Three Lectures on Organizational Structures

- Lecture 1 - Typology of generic organizational architectures
  - Their advantages and disadvantages
- Lecture 2 - Simple models of complexity and flexibility; their relationship to each other for each of the generic architectures
- Lecture 3 - Relationships of generic architectures to national cultures

Overview of Organizational Structures and Generic System Architectures

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Some assumptions/biases

- Generic system architectures and generic human organizational structures have much in common, but there are differences between them
- It is useful to understand the "extreme" generic or ideal architectures – real systems will usually be based on mixtures of such forms, and on forms that are "near" the ideal structures
- Our hope is to understand "messy" systems by understanding generic and relatively clean types
- Following Einstein our models should be as simple as possible and not simpler
- The emphasis here is on structure of implementations, not on matching function to form. Our goal is to understand the advantages and disadvantages of generic structures

Typology of Organizational Structures and System Architectures

- Small(ish) scale
  - Teams (human organizations), families of components
  - Clans (connections of teams) – may form a layer
- Hierarchies (both in technical systems and human organizations and industries)
  - Tree structured hierarchies (often simply called hierarchies)
  - Layered hierarchical structures
  - Mixed (hybrid) trees and layers
  - Layered industries
- Networks
  - Hierarchies as networks
  - Networks with hierarchies as components – (e.g., national economies)

Team structures

- The diagram shows a team with 5 members or nodes– a fully connected graph with n(n - 1)/2 edges for n nodes
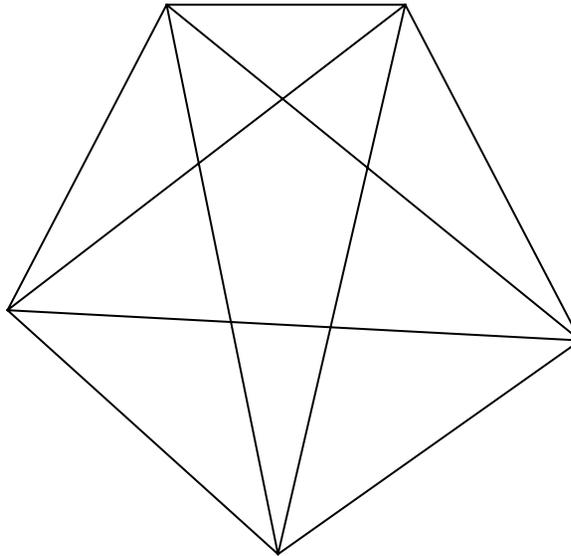
Some Characteristics of Team Structures

- Successful human teams or families rely on <u>trust</u> and <u>cooperation</u>

- Team members are expected to emphasize the success of the team, rather than the individual

- Teams can be very flexible and thus robust to certain "attacks" ; if one member is sick, the others ought to be able to take over their role; they can handle many classes of changes in specs with relative ease

- Human teams are relatively small in size – volume of output is limited in scale and scope; 7±2 limits (George Miller - 1956); however, output can be large given enough time (one person, Richard Stallman, wrote most of GNU/Linux over 15 years)

Clans

- A clan is a connected set of teams or human families – a network of families. Each family has one or more members that are connected to some members of another family or team (e.g., the Rothschild banking families, Chinese trading firms, Italian shoe-making families [Piore and Sabel "The Second Industrial Divide"])
- Clans are somewhat hierarchical (e.g., they may have a set of patriarchs or matriarchs or team leaders)
- Clans are also based on cooperation and trust, although less so than a single team or family
- Clans can form a layer in a layered hierarchy

Hierarchies

- Hierarchies are associated with an ordering, a ≤ relationship
- The ordering (a partial order) can be associated with a level-number or layer depth for each node in the hierarchy
- In a strict order (a < relationship) there are no cycles. For example, you cannot be your boss's boss. In a ≤ ordering, a node can have direct edges to its brother or cousin nodes.
- Hierarchies are thousands of years old in their economic, military, industrial, political, religious and social manifestations

