Lecture 1 Outline

- Organizational Information about the course
- Architectural Definitions and Role in ESD
- Systems Typology
- Network “Analysis” Preview
- Pre-work for Lecture 2

Advanced System Architecture
ESD.342/EECS 6.883 2010

- Learning Objectives for this course:
  - Gain a research-level understanding of system architecture
  - Learn existing theoretical and analytical methods with particular emphasis on network analysis
  - Begin to develop some modeling skills of possible benefit in complex engineering systems
  - Compare systems in different domains (communication, engineering, organizations, infrastructures, and biology) and understand what influences their architectures
  - Apply/extend existing theory and modeling in case studies

Student Course Activities

- Read the academic literature, including faculty notes and papers
- Learn and practice some existing analytical methods, mainly network methods
- Appreciate the wide range of domains where theory and methods have been applied
- Critique existing theory and methods
- Share knowledge and experience
- Analyze some real systems in detail
- Distill common concepts that emerge from theory and that apply to many kinds of systems

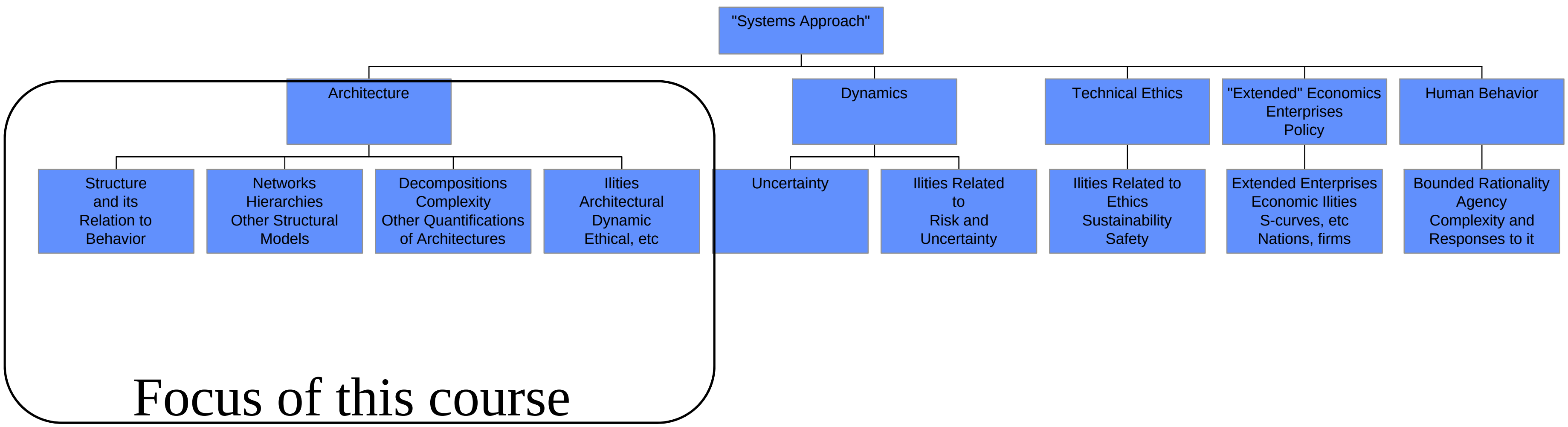
Learning Support for ESD 342

- Class lecture/discussion
- Text: *Six Degrees* by Duncan Watts (**get a copy soon**)
- Additional Assigned Literature to read before class
- Optional background literature available on the class web page
- Two classes to learn about the available software.
- Two homework assignments to learn to use the software
- Case study (small) group project with periodic reports in class

Grading Formula

- 15% in-class participation (especially reading connections)
- 25% assignments
- 60% Project
  - 20% Final Written Report
  - 15% Final Presentation
  - 15% Modeling Status Presentation
  - 10% 1^{st} Status Presentation

