

Overview of Organizational Structures and System Architectures

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Some assumptions/biases

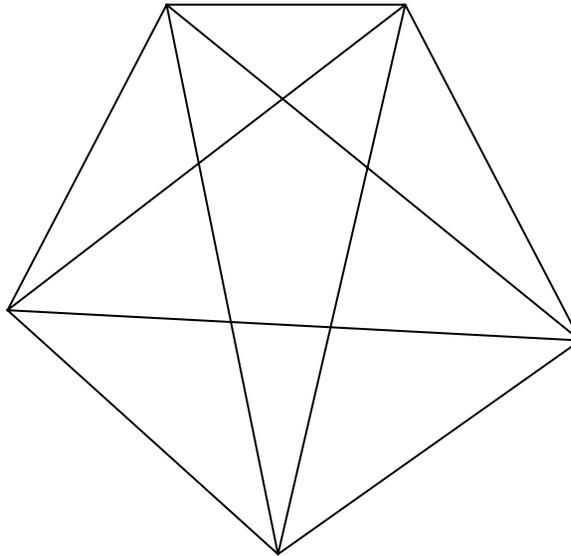
- Generic system architectures and generic organizational structures have much in common
- A key tension in system architectures and human organizations is between an emphasis on cooperation or competition between nodes
- It is useful to understand the “extreme” generic architectures – real systems will likely be based on mixtures of such forms
- Our goal is to understand “messy” systems by understanding generic and relatively clean types

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)
 - Tree structured hierarchies (often simply called hierarchies)
 - Layered hierarchical Structures
- Networks
 - Markets
 - Hub and Spokes
 - Small world
 - Grids
 - ...

Team structures

- The diagram shows a team with five members or nodes– a fully connected graph – ten interconnections or edges



Some Characteristics of Team Structures

- Successful human teams rely on trust and cooperation
- Team members are expected to emphasize the success of the team, rather than the individual (e.g., the NE Patriots)
- 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
- Teams are relatively small in size – volume of output is limited in scale and scope; 7 ± 2 limits

Families of Parts

- Technical systems may use families of component parts
- AND, OR, NOT form a family of logic parts with which one can implement any digital logic device
- These parts are usually not themselves interconnected laterally

Clans

- A clan is a connected set of teams or human 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

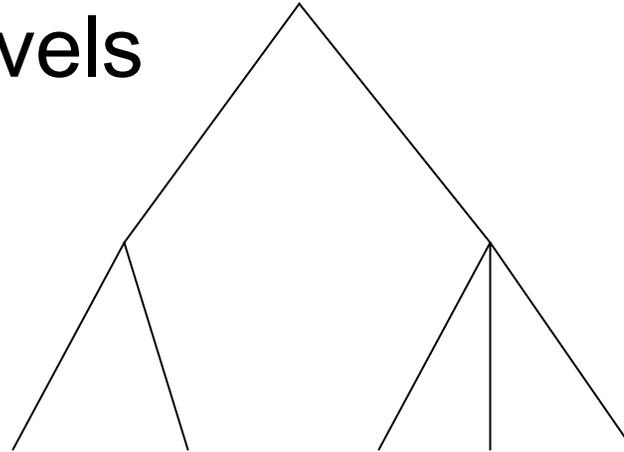
- Hierarchies are associated with an ordering, a \leq relationship
- The ordering (a partial order) determines a level-number or layer depth for each node in the hierarchy
- In a strict order (a $<$ relationship) there are no cycles. For example, you cannot be your boss's boss.
- Hierarchies are thousands of years old in their economic, 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) will have interconnections with nodes at the same layer
- Nodes at the same layer usually are at the same level of abstraction
- Layer skipping is not permitted in pure layered forms, but is not too problematic most of the time (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-cyclicity is a modeling limitation, but it may turn out that one might be able to allow one cycle to permit feedback, if we could analyze the rest of the hierarchy

