Organization and Levels of Organization

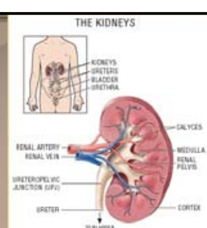
Characterization of a mechanism

Since the 17th century, science often appeals to mechanisms to explain phenomena

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

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

Multiple mechanisms in the same organ

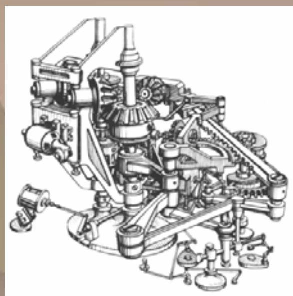


Kidneys perform a number of different phenomena

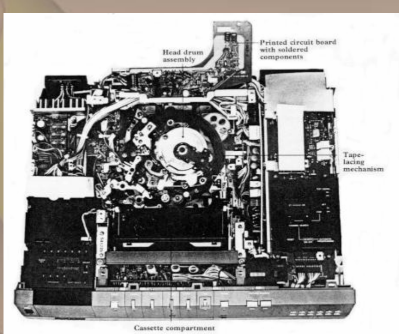
- Regulate blood composition
  - keep concentrations of various ions and other metabolites constant
- Keep water volume constant
- Remove waste substances (urea, ammonia, drugs, toxic substances)
- Keep blood acid/base concentration constant
- Help regulate blood pressure
- Stimulate the making of red blood cells
- Maintain body's calcium levels

Depending which phenomenon we focus on, we will attend to different components and processes—different mechanisms

Hard to Get Started When You Don't Know the Phenomenon



Even Knowing this is a Video Recorder Leaves Lots of Puzzles



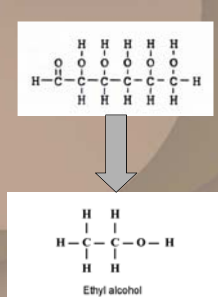
What are its working parts?

What does each contribute?

How do they work together?

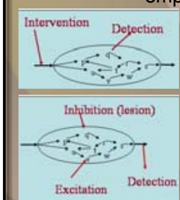
Sometimes You Need to Figure out Operations without Knowing the Parts

What are the operations in fermentation?



Understanding Mechanisms

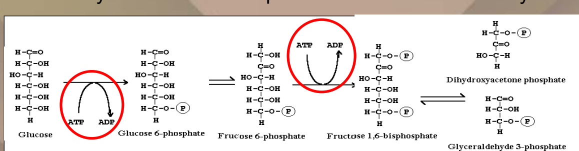
To explain the operation of a mechanism, must decompose it into its
- Working parts
- Operations
  - Often requires reverse engineering, but also empirical inquiry



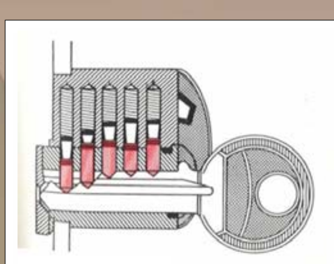
- Record operations of possible intermediaries while the mechanism is operating
- Inhibit possible intermediate processes to see if that stops the reaction—lesion experiment
- Insert possible intermediaries to see if they could produce the end product—excitation experiment

Mechanisms are organized

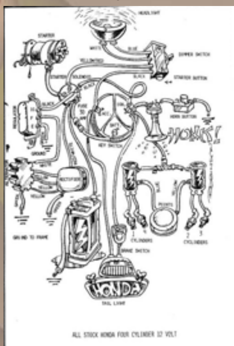
Mechanisms are not just components each doing their thing
- The components are organized so that the various operations carried out by the components feed appropriately into the operations of other components
- It is by virtue of these relations with other entities that they contribute to the performance of some activity



Organization is critical to the operation of a lock



Organization even more important in a system of active components

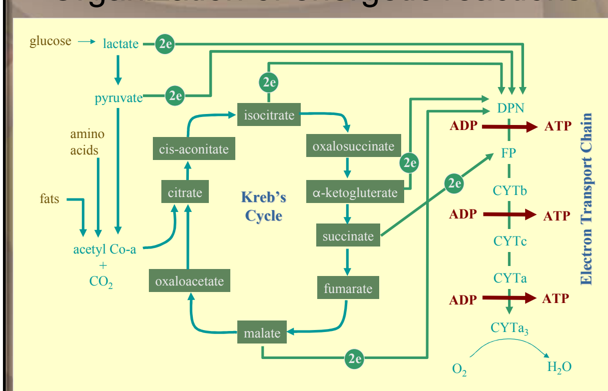


Using diagrams to portray organization

It is very difficult to understand the organization of a complex system from a verbal description

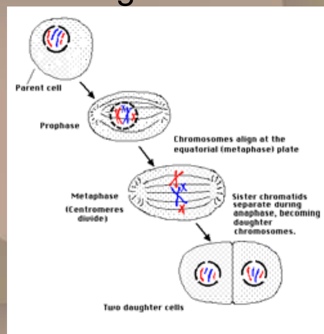
- Diagrams are able to show in two dimensions the spatial layout of a mechanism
- Often, though, diagrams must also show the activity of the mechanism
  - This must usually be done through arrows

Organization of energetic reactions



Diagramming steps in a process in separate diagrams

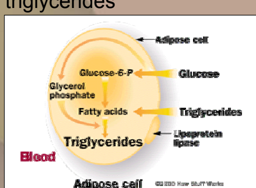
- Show organization at successive stages in the process of cell division
- Use arrows to reflect the progression of stages

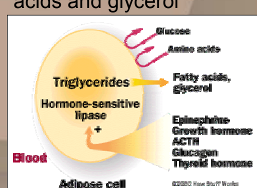


Mechanisms with multiple states

When insulin present, fatty acids and glucose are absorbed into fat cells and synthesize triglycerides

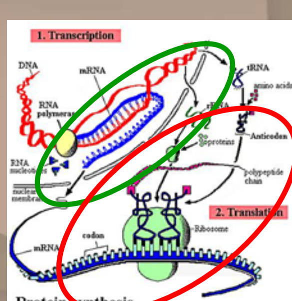
When insulin absent: Hormones enter the cell, activating lipases, which break down fats into fatty acids and glycerol





Diagramming steps in a process in a common diagram

Use arrows to trace the movement of components from one location to another: here, move various RNAs from the DNA of the nucleus to the ribosomes in the cytoplasm



Organization creates systems

If the organization is appropriate, the components comprise a new entity

- One existing at a higher-level of organization

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

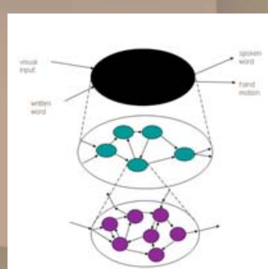
- Nervous system
- Circulatory system

Levels of mechanism

The system as a whole engages its environment by performing its activity

That system is comprised of components that perform different activities

Those components in turn are comprised of components that perform yet different activities



Holism versus reductionism

Tension:

- Emphasizing organization focuses on the integration of the components into a whole system
- Emphasizing components focuses on the decomposition of the system into separate components

Often conflict between holists (vitalists) and reductionists

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

Mechanistic explanations: both reductionist and holist

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

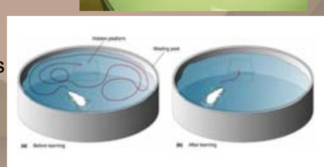
Look both
- Upwards to higher levels of organization in which the mechanism performs its activity and thereby interacts with other entities

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

Delineating the phenomenon of spatial memory

To understand spatial memory you must know how it is exhibited, including in what larger contexts

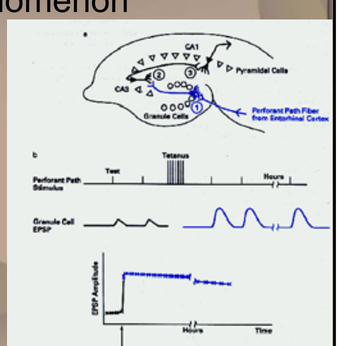
In the Morris water maze, rats quickly learn where the submerged platform is and swim directly to it



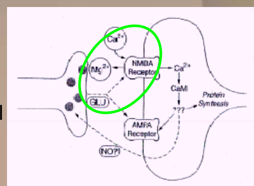
Going inside to explain the phenomenon

Inside the rat's brain one finds a structure—the hippocampus—that, if removed, leaves the rat unable to navigate (inhibition or lesion experiment)

Inserting an electrode into the structure one finds cells that respond to specific places (recording experiment)



Molecular changes and long-term potentiation



Presynaptic neuron releases glutamate

Glutamate binds to the NMDA receptor on the post-synaptic cell

Change in NMDA receptor exposes pore, which however remains blocked by Mg^{++} ions

If the postsynaptic cell fires, Mg^{++} float out of the channel, letting Ca^{++} ions enter

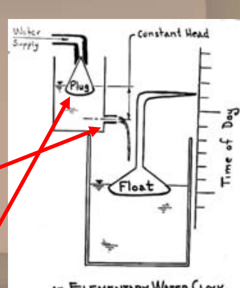
This initiates a series of biochemical reactions in the postsynaptic cell, only some of which are known

Multi-level account of memory

- Organisms develop memories
- Particular parts of their brains are especially important for encoding or storing memories
- Within these components, biochemical changes result in altered systems that behave differently in the future

- The operations of these components only results in memory insofar as their operations are properly coordinated with each other
  - Organization often produces surprising results from even simple components

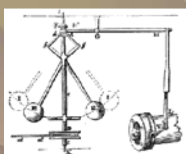
Beyond Linear Organization: Negative Feedback



- 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 wate when it got too high in the 3rd Century BCE

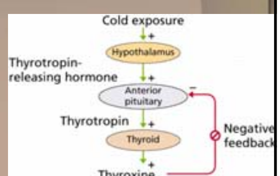
Industrialization and Negative Feedback

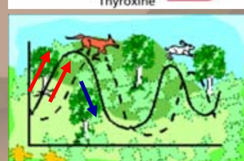
- James Watt faced a serious practical challenge
  - How to control the speed of the steam engine so that all appliances would run at the same rate despite different number being on line at a time
  - Devised an elegant mechanism for feedback control