ESD’s Domains



Why We Care

- Lots of things have architectures
  - Physical things - objects, large natural systems
  - Human designed things - products, systems, missions, processes (engineering and others), organizations, projects, infrastructures, software, databases, political and economic systems
  - Natural things - cells, organisms, herds, ecosystems
- Their architectures either determine, strongly influence, or are (at least) correlated with their behavior, properties and changes over time
- Understanding architectural progress and evolution is thus a key to understanding systems over time (or at any given time)
- Thus, architecture has practical and fundamental importance for engineering systems

A “Perfect” Theory of Architecture Would Permit Us To:

- Characterize
- Measure
- Understand at a fundamental level
- Design, operate, evaluate, improve
- Predict future behavior

- For a given system architecture

A Definition of Architecture from a Practice Perspective

"An architecture is the conceptualization, description, and design of a system, its components, their interfaces and relationships with internal and external entities, as they evolve over time."

John W. Evans

Source: "Design and Inventive Engineering" Tomasz Arciszewski Fall 2004

- Similar to: "An architecture is a plan for change."

Joel Moses

Two definitions of Architecture from a Fundamental Perspective

- The architecture of a complex system is a description of the structure or **regularity** of the interactions of the elements of that system (inherently the non-random and longer lived aspects of the system relationships).
- The architecture of a complex system describes the functional character of the elements and the structure of the relationships among the elements

Baldwin and Clark (intermediate between practice and fundamental?)

- An architecture declares the modules and defines their functions*
- It also declares and defines the interfaces, including which modules they relate and what relations are supported*
- Finally it declares or embraces standards that define common rules of design, structure, interfaces, or behavior not otherwise declared, including performance evaluation
- * are part of typical system engineering

Our Viewpoints

- Importance of ideology in framing generic architectures and attitudes toward them
- Importance of data and domain knowledge
- Value of doing case studies with quantitative results
- We will learn more about such architecture/structure by examining a wide variety of systems such as biological, sociological, economic at a variety of levels in addition to the technological and organizational systems of most direct interest to us, because
- These systems are similar in many ways, perhaps more than we think
- We will use network methods - a deliberately chosen level of abstraction- but will also touch upon agent based models and evolutionary dynamics
- Since we want to influence structure (not just accept it as we are interested in ***design***), we will also explore how structure is determined by looking at system *typologies and constraints* that influence or determine the structure

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Systems *Context* Typology I

- Technical Systems
  - Power-oriented (e.g., cars, aircraft, their engines, etc.)
  - Information-oriented
    - Physically realized: e.g., telephone network, Internet
    - Non-physical: e.g., software, mathematical systems (Macsyma, Mathematica)
- Organizations (of humans)
  - Teams
  - Hierarchies
  - Networks
- Social/economic “systems”
  - Markets
  - Social Classes
  - Social networks like coauthors, citation lists, e-mails, terrorists
  - Behaviors: e.g., rumors, diseases, herd mentality
- Biological systems
  - Cells
  - Animal body plans
  - The process and role of evolution
  - Ecologies

Systems *Context* Typology II

- Overtly designed
  - Can be an architect
  - A design strategy is possible to imagine
  - Products, product families
  - Cars, airplanes
  - Bell System
  - Organizations
  - Centrally-planned economies

- Partially designed
  - Architect not common
  - Protocols and standards are crucial
  - Design strategy may not be practical
  - May be designed in small increments
  - Usually grow with less direction from a **common** strategy over longer times
  - Regional electric grids
  - City streets
  - Federal highway system
  - *MIT?*

- Non-designed systems
  - No architect
  - Respond to context
  - Change, develop
  - Differentiate or speciate
  - Interact hierarchically, synergistically, exploitatively
  - Cells, organisms, food webs, ecological systems
  - *Friendship groupings?*
  - *Co-author networks?*

In all cases, the laws of physics and legacy are important influences

Decomposability, hierarchy and time dependence are also significant in all 3 cases

Systems Typology : Complex Systems *Functional* Classification Matrix from Magee and de Weck

