King Fahd University of Petroleum & Minerals Computer Engineering Dept

COE 587 – Performance Evaluation And Analysis

Term 152

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Slides are based on the textbook:

R. Jain, "Art of Computer Systems Performance Analysis," Wiley, 1991, ISBN:0471503363

Book website:

http://www.cse.wustl.edu/~jain/books/perfbook.htm

Overview of Performance Evaluation

- **Examples of "performance" related problems:**
  - **Specifying performance requirements**
  - **Evaluating design alternatives**
  - **Comparing two or more systems**
  - **Determine the optimal value of a parameter**
  - **Finding performance bottleneck**
  - **Characterizing the load of the system**
  - **Determine the number and sizes of components**
  - **Predicting the performance for future loads**
  - **Etc.**

Terminologies

- **System: any collection of hardware or software, and firmware components**
  - **E.g. CPU, Network link, etc.**
- **Metrics: Criteria used to evaluate the performance of the system**
  - **E.g. total delay in a queue, blocking rate, etc.**
- **Workloads: Requests made the users of the system**
  - **E.g. customer arrival rate**

Topics of the Textbook/Course

1. An Overview of Performance Evaluation
2. Measurement Techniques and Tools
3. Probability Theory and Statistics
4. Experimental Design And Analysis
5. Simulation (with emphasis on discrete-time event driven simulations)
6. Queueing Models

Chapter 1: An Overview of Performance Evaluation

Example 1.1:

What performance metrics should be used to compare the performance of the following systems?

(a) Two disk drives
(b) Two transaction processing systems
(c) Two packet retransmission algorithms
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- **Focus of part 1 of textbook**
  - **Select appropriate evaluation techniques, performance metrics, and workloads for a system.**

Measurement Techniques and Tools

Example 1.2:

What type of monitor (software or hardware) would be more suitable for measuring the following quantities:

(a) Number of instructions executed by a processor
(b) Degree of multiprogramming on a timesharing system
(c) Response time of packets on a network
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- **Focus of part 2 of textbook**
  - **Conduct performance measurements correctly.**

Probability Theory and Statistics

Example 1.3:

The number of packets lost on two links was measured for four file sizes as shown in Table.

Which link is better?

Table: Packets lost on two links.

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

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- **Focus of part 3 of textbook**
  - **Use of proper statistical techniques to compare several alternatives.**

Experimental Design And Analysis

<u>Example 1.4:</u>

The Performance of a system depends on the following three factors:

(a) Garbage collection technique used: G1, G2, or none.
(b) Type of workload: editing, computing, or artificial intelligence (AI).
(c) Type of CPU: C1, C2, or C3.

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- **Focus of part 4 of textbook**
  - **To design measurements and simulation experiments to provide the most information with the least effort.**

Simulation

<u>Example 1.5:</u>

In order to compare the performance of two cache replacement algorithms:

(a) What type of simulation model should be used?
(b) How long should the simulation be run?
(c) What can be done to get the same accuracy with shorter run?
(d) How can one decide if the random-number generator in the simulation is a good generator?

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- **Focus of part 5 of textbook**
  - **Perform simulations correctly**

Queueing Models

Example 1.5:

The average response time of a database system is 3 seconds. During a 1-minute observation interval, the idle time on the system was 10 seconds. Using a queueing model for the system, determine the following:

(a) System utilization
(b) Average service time per query
(c) Number of queries completed during observation time
(d) Etc.

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- **Focus of part 6 of textbook**
  - **Use simple queueing models to analyze the performance of systems**

The Art of Performance Evaluation – cont'd

Example 1.7:

The throughputs of two systems A and B were measured in transactions per second. The results are shown in Table.

Table: Throughput in transactions per second.

System	Workload 1	Workload 2
A	20	10
B	10	20

Which system is better?

The Art of Performance Evaluation – cont'd

- **Possible answers:**

1. **Use the average of the two workloads**

Table: Throughput in transactions per second.

