NME130 – Networked Systems

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Goal and assumption

- Topics to cover on networks
  - As part of a 2-term sequence on Information Systems
  - Close coupling of mathematical tools and their application in networking
- Estimated time for each topic
  - Relatively detailed coverage of small #topics
  - i.e., lectures rather than seminars
- Many overlaps with other NME courses or other areas in NME130 will be cleaned up later

Themes

- Not sure yet what the right themes should be for this Net Sys module
  - Will emerge naturally during or after first offering
- Focus on
  - Interaction of graph structures and optimization, linear algebra, stability
  - Canonical problems, optimality conditions, duality, other structural properties
  - Key algorithms and their complexity
  - Networking applications (broadly defined)

Potential topics

Math tools
Basic graph theory
Network flows
Convex optimization
CDS theory
Stochastic processes

- Graphical models not covered
  - Covered in "Synthesis theory": Bayesian nets, BP

Potential topics

Networking applications	Math tools
Shortest path routing; High speed switch scheduling	Network flows
Internet basics; protocol decomposition; congestion control	Convex opt, Stability, stochastic processes
Cooperative consensus & control, multi-agent dynamics	Graph theory, convex opt, stability, stochastic processes
Wireless	Matroid theory, info theory, … (?)

Wireless is probably too broad to fit, but may choose a couple subtopics?

You can help

Suggestions on

- Specific (sub)topics
- Key references
- Organization (focus only after above 2)

Summary of Discussions

Several (recurring) open questions were raised regarding the purpose, approach, and structure of NME130 modules

- What are the goals of NME/NME130/ NME130-Net Systems?
- What and how to integrate?
- How to coordinate among NME130 modules and NME courses (pre-requisites, concurrent, limited time)?

Discussion: NME130 goals?

- To advocate a certain point of view on networked system?
- To teach foundational math tools motivated by net applications?
- To teach networking specifics with an analytical approach?
- To illustrate how to think about net problems, not so much on specific details?

Discussion: NME130 goals?

I think we can only consistently do one of the following three:

- Information systems domain knowledge, with NME perspective
- Math tools, with IS applications
- A point of view, illustrated by some math tools applied to some IS problems

… and our choice will determine what materials to cover and how.

Doing a mix is possible but riskier

Discussion: how to integrate?

- Need simultaneously be more concrete and applied and more abstract and foundational
- Can we do better than keeping these separate, connected but not integrated?
  - A tools course that focuses on math foundations motivated by applications
  - An applications course that consists of case studies, domain specific problems solved by math tools

Discussion: logistics

- There are many overlaps among NME courses and among modules of NME130
- Best compression will require careful coordination
- The current set of modules seem too ambitious for 2 terms, but we can cut after the first pass of all modules

Discussion: a possible choice

A possible choice for NME130-NetSys is case-study oriented:

- Assume all math tools covered elsewhere
- Focus on a select set of networking topics (in Internet and/or biology)
- Teach key elements in sufficient detail that students understand well the domain knowledge covered
- NME point of view to the subject will emerge naturally but as a by-product

Example topics and estimated time

(The following slides were not discussed in detail because the choice of topics and approach will depend on our decision to the questions in the previous slides. Will re-visit later.)

Graph theory and network flows

- Shortest path algorithms & network routing
- Max-flow min-cut theorem & algorithms
- Bipartite matching & scheduling in high-speed switches
- Minimum spanning trees and multicommodity flows
- Menger’s connectivity theorem and reliability(?)

Graph theory and network flows

- References
  - Ahuja, Magnanti, Orlin: Network flows
  - Bollobas: Modern Graph Theory (Ch III)
  - Cormen, Leiserson, Rivest: Intro to Algorithms
  - Papers by Walrand, McKowen, Prabhakar on switch design, etc

Convex opt, stability theory & congestion control

- Convex optimization & duality basics
- Internet basics & protocol decomposition
- Lyapunov stability theorem
- Passivity theorem
- Nyquist stability theorem
- TCP congestion control
- Differential topology & general eq theory
- Heterogeneous congestion control

Convex opt, stability theory & congestion control

- References:
  - Opt: Boyd/Bertsekas
  - Lyapunov: Khalil
  - Passivity:
    - Brune, O. "Synthesis of a finite two terminal network whose driving-point impedance is a prescribed function of frequency", Journal of Mathematics and Physics, vol. 10, 191-236, 1931.
    - Anderson, B. D. O. "Network analysis and synthesis: A modern systems theory approach," Englewood Cliffs, NJ: Prentice-Hall, 1973.
  - Nyquist: Wang & Desoer, Paganini, Vinnicombe
  - TCP: Kelly, Low & Lapsley, Papachristodoulou, Li & Doyle, Walrand, Tang, etc.

Graph+stability theory and cooperative control

- Adjacency matrix & Laplacian
  - Eigenvalue distributions & combinatorial properties of graphs
- Cooperative consensus and control

- References
  - Bollobas: Modern Graph Theory (Ch VIII)
  - Papers by Murray, Jadbabaie, Tsitsiklis

Estimated time

- Graph theory and network flows, switch design
  - 7-12 hrs
- Convex optimization + stability theory and protocol decomposition, congestion control
  - 6-8 hrs
- Graph theory + stability theory and cooperative consensus & control
  - 5-6 hrs
- Total: 18 – 26 hrs
  - Much shorter if math tools are covered elsewhere and this module only focuses on a few case studies

- Wireless network connectivity & throughput?
- Matroid theory + application (wireless?)

Wireless network

- Not sure exactly what materials yet, but …
- Transport capacity (Kumar,et al)
- Wireless network connectivity (Tse, Hassibi, Franceschetti, et al)

- Related to network information theory that will probably be covered in another module

Matroid theory & application(?)

- Not sure exactly what materials yet
- References