Trees and Layers

- Tree structures are hierarchies where each node (other than the root node) has exactly one parent in the level immediately above it
- Layered structures can and usually do have multiple parents and/or can change parents readily
- Some layered structures (especially in human organizations and industries) will have interconnections with nodes at the same layer
- Nodes at the same layer usually are at the same level of abstraction – not generally true of tree structures
- Layer skipping is not permitted in pure layered forms, but is not too problematic most of the time due to understanding of context (e.g., mathematicians don't usually get confused about 0, even when it means a 2x2 matrix whose entries are all 0)
- Hierarchies have no cycles, except within a single layer

Non-standard trees

- An impure tree with non-standard interconnections, relatively complex (and somewhat messy)
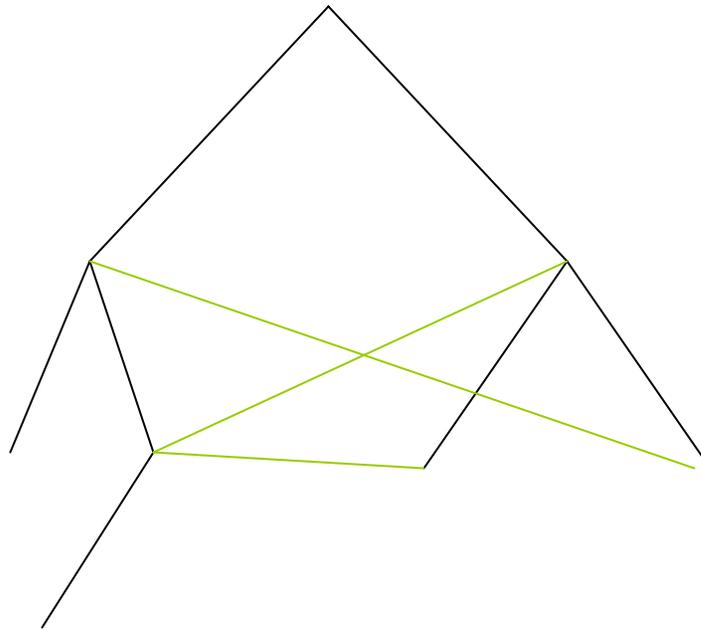
Characteristics of tree structures

- Pure trees are hierarchies where the nodes can have exactly one parent (except for the root of the tree)
- Tree structures (bureaucracies in sociology and organization theory) lend themselves to competitive environments. Whole sub-trees or the design of subsystems can be assigned to individuals whose performance may be judged in competition with others at the same level of the hierarchy. Good performance may lead to promotions, raises, and additional resources

Tree Characteristics - 2

- Pure trees are relatively inflexible. It is hard to make internal changes and maintain pure 'treeness'. It is also hard to get around a non-working node or edge, thus such structures are relatively inflexible and not robust.

- Tree structures are a general form. Trees can describe small, medium and large structures in both engineering systems and human organizations

- Tree structures are associated with top-down design, a reductionistic approach to breaking problems up into smaller and smaller subproblems

- Partly due to its generality, the top-down approach may be abused – poor decompositions are possible, even likely

Examples of Tree Structures

- Classic organizational structures/charts

- The bottom of a V in a system engineering or software engineering's top-down decomposition process

- Problem solving decomposition process (Alan Newell and Herb Simon's "Logic Theorist" (1956) - An AI program that proved theorems in Russell and Whitehead's "Principia Mathematica")

Layered Hierarchies

- Layered structure with three layers and no horizontal interconnections, may connect to any or even all nodes in layer immediately above or below. I believe that layered hierarchies are not well understood in the US. We'll discuss this later in the term.