Process/Operand	Matter (M)	Energy (E)	Information (I)	Value (V)
Transform or Process (1)	**GE Polycarbonate Manufacturing Plant**	**Pilgrim Nuclear Power Plant**	**Intel Pentium V**	**N/A**
Transport or Distribute (2)	**FedEx Package Delivery**	**US Power Grid System**	**AT&T Telecommunica tion Network**	**Intl Banking System**
Store or House (3)	**Three Gorge Dam**	**Three Gorge Dam**	**Boston Public Library (T)**	**Banking Systems**
Exchange or Trade (4)	**eBay Trading System (T)**	**Energy Markets**	**Reuters News Agency (T)**	**NASDAQ Trading System (T)**
Control or Regulate (5)	**Health Care System of France**	**Atomic Energy Commission**	**International Standards Organization**	**US Federal Reserve (T)**

Some Things Do Not Have Architectures with Internal Structure

- Random Networks
- Perfect gases
- Crowds of people
- Their behavior can still be analyzed –*indeed they are usually easier to analyze than real systems*. Thus, they often form a baseline for comparison to things that do have architectures with significant structure

Structural Typology

- Totally regular
  - Grids/crystals
  - Pure Trees
  - Layered trees
  - Star graphs
- Deterministic methods used

- Real things
  - The ones we are interested in
- New methods or adaptations of existing methods needed

- No internal structure
  - Perfect gases
  - Crowds of people
  - Classical economics with invisible hand
- Stochastic methods used

- Less regular
  - "Hub and spokes"
  - "Small Worlds"
  - Communities
  - Clusters
  - Motifs

Comments on Typologies: Attributes of Effective Classification

- Standards for Taxonomy
  - ***Collectively Exhaustive and Mutually Exclusive***
  - ***Internally Homogeneous***
  - Stability
  - Understandable Representation and Naming

- None of the approaches just reviewed really fulfill these criteria. Interestingly (more later in course), ***no categorizations*** of man made or evolved systems have ever been found that fulfill these criteria. At least one natural ***system categorization has been found that does fulfill*** these criteria (Mendeleyev) and has even been the basis of future successful predictions.

What has been going on recently in "The New Science of Networks"?

- The ***Physicists and their friends*** have come to this area strongly starting with the paper in Nature by Watts and Strogatz in 1998
- The publications started with a few per year and now have reached 1000's per year in various journals (plus 3 books).

