Lecture 2 Outline

- Terms and Definitions for Engineering Systems
- Project discussion
- Biases and prejudices about systems and structure
  - Magee
  - Moses
  - Whitney
  - Class participants introduction
- Return to Network Analysis Preview
  - Some Network Terms and Definitions
  - Networks metrics and types
  - Research Front Issues

Terms and Definitions

Review/discuss Terms and definitions document that was posted

- System
- Function
- Performance
- Properties or characteristics
  – Broad term includes functions of direct interest to users but also other characteristics
  – Complexity, uncertainty, emergence (next slide)
  – Properties affecting Life-cycle or broad concerns ("ilities")
- Ilities
  – Flexibility/Evolvability
  – Robustness
  – Sustainability

Other System Characteristics

- Complexity
- Uncertainty
- Emergence

What are the relationships, especially trade-offs, between forms, functions, ilities, performance and these characteristics?

Other Words/Phrases That We Will Use and Need to Understand

- Element, module, component, agent
- Pattern (repeating), motif
- Interface, boundary
- Functional Performance Dynamics
- Integrality, modularity, dependence, independence, central control, distributed control, autonomy
- Relationship, interaction, path
- Hierarchy, layer, platform
- Decomposition, integration
- Cluster, clique

Form and Function

- Function
  – (narrow) what the system does, as opposed to Performance and Ilities
  – (broad) combines function, performance and ilities
- What is the relationship between Form (assume meaning is equivalent to the definitions we discussed for structure or architecture in lecture 1) and Function?

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Project Goals

- Analyze and attempt to improve upon an existing large scale system (or organization)
- Understand the domain of the system (and its history, if relevant)
- Use Course Material on the system
  - Pay attention to data availability and quality, and note any observational limits
  - Test methods and tools for usefulness
  - Identify opportunities for quantitative analysis and necessary qualitative aspects
  - Identify hierarchy of various types if applicable
  - Apply network analysis and other quantitative tools
  - Identify architectural types and compare to canonical forms
  - Understand system ilities and constraints
  - Make comparison to other systems

Project Deliverables

- **Meetings with assigned project faculty:** should occur at least once in each phase, that is, a week or two before each presentation
- **LEC #12**: Each project team gives a 10 minute presentation on their **project status**
- **LEC #21**: Each project team gives a 12 minute presentation on **the quantitative aspects of their project** (network analysis and other tool application)
- **LEC #24**: Each project team to give 20 minute (2 person teams) **final presentations** on their project.
- **Presentation Constraints**:
  - **Each project member** is required to give a minimum of **two (partial) presentations** during the term.
  - Presentation times are relatively short and will be held
- **LEC #25**: Final Written report due at noon for all projects.

Further Project Information

- A Project Information document is posted in the project section of the web site containing the information on the last two slides plus
- Final Presentation Objectives
- Final Report Content (a relatively detailed outline)

Project Ideas

- Build and analyze a collection of social network data- for example from MySpace
- Map the New England power grid from 1965 blackout reports
- Build and analyze networks from Amazon's “people who bought this book also bought…” or something analogous from eBay
- Look at propagation of videos or other messages on YouTube (or editing on Wikipedia)
- Look at starting lineups in baseball, trying to correlate starting pitchers and key batters, or day/night, etc.
- Compare public transit layouts in large cities world wide
- Make an agent model of distribution system growth, such as nerves, capillaries, transit or highways
- Look at citations among protocols done by the World-wide web consortium to build and analyze a network
- Examine patent citations to determine interconnectedness and to identify “root technologies”
- Study functional performance of a system over time and relate it to an objective structural description of the system over time.

Project Next Steps - assignment 1

- Project proposal (details on site in General area)
  - Propose a ***system*** to use as a semester case study for application of course knowledge.
  - Describe it briefly:
  - Include a name or descriptive title for the system
  - Roughly delineate a "boundary" or what is in and what is out of your system.
- Tell us briefly:
  - Why the proposed system is interesting to you
  - What you hope to learn by studying it
  - What **data sources** are you aware of that may help you build a specific model that can be objectively exercised
  - What you hope the results of the study will add to our collective knowledge about system architecture
- Due dates:
  - To instructors (1 page Word document) the day before LEC #12
  - Bring **10 copies to class** for group discussion

C L Magee Biases

- Based upon **Practice** Experience
  - ***Legacy*** is more important than one usually realizes in the design of real systems
  - ***Standards and protocol design*** is the major way to influence the “design” of real world complex systems
- Based upon **Materials Science** Education and Research Experience
  - Physics as “model” discipline
    - Observations of reality are the gold standard and much work is involved in “refining and understanding” observations
    - Mathematical models are essential for real progress
  - Materials Science Mantra as a Metaphor for what we are trying to do in Systems Architecture

More on CLM Biases

- Physicists (and copiers) Biases
  - The key to any Scientific Advance is to "explain the complex visible by some simple invisible" (*mechanism*) Jean Perrin
  - "Unless you can quantitatively measure it, you do not know what you are talking about" Lord Kelvin (Thompson)
  - Caveat (age of earth estimated from Temperature of earth)
- Came to Software/information technology later (1970's but mostly 1990's)
- Came to biology later (systematics of interest earlier but mostly 2000's)
- Strong interest in Economics even in UG education
- Another "bias" of mine is that the **permanence of biases** varies among **individuals**

The Materials Science Mantra

“processing”>”structure”

“structure”>”properties”

A Metaphor for Architecture of Engineering Systems ?

THE METAPHOR EXPANDED I

- PROCESSING> STRUCTURE> PROPERTIES
- Structure ~ Architecture
- Where is Design?
- Where is Behavior?
- **Structure** determines/affects **properties**
  - **Structure** is a multi-dimensional term that includes many scales and concepts simultaneously (and thus is not a “simple invisible”)
  - **Properties** include attributes that encompass dynamics, behavior and “ilities”.
  - Relationships between Structure and Properties are plentiful and became strongest as material classes under detailed study increased
  - Solid Mechanics, dislocation theory, atomic theory are some key enablers of deriving mechanisms to explain relationships

THE METAPHOR EXPANDED II

- **Processing** determines **Structure**
  – Different Processing Modes (casting, forging, crystal growth, e- beam deposition, etc.) have different ***control parameters*** (Temperature gradient, stresses, pressure, magnetic and electrical fields, composition, etc.) that affect/determine properties.
  – ***Design*** is thus *modifying the processing modes and control parameters to obtain the desired combination of properties*. ***Understanding structure is the chief enabler of effective design***
  – Thermodynamics, phase transformations, thermal and fluid sciences, solid mechanics are useful fundamentals underlying Process/structure relationship
- Engineering Systems Analogies

THE METAPHOR EXPANDED III

- Structure Characterization
  - Materials-Multiple Dimensional and very broadly construed: examples…..
- Engineering Systems Possibilities for Architecture Characterization.. much of the focus of this course in my metaphor

Learnings from Materials Science Experience

- Utility as Scientific framework has been easier to establish than as practice enabler
- Possible Lessons
  - Both Structure and Properties have to be viewed flexibly to make real progress
  - Quantitative Theories relating properties and structure are best evaluated while studying multiple systems
  - Details matter (observation and models)
  - "Concepts" emphasis and meaning changes (e.g., genes)

My Biases Regarding Systems Architecture

Joel Moses

February 2008

My background and interests in systems architecture

- Born in Israel to German and Romanian parents
- Came to US 50 years ago
- Education
  - Pure math bachelors
  - Applied math masters
  - PhD in artificial intelligence/computer science/pure math
  - Not overwhelmed by math approaches, unless they give great insight to major issues
- MIT activities
  - Built MACSYMA system for math formulas
    - Uses abstract algebra heavily
    - Uses layered abstractions for formula manipulation
    - Several thousand references to MACSYMA in Google Scholar
  - Head EECS department
    - Found some management issues similar to issues in AI and software engineering
  - Dean of Engineering
    - Originated SDM program, began discussions of ESD
  - Provost
  - Institute professor, EECS prof, ESD prof
  - Acting Director CTPID

