From Causation to Mechanisms

Review

- Experiments provide the best evidence of a causal relation, but sometimes they are not possible.
- Since it is impossible physically or morally to manipulate the independent variable.
- Two strategies:
  - Prospective studies: Divide groups according to the independent variable and investigate correlation with the dependent variable.
  - Retrospective studies: Divide group according to the dependent variable and investigate correlation with the independent variable.

Two limitations of causes for science

- Individual causal relations do not accomplish much. It requires a coordinated system of causes to get something done.
- What relates causes to their effects? Typically there are processes intervening between causes and their effects.

Between and within causal relations scientists look for mechanisms:

Parts (entities) and operations (activities) organized to produce an phenomenon.
The Ubiquity of Mechanisms in Science

- Mechanisms in physical sciences
  - Solar system mechanics
  - Mechanisms of chemical reactions
- Mechanisms in biological sciences
  - Mechanisms of photosynthesis
  - Mechanisms of reproduction
- Mechanisms in behavioral sciences
  - Mechanisms of memory encoding
  - Mechanisms of decision making
- Mechanisms in social sciences
  - Mechanisms of consensus formation

Mechanisms as Coordinated Causation

- Mechanisms are made of parts causing changes in other parts, enabling mechanisms to cause changes in yet other things
- Muscles in heart contract while valves open and shut, enabling the heart to move blood through arteries and veins
- Understanding a mechanism requires experimental procedures designed to figure out the parts, their causal operation, and how these operations are coordinated so that the mechanism can produce its effect

Designing Mechanisms vs Discovering Mechanisms

- The challenge in engineering is to design new mechanisms that produce the phenomena we are interested in
  - Typically, engineers begin with an objective and recruit parts already known to perform operations
  - Their challenge is to discover new modes of organization that enable the parts to together do something new
- Scientists do not have access to the design manuals of the mechanisms operative in the natural world
  - They must reverse engineer them—discover the parts, the operations, and the organization
Early simple machines used human energy but extended its capacity.

- In these cases, shape and spatial layout explain the causal efficacy.

In these cases, shape and layout together with coordination of parts explain the effect.

Permit the performance of activities that otherwise would not be possible.
Combining simple mechanisms

Engineering: organizing components to produce effects

Common force for creating new machines: warfare

The Gastrophetes or belly bow, introduced around 400 BCE, designed to launch arrows further and more accurately than the traditional bow.

The Oxybeles, introduced around 375 BCE, provided ever greater power and accuracy.

Ballista, introduced around 50 BCE, used more for throwing stones than arrows.

Onager, developed around 350 CE, was a low cost way of launching projectiles such as clay balls with Greek fire inside.
Common force for creating new machines: warfare

Trebuchet: a counterweighted catapult designed to throw heavy projectiles

Such as pianos!
- Chris throwing Maggie's piano in Northern Exposure

From Simple to Complex

Common theme in both engineering and science
- Begin with simple designs but increasingly engineer or discover more and more complex mechanisms
- Large numbers of parts
- Performing many different operations
- Coordinated in ever more complex ways

Nature as a machine: Rene Descartes

"I have described this earth and indeed the whole universe as if it were a machine: I have considered only the various shapes and movements of its parts" (Principia IV 188).

All action in the physical universe due to shape and motion of physical matter
- No vacuum
- No action at a distance

Magnetism: Screw-shaped particles (formed in vortices) fit into threads in iron.
Robert Boyle: Restorer of the Mechanical Philosophy

- Introduced the name mechanical philosophy.
- Air pump—adapted design of Otto von Guericke
- Air molecules as springs
- Boyle’s law: "the hypothesis, that supposes the pressures and expansions to be in reciprocal proportion"

Descartes: Animals as machines

- Impressed by the statuary in the Royal Gardens that moved by hydraulic principles
- Animal bodies are purely mechanical devices
- Circulation of blood due to heating in the heart, causing the expansion of droplets of blood, which then forced their way through the arteries
- Nerve transmission and brain activity purely mechanical (albeit influenced by the mind in humans)

Humans as machines

- Descartes could not conceive of a mechanism that could think or use language
  - Accordingly, held that the human capacity for thought was not due to a mechanism
  - Rather, thought due to a non-material mind
- Julien Offray de La Mettrie objected that Descartes did not go far enough—all human activities, including thinking explained in mechanical terms
  - Man the Machine in 1748
Newton: Expanding the mechanical philosophy
Endorsed the mechanical philosophy
Light and heat nothing but particles in motion

"I wish we could derive the rest of the phenomena of Nature by the same kind reasoning from mechanical principles, for I am induced by many reasons to suspect that they may all depend upon certain forces by which the particles of bodies, by some causes hitherto unknown, are each mutually impelled towards one another, and cohere in regular figures, or are repelled and recede from one another. These forces being unknown, philosophers have hitherto attempted the search of Nature in vain; but I hope the principles here laid down will afford some light either to this or some truer method of philosophy."

