CE 661: Algorithms in Transportation

Instructor: Professor Satish Ukkusuri

Prerequisite: Undergraduate calculus, knowledge of probability, statistics and linear algebra at the undergraduate level. Basic programming skills in languages such as C++, VB or Java.

Credits: 3

Day/Time: Tuesday (3:30 – 6:20 PM). **Location**: HAMP 3153

Texts:
- Sheffi, Y. *Urban Transportation Networks: Equilibrium Analysis with Mathematical programming methods*. Prentice-Hall Inc., Englewood Cliffs, NJ, 1985. [Out of print]. Required handout from this text will be distributed in class. You can download a free copy of the book here: http://web.mit.edu/sheffi/www/urbanTransportation.html
- D. Easley, J. Kleinberg. Networks, Crowds, and Markets: Reasoning About a Highly Connected World. Cambridge University Press, 2010.

Main References:
- Ahuja, R.K., Magnanti, T.L. and Orlin, J.B. *Network Flows: Theory, Algorithms and Applications*. Prentice-Hall Inc., 1993.
- Cascetta, E. *Transportation systems engineering: theory and methods*. Dordrecht ; Boston, MA : Kluwer Academic, 2001.
- Bell, M.G.H., and Iida, Y. *Transportation Network Analysis*. John Wiley & Sons, 1997. ISBN 0471 96493 X

Journal References:
Transportation Research – Part B
Transportation Science
Networks and Spatial Economics

Course Description:
This course provides an introduction to conceptual, methodological and mathematical foundations of the analysis of transportation networks. A review of basic graph theory and mathematical programming techniques will be provided in the beginning.   The first half of the course will discuss network algorithms and analytical formulations to find equilibrium flow patterns over an urban transportation network.   The second half of the course will discuss basic concepts related to the structure of complex networks. For the first half, the basic solution methodology is based on formulating the problem as a nonlinear optimization problem and solving it

under different assumptions of trip making. Extensive use of intuitive arguments, counterintuitive phenomenon (paradoxes) and network structures will be utilized to illustrate many situations graphically. In addition, computing the solutions *efficiently* using various network algorithms will be discussed. For the second half, basics concepts related to homophily, strength of ties, power laws, small world phenomenon and the cascading behavior in networks will be discussed.

Course Objectives:
A student completing this course is expected to be able to:
1. Analyze transportation systems using game theory and optimization by drawing on analogies between the interactions of supply and demand in economic markets.
   a. Define selfish routing (user equilibrium) and system optimal problems
   b. Develop solution algorithms for large scale networks
2. Apply concepts of complex networks to various engineered networks
3. Apply specialized network structures to solve selfish routing games efficiently.
4. Apply how information, beliefs, and ideas diffuse in complex networks. Realize the interdependence of the social network with the transportation network
5. Rigorously formulate and apply various extensions of the selfish routing game – traffic assignment with elasticity, stochastic user equilibrium, network design and OD estimation.
6. Use software to analyze various large scale transportation networks and understand issues from real world practitioners

Tentative Course Outline:

Block 1 *Conceptual Foundation [**Weeks 1-3**]*
- Concept of equilibrium/selfish routing in transportation networks
- Network Representation and Game Theory
- Link Performance functions
- Solving simple user equilibrium problems
- Braess's Paradox
- Basic concepts in minimization problems
- Basic concepts in graph theory

Block 2 *User Equilibrium [**Weeks 4-5**]*
- Formulating the traffic assignment problem
- Existence and Uniqueness of Equilibrium
- System Optimization formulation
- Review of some optimization algorithms – Interval reduction methods, Method of Successive Averages, Convex combinations method
- Solving for user equilibrium – MSA and Frank Wolfe approaches
- Algorithm B

- TAPAS and Gradient Based Algorithms

Block 3 *Extensions of User Equilibrium [**Weeks 6-8**]*
- User equilibrium with elastic demand – formulation and solution algorithm
- Constrained traffic equilibrium – entropy based models
- User equilibrium with asymmetric cost functions – algorithm, proof of solution and convergence
- Stochastic User Equilibrium (SUE)
  - ✓ Review of discrete choice models
  - ✓ Concept of route choice and expected perceived travel time
  - ✓ Formulation of SUE, equivalence conditions, uniqueness
  - ✓ Solution algorithm for SUE
  - ✓ Another paradox of traffic flow
- Network Design

Block 4 *Fundamentals of Complex Networks [**Weeks 9-10**]*
- Strength of Weak Ties
- Betweenness Measures and Graph Partitioning
- Homophily
- Affiliation
- Tracking Link Formation in Social Networks

Block 5 *Small World Phenomenon and Power Laws [**Weeks 11-12**]*
- Measuring Popularity and Criticality of Network Elements
- Power Laws
- Rich Get Richer Models and their Unpredictability
- Six Degrees of Separation
- Structure and Randomness in Networks

Block 6 *Cascading Behavior in Networks [**Weeks 13-14**]*
- The Phenomenon of Diffusion
- Modeling Diffusion in Networks
- Diffusion, Thresholds and Weak Ties
- Extensions to the basic Diffusion Model

Format: Classes will be in a combination of lecture and discussion. Students are expected to participate actively in class discussions.

Homework:
- Problem sets will be given, and the analysis of these assignments will be the basis for some class discussion
- Problem sets are due at the beginning of class on designated days; late problem sets will not be accepted.

Grading Policy:

Problem Sets	30%
Exam	35%
Paper + Presentation	(25 + 10)%

For the problem sets, you may (are encouraged to) discuss with other students but the final written solution should be your own work. The exam will be open textbook and open class notes.

The paper must be scholarly and, if possible, should have some original input from the student. The paper should be prepared according to PLoS One format and should be of a comparable quality. The instructor will have the final approval of the topic.

Student Feedback:

Throughout the semester, students are especially encouraged to bring attention of the professor any difficulties/issues encountered during the lectures. The primary purpose of this is to provide the instructor with continuous feedback on how to improve the classroom-learning environment.