Some of my attitudes regarding systems

- I believe that one's background (e.g., national origin, educational experiences) biases the way one approaches complex systems
- National ideologies (e.g., how individualistic or communitarian the society is) contain biases regarding the architecture of systems and organizations
- Undergraduate majors can have implicit assumptions that can also bias one's approaches
- If you know perfectly well what to do, then there is no problem, but usually one does not know exactly what to do, and the environment keeps changing. Thus ideologies and related attitudes play an important role

A guide to my interests in system architecture

- I do not differentiate much between system architectures and organizational structures
- I am far less interested in system function or performance, since in CS there are many ways to achieve any particular function
- Another reason I am less interested in function and performance is that I emphasize the changes that will take place in a system over time. The rate of change is very important in this analysis. I emphasize medium rates of change. One shot systems (thus low rates of change) or systems that undergo revolutionary changes are of relatively little interest to me, except as extremes.
- Systems architecture to me should emphasize the changes that take place over the lifetime of a system. Thus it is quite different from systems engineering which usually involves designing a system to specific requirements.

Guide (2)

- I am most interested in architectures that include hierarchies, both tree structured hierarchies and layered hierarchies. In a world where things change a lot, architectures are aspects that change less, and thus are important building blocks.
- I am also interested in certain types of networks, such as hub and spokes
- I believe that 'ilities' are very important for us to understand, especially ones that relate to change, such as flexibility. The ability to cope with continual change is the most important characteristic of complex systems for me.
- Flexibility and complexity in relation to architecture is an important issue to me
- There is no ideal answer to many systems issues, such as architecture. Much depends on the environment and how it will change over time

Optimization

Overall system optimization makes little sense if one emphasizes change. This is especially true if the time needed to implement the changes is so high that the system requires additional changes before one is done implementing the previous ones.

There is a tendency to overestimate the loss in efficiency when one architects a system to be flexible.

Assumptions and Biases-Whitney

- Every design and system has multiple phenomena operating at the same time
- This has several consequences
  - Parts must be designed and tested separately and then tested together
  - Analytical models and simulations will not be able to encompass all the important things that could happen or must be understood
  - A “digital” plug-play or modular approach will not work and may not even lead to a good design

Things That Are Important

- Geometry, geometric relationships, and visualization
- Mass and space occupancy
- Motion (dynamic space occupancy, acceleration loads)
- Forces, loads, load paths
- Tight coupling that's unavoidable: propagation of loads, heat, fluid, vibration, fatigue - generally linkage of effects and time-driven effects
- Ever-present constraints
  - Generic: the laws of physics
  - Specific, often enterprise-driven: space, weight, cost in this particular design

Things We Usually Don't Think About Because They Won't Happen

- A theory that will tell us the right way to design something, tell us how far off the optimum we are, or tell us what to do to get to the optimal design
- The idea that it will be right the first time
- The idea that we will have time to be sure it is right
- The idea that you can get it done without someone who really knows what they are doing

Other Thoughts

- The "right way" usually is found and after a while a search is no longer needed (airplane wing, car engine); no canonical architectures exist, such as trees, but consensus architectures for specific kinds of things emerge
- No single part is the hero that makes the product work; the product's architecture, the way the parts work together, is the key thing
- Sometimes no agreement or convergence occurs (car door design) - or else a comfort zone emerges after lots of experimentation, and people are reluctant to try something different
- More design and testing time are devoted to finding and mitigating side effects than in assuring achievement of basic function and performance

What's Basic to MechE

A. Analytical
   1. Need to consider basic physical phenomena as part of every design exercise
   2. Must know the limits of the models
   3. Must do geometric reasoning
   4. Each phenomenon has its own detailed models
   5. "Stochastic world" not a high priority

