Organization and Levels of Organization

Review: Characterization of a mechanism

Since the 17th century, science often appeals to mechanisms to explain what links a cause with its effect

A mechanism consists of parts (entities) and operations (activities) organized to produce a phenomenon

- **Phenomenon**—what the mechanism does
- **Parts**—the operating parts of the mechanism
- **Operations**—the work done by the parts that contributes to the activity
- These parts and operations are **organized**

Review - Characterization of a Mechanism

- A mechanism consists of parts (entities) and their operations (activities) organized to realize a phenomenon
  - Engineers and designers construct mechanisms from pre-existing parts
  - Scientists must reverse engineer mechanisms —discover the parts, their operations, and organization
- Discovering parts and operations requires decomposing mechanisms

Clicker Question

The goal in decomposing a mechanism is

- To carve the mechanism up into parts
- To render the mechanism inoperable by removing its parts
- To identify the parts and operations in the mechanism
- To figure out how the mechanism is organized

Review: Strategies for Figuring out the Operations in a Mechanism

Discovering the operations in a mechanism often requires experiments (manipulate variables and record effects)

- Lesion experiments—inhibit a component and measure effect on the whole system to see what capacity is lost
- Excitation experiments—excite a component and measure effect on the whole system to see what capacity is enhanced
- Recording—present stimulus to the whole and record activity of one of its components to see which has changed

Clicker Question

The point of a lesion experiment is to

- Disable the mechanism from operating
- To identify which component most responds to a stimulus
- To idenitify which capacity of the mechanism is lost when a part is removed
- To discover which capacity of the mechanism is enhanced when a part is stimulated

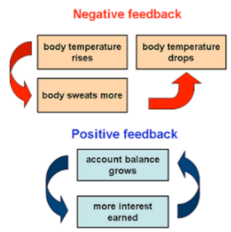
Temporal Organization: From Sequential to Feedback

Since we act in time, we tend to think of operations organized in sequence

A⇨B⇨C⇨D⇨E⇨F

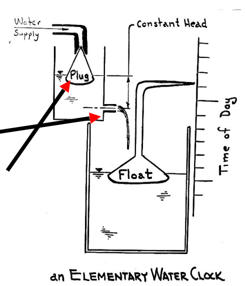
But feedback is a powerful design principle

- Negative feedback:
  - to keep a process within limits
  - to generate oscillations
- Positive feedback:
  - to maintain an active system



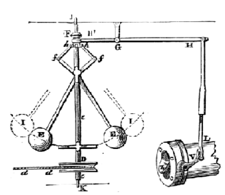
Origins of Negative Feedback

- The idea of organizing causal effects to be both forward and backward, with backward used for control, was rediscovered many times in history
- Water clocks required constant water pressure
- Ktsebios invented the idea of a plug to shut off water when it got too high in the 3rd Century BCE



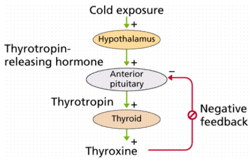
Industrialization and Negative Feedback

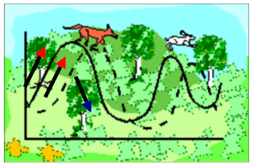
- James Watt faced a serious practical challenge
  - How to control the speed of the steam engine so that all appliances would run at the same rate despite different number being on line at a time
  - Devised an elegant mechanism for feedback control



Negative Feedback and Biology

- Critical that biological systems be able to maintain themselves in the face of environmental change
  - Homeostasis
- Feedback in organism-organism interaction
  - Predator-prey interactions
    - After prey increase, predators also increase
    - After predators increase, prey begins to decrease
  - Lotta-Volterra model





Clicker Question

In negative feedback

A product of an operation is used to stop or reduce the operation itself

A product of an operation is used to stop other reactions downstream from it

Negativity is fed back through the system

A negative result is obtained by stopping an earlier process

Clicker Question

A general use of negative feedback is

To raise the number of negative outcomes

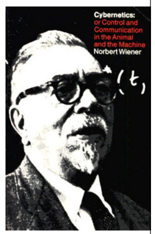
To insure maximal efficiency in the operation of a mechanism

