ORI 390R.8 - Queueing Theory

- **Time & Place:** Tue & Thurs 11:00am-12:30pm, ETC 5.132
- **Professor:** John J. Hasenbein
  - **Office:** ETC 5.128B
  - **Phone:** 471-3079
  - **Email:** *jhas@mail.utexas.edu* (This is the best way to contact me.)
  - **Office Hours:** Mondays, 10:30am–12noon. You can also email me for an appointment.
- **Class Web Page:** We will be using the *Canvas* system, which is accessible through UT Direct. All class materials will be available via this system.
- **Suggested Text**:

  Analysis of Queues: Methods and Applications by Natarajan Gautam (CRC Press 2012).

  Other texts that will be useful during the class are listed below.

  1. ***Fundamentals of Queueing Theory*** by Donald Gross, John F. Shortle, James M. Thompson, and Carl M. Harris (4th edition, Wiley 2008).
  2. ***Fundamentals of Queueing Networks*** by Hong Chen and David Yao (Springer 2001).
  3. ***Applied Probability and Queues*** by Søren Asmussen (2nd Edition, Springer 2003).
  4. ***Sample-Path Analysis of Queueing Systems*** by Muhammad El-Taha and Shaler Stidham (Kluwer 1999).
  5. ***To Queue or Not to Queue*** by Refael Hassin and Moshe Haviv (Kluwer 2003).
  6. ***Stochastic Modeling and the Theory of Queues*** by Ronald W. Wolff (Prentice-Hall 1989).
  7. ***Introduction to Stochastic Networks*** by Richard Serfozo (Springer 1999).
  8. ***Reversibility and Stochastic Networks*** by Frank P. Kelly (Wiley 1979, Out of print). See `http://www.statslab.cam.ac.uk/~frank/` for an online version of the book.
  9. ***Stability of Fluid and Stochastic Processing Networks*** by Jim Dai. An electronic copy of the notes will be posted on *Canvas*.
  10. ***Stochastic Networks*** by Sunil Kumar. An electronic preprint, not for distribution, will be posted on *Canvas*.
  11. ***Optimal Design of Queueing Systems*** by Shaler Stidham, Jr. (CRC Press 2009).
- **Grading:** Problem sets will be assigned roughly every two weeks. Your class grade will be based on your homework average (45%), a class project (35%) and class participation (20%). Generally, I will use the class participation component to boost your overall average, if you come to class and occasionally participate in class discussion.

  For the problem sets, you may discuss problems with your classmates and in fact are encouraged to do so. However, you should understand and write-up your <u>own</u> solutions. A good rule of thumb is that you should be able to explain to me the solutions you have submitted.

- **Prerequisites:** For this course, you should have a good knowledge of Poisson processes and discrete and continuous-time Markov chains. It is highly recommended that you have taken a course equivalent to ORI 390R.5 - *Applied Stochastic Processes*. I will assume that you are thoroughly familiar with all the topics in covered in that class.
- **Email Communication**: For this class, email will be used as an official form of communication for notifying you of new homework assignments and other class updates. The University of Texas email policy can be found at `http://www.utexas.edu/cio/policies/university-electronic-mail-student-notification-policy`.
- **Students with disabilities:** The University of Texas at Austin provides, upon request, appropriate academic adjustments for qualified students with disabilities.
- **Course Evaluation:** Near the end of the course you will have an opportunity to anonymously evaluate the course and instructor using the standard evaluation form.

Course Topics

Queueing theory is the study of stochastic processing systems, whose primary elements are "servers" and "customers." Customer arrival times and service times are assumed to possess some randomness and we use utilize a variety of methods from the theory of stochastic processes to analyze these systems. Applications of the theory are wide-ranging, including manufacturing, telecommunications, computer networks and servers, Internet traffic, inventory, and insurance/risk theory.

The course will be roughly divided into two major parts. In the first part we will discuss "classical" queueing theory, which generally involves one server systems or networks (many-server systems) with somewhat restrictive probabilistic assumptions, i.e., exponential service and interarrival times. In the second part, we will study a sample of topics from the modern theory of stochastic processing networks, developed mostly in the last 20 years. This theory attempts to address non-Markovian models, multiclass systems, and scheduling methods. The modern theory is quite powerful and the subject of intense research in the field.

Additional References

- **Stochastic Processes**
  - *Stochastic Processes*, by Sheldon M. Ross (2nd Edition, Wiley 1996)
  - *Modeling and Analysis of Stochastic Systems*, by Vidyadhar W. Kulkarni (2nd Edition, Chapman & Hall 2009)
  - *A First Course in Stochastic Processes*, by Samuel Karlin and Howard M. Taylor (2nd Edition, Academic Press 1975)

Course Topics & Suggested Readings

Gautam's book has material on nearly all of these subtopics, but lectures are derived from the various sources listed.

I. General Laws and Analysis of Single Station Systems

- Intro to queueing theory, nomenclature (G: 1.1 and 1.3)
- Rate stability, Little's Law, and ASTA principles (ET and S, various).
- The M/M/1 Queue - Basics (G: 2.2.1)
- The M/M/1 Queue - Optimization
  - Game theoretic queues, Naor's model, unobservable queues (HH: 2.1–2.3, 3.1 and 3.2)
  - Optimizing simple queueing systems (Stidham, Chapter 1)
- The Erlang Classics - Erlang A, B, and C (G: see section headings)
- Advanced Erlang-C: Asymptotics and Bounds (Kumar, Chapter 1, through Section 1.4)
- Erlang distributions and generating functions (Wolff: 5.12)
- The M/G/∞ queue (Wolff: 2.6), M/G/1 and GI/M/1 queues (G: 4.1)
- The GI/G/1 queue, Kingman's upper bound and lower bounds (Wolff: 11.1 and 11.2)
- Scheduling rules for single server networks (Wolff: 5.14)

II. Classical Stochastic Networks

- Tandem and feedforward networks
- Open and closed Jackson networks (CY: 2.1 and 2.2)
- Reversibility (CY: 1.2 and 4.1, Kelly)

III. Stochastic Networks

A. Open Multiclass Queueing Networks
   - Open multiclass queueing networks (Dai: 1.2)
   - Service disciplines and dispatch rules (Dai: 1.2)
   - The functional SLLN, the 1D reflection map, and fluid limits (CY: 5.4, 6.1–6.3)
   - Traffic equations (Dai: 1.4)
   - Fluid networks (Dai: 2.2 and 2.3)

B. Stability and Throughput Optimality
   - Stability results: Dai's Theorem and Chen's Theorem, converse results, Bramson's Lemma (Dai: 2.6)
   - Fluid and Queueing Dynamics (Dai: 1.5 and 2.2)
   - Lyapunov functions, global stability, and throughput optimality (Dai: 2.4)
   - Leaky bucket regulators (Dai: 2.9)

C. Further Topics in Stochastic and Fluid Networks
   - Networks with setups, batching, Harrison's framework
   - Fluid model optimization: makespan and holding cost