Papers with "Complex Networks" in Title

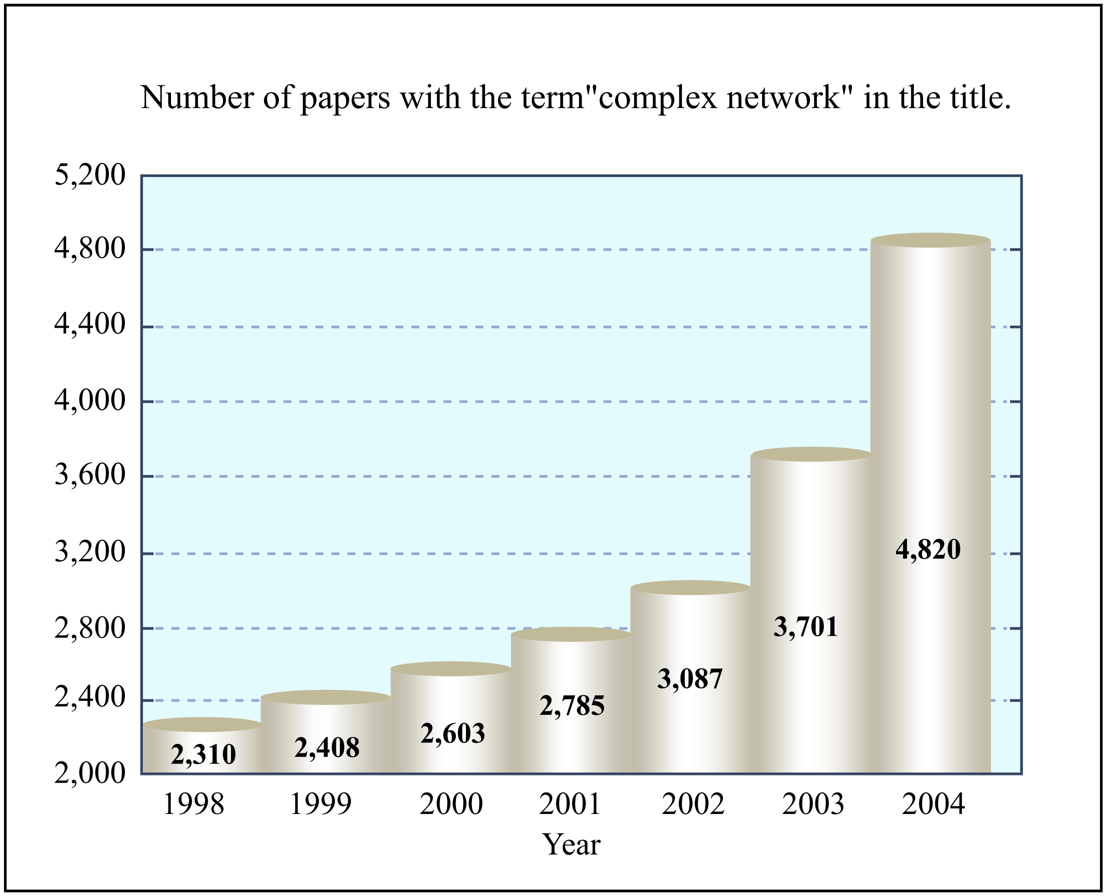

Image by MIT OpenCourseWare.

