Introduction to Simulation

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- Simulation: Key Questions
- Introduction to Simulation
- Common Mistakes in Simulation
- Other Causes of Simulation Analysis Failure
- Checklist for Simulations
- Terminology
- Types of Models

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Simulation: Key Questions

- What are the common mistakes in simulation and why most simulations fail?
- What language should be used for developing a simulation model?
- What are different types of simulations?
- How to schedule events in a simulation?
- How to verify and validate a model?
- How to determine that the simulation has reached a steady state?
- How long to run a simulation?

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Simulation: Key Questions (Cont)

- How to generate uniform random numbers?
- How to verify that a given random number generator is good?
- How to select seeds for random number generators?
- How to generate random variables with a given distribution?
- What distributions should be used and when?

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Common Mistakes in Simulation

1. Inappropriate Level of Detail:
   More detail $\Rightarrow$ More time $\Rightarrow$ More Bugs $\Rightarrow$ More CPU $\Rightarrow$ More parameters $\neq$ More accurate
2. Improper Language
   General purpose $\Rightarrow$ More portable, More efficient, More time
3. Unverified Models: Bugs
4. Invalid Models: Model vs. reality
5. Improperly Handled Initial Conditions
6. Too Short Simulations: Need confidence intervals
7. Poor Random Number Generators: Safer to use a well-known generator
8. Improper Selection of Seeds: Zero seeds, Same seeds for all streams

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Terminology

- **State Variables**: Define the state of the system
  Can restart simulation from state variables
  E.g., length of the job queue.
- **Event**: Change in the system state.
  E.g., arrival, beginning of a new execution, departure

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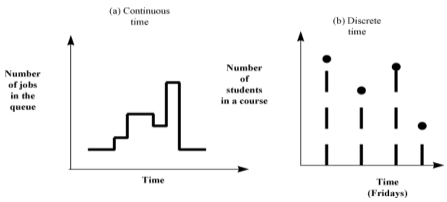
Types of Models

- **Continuous Time Model**: State is defined at all times
- **Discrete Time Models**: State is defined only at some instants



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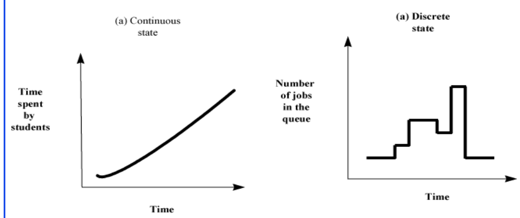
Types of Models (Cont)

- **Continuous State Model**: State variables are continuous
- **Discrete State Models**: State variables are discrete



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Types of Models (Cont)

- Discrete state = Discrete event model
- Continuous state = Continuous event model
- Continuity of time ≠ Continuity of state

- Four possible combinations:

1. discrete state/discrete time
2. discrete state/continuous time
3. continuous state/discrete time
4. continuous state/continuous time models

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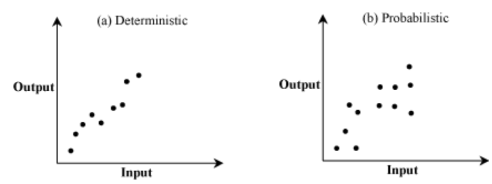
Types of Models (Cont)

- **Deterministic and Probabilistic Models**:



- **Static and Dynamic Models**:

CPU scheduling model vs. $E = mc^2$.

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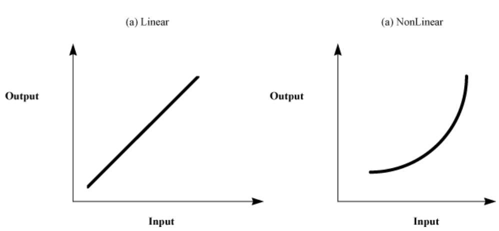
Linear and Nonlinear Models

- Output = fn(Input)



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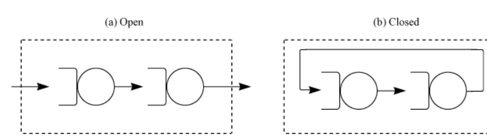
Open and Closed Models

- External input ⇒open



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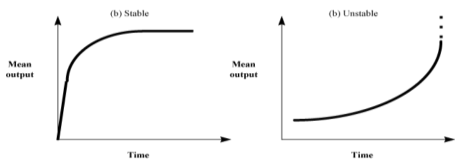
Stable and Unstable Models

- Stable ⇒Settles to steady state
- Unstable ⇒Continuously changing.



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Computer System Models

- Continuous time
- Discrete state
- Probabilistic
- Dynamic
- Nonlinear
- Open or closed
- Stable or unstable

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Selecting a Language for Simulation

1. Simulation language
2. General purpose
3. Extension of a general purpose language
4. Simulation package

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Simulation Languages

- Save development time
- Built-in facilities for time advancing, event scheduling, entity manipulation, random variate generation, statistical data collection, and report generation
- More time for system specific issues
- Very readable modular code

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General Purpose Language

- Analyst's familiarity
- Easy availability
- Quick startup
- Time for routines for event handling, random number generation
- Other Issues: Efficiency, flexibility, and portability
- Recommendation: Learn at least one simulation language.

