeling and Simulation

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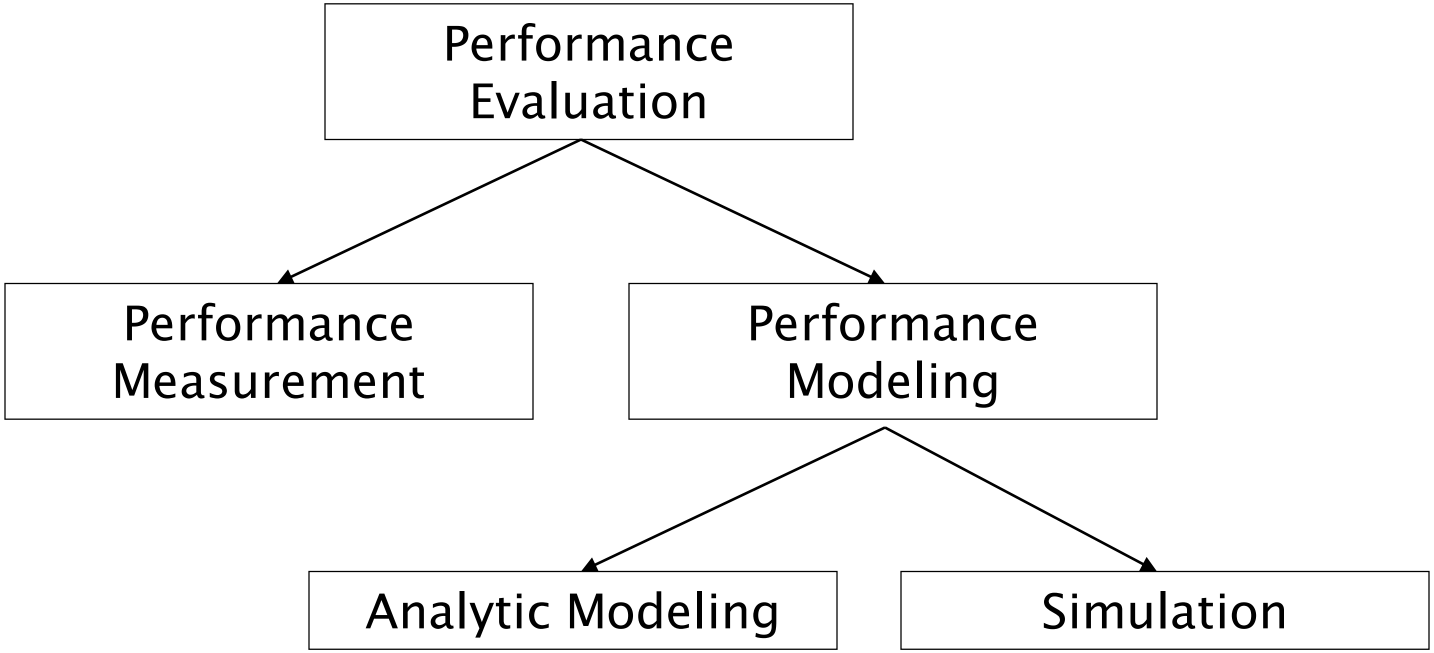
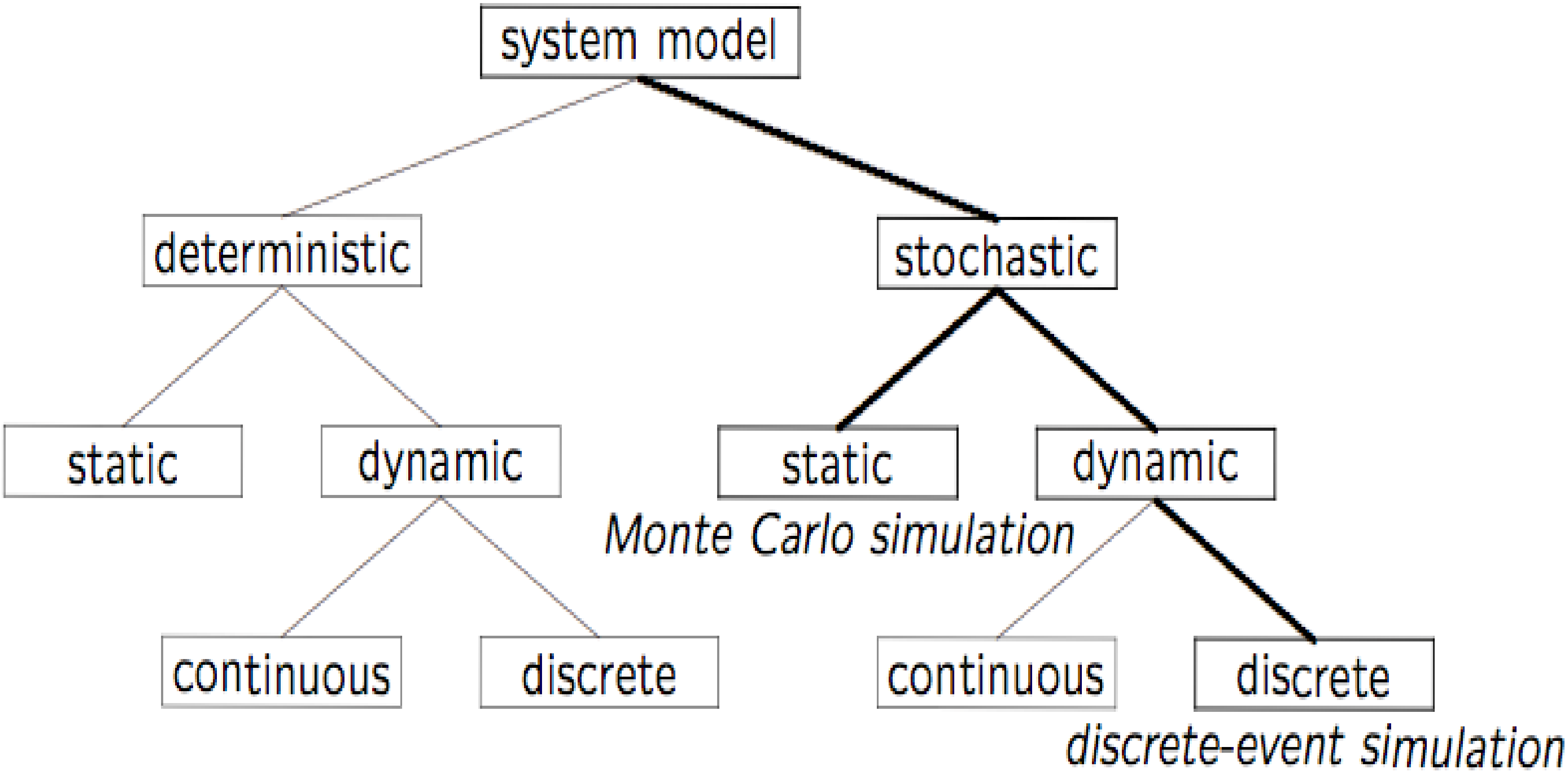
Recap: Performance Evaluation