To keep the operation of a mechanism within boundaries

To make sure that predators don't destroy their prey

Recognizing the Generality of Negative Feedback

- Challenge: how to control gun fire targeting aircraft
  – Use feedback from the first shot to correct the next
  – Later, heat seeking missiles and beyond



- Recognizing the commonality between control of anti-aircraft fire and control in biological system, Norbert Wiener created an interdisciplinary movement
  – Cybernetics—from the Greek for helmsman

Ubiquity of Negative Feedback

- Negative feedback has become ubiquitous so that we hardly notice it
  – Until something goes wrong and the system runs out of control
  – Or we notice the resulting oscillations

From Simple to Complex Systems

- Human engineering in the 20th century increasingly produced systems with more and more parts performing different operations and interacting in non-sequential and non-linear (non-additive) ways, creating challenges
  – How to get such systems to do what they were designed to do?
  – How to predict the behavior of such systems?
  – How to control them and insure their survival in the face of noise?

With complex interactions comes unpredictability

Computers are governed by rules and so their behavior is in principle totally predictable

- But the interaction of even very simple rules can produce totally unexpected results

Example: Conway's Game of Life

- Each cell in a grid is a unit that can be on or off (alive or dead)
  - Whether a cell is alive or dead on the next cycle determined from the state of its neighbors on the current cycle

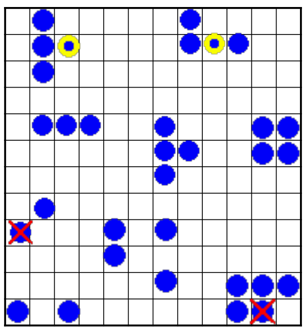
The Game of Life

Rules:

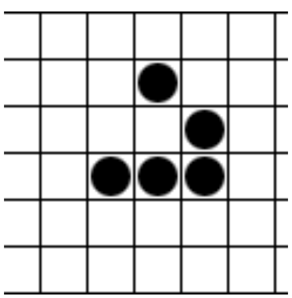
A dead cell with exactly three live neighbors becomes a live cell (birth).

A live cell with two or three live neighbors stays alive (survival).

In all other cases, a cell dies or remains dead (overcrowding or loneliness).



Emergent Behavior



Six degrees of separation

Why did AIDs and swine flu spread so quickly?

After Marconi created the telegraph and networks developed, claim that it would take an average of 5.83 telegraph stations to link any one person to another

Stanley Milgram and Acquaintance Networks

- How many acquaintance would it take to connect two randomly selected individuals in the US?
- Sent letters to randomly selected people in Midwest with the name of a target person and the following directions
  1. Add your name to the roster at the bottom.
  2. Detach one postcard. Fill it out and return it to Harvard Univ.
  3. If you know the target person on a personal basis, mail this folder directly to him (her).
  4. If you do not know the target person on a personal basis, do not try to contact him directly. Instead, mail this folder to a personal acquaintance who is more likely than you to know the target person.
- Mean number of intermediate persons was 5.5
  - So round up to 6 for 6 degrees of separation

The Kevin Bacon game

Created by three Albright College fraternity brothers in 1994

Pick an actor or actress
- If they have ever been in a film with Kevin Bacon, then they have a Bacon number of 1
- If they have never been in a film with Kevin Bacon but have been in a film with somebody else who has, then they have a Bacon number of two
- And so on . . .

Hitchcock and Bacon

Alfred Hitchcock was in *Show Business at War* (1943) with Orson Welles, and Orson Welles was in *A Safe Place* (1971) with Jack Nicholson, and Jack Nicholson was in *A Few Good Men* (1992) with Kevin Bacon!

Hitchcock's Bacon number is 3

Bacon numbers

Of the 225,000 actors listed in the Internet Movie Database as of April 1997:

- 1300 have a Bacon number of 1
- 80,000 have a Bacon number of 2
- 140,000 have a Bacon number of 3
- No American actor, living or dead, has a Bacon Number greater than 4
- There are 20,000 foreign actors who can never be connected to Bacon and therefore have a Bacon number of infinity
- No one else has a Bacon number higher than 8

The small world simulation model

Duncan Watts, as a graduate student, was studying the ability of crickets to synchronize their chirps or fireflies to synchronize their flashes

- Coupled oscillators
- How many links to connect up large populations of oscillators?