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Extensions of a General Purpose Language

- Examples: GASP (for FORTRAN)
  - Collection of routines to handle simulation tasks
  - Compromise for efficiency, flexibility, and portability.

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Simulation Packages

Example: QNET4, and RESQ

- Input dialog
- Library of data structures, routines, and algorithms
- Big time savings
- Inflexible ⇒Simplification

Types of Simulation Languages

- **Continuous Simulation Languages**:
  - CSMP, DYNAMO
  - Differential equations
  - Used in chemical engineering
- **Discrete-event Simulation Languages**:
  - SIMULA and GPSS
- **Combined**:
  - SIMSCRIPT and GASP.
  - Allow discrete, continuous, as well as combined simulations.

Types of Simulations

1. Emulation: Using hardware or firmware
   E.g., Terminal emulator, processor emulator
   Mostly hardware design issues
2. Monte Carlo Simulation
3. Trace-Driven Simulation
4. Discrete Event Simulation

Types of Simulation (Cont)

Monte Carlo method *[Origin: after Count Montgomery de Carlo, Italian gambler and random-number generator (1792-1838).] A method of jazzing up the action in certain statistical and number-analytic environments by setting up a book and inviting bets on the outcome of a computation.*

- The Devil's DP Dictionary
McGraw Hill (1981)

Monte Carlo Simulation

- Static simulation (No time axis)
- To model probabilistic phenomenon
- Need pseudorandom numbers
- Used for evaluating non-probabilistic expressions using probabilistic methods.

Monte Carlo: Example

$$I = \int_0^2 e^{-x^2} dx$$

$$x \sim \text{Uniform}(0, 2)$$

Density function $f(x) = \frac{1}{2}$ iff 0 · x ·2

$$y = 2e^{-x^2}$$

Monte Carlo: Example (Cont)

$$\begin{aligned} E(y) &= \int_0^2 2e^{-x^2} f(x)dx \\ &= \int_0^2 2e^{-x^2} \frac{1}{2} dx \\ &= \int_0^2 e^{-x^2} dx \\ &= I \end{aligned}$$

$$x_i \sim \text{Uniform}(0, 2)$$

$$y_i = 2e^{-x_i^2}$$

$$I = E(y) = \frac{1}{n}\sum_{i=1}^{n} y_i$$

Trace-Driven Simulation

- Trace = Time ordered record of events on a system
- Trace-driven simulation = Trace input
- Used in analyzing or tuning resource management algorithms
  Paging, cache analysis, CPU scheduling, deadlock prevention
  dynamic storage allocation
- **Example**: Trace = Page reference patterns
- Should be independent of the system under study
  E.g., trace of pages fetched depends upon the working set size and page replacement policy
  - Not good for studying other page replacement policies
  - Better to use pages referenced

Advantages of Trace-Driven Simulations

1. Credibility
2. Easy Validation: Compare simulation with measured
3. Accurate Workload: Models correlation and interference
4. Detailed Trade-Offs:
   Detailed workload ⇒Can study small changes in algorithms
5. Less Randomness:
   Trace ⇒deterministic input ⇒Fewer repetitions
6. Fair Comparison: Better than random input
7. Similarity to the Actual Implementation:
   Trace-driven model is similar to the system

⇒ Can understand complexity of implementation

Disadvantages of Trace-Driven Simulations

1. Complexity: More detailed
2. Representativeness: Workload changes with time, equipment
3. Finiteness: Few minutes fill up a disk
4. Single Point of Validation: One trace = one point
5. Detail
6. Trade-Off: Difficult to change workload

Discrete Event Simulations

- Concentration of a chemical substance
  ⇒Continuous event simulations
- Number of jobs ⇒Discrete event
- Discrete state ≠ discrete time

Components of Discrete Event Simulations

1. Event Scheduler
   (a) Schedule event X at time T.
   (b) Hold event X for a time interval dt.
   (c) Cancel a previously scheduled event X.
   (d) Hold event X indefinitely
   (e) Schedule an indefinitely held event.

2. Simulation Clock and a Time Advancing Mechanism
   (a) Unit-time approach
   (b) Event-driven approach

Components of Discrete Events Sims (Cont)

3. System State Variables
   Global = Number of jobs
   Local = CPU time required for a job
4. Event Routines: One per event.
   E.g., job arrivals, job scheduling, and job departure
5. Input Routines: Get model parameters Very parameters in a range.
6. Report Generator
7. Initialization Routines: Set the initial state. Initialize seeds.
8. Trace Routines: On/off feature
9. Dynamic Memory Management: Garbage collection
10. Main Program

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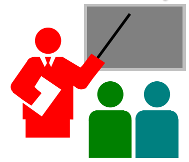
Summary



1. Common Mistakes: Detail, Invalid, Short
2. Discrete Event, Continuous time, nonlinear models
3. Monte Carlo Simulation: Static models
4. Trace driven simulation: Credibility, difficult trade-offs

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