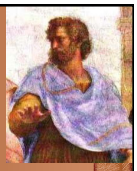
Early mechanist ideas in biology: Harvey, Descartes, and Boyle

1. How did biologists come to know what they (think we) know about living organisms?
2. How do appeals to mechanisms figure in biological explanations?

Like all other disciplines, biology starts with Aristotle! 384-322 BCE



- Essentialism
- 'hylomorphic' view — *hylê* 'matter', *morphê* 'form, shape'
  - bronze sphere: bronze matter and spherical form
  - ax: wood and iron (matter) and the shape and organization required for chopping
- Form:
  - More than mere shape
  - What makes an object the sort of thing it is

Soul: the form of a living thing

- Three types of soul
  - *Vegetative* (*plant*): nutrition, growth and reproduction: botany
  - *Animal:* add sensation and locomotion: zoology
  - *Rational*: add 'intellect' or 'thinking of' (*nous*): psychology
- Soul imposes form on matter—in nutrition: "the active principle of growth lays hold of an acceding food which is potentially flesh and converts it into actual flesh."
- More precisely: different forms in different species and genera
  - Separated cetaceans (marine mammals) from fish and identified them as more like mammals
    - Live birth

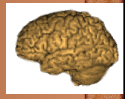
Aristotelian classification

Animals

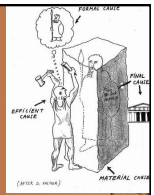
With blood	Without blood
Viviparious (live-bearing) quadrupeds (mammals)	cephalopods (e.g., octopus)
Birds	crustaceans
Oviparous (egg-laying) quadrupeds (reptiles and amphibians)	insects (including also spiders, scorpions, and centipedes)
Fishes	shelled animals (e.g., molluscs and echinoderms)
Whales	"zoophytes" or plant-animals (e.g., cnidarians)

Aristotle's Anatomy and Physiology

- Digestive system converted food into blood by the action of heat
- Breathing functioned mainly to cool the body
- Kidneys cleansed the body of wastes
- The heart generated the heat required to turn food into blood
- The heart also represented the location of the human mind, the source of intellect, consciousness, emotions, and motivations
- The brain contributed to cooling of the body



Aristotle's Four "Causes": Aitia



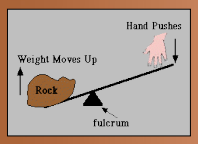
- *Material*: that out of which something is, e.g. the bronze of a statue
- *Formal*: the structure which the matter realizes and in terms of which the matter comes to be something determinate, e.g., the Hermes shape in virtue of which this quantity of bronze is said to be a statue of Hermes
- *Efficient:* the agent responsible for a quantity of matter coming to be informed, e.g. the sculptor who shaped the quantity of bronze into its current Hermes shape
- *Final*: the purpose or goal of the compound of form and matter, e.g. the statue was created for the purpose of honoring Hermes

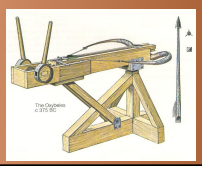
Aristotle's teleology

- Things in the world seem to have purposes or functions in that things seem to be organized so as to do things
  - Contrast Empedocles: due to chance
- "What is it, then, that grows? Not what it is growing from, but what it is growing into." (*Physics* 193b18)
- Extended this view from physical entities and artifacts to human activity

"Aristotelian" mechanics

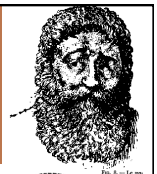
- Mechanics operates against nature





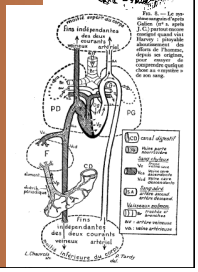
The Oxybeles, introduced around 375 BCE, made it possible to launch arrows with greater power and accuracy than previous devices

Galen (131-201)



According to Galenic physiology, arteries and veins each carried different types of blood away from the heart

- Venous blood carried nutrients from the liver through the right side of the heart to the body
- Arterial blood is vivified by the lungs and carried to the left side of the heart to the body
- Slight seepage from right to left
- Heart operated to suck blood in from the veins
- Both types of blood consumed by the body's tissues



Fabricius Ab Aquapendente and the valves of the veins

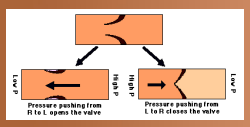
"Little doors of the veins is the name I give to certain very thin little membranes occurring on the inside of the veins....They have their mouths directed towards the root of the veins [i.e. the heart], and in the other direction are closed. Viewed from the outside they present an appearance not unlike the swellings which are seen in the branches and stem of a plant.

"In my opinion they are formed by nature in order that they may to a certain extent delay the blood and so prevent the whole of it flowing at once like a flood either to the feet, or to the hands and fingers, and becoming collected there."

On the Valves of the Veins (De Venarum Ostiolis) 1574 or 1603

William Harvey's evidence against Galen

Determined that the valves in the veins would only permit flow into the heart, not out



But the Galenic theory predicted that blood could flow away from the heart in the veins as well as in the arteries

William Harvey's evidence against Galen- 2

An assumption of the Gelenic theory is that all the contents of arterial and venous blood originate in food and is dispersed

Harvey measured the amount of blood in the heart at a time (approx. 2 ounces) and multiplied by number of heart beats an hour (2,000)

Estimated that 40 pounds of blood sent out per hour

This turns out to be a gross underestimate

Even grossly underestimated, the amount exceeded the quantity of food and liquid a person consumes

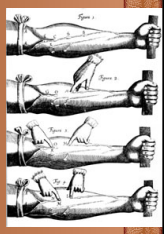
- where does it come from?
- and where does it all go?