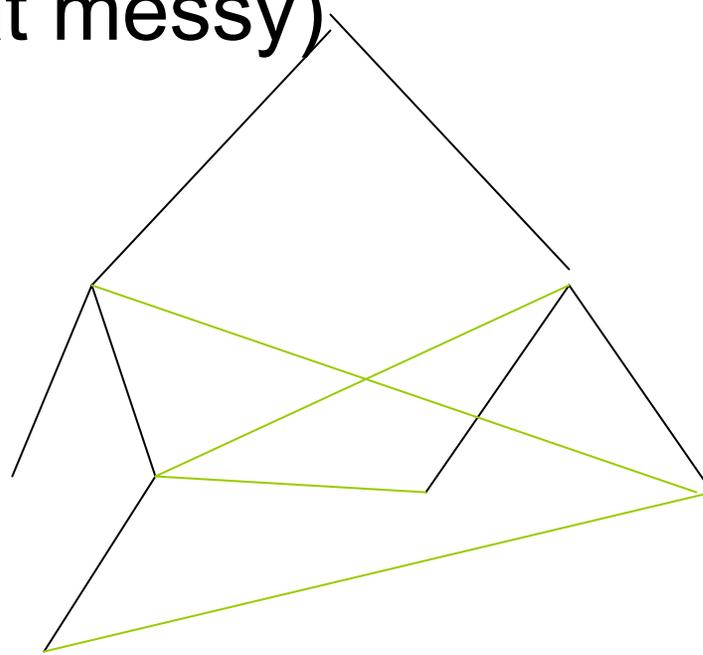
Tree Structures

- A tree with 8 nodes and 7 edges or links, 5 paths from root node to bottom or leaf nodes, 3 levels



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 root)
- 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
- Trees are relatively inflexible. It is hard to make internal changes and maintain 'treeness'. It is also hard to get around a non-working node or edge.
- Trees can describe small, medium and large structures in both engineering systems and human organizations
- Tree structures are associated with top-down design, 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
- The bottom of a V in a system or software engineering's top-down decomposition process
- Problem solving decomposition process (Alan Newell and Herb Simon's "Logic Theorist" (1956))

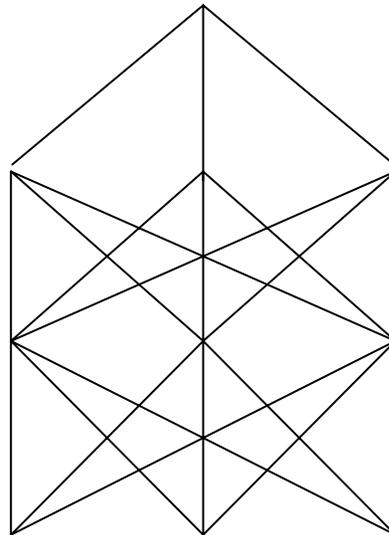
Layered Hierarchies

- Layered structure with three layers and no horizontal interconnections, may connect to any or even all nodes in layer immediately above or below. I claim that layered hierarchies are not well understood in the US.

Layer 1

Layer 2

Layer 3

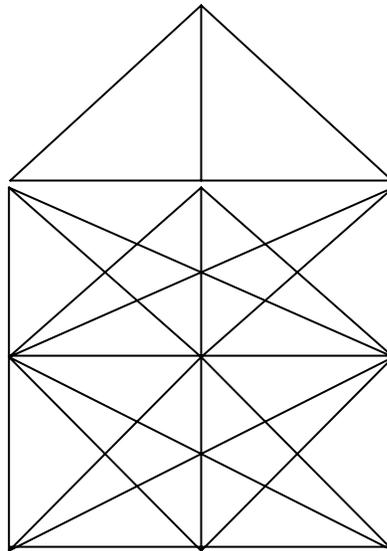


Characteristics of Layered Structures

- Technical systems that use layering, such as the telephone system or the Internet, are usually based on abstractions
- These abstractions are often related to protocols and standards (e.g., TCP/IP)
- The nodes or elements on 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 grows a great deal
- Each horizontal cut (creating a layer) is a significant architectural/design decision and has nontrivial impact

Layered Hierarchies with Horizontal Interconnects

- Three layers, a root node, 10 nodes, with horizontal interconnections

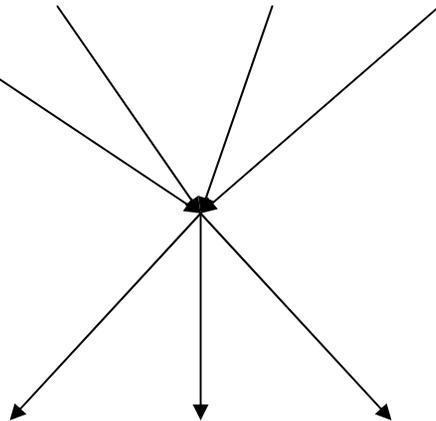


Variations on Layered Systems

- Layered systems can have high complexity due to the potentially large number of interconnections between 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 complexity (and cost of interconnections)
- We use a mixed tree and layer architecture in human organizations