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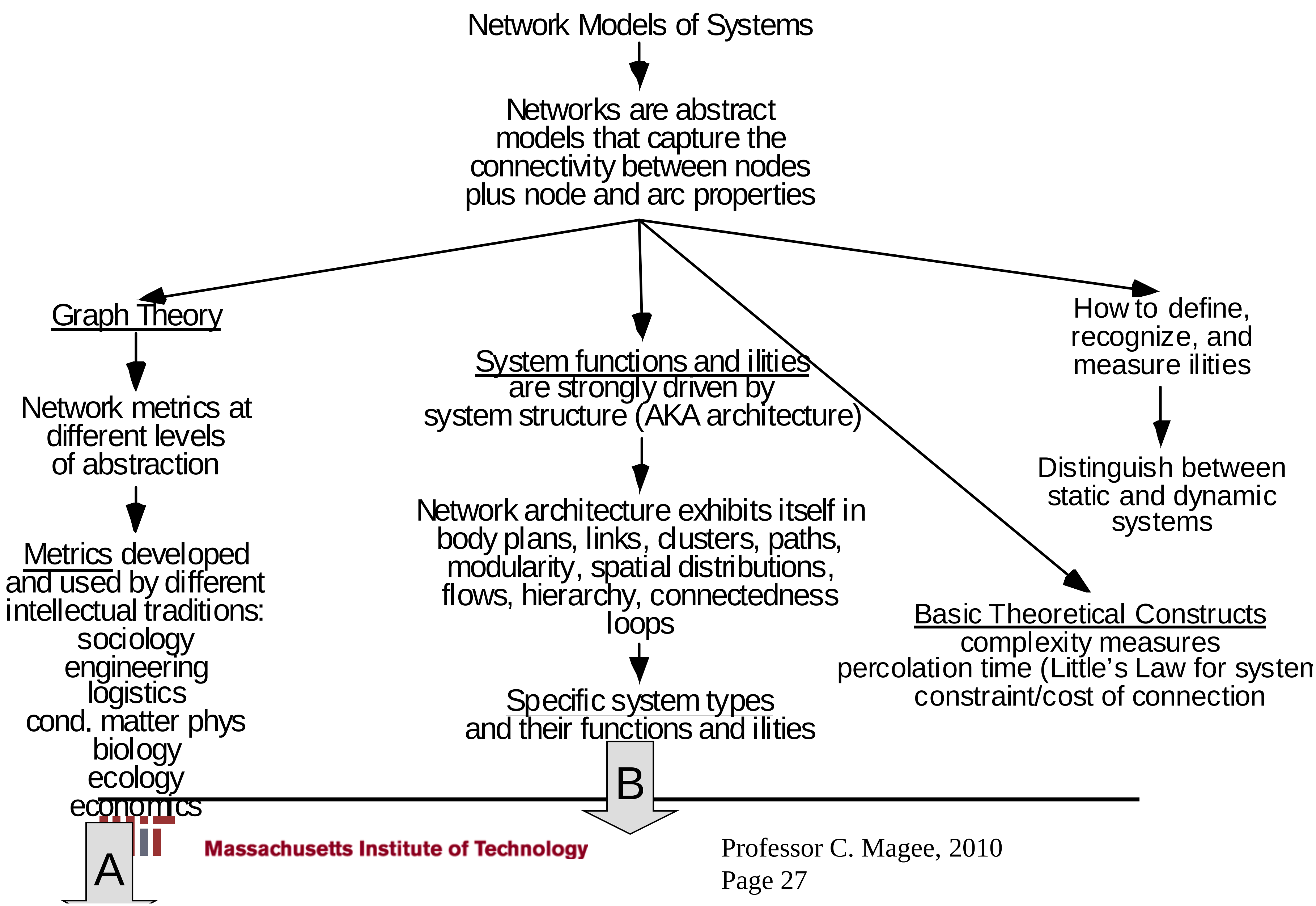
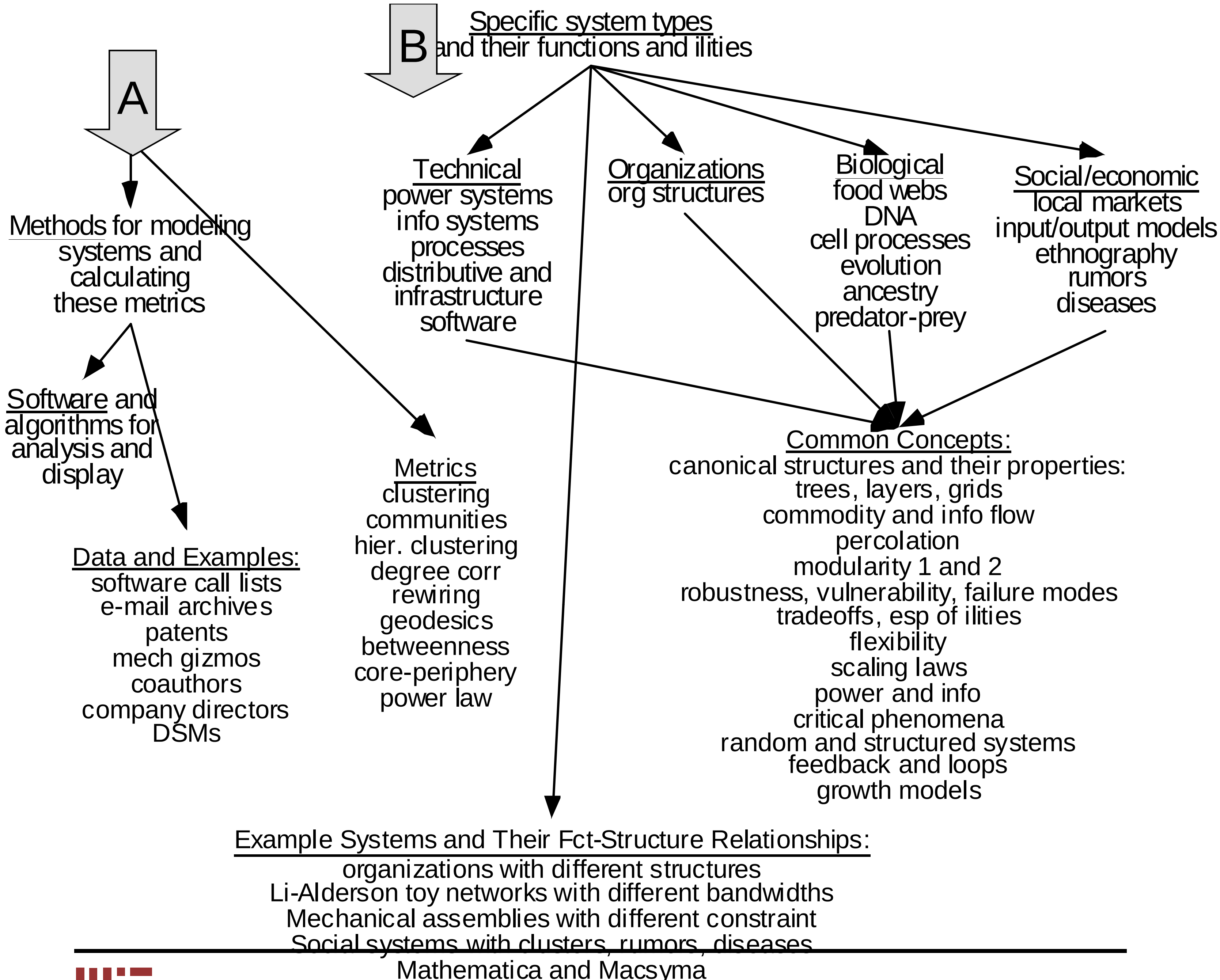
- All of the effort builds upon work done by sociologists and Operations Researchers over the preceding 40 or more years.
- Strong activities now exist at a variety of academic institutions:
  - The University of Michigan
  - Oxford University
  - The Sante Fe Institute
  - Columbia University
  - Notre Dame University
  - Many others

