Electrical & Computer ENGINEERING

Carnegie Mellon

Course Syllabus

18-687: *Analytical Performance Modeling & Design of Computer Systems*
Fall 2018

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Course Description:
In designing computer systems one is usually constrained by certain performance requirements. For example, certain response times or throughput might be required of the system. On the other hand, one often has many choices: One fast disk, or two slow ones? What speed CPU will suffice? Should we invest our money in more buffer space, or a faster processor? Which migration policy will work best? Which task assignment policy will work best? How can we redesign the scheduling policy to improve the system performance? Often answers to these questions are counter-intuitive. Ideally, one would like to have answers to these questions before investing the time and money to build a system. This class will introduce students to analytic stochastic modeling with the aim of answering questions such as those above. Topics covered include Operational Laws, Markov Chain Theory, Queuing Theory, Modeling Empirical Loads, Simulations, and Management of Server Farms.

Number of Units: 12

Pre-requisites: 36-217 (Grade of D or higher is required in the prerequisites)

Graduate Area: Algorithms/Complexity/Programming Languages

Class Lecture:

- *Monday and Wednesday* *12:30pm – 2:20pm* WEH 5328 (PIT)
- *Monday and Wednesday* *9:30am – 11:20am* B23 118 (SV)

Required Textbook:
Performance Modeling and Design of Computer Systems: Queueing Theory in Action, Mor Harchol-Balter, Cambridge University Press, NY, 2013. *(ISBN: 978-1107027503)*

Suggested Reading:
Random Variables, and Stochastic Processes, A. Papoulis and S. U. Pillai, Probability, 4th ed., McGraw-Hill, 2001. *(ISBN: 978-0071226615)*

Probability and Random Processes for Electrical Engineering, A. Leon-Garcia, 2nd ed., Prentice Hall, 1993. *(ISBN: 978-0131471221)*

Data Networks, D. Bertsekas and R. Gallager, Prentice-Hall, 1992. *(ISBN: 978-0132009164)*

Scheduling Theory, Algorithms, and Systems, Michael Pinedo, Prentice Hall, 1995. *(ISBN: 978-3319265780)*

Brief List of Topics Covered:

- Operational Laws: Little's Law, response-time law, asymptotic bounds, modification analysis, performance metrics;
- Markov Chain Theory: discrete-time Markov chains, continuous-time Markov chains, renewal theory, time-reversibility; Poisson Process: memorylessness, Bernoulli splitting, uniformity, PASTA;
- Queueing Theory: open networks, closed networks, time-reversibility, Renewal-Reward, M/M/1, M/M/k, M/M/k/k, Burke's theorem, Jackson networks, classed networks, load-dependent servers, BCMP result and proof, M/G/1 full analysis, M/G/k, G/G/1, transform analysis (Laplace and z-transforms);
- Simulations: time averages versus ensemble averages, generating random variables for simulation, Inspection Paradox;
- Modeling Empirical Workloads: heavy-tailed property, Pareto distributions, heavy-tailed distributions, understanding variability and tail behavior, Matrix-analytic methods;
- Management of Server Farms: capacity provisioning, dynamic power management, routing policies;
- Analysis of Scheduling: FCFS, non-preemptive priorities, preemptive priorities, PS, LCFS, FB, SJF, PSJF, SRPT, etc.

Course Canvas:
To access the course canvas from an Andrew Machine, go to the login page at: https://cmu.instructure.com/. You should check the course canvas daily for announcements and handouts.

Course Wiki:
Students are encouraged to use the ECE wiki to provide feedback about the course at: http://wiki.ece.cmu.edu/index.php.

Grading Algorithm:

50%	Homework
25%	Midterm
25%	Midterm

HW Policy:
You will receive regular homework problems. These will be difficult. Start immediately so that you can take full advantage of office hours. Some of these homework problems may be repeated from previous years. Do not ask people who took this course in previous years to help you with the homeworks. This is considered cheating and will be reported to the dean. On the other hand, I strongly encourage you to collaborate with your current classmates to solve the homework problems after you have tried solving them by yourself. Each person must turn in a separate write-up. You should note on your homework specifically which problems were a collaborative effort and with whom.

Late homework submissions will NOT be accepted or graded!