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

2. **Normalize with respect to performance of system B**

Table: Throughput in transactions per second.

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

3. **Normalize with respect to performance of system A**

Table: Throughput in transactions per second.

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

Chapter 2: Common Mistakes and How to Avoid Them

- **Common mistakes in performance evaluation**
- **Systematic approach to performance evaluation**

Common Mistakes In Performance Evaluation (Box 2.1 in textbook – page 22)

1. **No goals or biased goals**
2. **Unsystematic approach**
3. **Analysis without understanding the problem**
4. **Incorrect performance metrics**
5. **Unrepresentative workload**
6. **Wrong evaluation techniques**
7. **Overlooking important parameters**
8. **Ignoring significant factors (parameters versus factors)**
9. **In appropriate experimental design**
10. **Inappropriate level of detail**
11. **No analysis or erroneous analysis**

Common Mistakes In Performance Evaluation (Box 2.1 in textbook – page 22) – cont'd

12. **No sensitivity analysis (relative importance of parameters)**
13. **Ignoring errors in input**
14. **Improper treatment of outliers (what are outliers?)**
15. **Assuming no change in the future**
16. **Ignoring variability (to determine variability is a more difficult task compared to determining the mean)**
17. **Too complex analysis – a simple analysis leading to the same conclusion is preferable**
18. **Improper presentation of results**
19. **Ignoring social aspects (writing and speaking skills versus substantive skills)**
20. **Omitting assumptions and limitations**

A Systematic Approach to Performance Evaluation (Box 2.2 in textbook – page 26)

1. **State goals and define the system**
2. **List services and outcomes**
3. **Select metrics**
4. **List parameters**
5. **Select factors to study**
6. **Select evaluation technique**
7. **Select workload**
8. **Design experiment**
9. **Analyze and interpret data**
10. **Present results**

What is the difference between parameter and factor?

How is a "workload" related to parameter and/or factor?

Case Study 2.1: Remote Procedure Call Project

- **Project Statement:**
  - Consider the problem of comparing remote pipes with remote procedure calls. In a procedure call, the calling program is blocked, control is passed to the called procedure along with a few parameters, and when the procedure is complete, the results as well as the control returns to the calling program. A remote procedure call is an extension of this concept to distributed computer systems. A program on one computer system calls a procedure object on another system. The calling program waits until the procedure is complete and the result is returned t. Remote pipes are also procedure like objects, but when called, the caller is not blocked. The execution of the pipe occurs concurrently with the continued execution of the caller. The results, if any, are later returned asynchronously.
- **Plan:**
  - **Define the system, services, metrics, parameters, etc.**
  - **Refer to textbook for details.**

Chapter 3: Selection of Techniques and Metrics

- **Topics:**
  - **Selecting an evaluation technique**
  - **Selecting performance metrics**
  - **Commonly used performance metrics**
  - **Utility classification of performance metrics**
  - **Setting performance requirements**

Selecting An Evaluation Technique

- **There are three techniques for performance evaluation**

Table: Criteria for selecting an evaluation technique.

Criterion	Analytical Modeling	Simulations	Measurement
1. Stage	Any	Any	Prototype
2. Time required	Small	Medium	Varies
3. Tools	Analysts	Computer languages	Instrumentation
4. Accuracy*	Low	Moderate	Varies
5. Trade-off evaluation	Easy	Moderate	Difficult
6. Cost	Small	Medium	High
7. Saleability	Low	Medium	High

* In all cases, results may be misleading or wrong.