Routers

- Routers are used in technical systems, such as telecommunications or microprocessor instruction interpreters, to reduce the number of interconnections (and thus complexity and cost) at some loss in performance



Examples of Layered Technical Systems

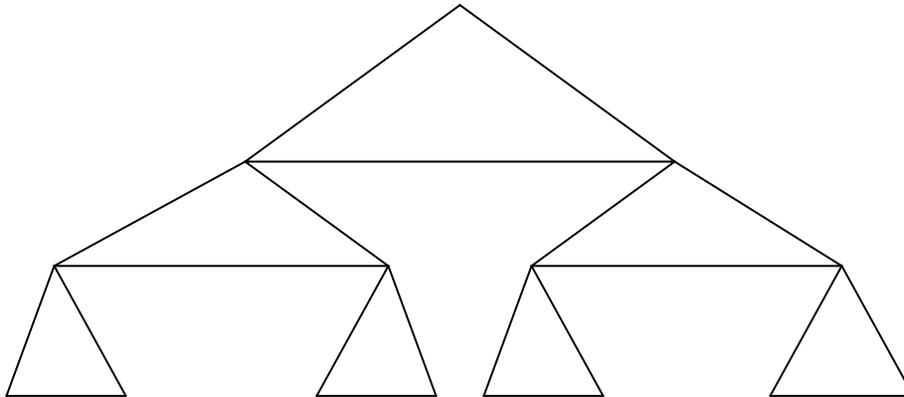
- The landline telephone system
- The Internet (based on the ISO 7-layer model)
- The hardware/software system in a PC (for example, a microprocessor contains an interpreter that is a router for instructions)
- Many software systems rely on layers of abstractions (see 6.001 text by Abelson and Sussman, and 6.004 text by Ward and Halstead)
- Automobile platforms
- “Towers” in abstract algebra – each layer may be an infinite set (e.g., integers, rationals)
- All of the above, except for automobile platforms, are low power systems

Performance and Flexibility

- A key argument against technical layered systems is the loss of performance through the stages of routing or 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
- One can also permit the breaking through of the “abstraction barrier” in order to achieve more performance, although this is to be discouraged as a general strategy

Mixed Trees and Layers

- Layered human organizations are locally relatively horizontal and globally tree structured. Locally they 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, although they come at it from a very different perspective)



Characteristics of Layered Human Organizational Structures

- Members of a given layer can have multiple parents or 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 will need to work at some point

Examples of Human Layered Organizations

- Large partnerships (e.g., law firms, accounting firms with senior partners, junior partners and associates)
- Universities prior to introduction of research - oriented departments in the 19th century; there is still memory in universities of this organizational structure (e.g., provost/rector, full professors, associate professors and assistant professors)
- The Catholic Church (Pope, cardinals, bishops, priests)
- 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 overlaid 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.’

Networks

- There are many types of networks, with differing values of properties of interest to us, such as flexibility and robustness
- Grid networks can be extremely flexible, but likely at some loss of control
- Market-type networks are usually associated with great competition
- Networks can have hierarchical structures of various types as nodes. Some of your projects are intended to see whether one can find such structures within the data sets

Looking Ahead

Complexity and Flexibility
Structures and Ideologies

Complexity and flexibility of the various structures

- Teams and families will have high complexity and very high flexibility – limited in size because of the large complexity of interconnections
- Tree structures will have low complexity and very low, even negative flexibility
- Grid networks will have low complexity and very high flexibility (and thus some robustness)
- Layered structures will have intermediate complexity (which can be reduced using routers or mixed trees) and intermediate flexibility, but better control than most network types
- 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 and individualism (e.g., US and to a lesser degree Britain). Charles Darwin and Adam Smith were British
- Others emphasize cooperation, trust 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
- 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. See Suzanne Berger “How We Compete” for a recent analysis

Ideological Biases

- The US not only increasingly emphasizes individualism and competition, but also tends to distrust key aspects of cooperative organizations 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 close to feudalism
- Germany, Italy and Japan became modern nation-states in the 1860's, later than Britain, France and the US, and are closer to their feudal past and its cooperative aspects
- More on this point later in the term.