Start by assuming that you line up all people in a very large circle

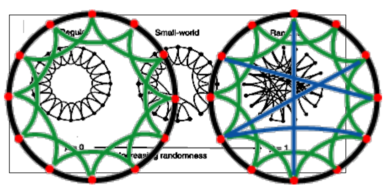
Largest and smallest worlds

One extreme
- Since on average each person has 1000 friends, assume they know the 500 people to their left and 500 to their right
- On average, you will have 2.5 million degrees of separation from other people

Other extreme
- Each person picks 1000 friends at random from whole world population
- Now on average you have 4 degrees of separation from other people

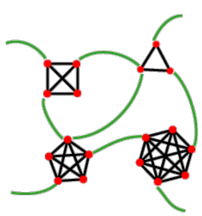
How many links have to be changed to dramatically shrink the largest world?

Very few! With probability of random rewiring of .01, the path length drops 5 fold
- Quickly the number of degrees of separation drops to approximately 6
- And then it drops very, very slowly



Networks with Small Separations

- Species in food web: 2 links
- Molecules in the cell are separated on average by 3 chemical reactions
- Scientists in various fields of science are separated by 4 - 6 co-authorship links
- Neurons in the brain are separated by 14 synapses.
- Web pages are separated by 19 links



Clicker Question

How does the small-worlds phenomenon explain the rapid spread of a disease through a population?

Since everyone knows everyone else, each person spreads the disease to others quickly

The world is quite small given the number of diseases out there

Although most people are interact mostly with their neighbors, a few people travel, providing long-range connections between local groups

The bacteria of the world are so connected that each knows others, who know others, etc. so that they communicate quickly

Applications of small world phenomenon

How do diseases spread?

How can an accident at a single power station bring down the rest of the grid?

How does a joke spread across the Internet?

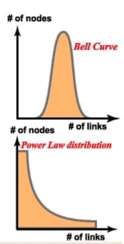
Why do women's menstrual cycles synchronize when they live together?

How are the neurons of the brain connected?

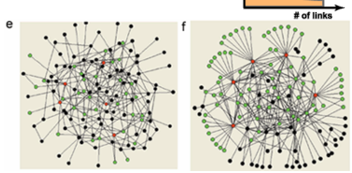
How can an you prevent a crowd from panicking?

How do you design the most efficient office building?

Beyond Equality



- In many networks, not every node has equal probabilities of being connected to other nodes
  - Number of nodes is not distributed normally
- Most nodes are connected with only a small number of other nodes
- But a few are highly connected
  - and some are even more highly connected, fitting a power-law
  - resulting in hubs

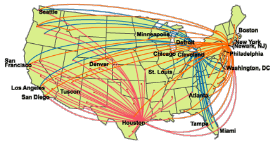


Random Hub (scale-free)

Random versus Scale-free (Power Law) Distribution

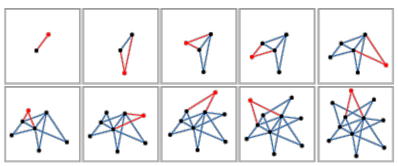
Random

Hubs



How Scale-free Networks Might Arise; Rich Get Richer

- First nodes in a network tend to collect more links over time
- New units preferentially add connections to ones with more connections (links to web pages)



Scale-Free Networks Make for Robust Systems

- Natural networks constantly loose nodes
  - Every day you loose neurons (more if you drink!)
    - If any given neuron was absolutely essential, you would be at great risk
      - but most have relatively little effect
  - Many species go extinct each year
    - If any were essential to the food chain, we would all be at high risk
      - but most are not essential
  - Nodes on the internet go down regularly
    - If any were essential, the network would crash frequently
      - fortunately, most are not

Scale-free Networks and Robustness

- Scale-free systems are more robust than random or equally distributed ones
  - Most loses will affect minimally connected nodes
  - But at a critical point, the network will split into unconnected islands
- The internet could probably survive loss of 80% of sites if chosen randomly
  - But if hackers target only the largest hubs, they could bring down the system
- The same holds for
  - Proteins in your body
  - Species in our ecosystem

Clicker Question

How can scale-free organization make mechanisms robust?

