Introduction to Simulation

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Audio/Video recordings of this lecture are available at:

http://www.cse.wustl.edu/~jain/cse567-17/

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

Introduction to Simulation

The best advice to those about to embark on a very large simulation is often the same as Punch's famous advice to those about to marry: Don't!

-Bratley, Fox, and Schrage (1986)

Common Mistakes in Simulation

1. Inappropriate Level of Detail:
   More detail ⇒ More time ⇒ More Bugs ⇒ More CPU ⇒ More parameters ≠ More accurate
2. Improper Language
   General purpose ⇒ 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

Other Causes of Simulation Analysis Failure

1. Inadequate Time Estimate
2. No Achievable Goal
3. Incomplete Mix of Essential Skills
   (a) Project Leadership
   (b) Modeling and
   (c) Programming
   (d) Knowledge of the Modeled System
4. Inadequate Level of User Participation
5. Obsolete or Nonexistent Documentation
6. Inability to Manage the Development of a Large Complex Computer Program Need software engineering tools
7. Mysterious Results

Checklist for Simulations

1. Checks before developing a simulation:
   (a) Is the goal of the simulation properly specified?
   (b) Is the level of detail in the model appropriate for the goal?
   (c) Does the simulation team include personnel with project leadership, modeling, programming, and computer systems backgrounds?
   (d) Has sufficient time been planned for the project?
2. Checks during development:
   (a) Has the random number generator used in the simulation been tested for uniformity and independence?
   (b) Is the model reviewed regularly with the end user?
   (c) Is the model documented?

Checklist for Simulations (Cont)

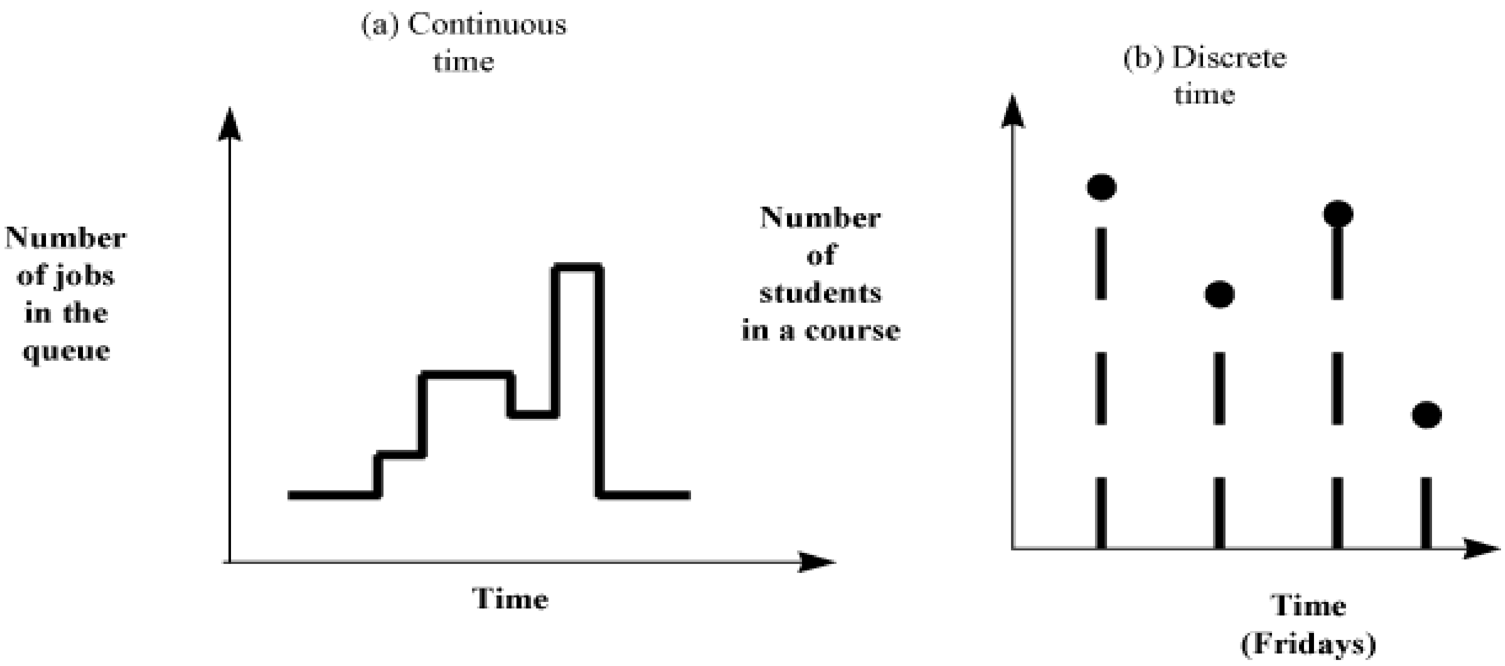
3. Checks after the simulation is running:
   (a) Is the simulation length appropriate?
   (b) Are the initial transients removed before computation?
   (c) Has the model been verified thoroughly?
   (d) Has the model been validated before using its results?
   (e) If there are any surprising results, have they been validated?
   (f) Are all seeds such that the random number streams will not overlap?

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

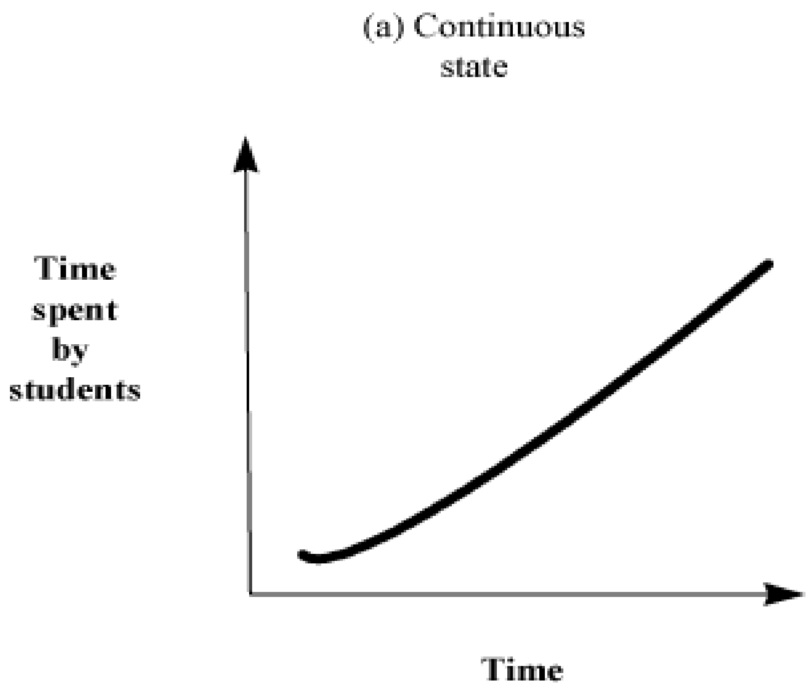
Types of Models

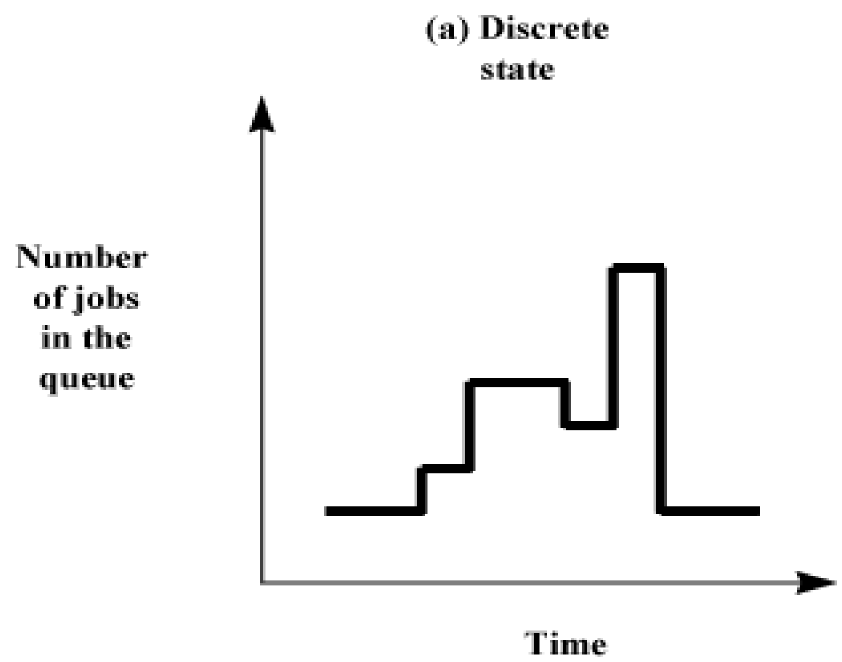
- **Continuous Time Model**: State is defined at all times
- **Discrete Time Models**: State is defined only at some instants



Types of Models (Cont)

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





Types of Models (Cont)

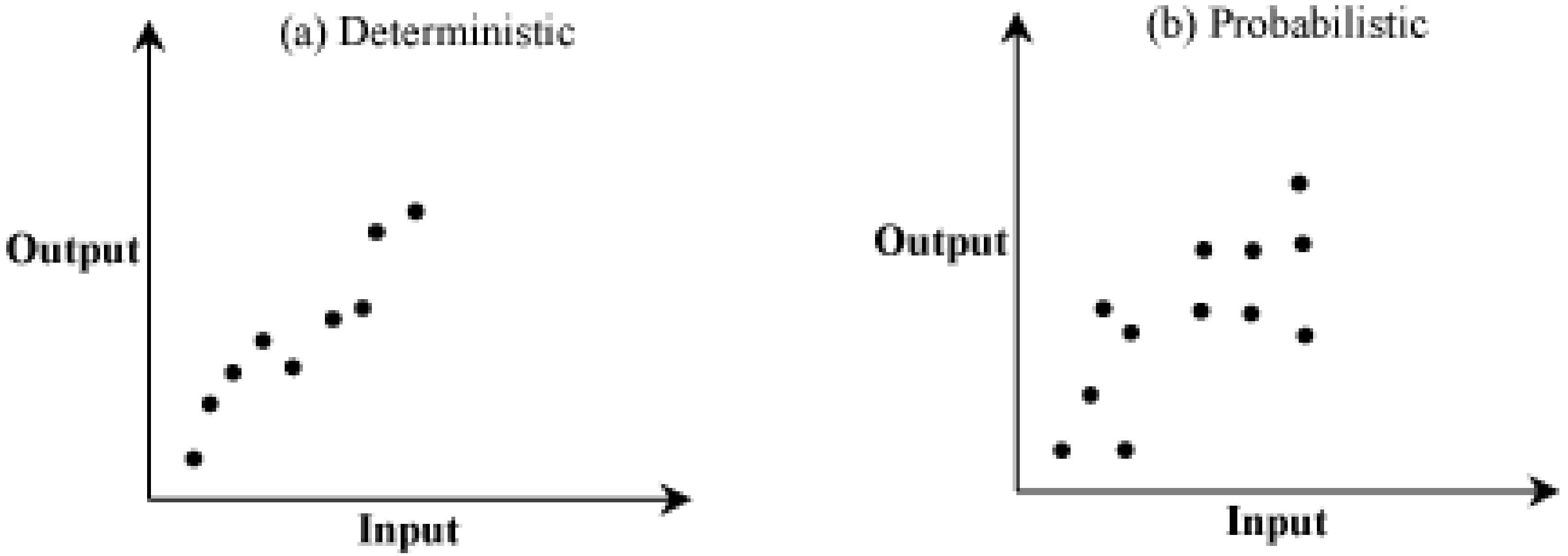
- Discrete state = Discrete event model
- Continuous state = Continuous event model
- Continuity of time ≠ Continuity of state

- Four possible combinations:

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

Types of Models (Cont)

- **Deterministic and Probabilistic Models**:

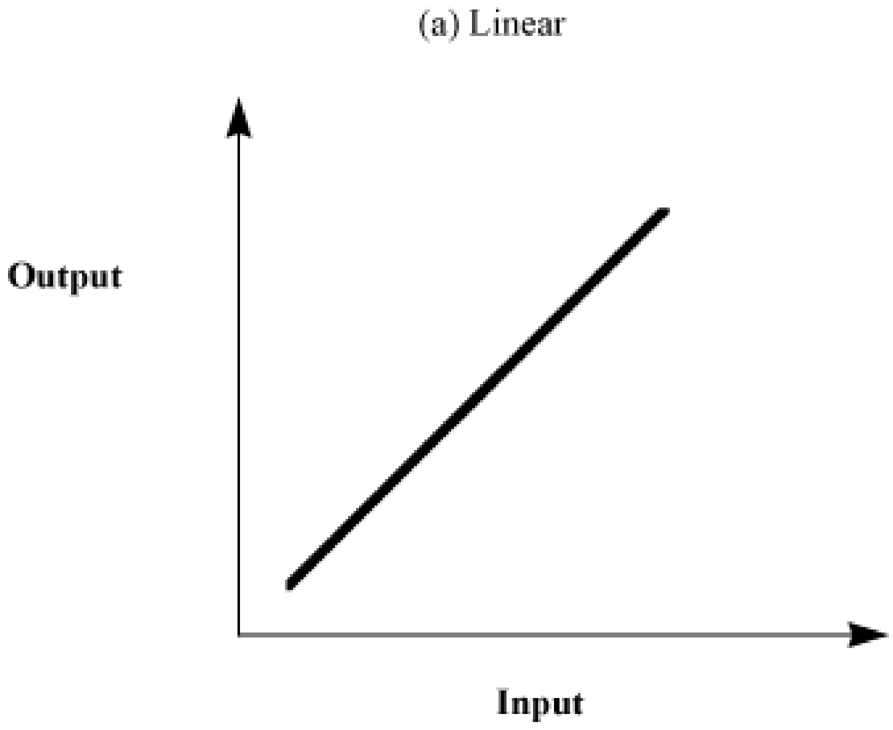


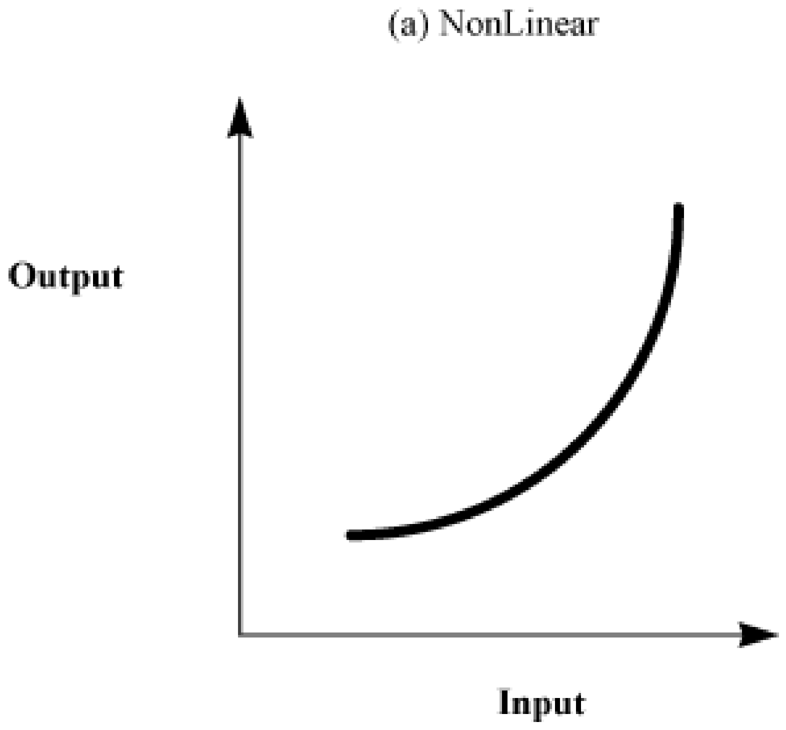
- **Static and Dynamic Models**:

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

Linear and Nonlinear Models

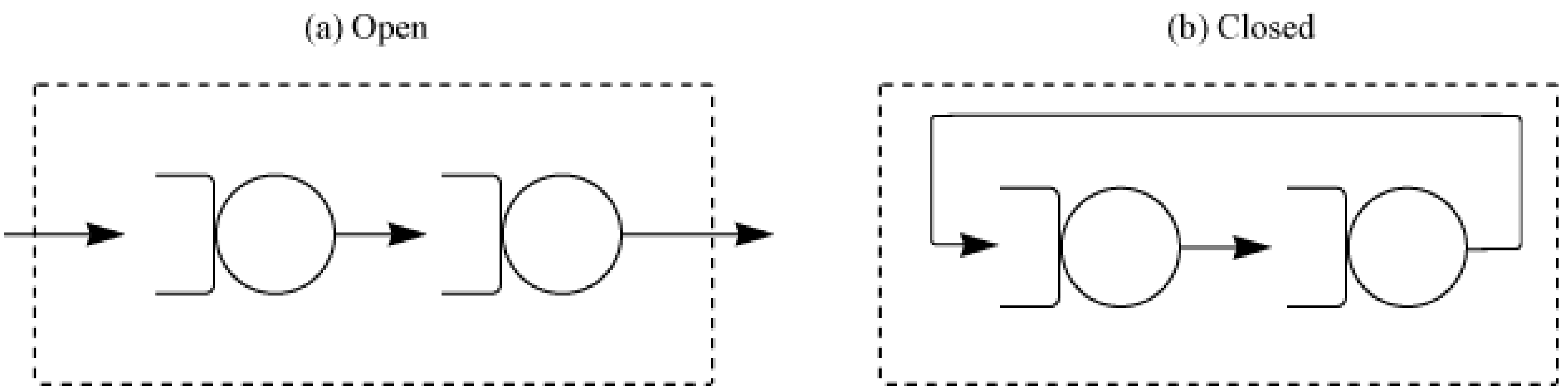
- Output = fn(Input)