Layer 1

Layer 2

Layer 3
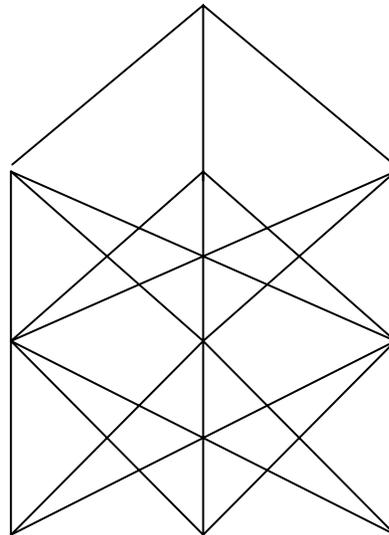
An example is matrix addition and multiplication,
based on vector procedures, which are based on element arithmetic

Characteristics of Generic Layered Structures

- Technical systems that use layering, such as the Internet or many software systems, are usually based on abstractions

- These abstractions are sometimes related to protocols and standards (e.g., TCP/IP)

- Technical systems that rely on protocols and standards, such as TCP/IP, have layers that handle these standards. Humans often use standards in an implicit fashion due to their intelligence, and thus human organizations can have fewer layers than technical systems of similar size and complexity.

- Intelligence in the Internet is at the end nodes, not in the center. "Net Neutrality" is an attempt to continue this approach, thus preventing firms from profiting from special knowledge used during the network operation.

Characteristics of Layered Structures - 2

- The nodes or elements in a given layer belong to a set of elements at the same level of abstraction – not necessarily true of tree structures

- Nodes may have multiple parents at the layer immediately above them and may change parents over time

- The number of layers usually tends to be small (3, 5, 7 are typical); when the number of layers is high as in mathematical logic and some CS situations, the complexity growth becomes a serious issue

- Each horizontal cut (thus creating a layer) is a significant architectural/design decision and has nontrivial impact

Layered Hierarchies with Lateral Interconnects

- Three layers, a root node, 10 nodes, with horizontal (lateral) interconnections
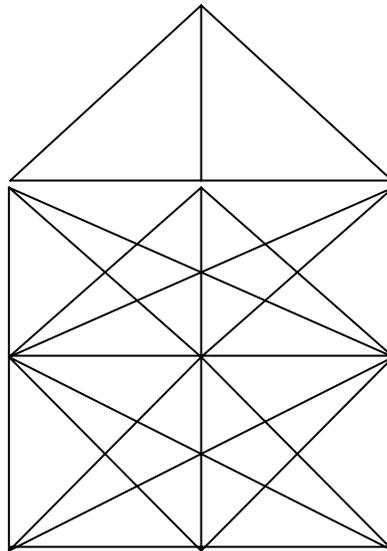
Lateral Interconnects in Human Organizations and Industries

- Horizontal interconnects rely on and foster cooperation and team work

- Such interconnects add to the complexity of each node and the overall system. In human organizations such interconnections require practice and trust

- Thus one needs to learn to cope with somewhat greater complexity in organizations, as well as adopt mechanisms for reducing complexity

- Industries, such as health care or university education, can be viewed as layered – we'll discuss this later

- Three layers are very common in human organizations and industries

Variations on Layered Systems

- Layered systems can have high complexity due to the potentially large number of interconnections between layers (as well as within layers)

- Thus we introduce two variations to reduce complexity, one for technical systems, and one for human organizations

- We use routers in technical systems to reduce system complexity (and the cost of interlayer interconnections), although the routers themselves are complex

- We use a mixed or hybrid tree and layer architectures in human organizations and in some technical systems as well

Routers

- Routers are used in technical systems, such as telecommunications systems, in order to reduce the number of interconnections (and thus system complexity and cost) at some loss in performance. Routers themselves are complex and not cheap
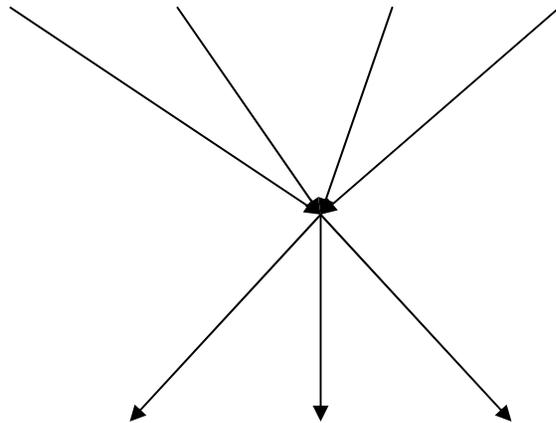
Examples of Layered Technical Systems