Simulation Model Taxonomy (preview)



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Terminology (1 of 2)

- A *system* is defined as a group of objects that interact with each other to accomplish some purpose
  - A computer system: CPU, memory, disk, bus, NIC
  - An automobile factory: Machines, components parts and workers operate jointly along assembly line
- A system is often affected by changes occurring outside the system: system environment
  - Hair salon: arrival of customers
  - Warehouse: arrival of shipments, fulfilling of orders
    - Effect of supply on demand: relationship between factory output from supplier and consumption by customers

Terminology (2 of 2)

- Entity
  - An object of interest in the system: Machines in factory
- Attribute
  - The property of an entity: speed, capacity, failure rate
- State
  - A collection of variables that describe the system in any time: status of machine (busy, idle, down,…)
- Event
  - An instantaneous occurrence that might change the state of the system: breakdown

- Develop a simulation program that implements a computational model of the system of interest
- Run the simulation program and use the data collected to estimate the performance measures of interest (often involves the use of randomization)
- A system can be studied at an arbitrary level of detail

- Quote of the day:

  "The hardest part about simulation is deciding what NOT to model."

  - Moe Lavigne, Stentor, Summer 1995

Advantages of Simulation

- New policies and procedures can be explored without disrupting the ongoing operation of the real system
- New designs can be tested without committing resources for their acquisition
- Time can be compressed or expanded to allow for a speed-up or slow-down of the phenomenon under study
- Insight can be obtained about the interactions of variables, and which ones have the most impact on system performance
- Can obtain answers to “What if…” questions

Disadvantages of Simulation

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- Model building requires special training
  - An important role for courses like CPSC 531!!
  - Vendors of simulation software have been actively developing packages that contain models that only need input (templates), which simplifies things for users
- Simulation results can be difficult to interpret
  - Need proper statistical interpretation for output analysis
- Simulation modeling and analysis can be time-consuming and expensive, both for the modeler, as well as in compute time (if not done judiciously)

When Simulation Is Not Appropriate

- When the problem can be solved by common sense
- When the problem can be solved analytically
- When it is easier to perform direct experiments
- When cost of simulations exceeds (expected) savings for the real system
- When system behavior is too complex (e.g., humans)

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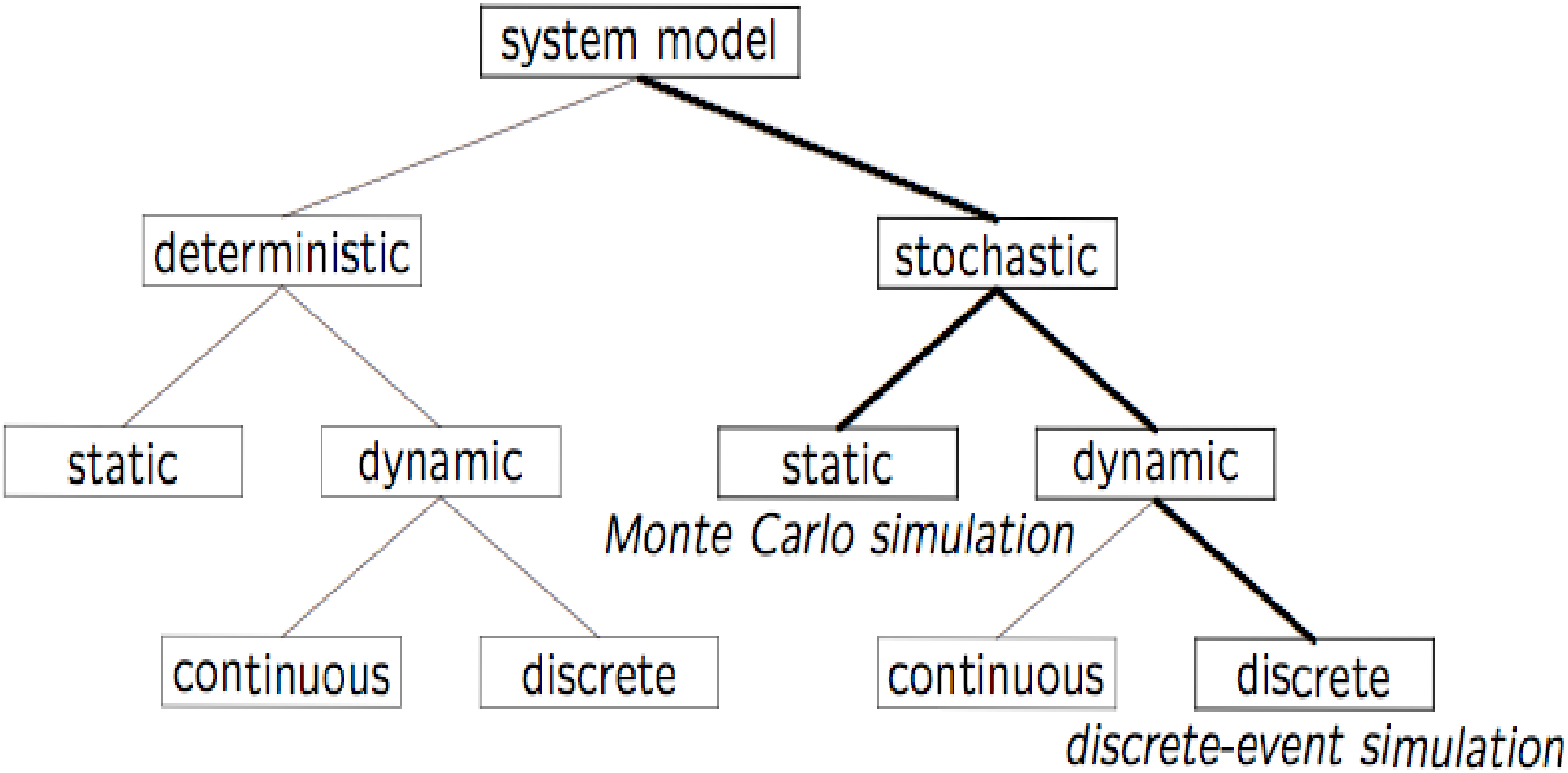
Common Mistakes in Simulation