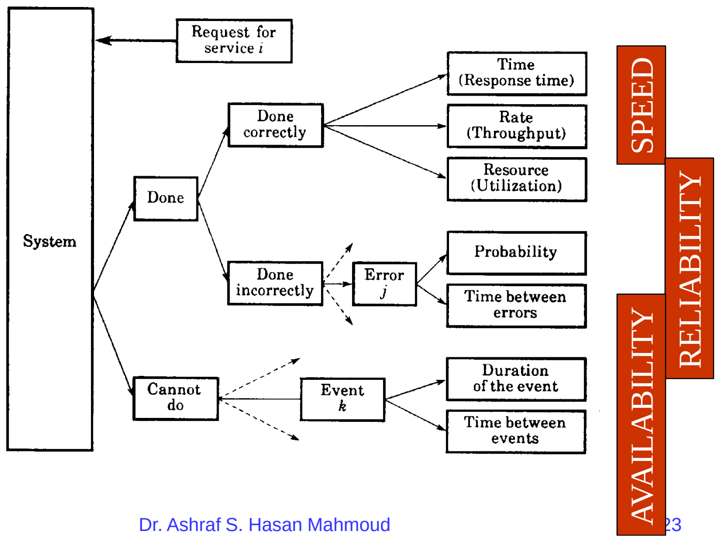
Selecting An Evaluation Technique - Considerations

- Generally you want the evaluation to be performed by TWO or MORE techniques
  - Typically – analysis followed by simulation
- Until validated, all evaluation results are suspect
- Validation rules:
  - Simulation results MUST be validated by analysis or measurements
  - Analysis results MUST be validated by simulation or measurements
  - Measurement results MUST be validated by simulation or modeling
- Results should not be counterintuitive

Selecting Performance Metrics

- List the services for system
- For every service numerate performance related metrics
- Example: Gateway forwarding packets
  - Service – forwarding packets
  - Service performed correctly → time for each packet, rate of forwarding, resources consumed ➔ (time-rate-resource) = (responsiveness, productivity, utilization)
    - Resource with highest utilization is the BOTTLENECK
  - Service performed incorrectly → Error
    - Classification of errors (prob of each class occuring)
  - Service not performed → system down, fail, or unavailable
    - Classification of failures

Selecting Performance Metrics – cont'd



Selecting Performance Metrics – Considerations

- **Individual versus global**
  - **Example – user metrics versus network metrics**
  - **Maybe conflicting**
- **Low-variability – helps reduce the # of repetitions required to obtain a given level of statistical confidence (chapter 12)**
  - **Metrics that are ratios of two variables have a larger variability than either of the two variables – try to avoid!!**
- **Nonredundancy – two variables convey essentially the same information**
  - **Example – average waiting time in a queue and average number of requests in a queue – related**
- **Completeness – All possible outcomes of system should be reflected in the set of metrics**

Jain's Fairness Index

- **Example: network, a multiuser system, etc.**
- **Fairness: Added metric – Variability of throughput across users**
- **For a given set of user throughputs (x_1, x_2, ..., x_n), the fairness index is calculated as**

$$f\left(x_1, x_2, \ldots, x_n\right) = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n\sum_{i=1}^{n} x_i^2}$$

- **Note that for xi ≥ 0, f ∈ [0,1]**
  - **f = 0 → no fairness at all**
  - **f = 1 → 100% fair**

Jain's Fairness Index - Example

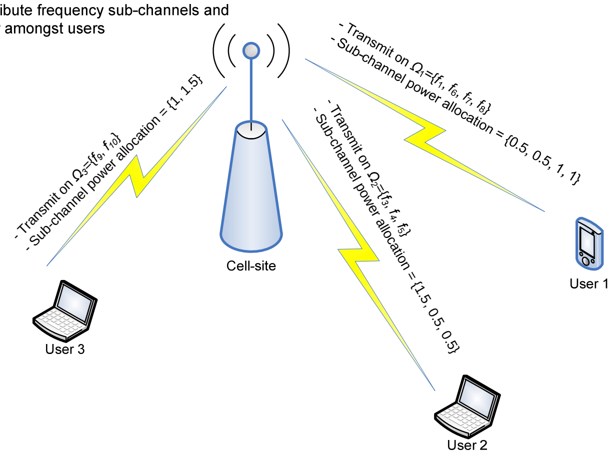
- **Khalaf, M.: Resource Management for OFDMA Systems Using Ant Colony-based Optimization Technique, Master Thesis submitted to Deanship of Graduate Studies, King Fahd University of Petroleum and Minerals (Jan 2012).**