B. Design
   1. Main functions and failure modes involve multiple interacting phenomena and constraints in every design
   2. Side effects operate at high power
   3. Good designs are "elegant"
   4. "System view" not a high priority in education or most practice areas - combination of good components will do
   5. Integrated models are unreliable or do not exist

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Network Analysis Terminology

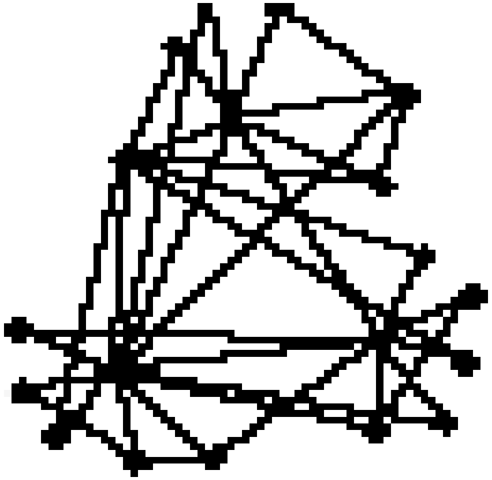
- **Node** = Vertex (Element, Component, Subsystem, Agent)
- **Link** = Edge (Relationship, Interaction, Flow, Interface?)
- **Random, rewiring,**
- **Degree** (average degree, degree distribution)
- **Path Length** (Path)
- **Size, density, sparseness, Connectivity**
- **Community =** Clique, (cluster?, module?), **modularity**
- **Degree Correlation Coefficient**
- **Centrality, Prestige, closeness, proximity, Betweenness, Assortative Mixing, Homophily**
- **Motifs =** Patterns
- **Self-similarity, Scale-Free?, Scale Rich?**
- **Preferential Attachment**
- **Metrics, Constraints**

Metrics (as used in this class)

- A network analysis metric is a ***quantitative characteristic*** of a system that is derived from ***representing the observed system as a network*** (and applying graph theory or other means of quantitative calculation)

Network metrics

- Size
- Density of interactions, sparseness
- Path Length –dependence on size



Network Metrics I

- n, the number of nodes
- m, the number of links
- 2m/n is the average degree <k> as the number of links on a given node, k, is the degree.
- m/[(n)(n-1)] or <k>/(n-1)is the "inverse sparseness" or normalized interconnection "density"
- Path length, *l*

$$l = \frac{1}{\frac{1}{2}n(n-1)} \sum_{i \geq j} d_{ij}$$

  - "Small Worlds"
  - In a "Small World", *l* is *relatively* small
  - And at given <k>, *l* ~ to *ln n or less rapid rise is taken to mean "Small World" (**where clustering is high**)*