- Poor (pseudo) random number generators
  - Best to use well-known or well-understood generator
- Improper selection of seeds for PRNG
  - Short periods; same seeds for all streams
- Inappropriate level of detail:
  - More detail → more time → more bugs
  - More parameters ≠ more accurate
- Improperly handled initial conditions (warmup)
- Improperly handled ending conditions (cooldown)
- Run-length too short to achieve steady-state
  - Need proper output analysis, confidence intervals

Types of Simulations

- Monte Carlo simulation
- Time-stepped simulation
- Trace-driven simulation
- Discrete-event simulation
- Continuous simulation

Simulation Model Taxonomy



Simulation Examples

- Monte Carlo simulation (see Assignment 1)
  - Estimating π
  - Craps (dice game)
- Time-stepped simulation
  - Mortgage scenarios
- Trace-driven simulation (see Assignment 2)
  - Single-server queue (ssq1.c)
- Discrete-event simulation (see Assignments 3 and 4)
  - Witchcraft hair salon

Monte Carlo Simulation

Named after Count Montgomery de Carlo, who was a famous Italian gambler and random-number generator (1792-1838).

- Static simulation (no time dependency)
- To model probabilistic phenomenon
- Can be used for evaluating non-probabilistic expressions using probabilistic methods
- Can be used for estimating quantities that are "hard" to determine analytically or experimentally

Trace-Driven Simulation

- Trace = time-ordered record of events in system
- Trace-driven simulation = Trace input
- Often used in evaluating or tuning resource management algorithms (based on real workloads):
  - Paging, cache analysis, CPU scheduling, deadlock prevention, dynamic storage allocation
- Example: Trace = start time + duration of processes
- Example: Trace = size in bytes of file written to disk
- Example: Trace = mobile device ID and call duration

Advantages of Trace-Driven Simulations

- Credibility
- Easy validation: compare simulation with measurement
- Accurate workload: models correlation and interference
- Fair comparison: better than random input
- Similarity to the actual implementation:
  - trace-driven model is similar to the system
  - can understand complexity of implementation

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Disadvantages of Trace-Driven Simulations