Jain's Fairness Index – Example – cont'd

- **System Model**

RRM procedure – resources:
- Available sub-channels = $\{f_1, f_2, \ldots, f_{10}\}$
- Total cell-site power budget 10 Watts

RRM procedure – Task:
- Distribute frequency sub-channels and power amongst users



Jain's Fairness Index – Example – Mathematical Model

- Some algorithm is used to obtain Ω_k (set of allocated subchannels for kth user) for $k = 1, 2, \ldots, K$ such that Ω_k are disjoint for all k.
- Compute $p_{k,n}$ that fulfills the following optimization problem is:

$$\max_{p_{k,n}} \sum_{k=1}^{K} \sum_{n \in \Omega_k} \frac{1}{N} \log_2\left(1 + p_{k,n} H_{k,n}\right)$$

Convex optimization problem with some constraints

- Subject to

Power constraint ⇨ $$\sum_{k=1}^{K} \sum_{n \in \Omega_k} p_{k,n} \le P_{\text{total}} \quad p_{k,n} \ge 0 \qquad \text{for all } k, n$$

Proportional Fairness ⇨ $$\frac{R_1}{\gamma_1} = \frac{R_2}{\gamma_2} = \cdots = \frac{R_K}{\gamma_K}$$

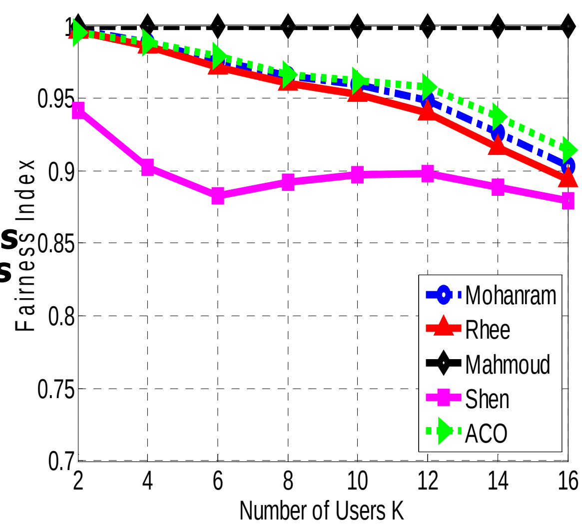
Constraint of interest! How to evaluate compliance?

Jain's Fairness Index – Example – cont'd

- **Constraint of interest** $\frac{R_1}{\gamma_1} = \frac{R_2}{\gamma_2} = \cdots = \frac{R_K}{\gamma_K}$
- **Once a solution is obtained, it is not necessary that it satisfies the above constraint 100% - How close?**
- **Use Jain's Fairness Index** $F = \frac{\left(\sum_{k=1}^{K} R_k/\gamma_k\right)^2}{K\sum_{k=1}^{K}\left(R_k/\gamma_k\right)^2}$
  - **A value for F = 1 ➔ 100% satisfied**
  - **A value for F = 0 ➔ not satisfied at all**

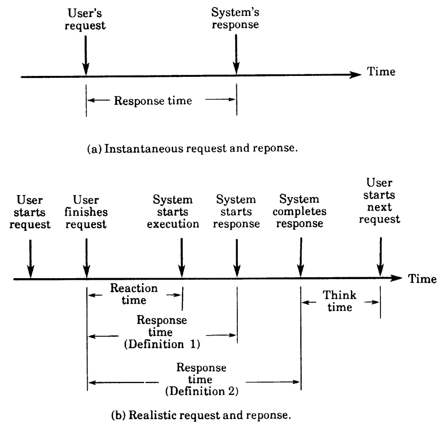
Jain's Fairness Index – Example – Sample Results - cont'd

- **Several algorithms (solutions) are evaluated**
- **Note fairness index ranges from 0 to 1**
- **Workload – number of users**



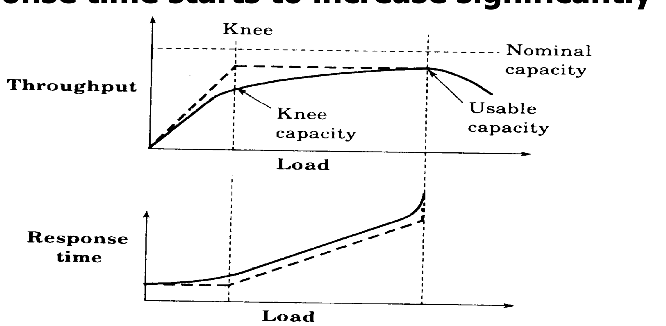
Commonly Used Performance Metrics

- Response time – interval between user's request and system response
- Turnaround time – time between submission till the full completion
- Reaction time – Time till system starts execution
- Stretch factor – ratio of response time at a particular load to that at the minimum load
- Throughput – rate of service for requests
  - MIPS/MFLOPS
  - Packet/sec or b/s
  - Transaction/sec



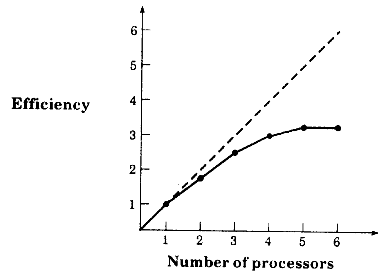
Commonly Used Performance Metrics – Capacity

- Nominal capacity – maximum achievable throughput under ideal workload conditions
  - Called "bandwidth" for computer networks
- Usable capacity – maximum throughput without exceeding a specified response time
- Knee Capacity – Throughput for system when response time starts to increase significantly



Commonly Used Performance Metrics – Efficiency/Utilization

- **Efficiency – maximum achievable throughput (usable capacity) to nominal capacity.**
- **Utilization – fraction of time the resource is busy serving requests**
- **Idle time – period the resource is not used**

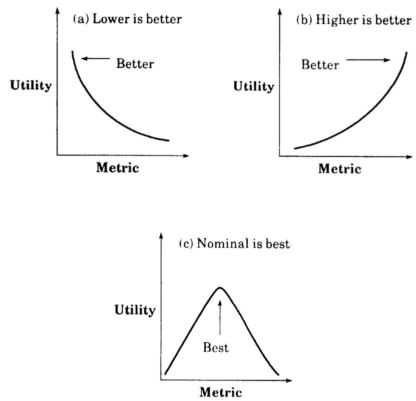


Commonly Used Performance Metrics – Reliability

- **Reliability – the probability of error OR mean time between errors (error-free seconds)**
- **Availability – the fraction of the time the system is available to service users**
  - **Downtime – duration the system is not available**
  - **Uptime – duration the system is available**
  - **Mean Time To Failures (MTBF) – mean uptime**

Utility Classification of Performance Metrics

- **Higher is better (HB) – e.g. Throughput**
- **Lower is better (LB) – e.g. Response time**
- **Nominal is best (NB) – e.g. Utilization**



Setting Performance Requirements

- **Example:**
  - **The system should be both processing and memory efficient. It should not create excessive overhead**
  - **There should be an extremely low probability that the network will duplicate a packet, deliver a packet to the wrong destination, or change data in a packet.**
- **Unacceptable requirements**
  - **Nonspecific**
  - **Nonmeasurable**
  - **Nonacceptable**
  - **Nonrealizable**
  - **Nonthorough**
- **Solution: requirements must be SMART → (S)pecific, (M)easurable, (A)cceptable, (R)ealizable, and (T)horough!**

Example Study – BGP Performance Evaluation

- **AlRefai, A.: BGP-based solutions for international ISP blocking. Master Thesis submitted to Deanship of Graduate Studies, King Fahd University of Petroleum and Minerals (2010)**

