CSE 567M
Computer Systems Analysis

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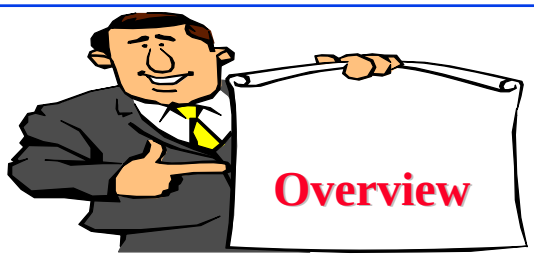
These slides are available on-line at:

http://www.cse.wustl.edu/~jain/cse567-08/



- Goal of this Course
- Contents of the course
- Tentative Schedule
- Project
- Grading

Goal of This Course

- Comprehensive course on performance analysis
- Includes measurement, statistical modeling, experimental design, simulation, and queuing theory
- How to avoid common mistakes in performance analysis
- Graduate course: (Advanced Topics)
  $\Rightarrow$ Lot of independent reading and writing
  $\Rightarrow$ Project/Survey paper (Research techniques)

Text Book

- R. Jain, "Art of Computer Systems Performance Analysis," Wiley, 1991, ISBN:0471503363 (Winner of the "1992 Best Computer Systems Book" Award from Computer Press Association")

Objectives: What You Will Learn

- Specifying performance requirements
- Evaluating design alternatives
- Comparing two or more systems
- Determining the optimal value of a parameter (system tuning)
- Finding the performance bottleneck (bottleneck identification)
- Characterizing the load on the system (workload characterization)
- Determining the number and sizes of components (capacity planning)
- Predicting the performance at future loads (forecasting).

Basic Terms

- **System:** Any collection of hardware, software, and firmware
- **Metrics:** Criteria used to evaluate the performance of the system. components.
- **Workloads:** The requests made by the users of the system.

Main Parts of the Course

- Part I: An Overview of Performance Evaluation
- Part II: Measurement Techniques and Tools
- Part III: Probability Theory and Statistics
- Part IV: Experimental Design and Analysis
- Part V: Simulation
- Part VI: Queueing Theory

Part I: An Overview of Performance Evaluation

- Introduction
- Common Mistakes and How To Avoid Them
- Selection of Techniques and Metrics

Example I

- What performance metrics should be used to compare the performance of the following systems:
  - Two disk drives?
  - Two transaction-processing systems?
  - Two packet-retransmission algorithms?

Part II: Measurement Techniques and Tools

- Types of Workloads
- Popular Benchmarks
- The Art of Workload Selection
- Workload Characterization Techniques
- Monitors
- Accounting Logs
- Monitoring Distributed Systems
- Load Drivers
- Capacity Planning
- The Art of Data Presentation
- Ratio Games

Example II

- Which type of monitor (software or hardware) would be more suitable for measuring each of the following quantities:
  - Number of Instructions executed by a processor?
  - Degree of multiprogramming on a timesharing system?
  - Response time of packets on a network?

Part III: Probability Theory and Statistics

- Probability and Statistics Concepts
- Four Important Distributions
- Summarizing Measured Data By a Single Number
- Summarizing The Variability Of Measured Data
- Graphical Methods to Determine Distributions of Measured Data
- Sample Statistics
- Confidence Interval
- Comparing Two Alternatives
- Measures of Relationship
- Simple Linear Regression Models
- Multiple Linear Regression Models
- Other Regression Models

Example III

- The number of packets lost on two links was measured for four file sizes as shown below:

File Size	Link A	Link B
1000	5	10
1200	7	3
1300	3	0
50	0	1

Which link is better?

Part IV: Experimental Design and Analysis

- Introduction to Experimental Design
- 2^k Factorial Designs
- $2^k r$ Factorial Designs with Replications
- 2^{k-p} Fractional Factorial Designs
- One Factor Experiments
- Two Factors Full Factorial Design without Replications
- Two Factors Full Factorial Design with Replications
- General Full Factorial Designs With *k* Factors

Example IV

- The performance of a system depends on the following three factors:
  - Garbage collection technique used: G1, G2, or none.
  - Type of workload: editing, computing, or AI.
  - Type of CPU: C1, C2, or C3.

How many experiments are needed? How does one estimate the performance impact of each factor?