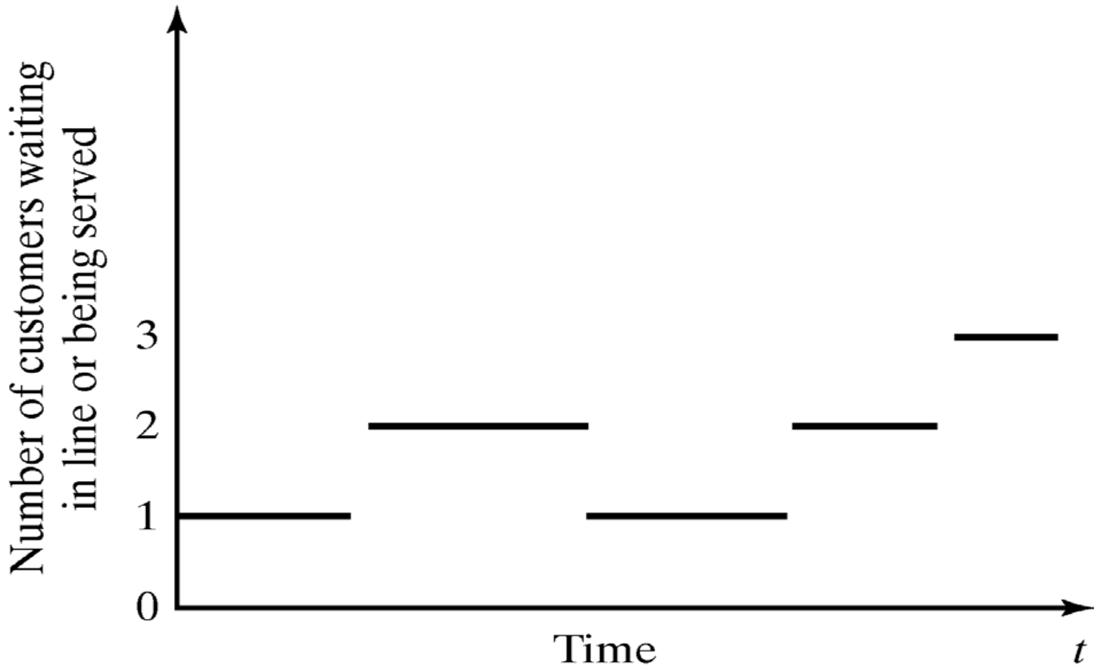
- Complexity: more detailed
- Representativeness: workload changes with time, equipment
- Data Collection: few minutes fill up a disk
- Instrumentation: granularity; intrusiveness
- Single Point of Validation: one trace = one point
- Difficult to change workload