Example Study – BGP Performance Evaluation – cont'd

- **Example:**
- **AS12 – autonomous system of interest**
- **AS4 – Main IISP**
- **AS4 – Secondary IISP**
- **Comm between LAN_West and LAN_East**

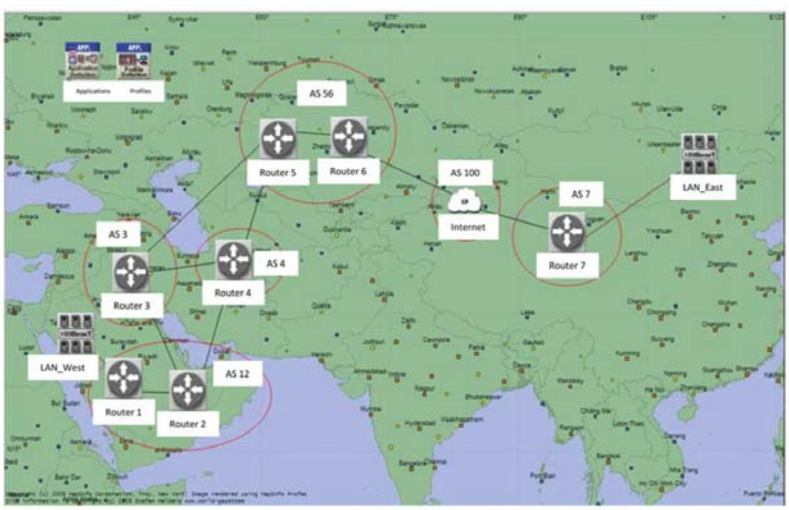


Fig. 11 OPNET simulation model

Example Study – BGP Performance Evaluation – cont'd

- **Selected mitigation techniques**
  - **AS-path shortening**
  - **More-specific prefixes**
  - **Use of communities**
- **Types of Traffic**
  - **HTTP**
  - **FTP**
  - **VOIP**
- **Background load**
  - **20%**
  - **50%**
  - **80%**
- **Internet delay**
  - **0.1 sec**
  - **5 sec**
- **Etc**
- **Performance metrics**
  - **Network convergence time**
  - **Throughput at router/link X**
  - **Packet drop**
  - **Page response time (HTTP)**
  - **Etc.**

1/17/2016 Dr. Ashraf S. Hasan Mahmoud 39

Example Study – BGP Performance Evaluation – cont'd

- **Sample result**
- **Note the confidence intervals!**

Ashraf Mahmoud, Ahmad Alrefai, Marwan Abu-Amara, Mohammed Sqalli, Farag Azzedin, "Qualitative Analysis of Methods for Circumventing Malicious ISP Blocking," Arab J. Sci. Eng. (2012) 37:1911-1928.

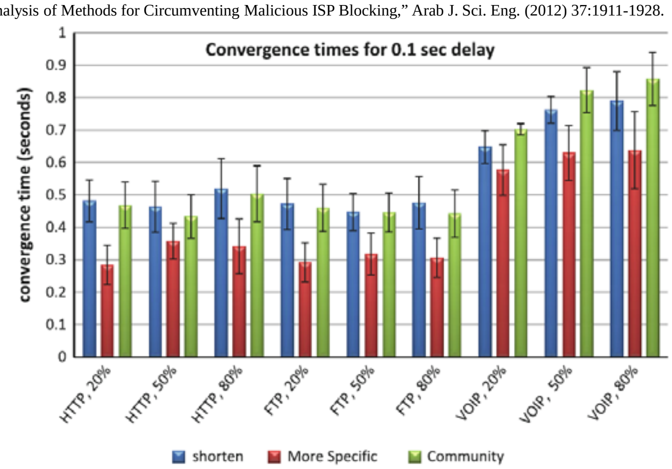


Fig. 12 Convergence time for BGP-based solutions assuming 100 msec average internet delay

1/17/2016 Dr. Ashraf S. Hasan Mahmoud 40