CSE 567M
Computer Systems Analysis

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These slides are available on-line at:

http://www.cse.wustl.edu/~jain/cse567-13/

- 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
- Matrix multiplication and inversion

Prerequisite

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

Tentative Schedule

Date	Topic	Chapter
1/14/2013	Course Introduction	
1/16/2013	Common Mistakes	2
	Selection of Techniques and Metrics	3
1/21/2013	*No Class: Martin Luther King Holiday*	
1/23/2013	Selection of Techniques and Metrics (Continued)	3
	Types of Workloads	4
	Workload Selection	5
1/28/2013	Workload Selection (Cont)	5
	Data Presentation	10
	Ratio Games	11
1/30/2013	Summarizing Measured Data	12
2/4/2013	Summarizing Measured Data (Cont)	12
	Comparing Systems Using Random Data	13
2/6/2013	Comparing Systems Using Random Data (Cont)	13
	Simple Linear Regression Models	14
2/11/2013	Simple Linear Regression Models (Cont)	14
	Other Regression Models	15
2/13/2013	Other Regression Models (Cont)	15
2/18/2013	***Mid-Term Exam 1***	

Tentative Schedule (Cont)

Date	Topic	Chapter
2/20/2013	Other Regression Models (Cont)	15
2/25/2013	Experimental Designs	16
	2k Experimental Designs	17
2/27/2013	Factorial Designs with Replication	18
3/4/2013	Factorial Designs with Replication	18
	Fractional Factorial Designs	19
3/6/2013	One Factor Experiments	20
	Two Factor Full Factorial Design w/o Replications	21
3/11/2013	*WUSTL Spring Break (No Classes)*	
3/13/2013	*WUSTL Spring Break (No Classes)*	
3/18/2013	Two Factor Full Factorial Designs with Replications	22
	General Full Factorial Designs	23
	Introduction to Queueing Theory	30
3/20/2013	Introduction to Queueing Theory (Cont)	30
	Analysis of Single Queue	31
3/25/2013	***Mid-Term Exam 2***	

Tentative Schedule (Cont)

Date	Topic	Chapter
3/27/2013	Queueing Networks	32
4/1/2013	Operational Laws	33
	Mean-Value Analysis	34
4/3/2013	Mean-Value Analysis (Cont)	34
4/8/2013	Introduction to Simulation	24
4/10/2013	Introduction to Simulation (Cont)	24
	Analysis of Simulation Results	25
4/15/2013	Analysis of Simulation Results (Cont)	25
4/17/2013	Random Number Generation	26
4/22/2013	Random Number Generation (Cont)	26
	Random Variate Generation	28
4/24/2013	***Final Exam***	

- Note final exam is in the last class before the reading period.

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 2 to 4 years ⇒ Not in books
- Better ones may be submitted to magazines or journals

Projects (Cont)

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

Example of Previous Case Studies

- Performance of Google App Engine and Amazon Web Service
- Availability and Sensitivity of Smart Grid Components
- Modeling and Analysis Issues in x86-based Hypervisors
- Image Sensor Performance
- Performance of Solving Laplace's Equation using Auto-Pipe
- Performance Modeling of Multi-core Processors
- Performance of Named Data Networking
- A Measurement Study of Packet Reception using Linux
- Performance Analysis of Robotics Systems
- Performance and Measurement Issues of Smart Phones Design
- Analysis of Online Social Networks
- Measurement Study on the BitTorrent File Distribution System
- A Survey of Wireless Sensor Network Simulation Tools

Case Studies (Cont)

- Database Systems Performance Evaluation Techniques
- A Survey of Hardware Performance Analysis Tools
- Analytical Modeling of Beyond Visual Range Air Combat
- A Survey of Network Simulation Tools: Current Status and Future Development
- Performance Analysis of Data Encryption Algorithms
- Case Study of the Performance of a Gamma-Ray Event Parameterization Application
- Survey on Performance Analysis of MAC protocols
- A Summary of Network Traffic Monitoring and Analysis Techniques
- A Survey of Network Performance Monitoring Tools

Case Studies (Cont)

- Survey of Network Performance Monitoring Tools
- SNMP and Beyond: A Survey of Network Performance Monitoring Tools
- A Survey of Network Traffic Monitoring and Analysis Tools
- Operating System and Process Monitoring Tools
- A Survey of Performance Analysis Tools
- Processor workloads
- Case Study: Performance Analysis of a Diversified Router
- Performance Analysis of Wireless Sensor Networks
- An Overview of Software Performance Analysis Tools and Techniques: From GProf to DTrace
- Survey of Software Monitoring and Profiling Tools

Case Studies (Cont)

- From Poisson Processes to Self-Similarity: a Survey of Network Traffic Models A Historical View of Network Traffic Models
- A Survey of Network Traffic Models
- Verification and Validation of X-Sim: A Trace-Based Simulator
- A Performance Model for a Thermally Adaptive Application Implemented in Reconfigurable HW

Project Schedule

Mon 2/25	Topic Selection
Mon 3/04	References Due
Mon 3/18	Outline Due
Mon 4/03	First Draft Due -> Peer reviewed
Mon 4/10	Reviews Returned
Mon 4/17	Final Report Due

Office Hours

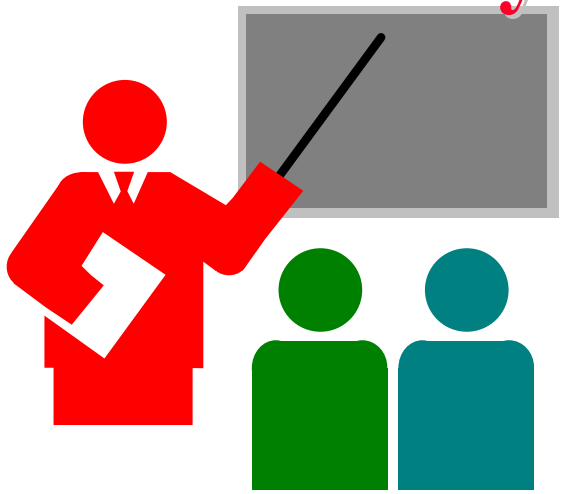
- Monday/Wednesday:11 AM to 12 noon
- Office: Bryan 523

- Teaching Assistant:
  - Michael Hall, Bryan 405G, mhall24@wustl.edu
  - Office Hours: Thursday/Friday 2PM-3PM

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 mean of uniform(0,1) variates is 1.

❑ ❑ The sum of two normal variates with means 4 and 3 has a mean of 7.

❑ ❑ 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 _____ = _____