Discrete-Event Simulation

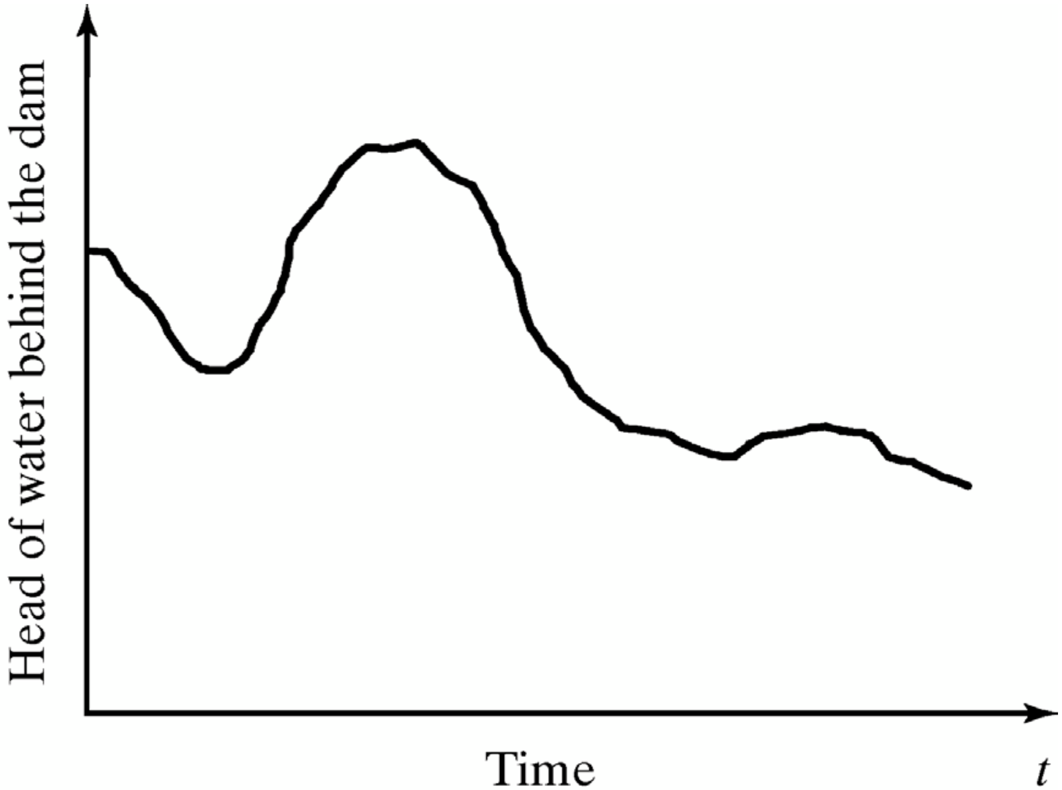
- A simulation model with three features:
    1. Stochastic:
       some variables in the simulation model are random
    2. Dynamic:
       system state evolves over time
    3. Discrete-Event:
       changes in system state occur at discrete time instances

Discrete and Continuous Systems

- A discrete system is one in which the system state changes only at a discrete set of points in time
  - Example: A restaurant

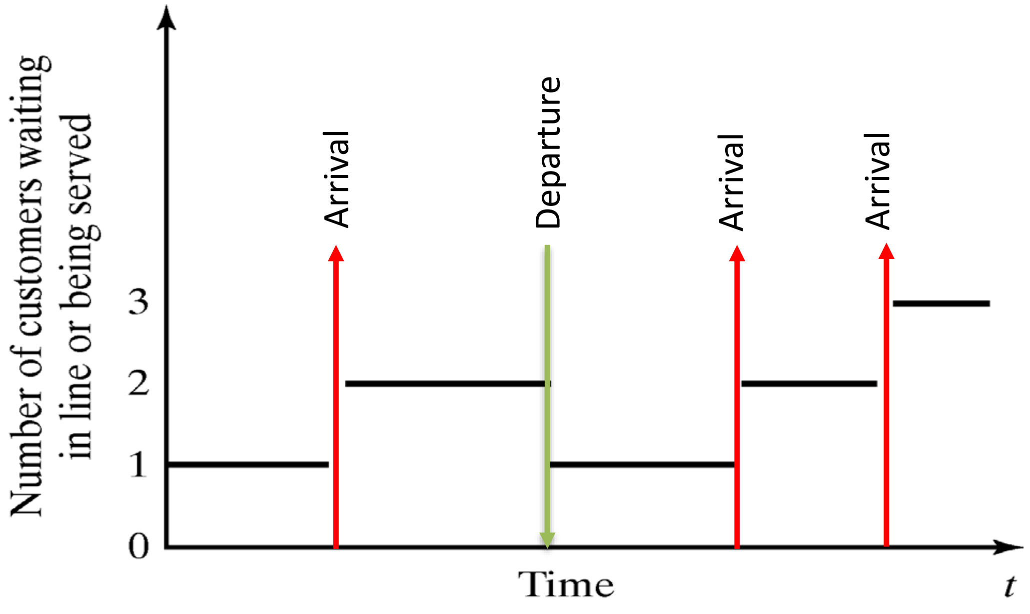


- A continuous system is one in which the system state changes continuously over time
  - Example: Water level in Bow River (or Bearspaw dam)



Discrete-Event Simulation

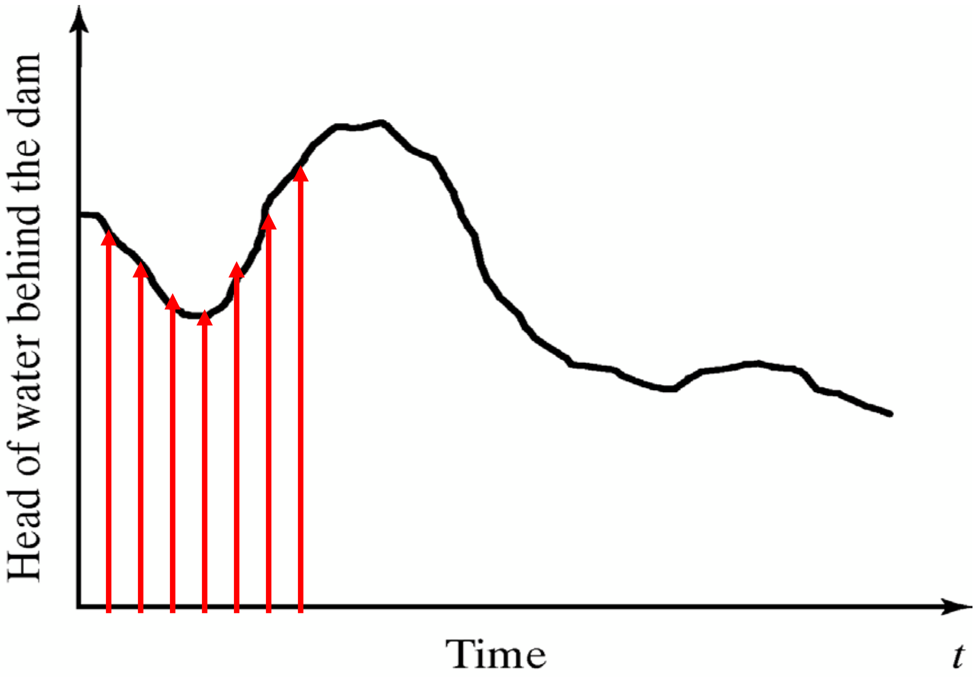
- A simulation model in which system state evolves over a discrete sequence of events in time
  - System state changes only when an event occurs
  - System state does not change between the events



Restaurant Example

Continuous Simulation

- A simulation model in which system state evolves continuously over time
  - Time is divided to small time slices
  - System state changes in every time slice