- The Internet (based on the ISO 7-layer model)
- The hardware/software system in a PC (for example, a microprocessor contains an interpreter that is a router for instructions)
- Many software systems rely on layers of abstractions (see 6.001 text on programming by Abelson and Sussman, and 6.004 text on computer architecture by Ward and Halstead)
- Automobile platforms
- "Towers" in abstract algebra – each layer may be an infinite set (e.g., integers, rationals, polynomials with rational number coefficients)
  - All of the above, except for automobile platforms, are low power systems
  - There are very many uses of layered systems in practice in CS, computer engineering, and communications, but layering is usually not taught as a design methodology

Performance and Flexibility

- A key argument against technical layered systems is the loss of performance through the stages of routing, or inefficiency in interpretation/compilation
- This was used against FORTRAN in the 1950's and against VLSI design languages in the 1970's
- As technologies mature, there often are discoveries that reduce the loss of performance
- For example, good compilers have made compiled FORTRAN code more efficient than almost any human-produced code. RISC computers have made it essentially impossible for humans to generate better code than compilers
- One can also permit the breaking though of the "abstraction barrier" in order to achieve more performance, although this is to be discouraged as a general strategy

22

Mixed (Hybrid) Trees and Layers

- Layered human organizations are sometimes locally relatively horizontal and globally tree structured. Locally they can form a team, and rely on leaders to form interconnections resulting in tree structures of clans (see Watts, Chapter 9, also in Dodd, Watts and Sabel's paper (later this term), although they come at it from a different perspective)
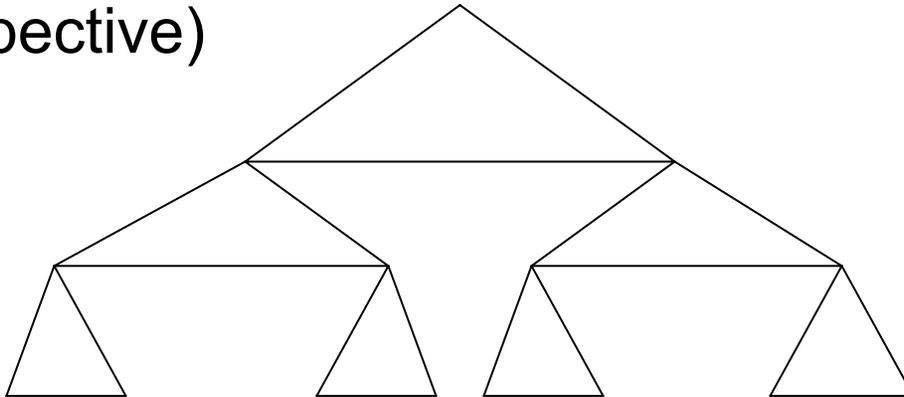
Characteristics of Layered Human Organizational Structures

- Members of a given layer can have multiple parents or bosses and can relatively easily switch parents at the layer above them
- Cooperation and trust are important attributes
- Members of a given layer can interact readily with other members at the same layer
- I believe that middle managers in such organizations recognize that a significant part of their job is increasing trust between their team members and members of other teams with whom they may need to work at some point

Examples of Human Layered (Mixed) Organizations

- Large partnerships (e.g., law firms or accounting firms with senior partners, junior partners and associates)

- Universities prior to introduction of research -oriented departments in the 19th century by von Humboldt; there is still memory in universities of this organizational structure (e.g., provost/rector, full professors, associate professors and assistant professors). Universities are thus partnerships of the faculty. Presidents who ignore this aspect of universities sometimes lose their positions

- The Catholic Church (Pope, cardinals (archbishops), bishops, priests). Before there were cardinals, the Pope was simply the Bishop of Rome, and deacons played the role of bottom layer.

