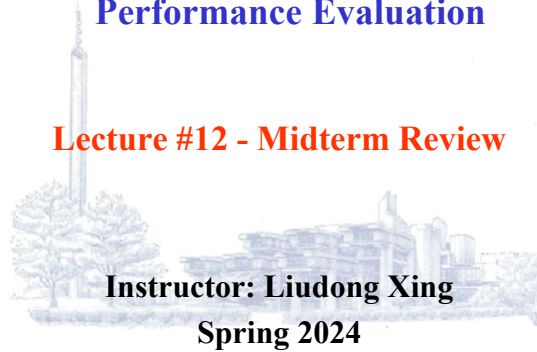**UNIVERSITY OF MASSACHUSETTS DARTMOUTH**

ECE 560 Computer Systems Performance Evaluation

Lecture #12 - Midterm Review

Instructor: Liudong Xing
Spring 2024

Administration Issues

- Homework#4 due **Today**

- Midterm Exam
  - On **March 6, Wednesday**
  - Review session today

- Project Annotated Bibliography
  - Refer to Project Description Section 2.2
  - Due: **March 22, Friday**

  No Classes Next Week (Week of March 11);
  Have a Great and Safe Spring Break!!
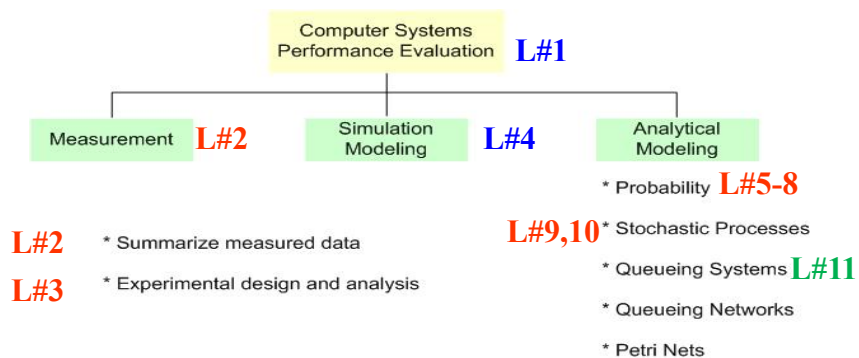
Midterm Exam

- **12:30pm-1:55pm, Wednesday, March 6**

- **Form:**
  - Open book, open notes, in-class exam
  - Calculators are allowed

- **Preparation:**
  - Lecture notes #2, 3, 5-7, 9, 10
  - Hands-on problems
  - Homework #1 - #4

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Midterm Review

Computer Systems Performance Evaluation **L#1**

Measurement **L#2**   Simulation Modeling **L#4**   Analytical Modeling

* Probability **L#5-8**

L#9,10 * Stochastic Processes

L#2 * Summarize measured data

L#3 * Experimental design and analysis

* Queueing Systems **L#11**

* Queueing Networks

* Petri Nets

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Midterm Review

I.   Overview of Computer Systems Performance Evaluation (CSPE)

II. Measurement Technique and Tool

III. Experimental design and analysis

IV. Simulation modeling techniques

V.   Analytical modeling techniques

1. Probability theory and statistics

2. Stochastic processes

3. Queueing systems (M/M/1)

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Part I: CSPE Overview

- Why PE?
  - To make sure the system can perform the intended function correctly, efficiently, and in a cost-effective manner.
- What to measure?
  - 5 classes of PE measures/metrics
    - Responsiveness, Usage level, Productivity, Mission-ability, Dependability
  - Relevance of measures to various application domains
    - General purpose computing, High availability, Real-time control, Mission oriented, Long-life
- How to do it?
  - 3 PE techniques (measurement, analytical modeling, & simulation)
  - criteria for selecting an appropriate one
    - Life-cycle stage, Time required, Tools, Accuracy, Trade-off analysis, Cost, Salability
  - A 10-step systematic approach to PE
    - A complete project often consists of several cycles through all those steps