Most components in a mechanism don't do much and so don't have bad effects when lost

Large mechanisms have so many components that loss of a few doesn't matter

Most components do things that are redundant with what others do, and so their loss has little effect

Most components have effects only on a few others and so their loss only affects a few others

The Downside of Scale-Free Networks

While most nodes don't have a huge effect on the overall system

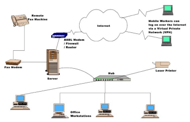
- those that are hubs do

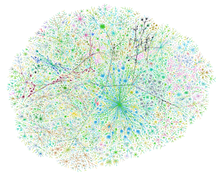
Loss of these can be catastrophic

- Shutting down LAX for a few days would radically disrupt air traffic
- Shutting down Google would disrupt internet activity
- Serious diseases often involve proteins that affect many physiological activities

Interconnected Components and Higher-Level Entities

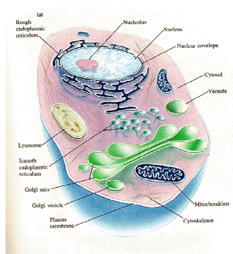
- Large webs of interconnectivity link nodes together into a larger system
  - Individual computers linked into networks that have life of their own





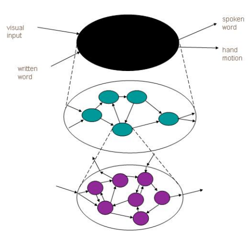
Segregating Components

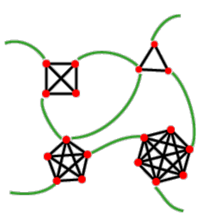
- While connectivity is often useful, so is segregation
- Boundaries such as membranes permit control over what is admitted
- Create subsystems that carry out their tasks somewhat independently from their
  environment
- These often correspond to mechanisms
  - sets of components that each contribute their activity to a joint function



Hierarchies of Mechanisms

- Mechanisms are made of mechanisms
- Mechanisms are parts of other mechanisms





Non-sequential Organization Creates Systems

When the components of a mechanism are highly interconnected, they begin to operate as a unit

- And constitute a new entity
- That exists at a higher-level of organization than the components

Often it is cyclic organization, involving later reactions influencing one's earlier in a pathway, that turn a set of operations into a *system*—a recognizable entity that does something

- Nervous system
- Circulatory system

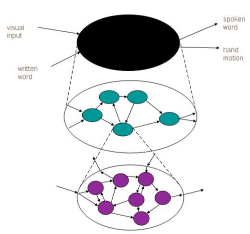
Clicker Question

Feedback relations (positive and negative) between parts and operations serve to

- Make it easier to identify the parts and operations of a mechanism
- Violate the principle that causation is directional
- Render the whole system into an entity at a higher level of organization
- Always render a mechanism unstable

Mechanistic Levels

- The system as a whole engages its environment by performing its activity
- That system is comprised of components that perform different operations
- Those components in turn are comprised of components that perform yet different operations



Holism versus reductionism

Tension:

- Emphasizing organization focuses on the integration of the components into a whole system (holism)
- Emphasizing components focuses on the decomposition of the system into separate components (reductionism)

As a result, holism (vitalism) and reductionism are often pitted against each other

- Holists charge that reductionists fail to consider the consequences of organization
- Reductionists charge that holists fail to provide explanations

Clicker Question

A reductionist, in contrast to a holist,

Focuses on how the components of the system fit into an integrated whole

Denies any importance to discovering the parts of the mechanism

Denies that organization plays any role in the operation of a mechanism

Emphasizes the discovery of components as the key to understanding how a mechanism behaves

Clicker Question

A holist, in contrast to a reductionist,

Places greater emphasis on the organization of the whole than on the identification of the parts

Thinks that the parts don't matter; all that matters is how they are organized

Denies that the parts of a mechanism are relevant to explaining what the mechanism does

Places primary emphasis on discovering the parts of a mechanism

Mechanistic explanations: both reductionist and holist

To understand a mechanism you must be both a holist and a reductionist

Look both
- Upwards to higher levels of organization at which the mechanism is an organized systems that performs its activity and thereby interacts with other entities

and
- Downwards to lower levels of organization in which parts perform their operations in interaction with other parts