Preface to *Principia*

Jacques de Vaucanson (1709-1782): “Moving Anatomy”

Mechanical duck
  could move in the typical, wagging way of a duck
  eat and digest fish
  excrete the remains in a “natural” way
Mechanism was driven by a weight
Consisted of more than a thousand moving parts, concealed inside the duck and the base on which the bird stood
Besides the duck, a flute and tambourine player

Applying mechanical ideas to living organisms

Living things seem to behave in complex ways that defy simple mechanical explanation

Vitalists maintained that the complexity and purposiveness of biological processes made mechanical explanation impossible

Mechanists developed more complex conceptions of mechanisms
Tropism

Two principles of Jacques Loeb:
(i) The movements of an organism to or from a center of a stimulus are caused by action of the stimulus on the receptors, and through these on the organs of locomotion, in consequence of which the animal turns until its body is symmetrically stimulated and an equilibrium obtained between the two sides.
(ii) These movements occur mechanically, as a result of physical and chemical changes in the receptors and effectors, with no real effort on the part of the organism.

Designing a tropistic machine

Designing a tropistic machine
Characterizing mechanisms

Parts (entities) and operations (activities) organized to produce an phenomenon

Start with a phenomenon of interest:
- tropism of plants
- cell division
- remembering events in one’s life
- increasing worker productivity

Describing the Phenomenon

Before setting out to explain a phenomenon, need to characterize it as accurately as possible
- Otherwise one risks trying to explain something that might not be possible
- An important role for purely observational research
  - Before seeking a mechanism by which the universe continues to expand, make sure it is
  - Before explaining mechanism of global warming, make sure it is really occurring
  - But the description of the phenomena may be revised in the process of figuring out the mechanism

Mechanisms have working parts

To understand a mechanism, one must decompose it—take it apart
- Literally—actually remove the parts to study them in isolation
- Figuratively—figure out what the parts are and what they do

In identifying components, focus both on their
- Structure
- Function
Structural components of cells

Cell components tend to have boundaries (membranes) that restrict access. Components have distinctive appearances, especially when stained.

Worry—since things have to be manipulated to be seen, is what you see reflective of what is there? Or is it a product of your manipulation: an artifact?

What are the parts of the brain?

Open up the skull, and you see a hunk of grey matter highly convoluted.

What are the working parts of the brain?

Sulci and Gyri? Lobes?

What are the working parts of the brain?

Korbinian Brodmann (1909) assumed differences in neuron type, density, layering, probably related to function.

Delineated areas in the brains of humans and many other species.
What are the working parts of the brain?

With improved tools, including tools for tracing the connectivity of neural processes (axons and dendrites), modern brain mappers have developed maps that seem to correspond to function.

What operations do the components perform?

Just locating and isolating a component doesn't reveal what the component does. How does one figure out what these things do? Sometimes probing an item in various ways will reveal what it does.

What operations do the components perform?

Often one must reason backwards from what the whole mechanism does to what operations are needed to perform that activity. Often these operations are not obvious:

- Reverse engineering
- Figuring out what task needs to be performed
- Using information about the type of operations that have been previously identified in similar systems
- Drawing upon analogies with machines made by humans
What are the operations in fermentation?

Strategies of discovering intermediate operations
- Isolate possible intermediaries
- 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

Organization
The third feature of mechanisms is that they are organized and that the organization matters.
Grains of sand in a sand pile are not organized: you can recombine the grains at will and nothing happens.
In mechanisms, one part depends on others, so organization matters.
Exemplary mechanism: the computer

In the mid-19th century Charles Babbage had the idea to mechanize computation.

The Difference Engine

The Analytical Engine

Creating programs: Ada Byron, Countess of Lovelace

Her mother had her trained in mathematics so she wouldn't be tempted to be a poet like her father.

Became friends with Babbage and helped sell his analytical engine to Italian sponsors.

Recognized the promise of a general computer: “developing and tabulating any function whatever. . . the engine [is] the material expression of any indefinite function of any degree of generality and complexity.”

Mechanizing computing

Sequences of simple mechanical operations could compute any given function.

A special version of such a machine could compute all computable functions: Universal Turing Machine.
Actual computers: Army, Census Bureau, and Predicting Elections

The question reverses

Computers became tools for modeling mental activities: designing computers to simulate:
- Perceiving
- Remembering
- Using language

Do computers think?
Remember, they were built upon the model of how the human mind was thought to work!

Do humans think by carrying out the same operations in the same way as computers?