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Part II: Measurement Technique & Tool

- 3 key issues related to performance measurements

  – 5 types of workloads that have been commonly used to compare CS
    - Addition instruction, Instruction mixes, Kernels, Synthetic programs, Application benchmarks

  – Performance monitors: tools used to observe activities on a system
    - Observe system performance, collect performance statistics, analyze data, display results
    - Concerning mechanisms that triggers the monitor into action
      – Event-driven, timer-driven (sampling)
    - Concerning the result displaying ability
      – On-line, batch
    - Concerning the level at which a monitor is implemented
      – Hardware, Software, Hybrid

  – Summarizing measured data
    - **By a single number**: mean, median, mode, geometric & harmonic mean
    - **Variability**: range, variance, COV, percentiles, SIQR, mean absolute deviation

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Part III: Experimental Design and Analysis

- **Frequently-used terms in experimental designs**
  – Response variables, factors (predictors, predictor variables), levels (treatments), primary factors, secondary factors, replication, designs, experimental units, interactions

- **Types of experimental designs**
  – Simple designs, full factorial designs, fractional factorial designs

- **A closer look at 2^k factorial designs**
  – *Regression equations* and *sign table* methods to quantify the effects of the factors and interactions on the system performance

$$y = q_0 + q_A x_A + q_B x_B + q_{AB} x_A x_B$$

I	A	B	AB	y
1	-1	-1	1	15
1	1	-1	-1	45
1	-1	1	-1	25
1	1	1	1	75
160	80	40	20	Total
40	20	10	5	Total/4

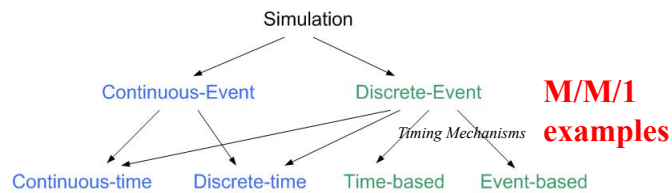Dr. Xing   Midterm Review   8

Part IV: Simulation Modeling

- Applications of computer simulations
- Basic concepts / definitions
  - System, model & model building, simulation, system state description, event, simulation time, run time
- Classifying simulations

Simulation

Continuous-Event   Discrete-Event   **M/M/1 examples**

Timing Mechanisms

Continuous-time   Discrete-time   Time-based   Event-based

- Suggested 10-step simulation process

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Midterm Review

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   1. **Probability theory and statistics**

   2. Stochastic processes

   3. Queueing systems (M/M/1)

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Probability Theory

- Sample spaces & events
- Field, σ-field, and probability measure
- Odds for/against an event
- Conditional probability, Total Probability Theorem, and Bayes' Formula
- Independence: mutually vs. pairwise

Random Variables (*r.v.*)

- Basic concepts: not random or variable, but a real-valued function: X: Ω → R
- Cumulative distribution function (**c.d.f.**) of a *r.v.: F(x)*

- **Discrete *r.v.***
  - Probability mass function (**p.m.f.**)
  - Important discrete *r.v.*s: Bernoulli, Binomial, Geometric, Poisson
- **Continuous *r.v.***
  - Probability density function (**p.d.f.**)
  - Important continuous *r.v.*s: Uniform, Normal, Exponential

Random Variables (*r.v.*) (Cont'd)

- **Important parameters of *r.v.*s**
  - Mean (expected value) and the *k*-th moment
  - Variance/standard deviation
  - Squared coefficient of variation (C.O.V.) and C.O.V.
- **Jointly distributed *r.v.***
  - Joint/marginal distribution function
  - joint/marginal/conditional p.m.f for discrete r.v.s
  - joint/marginal/conditional p.d.f. for continuous r.v.s
  - Independency, Expectation, Covariance, Correlation, Variance
  - **Min and Max Theorems and their application**

