Printed on acid-free paper

Photocopying. *In the U.S.A.*: This journal is registered at the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923.
Authorization to photocopy items for internal or personal use, or the internal or personal use of specific clients is granted by Kluwer Academic Publishers for users registered with the Copyright Clearance Center (CCC) Transactional Reporting Service, provided that the fee of USD 12.00 per copy is paid directly to CCC. For those organizations that have been granted a photocopy licence by CCC, a separate system of payment has been arranged. The fee code for users of the Transactional Reporting Service is 0169–3867/98/USD 12.00.
Authorization does not extend to other kinds of copying, such as that for general distribution, for advertising or promotional purposes, for creating new collective works, or for resale.
In the rest of the world: Permission to photocopy must be obtained from the copyright owner. Please apply to Dordrecht office.

Biology & Philosophy is published quarterly.
Subscription price (1998): USD 249.00 including postage and handling.
Periodicals postage paid at Rahway, N.J. USPS No. 000–395.
U.S. Mailing Agent: Mercury Airfreight International Ltd., 2323 Randolph Ave., