Engineering Systems Doctoral Seminar ESD.83-- Fall 2009

Class 9--Lec #9

Faculty: Chris Magee and Joe Sussman

Guest: Prof. Hamsa Balakrishnan, Aero & Astro and ESD

Class 9 overview

- Welcome, Overview and Introductions (5 min.)
- Dialogue with Professor Balakrishnan (55min)--Redaction provided by Kaushik Sinha
- Break (10 minutes)
- Discussion of ESD.83 faculty-provided theme-related papers led by Julio Pertuze (approximately 30-40 min)
- Theme and topic integration: Report from the front; Teaching and Learning Time -- (Sussman)
- Next Steps -preparation for Class 10 - (5 min.) (Sussman)

Theme and topic integration: Class 9, November 4, 2009

- Report from the front--New York Times, October 28, 2009 “Bay Bridge Failure Raises Questions About Long-term Safety” and some others…..
- “Teaching and Learning Time”-- Critical Infrastructure; Some Introductory Network Concepts; Organizations as Networks
- Class 10 Plan -- Your turn!

“Teaching and Learning Time”

- Critical Infrastructure
- Some Introductory Network Concepts
- Organizations as Networks
- To think about: Match-up of Class 9 with
  - Framing Questions
  - Learning Objectives

Critical Infrastructure

- What makes an infrastructure "***Critical***"-- YOUR IDEAS, PLEASE

Critical Infrastructure

- What makes an infrastructure "***Critical***"
- A matter of "taste"
  - Life safety?
  - HILP (High impact, low probability) events?
  - Large economic disruption?
  - Large societal disruption?
  - "You bet your company"?
  - "You bet your job"?

ESD Offsite

- June 2008
- Critical Infrastructures Breakout

- Identify Different Classes of Infrastructure and Think About Their Interactions
  - Transportation
  - Communication
  - Water Supply
  - Energy
  - Materials

All are Network-based--development of common methodologies across classes is the goal

Institutional Issues I

- And we should NOT lose sight of the *Institutional Issues* we face in CI
  - Organizational structure and institutional interactions (there are organizational cultures which are slow to change)
  - Need for huge resources and the notion of public/private partnerships to give access to new sources of capital and expertise
  - Legacy issues: we usually have an infrastructure in place - rarely a greenfield development

Institutional Issues II

- Multiple stakeholders with different perspectives, about which they often feel strongly
- Interaction of the institutional issues with the technological questions
- Working across classes of infrastructure presents additiional institutional issues (and it was hard enough already!)

CIs must be considered through the three ESD lenses

- New infrastructure networks: for these (like the cellphone network), first technology dominates; then as the system matures, social science and management considerations come to the fore
- "Legacy" infrastructure network: usually bound by institutional constraints that limit our options - "huge sluggish organizations"

Questions

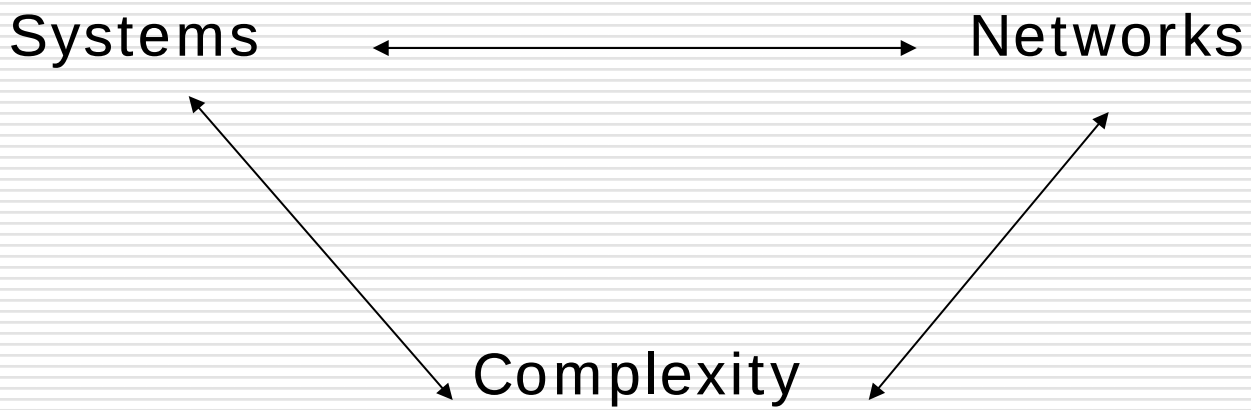
- Networks interact with each other - cascading failures
  - Intra-infrastructural - on highways, a crash at important node causes congestion throughout - or intermodally, the interplay between passenger air transportation and HSR for trips of less than 500 miles
  - Inter-infrastructural - the interaction between communications and transportation networks (ITS, eg)
- Interaction of the technologies with organizations - local deployment and communications issues - can the firefighters communicate with the police?
- What defines an infrastructure as critical?
- How does a system evolve to become critical?
- What does 'failure' mean? Spatially? Temporally?

Engineering Systems Research

- The value of historical case studies - serious scholarship - case studies - but from *an engineering systems viewpoint*
  - Katrina
  - 9/11
  - 2003 Power Failure

Some Introductory Network Concepts

Networks, "Systems" and Complexity



- It is very difficult (for me) to separate these ideas
- Questions of Connectivity
- Questions of Scale

Frances Fukuyama on Arthur Peacock

"In the words of Arthur Peacock "The concepts and theories…..that constitute the content of the sciences focusing on the more complex levels are often (not always) not reducible to those operative in the sciences that focus on their components". There is a hierarchy of levels of complexity in the sciences, with human beings and human behavior occupying a place at the uppermost level.

Each level can give us some insight into the levels above it, but understanding the lower levels does not allow one to fully understand the higher levels' emergent properties."

Frances Fukuyama in "Our Posthuman Future"

Marilyn Ferguson

"General systems theory says that each variable in any system interacts with the other variables so thoroughly that cause and effect cannot be separated. A simple variable can be both cause and effect. Reality will not be still. And it cannot be taken apart! You cannot understand a cell, a rat, a brain structure, a family, a culture if you isolate it from its context. Relationship is everything."

Marilyn Ferguson
The Aquarian Conspiracy—from Ali Mostashari's Chapter 3

Herbert Simon

"The fact that many complex systems have a... hierarchic structure is a major facilitating factor in enabling us to understand those systems."

Herbert Simon

Charles Handy-- A comment on history

"It was only later that I myself came to see that you have to oversimplify things sometimes in order to begin to understand them. Only when the basic frameworks are established can you add in the qualifications and complexity."

" **History** I found fascinating. I discovered a growing pleasure in seeking to unravel the causes of things, to reveal the interwoven connectedness of individuals, contexts and events. Historians have always known that life is never as simple as it appears. It was a way of thinking that became part of me. No one told me I was discovering for myself something I later found was termed 'systems thinking'. Later on, when I was directing programs at the London Business School, it was no surprise to find that the best students were often the historians." (bold mine)

Charles Handy

Networks - Introductory Concepts

- The idea of networks is intuitive - we sketch our nodes and links connecting them.
- But you need to think about
  - What do the nodes represent?
  - What do the links represent
  - What does connectivity imply?
- ESD has a broad range - this means we need to look at networks in a broad manner
- Complexity often arises in systems that have a network structure
- Network behavior is an emergent property of network structure and link and node characteristics

Network Types

- Physical
  - Transportation
  - Energy
  - Water
- Organizational
  - US Government
  - MIT
  - Social networks
- Conceptual
  - Systems Dynamics
- Other?

Networks - Some Basic Questions

- What flows on the links?
  - In physical network
  - In organization network
  - In conceptual network
- How do you characterize a link?
- What processes are performed at the nodes?
- How do you characterize the node?
- Level of network detail?
- Dynamic Vs. Static Network Structure

An Interesting (Vital?) Research Area for ESD:

- How do we analyze/design/ understand systems composed of networks of different types - physical, organizational, conceptual?

Networks in Organization Research

- The Network Paradigm in Organization Research: A Review and Typology
  - Stephan P. Borgatti and Pacey C. Foster
- Intraorganizational Networks: The Micro Side
  - David Krackhardt and Daniel J. Brass
- Temporarily Divide to Conquer: Centralized, Decentralized, and Reintegrated Organization Approaches to Exploration and Adaptation
  - Nicolaj Siggelkow and Daniel A. Levinthal
- Governing by Network: The New Shape of the Public Sector
  - Stephen Goldsmith and William D. Eggers
- Cooperation in Evolving Social Networks
  - Nobuyuki Hanaki, Alexander Peterhansl, Peter S. Dodds and Duncan J. Watts
- Consensus and Cooperation in Networked Multi-Agent Systems
  - Reza Olfati-Saber, Alex Fax and Richard M. Murray

The Network Paradigm in Organizational Research: A Review and Typology

Stephen P. Borgatti and Pacey C. Foster

Journal of Management, Vol. 29, No. 6, 991-1013 (2003)
DOI: 10.1016/S0149-2063_03_00087-4