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Stochastic Processes

- Basic concepts of stochastic processes
  - Definition: a family of random variables
  - Classification
    - Discrete parameter, continuous state
    - Discrete parameter, discrete state
    - Continuous parameter, continuous state
    - Continuous parameter, discrete state
  - Realization/sample path

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Stochastic Processes (Cont'd)

- **Counting processes**
  - Continuous-parameter discrete-state processes
- **Poisson processes**
  - o(h) notation
  - Definition
    - A Poisson process is a counting process satisfying independent/stationary increments and conditions on P[N(h)]
    - Number of arrivals (events) having Poisson distribution is equivalent to the inter-arrival time having exponential distribution
  - **Properties**
    - Superposition of independent Poisson processes
    - Decomposition of a Poisson process

Stochastic Processes (Cont'd)

- **Birth-and-Death Processes**

  - Definition & State-transition diagram

  - Differential-difference equations for $P[X(t)=n]=P_n(t)$

  - Special case: pure-birth processes
    - A Poisson process is a pure-birth process with a constant birth rate

  - Steady-state solutions to general birth-and-death processes

    - Based on

      $$\lim_{t\to\infty}\frac{dP_n(t)}{dt}=0,\quad \lim_{t\to\infty}P_n(t)=P_n,\quad \forall n=0,1,2,...$$

    - **Balance equations: rates in = rates out**

Stochastic Processes (Cont'd)

- Markov chains (discrete-state Markov processes)
  - Discrete-time Markov chains
    - One-step, n-step transition probabilities (matrix); homogeneous
  - **Ergodic** $\Pi(n) = \Pi(0)\, P^n$
    - <u>irreducible</u>: you can get from every state to every other
    - <u>aperiodic</u>: every state has period 1. For each state there are paths back to that state of various lengths
    - <u>for which all states are positive recurrent</u>: for each state, upon leaving the state you will return with probability 1 and within a finite mean time.
    - Stationary probability distribution **=** Long-run (limiting) probability distribution

$$\Pi = \Pi * P \quad \text{and} \quad \sum_i \Pi_i = 1$$

Balance equations: Rate entering = Rate leaving

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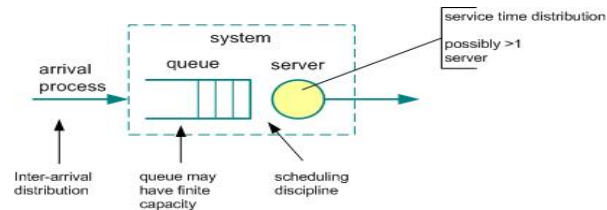   **3.   Queueing systems (M/M/1; Lecture#11)**

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Queueing Systems

- Fundamental elements

- Kendall notation: A/B/c/K/m/Z

Queueing Systems – Performance Measures

- Average number of jobs in the system (L) $L = \lambda W$
- Average time spent in the system (W: average response time)
  $L_q = \lambda W_q$
- Average number of jobs in the queue (L_q)
- Average time spent in the queue (W_q: average waiting time)

- $p_n(t)$: probability that there are n customers in the system at time t

- π_n: steady-state probability that there are n customers in the system

Performance Measures (Cont'd)

- Throughput (γ): rate at which jobs successfully depart from the system
- Blocking probability (P_B, for the finite buffer/queue size): probability an arriving job is turned away due to a full buffer
- Traffic intensity/offered load $\alpha = W_s / E[\tau] = \lambda / \mu$
- Server utilization $\rho = \alpha/c$

For stable operation: $\rho < 1, \quad \alpha < c$

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Birth-and-Death Queueing Systems

- M/M queues fitting the birth-and-death process
  - A customer arrival is a birth; a customer departure after completing service is a death
  - Both arrival process and service times are memoryless!
- Solution: *balance* equations
- M/M/1 performance evaluation

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Good Luck!!!

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