Negative Feedback and Biology

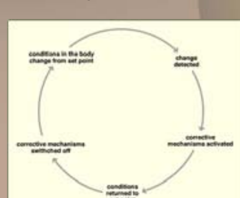
- Critical that biological systems be able to maintain themselves in the face of environmental change
  - Homeostasis
- Feedback in organism-organism interaction
  - Predator-prey interactions
    - As prey increase, so do predators
    - As predators increase, prey decrease
  - Lotta-Volterra model





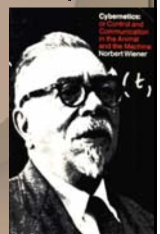
Closed Cycles and Systems

- Closed cycles of operations allow operations occurring later to regulate the occurrence of operations occurring earlier
- Operations occur at just the rate needed by the system
- Resulting in an enduring mechanism



Recognizing the Generality of Negative Feedback

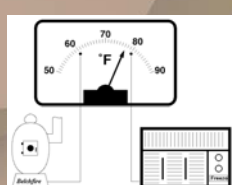
- Challenge: how to control gun fire targeting aircraft
  - Use feedback from the first shot to correct the next
  - Later, heat seeking missiles and beyond



- 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



From Simple to Complex Systems

- Human engineering in the 20^{th} century increasingly produced systems with more and more parts performing different operations
  - 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

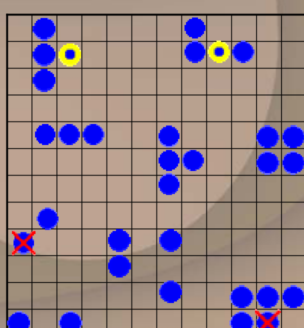
The Game of Life

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).



Six degrees of separation

Why did AIDs and typhoid 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

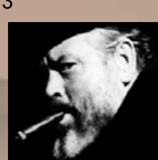
Pick an actor or actress

- 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
- 150,000 have a Bacon number of 3
- No American actor, living or dead, has a Bacon Number greater than four
- 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 eight

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

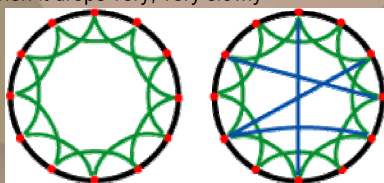
Other extreme

- 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 does it take to reduce separation dramatically?

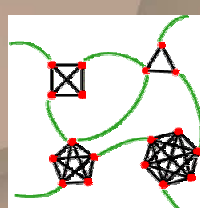
Very few! With probability of random rewiring of .01, the path length drops 5 fold

- 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 different 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



Applications of small world phenomenon

How do diseases spread?

Can anyone break into the old-boy network?

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?

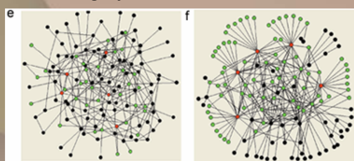
How are the neurons of the brain connected?

Can you prevent a crowd from panicking?

How do you design the most efficient office building?

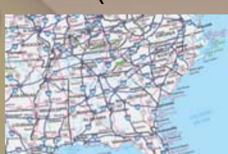
Beyond Equality

- In many networks, not every item has equal probabilities of being connected
- Most nodes are connected with only a small number of other nodes
- But a few are highly connected--hubs



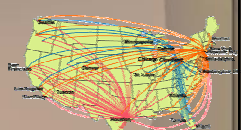
Random Hub (scale-free)

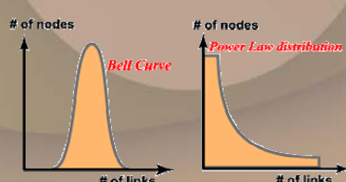
Random versus Scale-free (Power Law) Distribution



Random

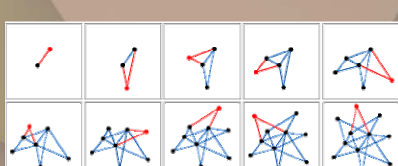
Hubs





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)



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 risk
  - Many species go extinct each year
    - If any were essential to the food chain, we would all be at high risk
  - Nodes on the internet go down regularly
    - If any were essential, the network would crash frequently

Scale-free systems and Robustness

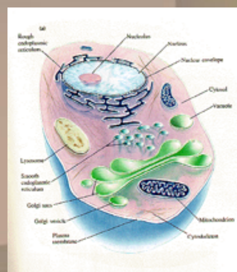
- Scale-free systems are more robust than random or equally distributed ones
  - Most loses will affect minimally connected nodes
  - But at a critical point, the network will split into unconnected islands
- The internet could probably survive loss of 80% of sites if chosen randomly
  - But if hackers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

Networks and Levels

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

Segregation Also Important

- Boundaries such as membranes permit control over what is admitted
- Create subsystems that are partly autonomous from their environment
- Herbert Simon
  - Nearly decomposable systems
  - *The Sciences of the Artificial*



Mechanisms and Hierarchies of Organized Systems

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