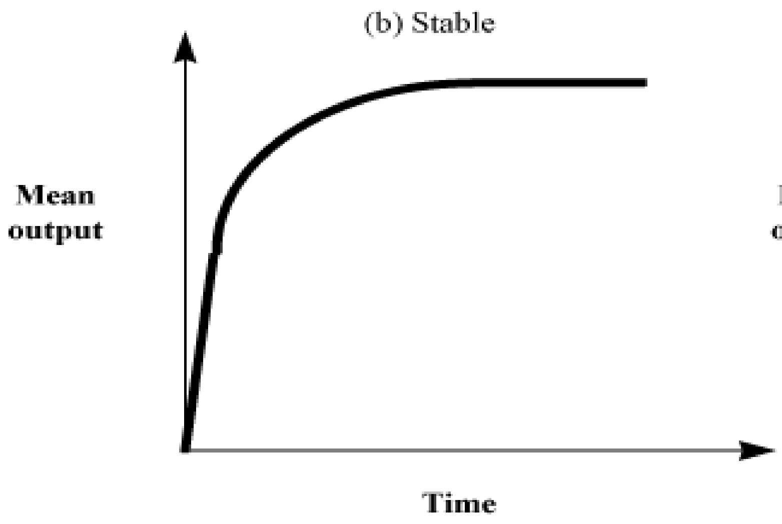
Open and Closed Models

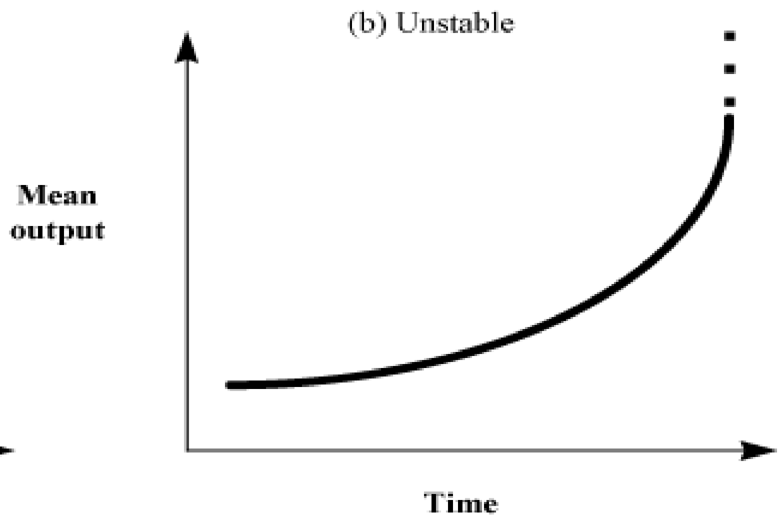
- External input ⇒ open



Stable and Unstable Models

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





Computer System Models

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

Homework 24

For each of the following models, identify all classifications that apply to it:

1. $\bar{y}(t+1) = \bar{y}(t) + a$
2. $y(t+1) = y(t) + 3$
3. $y(t) = t^{1.5}$
4. $y(t) = a + bt + ct^2$
5. $n(t+1) = 3n(t) + 5$
6. $y(t) = cos(wt + \psi)$

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 $0 \leq x \leq 2$

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

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

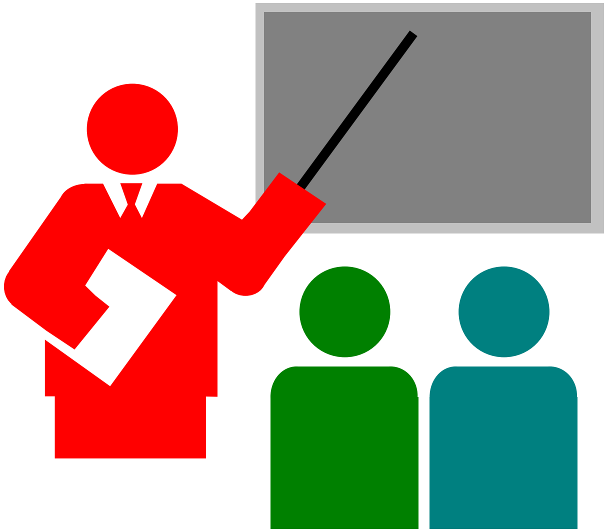
Disadvantages of Trace-Driven Simulations

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
  $\Rightarrow$ **C**ontinuous event simulations
- Number of jobs $\Rightarrow$ Discrete event
- Discrete state $\neq$ discrete time

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
5. Even Set Algorithms: Linked list, indexed linear list, heaps

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CSE567M: Computer Systems Analysis (Spring 2013),
https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof

CSE473S: Introduction to Computer Networks (Fall 2011),
https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcgy5e_10TiDw

Wireless and Mobile Networking (Spring 2016),
https://www.youtube.com/playlist?list=PLjGG94etKypKeb0nzyN9tSs_HCd5c4wXF

CSE571S: Network Security (Fall 2011),
https://www.youtube.com/playlist?list=PLjGG94etKypKvzfVtutHcPFJXumyyg93u

Video Podcasts of Prof. Raj Jain's Lectures,
https://www.youtube.com/channel/UCN4-5wzNP9-ruOzQMs-8NUw