Part V: Simulation

- Introduction to Simulation
- Types of Simulations
- Model Verification and Validation
- Analysis of Simulation Results
- Random-Number Generation
- Testing Random-Number Generators
- Random-Variate Generation
- Commonly Used Distributions

Example V

- In order to compare the performance of two cache replacement algorithms:
  - What type of simulation model should be used?
  - How long should the simulation be run?
  - What can be done to get the same accuracy with a shorter run?
  - How can one decide if the random-number generator in the simulation is a good generator?

Part VI: Queueing Theory

- Introduction to Queueing Theory
- Analysis of A Single Queue
- Queueing Networks
- Operational Laws
- Mean Value Analysis and Related Techniques
- Convolution Algorithm
- Advanced Techniques

Example VI

- The average response time of a database system is three seconds. During a one-minute observation interval, the idle time on the system was ten seconds.

Using a queueing model for the system, determine the following:

- System utilization
- Average service time per query
- Number of queries completed during the observation interval
- Average number of jobs in the system
- Probability of number of jobs in the system being greater than 10
- 90-percentile response time
- 90-percentile waiting time

The Art of Performance Evaluation

- Given the same data, two analysts may interpret them differently.

Example:

- The throughputs of two systems A and B in transactions per second is as follows:

System	Workload 1	Workload 2
A	20	10
B	10	20

Possible Solutions

- Compare the average:

System	Workload 1	Workload 2	Average
A	20	10	15
B	10	20	15

Conclusion: The two systems are equally good.

- Compare the ratio with system B as the base

System	Workload 1	Workload 2	Average
A	2	0.5	1.25
B	1	1	1

Conclusion: System A is better than B.

Solutions (Cont)

- Compare the ratio with system A as the base

System	Workload 1	Workload 2	Average
A	1	1	1
B	0.5	2	1.25

Conclusion: System B is better than A.

- Similar games in: Selection of workload, Measuring the systems, Presenting the results.
- Common mistakes will also be discussed.

Grading

- Exams (Best of 2 mid terms + Final) 60%
- Class participation 5%
- Homeworks 15%
- Project 20%

Prerequisites

- CSE 131: Computer Science I
- CSE 126: Introduction To Computer Programming
- CSE 260M: ~~Introduction To Digital Logic And Computer Design~~ (Not required)
- Basic Probability and Statistics

Prerequisite

- Statistics:
  - Mean, variance
  - Normal distribution
  - Density function, Distribution function
  - Coefficient of variation
    Correlation coefficient
  - Median, mode, Quantile
- C Programming

Tentative Schedule

- 8/27 Course Introduction
- 9/1 Memorial Day Holiday - No class
- 9/3 Common Mistakes Chapter 2
- 9/08 Selection of Techniques and Metrics Chapter 3
  - ✓ Types of Workloads Chapter 4
  - ✓ Workload Selection Chapter 5
- 9/10 Workload Characterization Chapter 6
- 9/15 Data Presentation Chapter 10
  - ✓ Ratio Games Chapter 11
- 9/17 Summarizing Measured Data Chapter 12
- 9/22 Comparing Systems Using Random Data Chapter 13
- 9/24 Comparing Systems Using Random Data (Cont)
- 9/29 **Mid-Term Exam 1**

Tentative Schedule (Cont)

- 10/1 Simple Linear Regression Models Chapter 14
- 10/6 Other Regression Models Chapter 15
- 10/08 Experimental Designs Chapter 16
  - ✓ 2k Experimental Designs Chapter 17
- 10/13 Factorial Designs with Replication Chapter 18
- 10/15 Fractional Factorial Designs Chapter 19
- 10/20 One Factor Experiments Chapter 20
  - ✓ Two Factor Full Factorial Design w/o Replications Chapter 21
- 10/22 Two Factor Full Factorial Designs with Replications Chapter 22
  - ✓ General Full Factorial Designs Chapter 23
- 10/27 Introduction to Simulation Chapter 24
- 10/29 Introduction to Simulation (Continued) Chapter 24
- 11/3 **Mid-Term Exam 2**

Tentative Schedule (Cont)

