Lahore University of Management Sciences

CS501 Applied Probability

(Cross-listed as: EE 515/MATH 439)

Fall 2016

Instructor	Dr. Ihsan Ayyub Qazi
Room No.	SBASSE 9-G14A
Office Hours	4pm-5pm (Tue/Thu)
Class Location	Academic Block A-15
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Course URL (if any)	LMS (https://lms.lums.edu.pk)

Course Basics				
Credit Hours	3			
Lecture(s)	2 Per Week		Duration	75 mins
Tutorial (per week)	1 Per Week		Duration	60 mins

Course Distribution	
Core	MS Computer Science
Elective	
Open for Student Category	All
Close for Student Category	None

COURSE DESCRIPTION

- *How does Google rank webpages in its search results?*
- *How are social networks, such as Twitter, able to handle billions of queries every day with large traffic fluctuations?*
- *Why simply changing the order of processing of jobs on a computer can reduce response times?*
- *What is the risk of using a new medical treatment?*

A common theme in all of the above questions is the need for decision-making in the presence of uncertainty. Probability theory provides us with a rich set of tools to precisely model uncertainty and analyze its effects. It is used in a variety of contexts including analyzing the likelihood of various events, design and analysis of randomized algorithms (i.e., algorithms that make probabilistic decisions), or modeling the behavior of systems that exist in environments with uncertain behavior (e.g., self-driving cars and autopilots in planes). Thus, probability theory plays a central role in fields such as computer science, engineering, management, and social sciences where uncertain situations occur frequently.

This course deals with the nature, formulation, and analysis of probabilistic situations and introduces the fundamentals of probability with special emphasis on applications. This course will provide a rigorous understanding of probability concepts including: random variables, expectations, joint distributions, limit theorems, and stochastic processes (including Markov Chains).

In addition, this course will cover two key applications areas where probability is extensively used: (a) queuing theory and (b) machine learning.

Why machine learning? Computers are increasingly being used as data analysis tools to obtain insights from the enormous amounts of data that is being collected in a variety of fields (now referred to as "big data"). Probability theory is now used as one of the key methods for designing new algorithms to model such data, allowing, for example, a computer to make predictions about uncertain or new events.

Why queuing theory? Any system (e.g., web server, a laptop factory) that has finite capacity and provides a service can potentially be modeled using queuing theory, which provides us with tools to predict system performance as well as design systems that achieve high performance. For example, using queuing theory we can answer questions such as "What is the average delay experienced by requests arriving at a web server?" and "Given demand and a size of a given hospital, how many doctors should be hired to ensure that the no patient waits for longer than 10mins with high probability?").

A key goal of this course is to act as a bridge between the theoretical foundations of probability and its applications.

COURSE PREREQUISITE(S)	
•	Good preparation in Calculus

COURSE OBJECTIVES	
•	To teach the fundamentals of probability theory
•	To introduce real-world applications of probability theory
•	To train students in applying probability concepts for solving real world problems

Learning Outcomes	
•	Students will have a clear understanding of key probability concepts
•	Students will be able to apply probability concepts to solve real-world problems
•	Students will become aware of several real-world applications of probability

Grading Breakup and Policy

Quizzes: 20%
Assignments: 20%
Mini-Project: 5%
Midterm Examination: 25%
Final Examination: 30%

Make-up Exam Policy

For any missed quiz, exam, or other course instrument (constituting less or more than 10% in aggregate), please file a request with the Office of Student Affairs (OSA) using the make-up exam petition form. The form must be submitted to the OSA, along with other required documents, **either prior to or within three working days of the exam**. The OSA will process the petition and the student will be notified of the decision at most within a week. A petition may either be accepted or declined. Please refer to your handbook for more details about missed components.

Examination Detail	
Midterm Exam	Yes/No: Yes Duration: 3 hours Preferred Date: TBA Exam Specifications: TBA
Final Exam	Yes/No: Yes Duration: 3 hours Exam Specifications: TBA

Textbook(s)/Supplementary Readings

Required Textbooks

- Introduction to Probability by Bertsekas and Tsitsiklis (2nd Edition, 2008)
- Performance Modeling for Computer Systems by Mor Harchol Balter (2013)

Optional Textbooks

- Introduction to Probability Models by Sheldon Ross (11th Edition, 2014)
- Probability and Random Processes for Electrical Engineering by Alberto Leon Garcia (3rd Edition, 2007)
- Mining of Massive Datasets by Jure Leskovec, Anand Rajaraman, Jeffrey David Ullman (2nd Edition, 2014)
- Machine Learning: a Probabilistic Perspective by Kevin Murphy (2012)

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Session	Topics	Recommended Readings
Basics of Probability		
1	Course Overview, Sample Space, Events, Counting	Chapters 1.1, 1.2, & 1.6
2	Conditional Probability, Bayes' Rule	Chapters 1.3, 1.4, & 1.5
3	Law of Total Probability, Independence,	Chapters 2.1
Probability Distributions		
4	Discrete Random Variables (RVs): Basic Concepts, PMF, Bernoulli RV & Common Discrete RVs (Binomial, Geometric, Poisson)	Chapters 2.2
5	Functions of RVs, Expectation, Variance	Chapters 2.3 & 2.4
6	Joint PMFs and Conditional Distributions	Chapters 2.5 & 2.6
7	Continuous RVs: Basic Concepts, PDF, CDF, Uniform RV	Chapters 3.1 & 3.2
8	Common Continuous RVs (Uniform, Exponential)	Chapters 3.1 & 3.3
9	Common Continuous RVs (Pareto, Normal), Central Limit Theorem **Case Study**: Job Size Distributions and CPU Load Balancing	Chapters 3.1, 3.3 + Notes
Advanced Probability		
10	Confidence Intervals, Joint PDFs, and Conditional PDFs	Chapters 3.4 & 3.5
11	Moment Generating Functions, Sums of RVs, Correlation, and Covariance	Chapters 4.1, 4.2, & 4.5
12	Inequalities (Markov, Chebychev, and Chernoff)	Chapters 7.1
13	Sample paths, Convergence of RVs & Law of Large Numbers (Weak and Strong)	Chapters 7.2-7.5
14	**MIDTERM EXAM**	
Stochastic Processes		
15	Bernoulli Process: Inter-arrival Times, K^{th} Arrival Time, Splitting and Merging	Chapter 5.1
16	Poisson Process: Inter-arrival Times, K^{th} Arrival Time, Splitting and Merging	Chapter 5.2
17	Finite-state Discrete-Time Markov Chains (DTMC)	Chapter 6.1
18	Finite-state DTMCs Wrap-up + Infinite-state DTMCs	Chapter 6.2-6.3 + Notes
19	Infinite-state DTMC Wrap-up	Chapter 6.2-6.3 + Notes
20	**Case Study**: Google Search and the Page Rank Algorithm	Notes
21	Continuous-Time Markov Chains (CTMC): Translating CTMCs to DTMCs	Chapter 6.4 + Notes
22	CTMC: Interpretation of CTMCs, Examples of CTMCs	Notes
Applications of Probability		
23	**Introduction to Queuing Theory**, Kendall's Notation, Little's Law, M/M/1	Notes
24	PASTA, M/M/m, M/M/m/m	Notes
25	M/G/1, Inspection Paradox, Introduction to Scheduling Theory	Notes
26	**Introduction to Machine Learning and Data Analysis**: Parameter Estimation (including Maximum Likelihood Estimation), Naïve Bayes	Notes
27	Logistic Regression	Notes
28	Deep Learning	Notes
29	Course Review	Notes