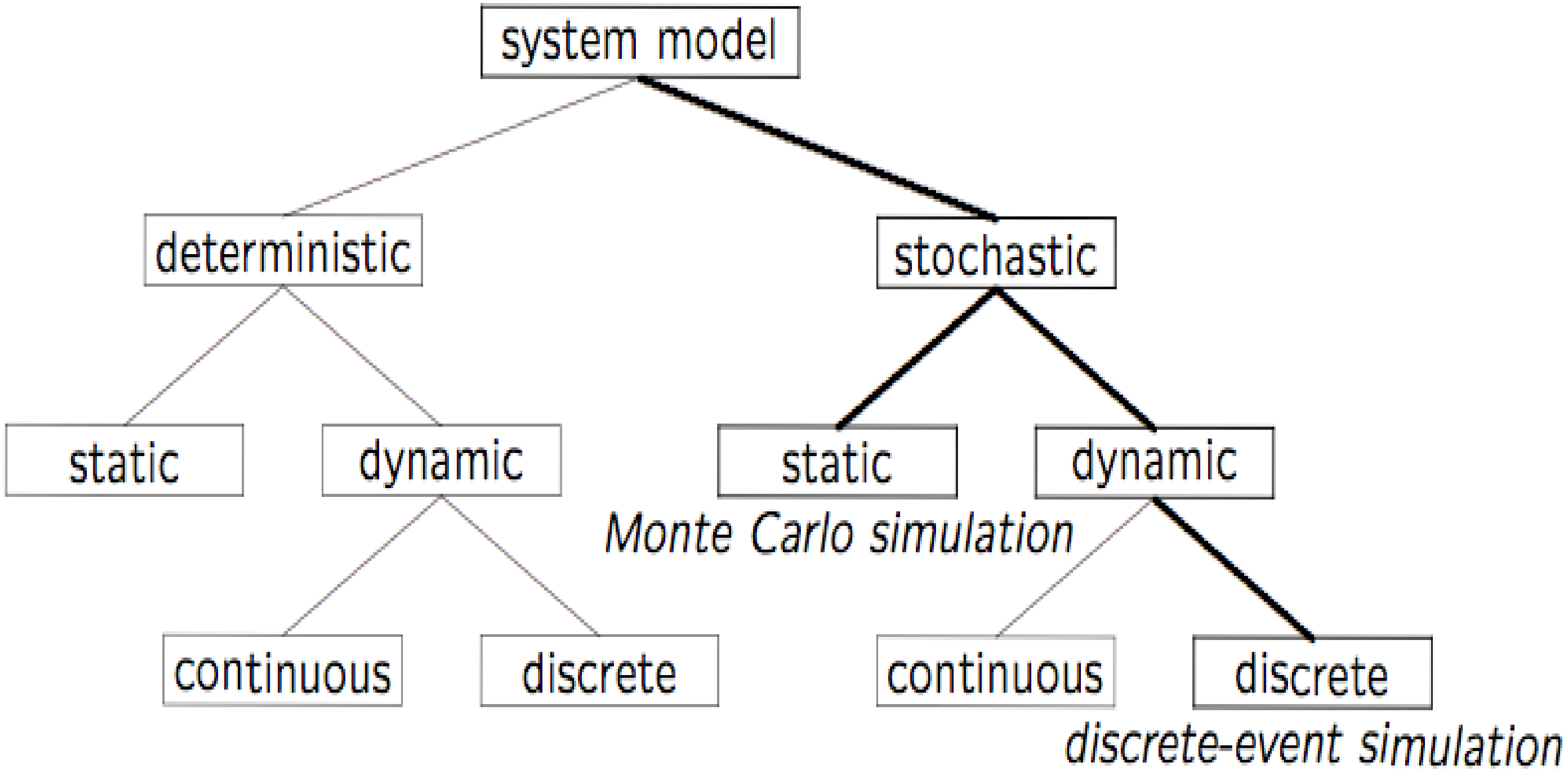


Dam Example

Characterizing a Simulation Model

- Deterministic or Stochastic
  - Does the model contain stochastic components?
- Static or Dynamic
  - Is time a significant variable?
- Continuous or Discrete
  - Does the system state evolve continuously or only at discrete points in time?

Simulation Model Taxonomy



DES Model Development

- How to develop a simulation 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 the model
  6. Validate the model
- Typically an iterative process

Three Model Levels

- Conceptual Model
  - Very high level (perhaps schematic diagram)
  - How comprehensive should the model be?
  - What are the state variables?
  - Which ones are dynamic, and which are most important?
- Specification Model
  - On paper: entitites, interactions, requirements, rules, etc.
  - May involve equations, pseudocode, etc.
  - How will the model receive input?
- Computational Model
  - A computer program
  - General-purpose programming language or simulation language?

Simulation Software

- General purpose programming languages
  - Flexible and familiar
  - Well suited for learning DES principles and techniques
  - E.g., C++, Java
- Simulation programming languages
  - Good for building models quickly
  - Provide built-in features (e.g., queue structures)
  - Graphics and animation provided
  - Domain specific
    - Network protocol simulation: ns2, Opnet
    - Electrical power simulation: ETAP
    - Design and engineering: Ansys, Autodesk
    - Process simulation: Simul8

Verification and 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?