- 11/5 Analysis of Simulation Results Chapter 25
- 11/10 Random Number Generation Chapter 26
- 11/12 Testing Random Number Generators Chapter 27
  Random Variate Generation Chapter 28
- 11/17 Introduction to Queueing Theory Chapter 30
  Analysis of Single Queue Chapter 31
- 11/19 Queueing Networks Chapter 32
  - ✓ Operational Laws Chapter 33
- 11/24 Operational Laws (Cont)
- 11/26 Mean-Value Analysis Chapter 34
- 12/1 Convolution Algorithm Chapter 35
- 12/03 TBD
- 12/8 **Final Exam**
- 12/10 **Class Meeting: Final Grades**

Projects

- A survey paper on a performance topic
  - Workloads/Metrics/Analysis: Databases, Networks, Computer Systems, Web Servers, Graphics, Sensors, Distributed Systems
  - Comparison of Measurement, Modeling, Simulation, Analysis Tools: NS2
  - Comprehensive Survey: Technical Papers, Industry Standards, Products
- A real case study on performance of a system you are already working on
- Average 6 Hrs/week/person on project + 9 Hrs/week/person on class
- Recent Developments: Last 5 to 10 years ⇒ Not in books
- Better ones may be submitted to magazines or journals

Example of Previous Case Studies

- Measure the performance of a remote procedure call mechanism used in a distributed system.
- Measure and compare the performance of window systems of two artificial intelligence systems.
- Simulate and compare the performance of two processor interconnection networks.
- Measure and analyze the performance of two microprocessors.
- Characterize the workload of a campus timesharing system.
- Compute the effects of various factors and their interactions on the performance of two text-formatting programs.
- Measure and analyze the performance of a distributed information system.

Case Studies (Cont)

- Simulate the communications controllers for an intelligent terminal system.
- Measure and analyze the performance of a computer-aided design tool.
- Measure and identify the factors that affect the performance of an experimental garbage collection algorithm.
- Measure and compare the performance of remote procedure calls and remote pipe calls.
- Analyze the effect of factors that impact the performance of two RISC processor architectures.
- Analyze the performance of a parallel compiler running on a multiprocessor system.

Projects (Cont)

- Develop a software monitor to observe the performance of a large multiprocessor system.
- Analyze the performance of a distributed game program running on a network of artificial intelligence systems.
- Compare the performance of several robot control algorithms.

- **Goal:** Provide an insight (or information) not obvious before the project.
- **Real Problems:** Thesis work, or job
- **Homeworks:** Apply techniques learnt to your system.

Project Schedule

Mon 10/6/06	Topic Selection
Mon 10/20/06	References Due
Mon 10/27/06	Outline Due
Mon 11/10/06	First Draft Due -> Peer reviewed
Mon 11/17/06	Reviews Returned
Mon 11/24/06	Final Report Due

Office Hours

- Monday: 11 AM to 12 noon
  Wednesday: 3:30 PM to 4:30PM
- Office: Bryan 405D
- Grader: Chakchai So-In, cs5@cec.wustl.edu

Frequently Asked Questions

- Yes, I do use "curve". Your grade depends upon the performance of the rest of the class.
- All homeworks are due on the following Monday unless specified otherwise.
- Any late submissions, if allowed, will *always* have a penalty.
- One 8.4x11 sheet allowed in the exam. Book not allowed. Time limited.
- Exams consist of numerical as well as multiple-choice (true-false) questions.
- There is negative grading on incorrect multiple-choice questions. Grade: +1 for correct. -1/(n-1) for incorrect.
- Everyone including the graduating students are graded the same way.

Summary

- Goal: To prepare you for correct analysis and modeling of any system
- There will be a self-reading and writing
- Get ready to work hard

Quiz 0: Prerequisites

True or False?

T F

❑ ❑ The sum of two normal variates is normal.

❑ ❑ The sum of two normal variates with means 4 and 3 has a mean of 12.

❑ ❑ The probability of a fair coin coming up head once and tail once in two throws is 1.

❑ ❑ The density function f(x) approaches 1 as x approaches ∞.

❑ ❑ Given two variables, the variable with higher median also has a higher mean.

❑ ❑ The probability of a fair coin coming up heads twice in a row is 1/4.

❑ ❑ The difference of two normal variates with means 4 and 3 has a mean of 4/3.

❑ ❑ The cumulative distribution function F(x) approaches 1 as x approaches ∞.

❑ ❑ High coefficient of variation implies a low variance and vice versa.

❑ ❑ If x is 0, then after x++, x will be 1.

Marks = Correct Answers _____ - Incorrect Answers _____ = _____