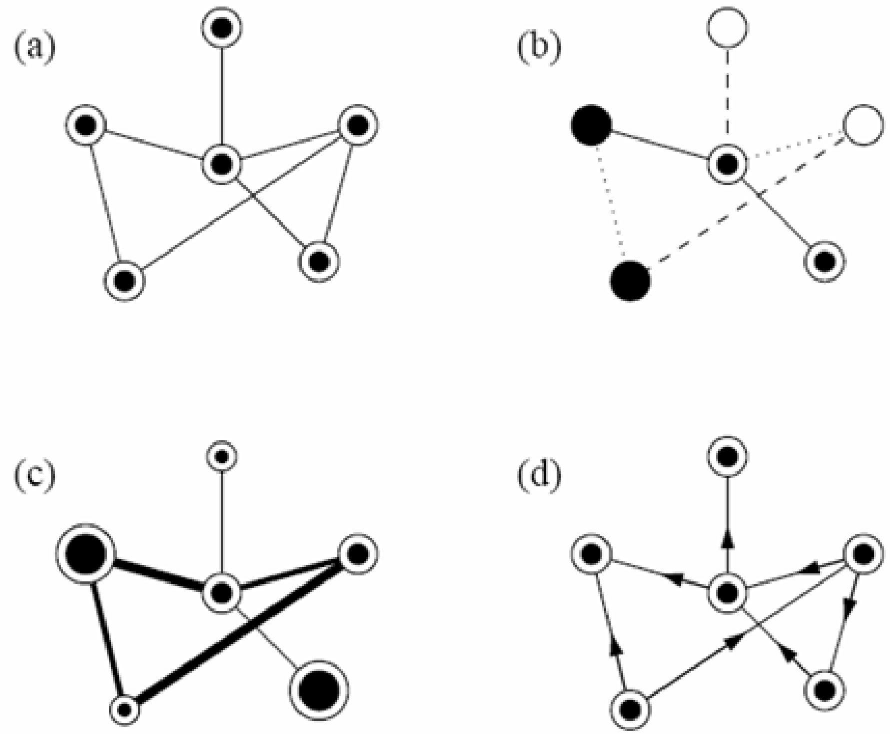
Various classes of networks

an undirected network with only a single type of node and a single type of link

a network with a number of discrete node and link types

a network with varying node and link weights

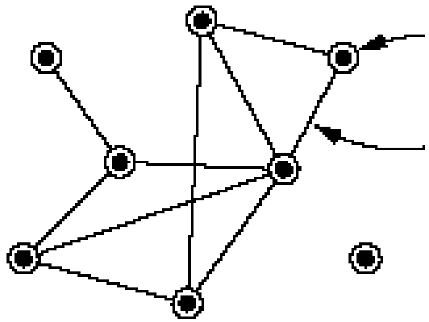
a directed network in which each link has a direction



Missing are networks that have nodes with multiple functions and that have multiple types of links. For example, nodes that transform energy and also calculate and that have links that pass information, control signals, energy, etc.

Source: M. E. J. Newman, *The Structure and Function of Complex Networks*, SIAM Review, Vol. 45, No. 2, pp . 167–256, 2003 Society for Industrial and Applied Mathematics

Network Analysis Essentials



- Network Analysis (or Science?) consists of a relatively simple way (Euler was first) of modeling or representing a system
  - Each Element (or subsystem or) is a ***node***
  - The relationship between nodes (elements or) is a ***link***
- The appeal of generality of application is based upon the very simple model for a system described by this representation combined with the mathematics of graph theory for quantifying various aspects of such models.
- A limitation for widespread utility is the simplicity
- The research front is where people are sacrificing as little simplicity as possible while making the models reflect more reality and thus have increased utility

Preliminary remarks on use of network analysis in research

- Please recognize that simply making a network representation of a system does not explain anything- **this is not research**.
- Indeed, to apply network analysis methods to a problem, a variety of issues must be explored and answered first
  - What node/link representations of the system in question are possible and how are they inter-related?
  - Which representations are most useful for answering (important, relevant) questions about the system?
  - What calculations and metrics are might be helpful in answering (important, relevant) questions about the system?
  - What are the shortfalls and limitations of these metrics?
  - What are the data that would be desired to build a useful model?
  - How much of the data can you really get?

Important topics at the “Research Front”

- How useful are the models and metrics that exist for architectural or structural attributes in the case of Engineering Systems (high complexity and **heterogeneity**)?
- Can we quantify important **properties such as flexibility and evolvability** and find analytical relationships to some structural metrics?
- Can we invent models and metrics for **heterogeneous** systems that are more useful indicators of important “properties of real systems”?
- Can we develop analytical models describing the influence of various **constraints** on complex system architecture?

More Research Front Topics

- To what extent are intuitively important aspects of architecture quantifiable and measurable?
- Are there useful paradigms, patterns, principles or other lessons from natural systems that researchers on real system architectures can use - and how can they be used?
- Assuming we know what functions, performance, and ilities we want, what methods can be used to create a suitable architecture?
- Assuming we know what architecture we want, what are the most effective ways of influencing the architecture of complex, evolving engineering systems?

ESD.342 Network Representations of Complex Engineering Systems
Spring 2010