- Masters, journeymen, apprentices in a given profession

- Large Japanese firms (to be discussed later in course)

Overlays

- Large partnerships (e.g., consulting firms) are often layered, and use project teams that may be best modeled as tree structures which are overlayed on the base structure

- Matrix organizations (two bosses) may be viewed as overlays as well. At MIT we have departments as well as centers, and most faculty members have a department head and a center director as 'bosses.' Centers usually own space and facilities, and departments hire and promote faculty (and also own space and facilities)

Layered Industries

- Higher Education – in California: research universities, Cal state schools, community colleges
- Health care – specialists, PCPs, Nurse– practitioners / physical therapists
- PCPs are frustrated in part because they are increasingly used as middle managers (e.g., aligning specialists at a higher level and physical therapists at a lower level), and that is not what they think they were trained to do

- Higher layers are usually more expensive
- If the state pays, people will wish to obtain services at highest level, with the state pressing for service at a more appropriate lower layer

Middle-out Design

- Assume a product is designed as a layered system

- Assume you wish to change the product
  - Start at a layer in the middle and <u>work up</u> to the new layer that can generate the new product
  - Make <u>changes at lower layers</u> than where you started as needed to efficiently implement the new product

Networks

- There are many types of networks, with differing values for the properties of interest to us, such as flexibility and robustness
- Grid networks can be extremely flexible, but often at some loss of control
- Market-type networks are usually associated with great competition, also loss of control
- Networks can have family or hierarchical structures of various types as nodes or as a collection of nodes.

Looking Ahead

1) Complexity and Flexibility

2) Structures and Ideologies

Complexity and flexibility of the various structures

- Teams and families will have relatively high complexity and very high flexibility – limited in size because of the large complexity of interconnections – $O(n^2)$

- Pure tree structures will have relatively low complexity (good) and very low flexibility (not good) considering their size

- Pure grid networks will often have relatively low complexity and very high flexibility (and thus some robustness), but likely low control

- Layered structures will have intermediate level of complexity (which can be reduced using routers or mixed trees) and intermediate flexibility, but better control than most networks

- Thus, there is no ideal generic architecture. Much depends on characteristics of the system to be designed

- More detailed analysis of complexity and flexibility of the various structures to come in the next lecture

Attitudes often associated with the various generic architectures

Teams/families – cooperative, trusting

Clans – relatively cooperative, trusting

Layered structures – relatively cooperative, trusting

Tree structures – competitive, individualistic

Market-type networks – competitive, individualistic

Relationships to cultures and ideologies

- Some cultures tend to emphasize competition, individualism and reductionism (e.g., US and Britain). Charles Darwin and Adam Smith were British

- Others emphasize cooperation, trust, holism and the role of community and often, unfortunately, put non-members down (e.g., Japan and to a lesser degree Germany and Northern Italy). Karl Marx and Max Weber were German, Freud was Austrian

- People can be brought up in either approach and in many others as well

- Modern cultures are learning from each other to some degree (e.g., the Toyota production system – lean manufacturing). Thus the role of ideology is getting somewhat diffused, but it is not completely gone. The differences even show up in psychological experiments. Japanese tend to note more of the background of a picture than Americans

Ideological Biases

- The US not only increasingly emphasizes individualism and competition, but also tends to distrust key aspects of cooperative organizations (e.g., tenure) and related technical structures

- A likely reason is that the people who came to the US in the 17th century were running away from a stratified (layered) society

- Germany, Italy and Japan became modern nation-states in the 1860's, later than Britain, France and the US, and are closer to their medieval past and its cooperative aspects

- More on this point later in the term

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