Tentative Course Calendar:

Date	Day	Class Activity
August		
27	Mon.	Classes begin. Introduction to class; Queuing theory basics
29	Wed.	Probability Review
September		
3	Mon.	Labor Day; No Classes
5	Wed.	Probability Review Ct'd.
10	Mon.	Time Avg. Vs. Ensemble Average, convergence, law of large numbers
12	Wed.	Operational Laws: Little's Law, Forced-Flow law
17	Mon.	Utilization Law, Bottleneck Law
19	Wed.	Modification analysis, Performance Bounds Discrete-Time Markov Chains
24	Mon.	Guest Lecture by Prof. Gauri Joshi on **How to Reduce Delay in Cloud Systems**
26	Wed.	No Class – Instructor Traveling
October		
1	Mon.	Ergodic Markov Chains
3	Wed.	Ergodicity Theory
8	Mon.	Ergodicity Theory ct'd
10	Wed.	Exponential Distribution and Poisson Process
15	Mon.	Continuous-time Markov Chains, M/M/1 and PASTA
17	Wed.	Transform Analysis, Server Farms: M/M/k and M/M/k/k
19	Fri.	Mid-Semester Break; No Classes
22	Mon.	Capacity Provisioning for Server Farms, M/M/∞
24	Wed.	**Recitation #1**
29	Mon.	**Test #1**
31	Wed.	Time Reversibility, Burke's Theorem, Networks of Queues, Jackson Product Form;
November		

5	Mon.	Closed Networks of Queues; Understanding variability and tail behavior, Pareto distributions, heavy-tailed distributions
7	Wed.	M/G/1 queue and Inspection Paradox
12	Mon.	M/G/1 transform analysis
14	Wed.	Management of Server Farms: task assignment policies
19	Mon.	Analysis of Scheduling: FCFS, non-preemptive priorities
21-23	W-F	Thanksgiving Holiday; No Classes
26	Mon.	Scheduling cont'd. Preemptive priorities, PS, LCFS
28	Wed.	Other scheduling techniques: Size based Policies
December		
3	Mon.	**Recitation #2**
5	Wed.	**Test #2**
7	Fri.	Last Day of Classes
11-15		Final Exam Period

Education Objectives (Relationship of Course to Program Outcomes):
*Append a brief description of what is done in the course to address each outcome***.**

(a) an ability to apply knowledge of mathematics, science, and engineering: <<description>>

(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability: <<description>>

(e) an ability to identify, formulate, and solve engineering problems:<<description>>

(g) an ability to communicate effectively: <<description>>

(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context:<<description>>

(i) a recognition of the need for, and an ability to engage in life-long learning

(j) a knowledge of contemporary issues: <<description>>

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice: <<description>>

ECE Academic Integrity Policy
(http://www.ece.cmu.edu/programs-admissions/masters/academic-integrity.html**):**

The Department of Electrical and Computer Engineering adheres to the academic integrity policies set forth by Carnegie Mellon University and by the College of Engineering. ECE students should review fully and carefully Carnegie Mellon University's policies regarding Cheating and Plagiarism; Undergraduate Academic Discipline; and Graduate Academic Discipline. ECE graduate student should further review the Penalties for Graduate Student Academic Integrity Violations in CIT outlined

in the CIT Policy on Graduate Student Academic Integrity Violations. In addition to the above university and college-level policies, it is ECE's policy that an ECE graduate student may not drop a course in which a disciplinary action is assessed or pending without the course instructor's explicit approval. Further, an ECE course instructor may set his/her own course-specific academic integrity policies that do not conflict with university and college-level policies; course-specific policies should be made available to the students in writing in the first week of class.

This policy applies, in all respects, to this course.

CMU Academic Integrity Policy (http://www.cmu.edu/academic-integrity/index.html**):**

In the midst of self exploration, the high demands of a challenging academic environment can create situations where some students have difficulty exercising good judgment. Academic challenges can provide many opportunities for high standards to evolve if students actively reflect on these challenges and if the community supports discussions to aid in this process. It is the responsibility of the entire community to establish and maintain the integrity of our university.

This site is offered as a comprehensive and accessible resource compiling and organizing the multitude of information pertaining to academic integrity that is available from across the university. These pages include practical information concerning policies, protocols and best practices as well as articulations of the institutional values from which the policies and protocols grew. The Carnegie Mellon Code, while not formally an honor code, serves as the foundation of these values and frames the expectations of our community with regard to personal integrity.

This policy applies, in all respects, to this course.

The Carnegie Mellon Code

Students at Carnegie Mellon, because they are members of an academic community dedicated to the achievement of excellence, are expected to meet the highest standards of personal, ethical and moral conduct possible.

These standards require personal integrity, a commitment to honesty without compromise, as well as truth without equivocation and a willingness to place the good of the community above the good of the self. Obligations once undertaken must be met, commitments kept.

As members of the Carnegie Mellon community, individuals are expected to uphold the standards of the community in addition to holding others accountable for said standards. It is rare that the life of a student in an academic community can be so private that it will not affect the community as a whole or that the above standards do not apply.

The discovery, advancement and communication of knowledge are not possible without a commitment to these standards. Creativity cannot exist without acknowledgment of the

creativity of others. New knowledge cannot be developed without credit for prior knowledge. Without the ability to trust that these principles will be observed, an academic community cannot exist.

The commitment of its faculty, staff and students to these standards contributes to the high respect in which the Carnegie Mellon degree is held. Students must not destroy that respect by their failure to meet these standards. Students who cannot meet them should voluntarily withdraw from the university.

This policy applies, in all respects, to this course.

Carnegie Mellon University's Policy on Cheating
(http://www.cmu.edu/academic-integrity/cheating/index.html) states the following:

According to the University Policy on Academic Integrity, cheating "occurs when a student avails her/himself of an unfair or disallowed advantage which includes but is not limited to:

- Theft of or unauthorized access to an exam, answer key or other graded work from previous course offerings.
- Use of an alternate, stand-in or proxy during an examination.
- Copying from the examination or work of another person or source.
- Submission or use of falsified data.
- Using false statements to obtain additional time or other accommodation.
- Falsification of academic credentials."

This policy applies, in all respects, to this course.

Carnegie Mellon University's Policy on Plagiarism
(http://www.cmu.edu/academic-integrity/plagiarism/index.html) states the following:

According to the University Policy on Academic Integrity, plagiarism "is defined as the use of work or concepts contributed by other individuals without proper attribution or citation. Unique ideas or materials taken from another source for either written or oral use must be fully acknowledged in academic work to be graded. Examples of sources expected to be referenced include but are not limited to:

- Text, either written or spoken, quoted directly or paraphrased.
- Graphic elements.
- Passages of music, existing either as sound or as notation.
- Mathematical proofs.
- Scientific data.
- Concepts or material derived from the work, published or unpublished, of another person."

This policy applies, in all respects, to this course.

Carnegie Mellon University's Policy on Unauthorized Assistance (http://www.cmu.edu/academic-integrity/collaboration/index.html) states the following:

According to the University Policy on Academic Integrity, unauthorized assistance "refers to the use of sources of support that have not been specifically authorized in this policy statement or by the course instructor(s) in the completion of academic work to be graded. Such sources of support may include but are not limited to advice or help provided by another individual, published or unpublished written sources, and electronic sources. Examples of unauthorized assistance include but are not limited to:

- Collaboration on any assignment beyond the standards authorized by this policy statement and the course instructor(s).
- Submission of work completed or edited in whole or in part by another person.
- Supplying or communicating unauthorized information or materials, including graded work and answer keys from previous course offerings, in any way to another student.
- Use of unauthorized information or materials, including graded work and answer keys from previous course offerings.
- Use of unauthorized devices.
- Submission for credit of previously completed graded work in a second course without first obtaining permission from the instructor(s) of the second course. In the case of concurrent courses, permission to submit the same work for credit in two courses must be obtained from the instructors of both courses."

This policy applies, in all respects, to this course.

Carnegie Mellon University's Policy on Research Misconduct (http://www.cmu.edu/academic-integrity/research/index.html) states the following:

According to the University Policy For Handling Alleged Misconduct In Research, "Carnegie Mellon University is responsible for the integrity of research conducted at the university. As a community of scholars, in which truth and integrity are fundamental, the university must establish procedures for the investigation of allegations of misconduct of research with due care to protect the rights of those accused, those making the allegations, and the university. Furthermore, federal regulations require the university to have explicit procedures for addressing incidents in which there are allegations of misconduct in research."

The policy goes on to note that "misconduct means:

- fabrication, falsification, plagiarism, or other serious deviation from accepted practices in proposing, carrying out, or reporting results from research;

- material failure to comply with Federal requirements for the protection of researchers, human subjects, or the public or for ensuring the welfare of laboratory animals; or

- failure to meet other material legal requirements governing research."

"To be deemed misconduct for the purposes of this policy, a 'material failure to comply with Federal requirements' or a 'failure to meet other material legal requirements' must be intentional or grossly negligent."

To become familiar with the expectations around the responsible conduct of research, please review the guidelines for Research Ethics published by the Office of Research Integrity and Compliance.

This policy applies, in all respects, to this course.

Take care of yourself. Do your best to maintain a healthy lifestyle this semester by eating well, exercising, avoiding drugs and alcohol, getting enough sleep and taking some time to relax. This will help you achieve your goals and cope with stress.

All of us benefit from support during times of struggle. You are not alone. There are many helpful resources available on campus and an important part of the college experience is learning how to ask for help. Asking for support sooner rather than later is often helpful.

If you or anyone you know experiences any academic stress, difficult life events, or feelings like anxiety or depression, we strongly encourage you to seek support. Counseling and Psychological Services (CaPS) is here to help: call 412-268-2922 and visit their website at http://www.cmu.edu/counseling/. Consider reaching out to a friend, faculty or family member you trust for help getting connected to the support that can help.

If you have questions about this or your coursework, please let me know.