Course Syllabus

18-687: Analytical Performance Modeling & Design of Computer Systems
Fall 2016

Instructor: Osman Yagan
Office Location: HH A302
Email Address: oyagan@andrew.cmu.edu
Office Hours: TBD

Teaching Assistant: Yong Zhuang
Email Address: yongzhua@andrew.cmu.edu
Office Hours: TBD

Course Management Assistant: Michelle Mahouski
Email Address: mmahousk@andrew.cmu.edu
Office Location: HH 1112

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)

Breadth Area: Algorithms/Complexity/Programming Languages

Undergraduate Course Designation: -
Undergraduate Course Area: -

Class Lecture:
- Monday and Wednesday 12:30pm – 2:20pm WEH 5328 (PIT)
- Monday and Wednesday 9:30am – 11:20am B23 212 (SV)

Required Textbook:

Suggested Reading:


Other Supplemental Materials: -

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 Blackboard:**
To access the course blackboard from an Andrew Machine, go to the login page at: http://www.cmu.edu/blackboard. You should check the course blackboard 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:**

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<thead>
<tr>
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<tbody>
<tr>
<td>45%</td>
<td>Homework</td>
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<tr>
<td>25%</td>
<td>Midterm</td>
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<tr>
<td>30%</td>
<td>Final</td>
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**HW Policy:**
You will receive regular homework problems. These will be difficult. Start immediately so that you can take full advantage of office hours. You will find office hours very helpful! 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.

**Tentative Course Calendar:**

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<thead>
<tr>
<th>Date</th>
<th>Day</th>
<th>Class Activity</th>
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<tbody>
<tr>
<td>August</td>
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<tr>
<td>29</td>
<td>Mon.</td>
<td>Classes begin. Introduction to class, Queuing theory basics.</td>
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<tr>
<td>31</td>
<td>Wed.</td>
<td>Probability Review</td>
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<tr>
<td>September</td>
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<tr>
<td>5</td>
<td>Mon.</td>
<td>Labor Day; No Classes</td>
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<tr>
<td>7</td>
<td>Wed.</td>
<td>Probability Review ct’d.</td>
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<tr>
<td>12</td>
<td>Mon.</td>
<td>Time Avg. Vs. Ensemble Average, convergence, law of large numbers</td>
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<tr>
<td>14</td>
<td>Wed.</td>
<td>Operational Laws: Little’s Law, Forced-Flow law, Utilization Law, Bottleneck Law</td>
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<tr>
<td>19</td>
<td>Mon.</td>
<td>NO CLASS (due to ToC and instructor traveling)</td>
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<tr>
<td>21</td>
<td>Wed.</td>
<td>NO CLASS (due to ToC and instructor traveling)</td>
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<td>26</td>
<td>Mon.</td>
<td>Modification analysis, Performance Bounds</td>
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<td>28</td>
<td>Wed.</td>
<td>Discrete-Time Markov Chains</td>
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<td>October</td>
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<tr>
<td>3</td>
<td>Mon.</td>
<td>Ergodicity Theory, Ergodic Markov Chains</td>
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<td>5</td>
<td>Wed.</td>
<td>Ergodic theory cont’d.</td>
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<tr>
<td>10</td>
<td>Mon.</td>
<td>Exponential Distribution and Poisson Process</td>
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<tr>
<td>12</td>
<td>Wed.</td>
<td>Continuous time Markov Chains, M/M/1 and PASTA</td>
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<tr>
<td>17</td>
<td>Mon.</td>
<td>Transform Analysis, Server Farms: M/M/k and M/M/k/k</td>
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<tr>
<td>19</td>
<td>Wed.</td>
<td>Capacity Provisioning for Server Farms, M/M/∞, Time Reversibility</td>
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<tr>
<td>24</td>
<td>Mon.</td>
<td>Burke’s Theorem, Networks of Queues, Jackson Product Form</td>
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<tr>
<td>26</td>
<td>Wed.</td>
<td>Classed and Closed Networks of Queues</td>
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November
2 Mon. Understanding variability and tail behavior. Modeling Empirical Workloads: heavy-tailed property, Pareto distributions, heavy-tailed distributions
7 Mon. Matrix-analytic methods
9 Wed. M/G/1 queue and Inspection Paradox
14 Mon. M/G/1 transform analysis, Power Optimization Problem
16 Wed. Management of Server Farms: task assignment policies
21 Mon. Analysis of Scheduling: FCFS, non-preemptive priorities
23 Wed. Thanksgiving Holiday; No Classes
28 Mon. Scheduling cont’d. Preemptive priorities, PS, LCFS
30 Wed. Other scheduling techniques: Size based Policies

December
5 Mon. SRPT and Fairness
7 Wed. Final Test (Last Day of Class)
12-16 Final Exam Period (not relevant for this course)

Education Objectives (Relationship of Course to Program Outcomes):

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

(b) an ability to design and conduct experiments, as well as to analyze and interpret data:

(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

(e) an ability to identify, formulate, and solve engineering problems

(f) an understanding of professional and ethical responsibility

(g) an ability to communicate effectively:

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

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

(j) a knowledge of contemporary issues:

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

ECE Academic Integrity Policy
(http://www.ece.cmu.edu/programs-admissions/mastersacademic-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](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](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.*