Harvey's direct experiment

When he applied a bandage to the upper arm, stopping flow in the (superficial) veins without interrupting flow in the (deep) arteries
- the veins would swell but not the arteries

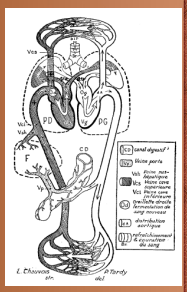
When he increased the bandage pressure so as to block the flow of blood in the arteries
- the veins did not swell

He reasoned from this that the blood entered the arm via the arteries and left via the veins



Harvey's Alternative Hypothesis

Rejecting Galen's hypothesis, Harvey proposed that there is only one kind of blood and that it circulates out from the art in the arteries and returns to the heart in the veins



Harvey's proposal

Since all things, both argument and ocular demonstration, show that the blood passes through the lungs and heart by the force of the ventricles, and is sent for distribution to all parts of the body, where it makes its way into the veins and porosites of the flesh, and then flows by the veins from the circumference on every side to the centre, from the lesser to the greater veins, and is by them finally discharged into the vena cava and right auricle of the heart, and this in such a quantity or in such a flux and reflux thither by the arteries, hither by the veins, as cannot possibly be supplied by the ingesta, and is much greater than can be required for mere purposes of nutrition; **it is absolutely necessary to conclude that the blood in the animal body is impelled in a circle**, and is in a state of ceaseless motion. (Harvey, 1628, *On the movement of the heart and blood in animals*)

Don't challenge Galen, unless you have friends in high places

The Heart as a Mechanism

- Harvey's challenge was not just to specific ideas about how blood function, but to the way of conceptualizing physiology and medicine
  - His focus was not on teleology, but on the efficient processes
  - These could be studied in the manner of ordinary physical machines
    - One could conduct experiments—manipulate parts of the system and observe the consequences

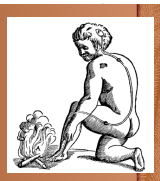
Nature as a machine: Rene Descartes

- "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.

Descartes: Animals as machines

Impressed by the statuary in the Royal Gardens that moved by hydraulic principles, Descartes proposed that
- 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
- Note: not Harvey's proposal!



Nerve transmission and brain activity purely mechanical (albeit influenced by the mind in humans)

Robert Boyle: Restorer of the Mechanical Philosophy

Introduced the name *mechanical philosophy*

Adapted and improved Otto von Guericke's design for the air pump

Viewed air molecules as springs

Boyle's law: "the hypothesis, that supposes the pressures and expansions to be in reciprocal proportion"

Boyle and Respiration

Boyle experimented with placing animals in the vacuum created with the air pump
- insects (fleshfly, bee, butterfly) drop to the ground immediately, but recover when air is readmitted. Why?
  - Lack of buoyancy?
  - Need for air to live?
- Tested other animals: mouse, non-flying insects (caterpillars) and they exhibited the same behavior

Boyle and Respiration - 2

- Boyle showed that if animals lived in a sealed container until death, new animals introduced in the container expire very quickly
  - Only a part of the air sustains life
  - "Whence we may conjecture, That the portion of Air which hath once served the respiration of Animals as much as it could, is no longer useful for the respiration of another Animal, at least of the same kind."
- A century later Joseph Priestley showed that plants could refresh the air
  - Identified the critical component "dephlogisticated air" and Lavoisier renamed it "oxygen"

Marcello Malpighi

- Discovered the capillaries, completing Harvey's picture of circulation
- Of particular importance, discovered small blood vessels surrounding the alveoli in the lung
  - If the lung collapses, the animal's heart stops
  - If the lung is re-inflated with a bellows, the heart begins to pulse "...even when it had almost ceased before, since then, by the pressure of the air, blood enters the left ventricle."

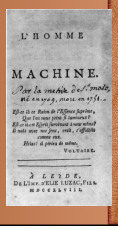
But what do the lungs do? Robert Hooke's experiments

- What do the lungs do? Cause circulation of the blood or provide new air?
- Hooke devised an experiment on a dog in which the lungs no longer contracted and dilated
  - Bellows supplied air to lungs with hole at opposite end so that air was provided, but no (or minimal) contraction
  - Heart continued to beat "for a pretty while....But upon ceasing this blast, and suffering the lungs to fall and lye still, the Dog would immediately fall into Dying convulsive fits; but as soon as reviv'd again by the renewing the fulness of his lungs, with the constant blast of fresh air."

Humans as machines

Descartes could not conceive of a mechanism that could think or use language

- And so viewed humans as composed of two substances, mind and body



Julien Offray de La Mettrie thought Descartes did not go far enough—all human activities, including thinking explained in mechanical terms: *Man the Machine* in 1748

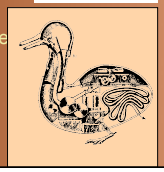
Jacques de Vaucanson (1709-1782): Moving Anatomy

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, Vaucanson designed mechanical flute and tambourine players