# Advanced System Architecture
# ESD.342/EECS 6.883
# 2006

- Goals of this course:
- Gain an understanding of system architecture
- Learn existing theoretical and analytical methods
- Compare systems in different domains and understand what influences their architectures
- Apply/extend existing theory in case studies

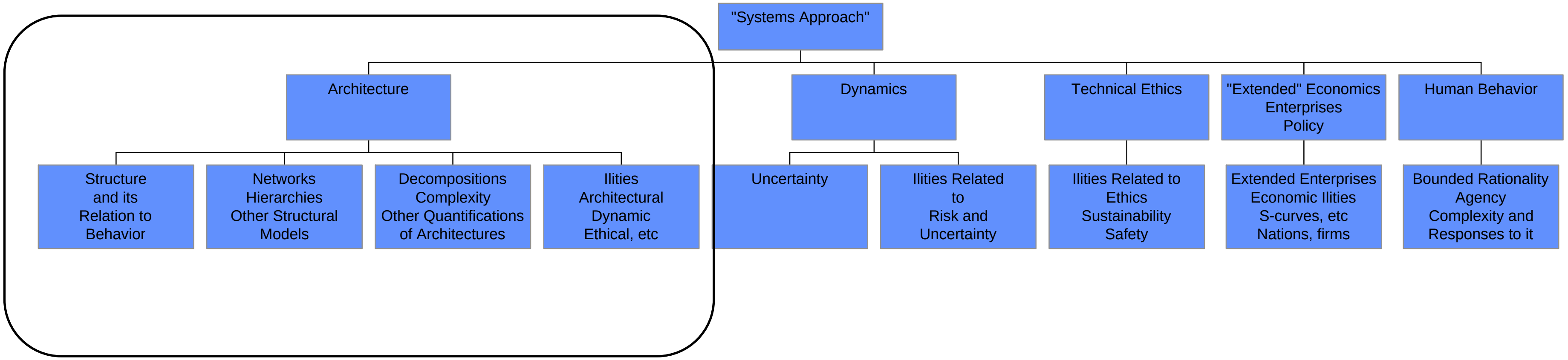
  

# The Faculty

- Chris Magee
- Joel Moses
- Dan Whitney

# ESD's Domains




Focus of this course

# What We Will Do in This Course

- Read the academic literature, including our own 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 our knowledge and experience
- Analyze some real systems in detail
- Distil common concepts that emerge from theory and that apply to many kinds of systems

# How The Course Will Be Organized

- Class lecture/discussion
- Text: *Six Degrees* by Duncan Watts
- Literature to read before class
- Three homework assignments and exercises to learn to use the software
- Case study project with periodic reports in class
- Class overheads, assigned reading, and optional reading posted on class website.

# Grading Formula

- 15% in-class participation (especially reading connections)
- 25% assignments
  - 5% Each for assignments 1 and 2
  - 15% for assignment 3
- 60% Project
  - 20% Final Written Report
  - 15% Final Presentation
  - 15% Modeling Status Presentation
  - 10% $1^{st}$ Status Presentation

# Class Resources

- You!
- Course website
  - Syllabus and schedule
  - Assigned readings
  - Background readings
  - Class overheads
  - Collection of MATLAB routines for doing network analysis
  - Online book on social network analysis methods (subset of what we will be using)

# Our Viewpoint

- Importance of data and domain knowledge
- Value of doing case studies with quantitative results
- Understanding of relevant literature in other domains like systems biology, ecology, and economics
- Importance of ideology in framing generic architectures and attitudes toward them

# Why We Care

- Lots of things have architectures
  - Physical things - objects, large natural systems
  - Human designed things - products, systems, missions, organizations, projects, infrastructures, software, databases, political and economic systems
  - Natural things - cells, organisms, herds, ecosystems
- Their architectures either determine, strongly influence, or are correlated with their behavior and properties
- Architectural progress and evolution can be observed in both built and natural systems
- There are multiple characteristics of architecture and thus there can appear to be multiple architectures if viewed through these different lenses.

# A "Perfect" Theory of Architecture Would Permit Us To:

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

# 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

# Instructor Biases

- Magee
- Moses
- Whitney
- Your turn Feb 14 (see assignment 1)

# Some Things Do Not Have Architectures with Internal Structure

- Random Networks
- Perfect gases
- Crowds of people
- Their behavior can still be analyzed and often forms 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”
  - -“Grown” including growth models

# Systems 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
- Categorizations and taxonomies of these systems also have architectures…
  - Linnean and other categorizations of “the tree of life”

# Systems Typology II

- Overtly designed
  - Can be an architect
  - A design strategy is practical
  - Products, product families
  - Cars, airplanes
  - Bell System
  - Organizations
  - Centrally-planned economies
- Infrastructures
  - Architect not common
  - Protocols and standards are crucial
  - Design strategy may or may not be practical
  - May be designed when small
  - Usually grow with less direction from a common strategy when large
  - Regional electric grids
  - City streets
  - Federal highway system
- Natural systems
  - No architect
  - Follow laws of physics
  - Respond to context
  - Change, develop
  - Differentiate or speciate
  - Interact hierarchically, synergistically, exploitatively
  - Cells, organisms, food webs, ecological systems

In all cases, there is legacy, possibly a dominant influence

# Systems Typology III: 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 Telecommunication 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)** |

# 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 really fulfill these criteria. Interestingly (more later in course), ***no categorizations*** of man made systems have ever been found that fulfill these criteria. ***Natural systems categorizations have been found that do fulfill*** these criteria (Linnaeus and Mendeleyev) and these have even been the basis of future successful predictions.

# How to Learn

- 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
- 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
- We will use network methods - a choice of level of abstraction

# Important topics at the "Research Front"

- How useful are the metrics that exist for architectural or structural attributes in the case of Engineering Systems (high complexity and heterogeneity)?
- Can we invent metrics for heterogeneous systems that are more useful indicators of important "properties of real systems"?
- Can we quantify important properties such as flexibility and find analytical relationships to some structural metrics?

# 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?

# Terms and Definitions

- System
- Function
- Performance
- Cost
- Properties or characteristics
  - Complexity, uncertainty, emergence
- Ilities - often have life-cycle importance
  - Flexibility
  - Robustness
  - Sustainability
  - Others?

# 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 and Function?

# Other System Characteristics

- Complexity
- Uncertainty
- Emergence
- Various definitions have been proposed

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

# Other Words That We Will Use and Need to Understand

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