- Networks in organizations research
  - What are the forces that shape networks?
  - How do they grow, shrink, etc?
- Dimensions of Network Research
  - Direction of causality
  - Levels of analysis

- Direction of Causality
  - A fundamental dimension distinguishing among network studies is whether the studies are about the causes of network structures or the consequences.
  - How networks evolve vs. how they perform

- Levels of Analysis
  - Basic level is dyadic (ties between the actors)
  - Next level up are whole networks
  - For example, suppose we examine how an actor's centrality in the communication network of an organization relates to her ability to innovate and solve problems (e.g. Perry-Smith & Shalley, 2003). This is an actor-level analysis, one step up (i.e. more aggregate, fewer values) from the dyadic level.

Intraorganizational Networks

The Micro Side

David Krackhardt and Daniel J. Brass

Chapter 8 in Stanley Wasserman and Joseph Galaskiewicz. (1994). Advances in social network analysis: research in the social and behavioral sciences. Thousand Oaks, CA: Sage Publications.

- Tichy (1981) suggests organization research incorporate a network perspective
- A lot of subsequent network research work on interorganizational questions
- Much less network research on organizational behavior (OB)
- Macro-research (interorganization) performed by sociologists - comfortable with network ideas; micro-research (intraorganizational) performed by psychologists considering networks of individuals; psychologists have been slower to use network ideas
- The above is the classic “scale” issue

Temporarily Divide to Conquer: Centralized, Decentralized, and Reintegrated Organization Approaches to Exploration and Adaptation

Nicolaj Siggelkow and Daniel A. Levinthal

Organization Science. 14(6):650-659.(November 2003)

- To create a competitive advantage, firms need to find activity configurations that are not only internally consistent, but also appropriate given the firm's current environment.
- This challenge is particularly acute after firms have experienced an environmental change that has shifted the existing competitive landscape and created new, high-performing sets of activity choices.
- How should firms organize to explore and search such an altered performance landscape?

- While it has been noted that adaptive entities need to maintain a balance of exploration and exploitation, little is known about how different organizational structures moderate this balance.

- With the help of an agent-based simulation model, we study the value of three different organizational structures:
  - A centralized organization, in which decisions are made only at the top level of the firm as a whole.
  - A decentralized organization, in which decisions are made independently in two divisions.
  - A temporarily decentralized firm, which starts out with a decentralized structure and later reintegrates.

- We find that if interaction among a firm's activities are pervasive, neither the centralized nor the permanently decentralized organizational leads to high performance.
- In this case, temporary decentralization - an organizational structure that has not found much attention in the literature - yields the highest long-term performance.

Governing by Network

The New Shape of the Public Sector

Stephen Goldsmith and William D. Eggers

Publisher: Brookings Institution Press
Pub. Date: 2004
ISBN: 9780815731290

- "From business to warfare, networked organizational forms are supplanting hierarchies. Now, Goldsmith and Eggers, two of America's most innovative policy thinkers, show how the networking trend is transforming government. This book is a must read for anyone concerned with how to make government better and more cost effective."

  - *Mitt Romney*, Governor of Massachusetts

- "Government alone cannot address society's most pressing challenges. Instead, new kinds of collaboration are needed, with the private sector and social enterprises playing central roles. Goldsmith and Eggers offer a penetrating and insightful treatment of how to make the new collaborative and networked approach to government actually work. We are in the process of rewriting the rules of public management, and this book is a major contribution."

  - *Michael E. Porter*, Harvard Business School

Chapter 1- The Bottom Line I

- The era of hierarchical government bureaucracy is coming to an end. Emerging in its place is a fundamentally different model - governing by network - in which government executives redefine their core responsibilities from managing people and programs to coordinating resources for producing public value.
- Governing by network represents the confluence of four trends that are altering the shape of public sectors worldwide:
  - The rise in the use of private firms and nonprofits to do governments work,
  - Efforts to "join up" governments horizontally and vertically to streamline processes from the perspective of the customer-citizen,
  - Technological breakthroughs that dramatically reduce the costs of partnering, and,
  - Increased citizen demands for more choices in public services

Chapter 1- The Bottom Line II

- As governments rely less on public employees and more on a web of partnerships and contracts to do the public's work, how well an agency manages networks contributes as much to its successes as how well it manages its own public employees

Chapter 2-- The Bottom Line

- Networks encourage the kind of experimentation so critical to the innovation process by enabling government to explore greater range of alternatives involving a variety of providers.
- Networks also enable a government to concentrate on its core mission by leveraging the expertise of “best of breed” providers.
- Networks enhance flexibility. By using outside partners to deliver a service or accomplish a task, managers can increase, decrease, or change resources on short notice
- The decentralized, fluid form of a network and the autonomy of each member allows for decision-making at the most appropriate level for the citizen.