Why might *We* (who are interested in design, management, behavior, etc. of complex systems) care?

- A strong mathematical basis is being established for developing relatively tractable models of large-scale complex systems
  - *We* need more modeling tools that are useful for large-scale systems with many elements, interactions and complex behaviors
- Quantifiable metrics are being developed that ***may*** be of use in predicting behavior of complex large-scale systems
  - *We* need such metrics as they would be valuable in designing and managing our systems
- Algorithms for extracting information from complex systems are being developed and these can improve “observability” of such systems.
- New visual representations for complex systems are being developed

An Architecture for ESD.342




A
B
Specific system types
and their functions and ilities
Methods for modeling
systems and
calculating
these metrics
Technical
power systems
info systems
processes
distributive and
infrastructure
software
Organizations
org structures
Biological
food webs
DNA
cell processes
evolution
ancestry
predator-prey
Social/economic
local markets
input/output models
ethnography
rumors
diseases
Software and
algorithms for
analysis and
display
Metrics
clustering
communities
hier. clustering
degree corr
rewiring
geodesics
betweenness
core-periphery
power law
Common Concepts:
canonical structures and their properties:
trees, layers, grids
commodity and info flow
percolation
modularity 1 and 2
robustness, vulnerability, failure modes
tradeoffs, esp of ilities
flexibility
scaling laws
power and info
critical phenomena
random and structured systems
feedback and loops
growth models
Data and Examples:
software call lists
e-mail archives
patents
mech gizmos
coauthors
company directors
DSMs
Example Systems and Their Fct-Structure Relationships:
organizations with different structures
Li-Alderson toy networks with different bandwidths
Mechanical assemblies with different constraint
Social systems with clusters, rumors, diseases
Mathematica and Macsyma

Topics to think about for Thursday

- Terms and Definitions: Read the web-site document and suggest other terms or differences you have with the "official ESD definitions".
- Biases and points of view about systems and structure-The three faculty will tr y to discuss their separate biases and prejudices which largely come from educational training (undergraduate school most strongly?). We would like you each to introduce yourselves to the class and give some possible biases you have.

ESD.342 Network Representations of Complex Engineering Systems
Spring 2010