The Design Phase: 5 Questions

- What goals does the government hope to accomplish?
- Which tools will be used to form and activate the network?
- Who are the most appropriate partners to help government accomplish its goals?
- How should the network be designed given the professed goals?
- How should the network be governed and managed?

- By starting first with mission and then configuring the process, network government can offer a fundamental change from traditional government that often looks first to process and then to mission.

Coping with Change

- Creating a Flexible Network Design
  - The structure of government with its lumbering personnel process and its self-inflicted legal constraints limits flexibility. Networking, through alliances with the highly fluid private sector, allows governments to adapt better to changing circumstances. For this reason, an inflexible network violates its very purpose.
- The network should have the ability to:
  - Add or subtract partners or services
  - Broaden or shrink its scope
  - Incorporate missing elements
  - Allow and share unanticipated successes
  - Collaboratively manage unplanned failures
  - Revise performance goals

Cooperation in Evolving Social Networks

Nobuyuki Hanaki, Alexander Peterhansl,
Peter S. Dodds and Duncan J. Watts

MANAGEMENT SCIENCE
Vol. 53, No. 7, July 2007, pp. 1036-1050
DOI: 10.1287/mnsc.1060.0625

Individual Behaviors and Interaction Structures

- We study the problem of cooperative behavior emerging in an environment where individual behaviors and interaction structures coevolve.
- Players not only learn which strategy to adopt by imitating the strategy of the best-performing player they observe, but also choose with whom they should interact by selectively creating and/or severing ties with other players based on a myopic cost-benefit comparison

Scalable Cooperation

- We find that scalable cooperation - that is, high levels of cooperation in large populations - can be achieved in sparse networks, assuming that individuals are able to sever ties unilaterally and that new ties can only be created with the mutual consent of both parties.
- Detailed examination shows that there is an important trade-off between local reinforcement and global expansion in achieving cooperation in dynamic networks.

A counterintuitive outcome

- As a result, networks in which ties are costly and local structure is largely absent tend to generate higher levels of cooperation than those in which ties are made easily and friends of friends interact with high probability, where the latter result contrasts strongly with the usual intuition.

A Social Dilemma

- The crux of all cooperation problems is the notion of a *social dilemma*: Individuals in a pair, group, community, organization, or society are faced with a choice between two alternative courses of action, one of which is *prosocial* (e.g., “cooperation”) and the other selfish (e.g., “defection”), where the former imposes a greater direct cost or confers less benefit on the individual than the latter

- The dilemma arises because each individual is by definition always better off behaving selfishly, but when all individuals do so, the collective outcome is worse for everyone than if prosocial behavior had prevailed

Main Contributions

- (1) to extend the standard modeling framework to include partner choice (what we call *interaction dynamics*) as well as the usual action choise (*behavioral dynamics*) in an individual's repertoire of decisions; and, in particular,
- (2) to examine the effect of a *triadic closure bias* (Rapoport 1963) - the tendency of an individual to connect to a "friend of a friend" - on both interaction dynamics and behavioral dynamics.

Consensus and Cooperation in Networked Multi-Agent Systems

Reza Olfati-Saber, J.Alex Fax, Richard M. Murray
Proceedings of the IEEE, vol. 95, no. 1, pp. 215-233, Jan. 2007.

Introduction

- This paper provides a theoretical framework for analysis of consensus algorithms for multi-agent networked systems with an emphasis on the role of directed information flow, robustness to changes in network topology due to link/node failures, time-delays, and performance guarantees

Networked Dynamic Systems--A Variety of Applications

- We discuss the connections between consensus problems in networked dynamic systems and diverse applications including synchronization of coupled oscillators, flocking, formation control, fast consensus in small-world networks, Markov processes and gossip-based algorithms, load balancing in networks, rendezvous in space, distributed sensor fusion in sensor networks, and belief propagation

Simulation Results

- Simulation results are presented that demonstrate the role of small-world effects on the speed of consensus algorithms and cooperative control multivehicle formations

"Consensus"

- In networks of *agents* (or dynamic systems), "consensus" means to reach an agreement regarding a certain quantity of interest that depends on the state of all agents.
- A "consensus algorithm" (or protocol) is an interaction rule that specifies the information exchange between an agent and all of its neighbors on the network.

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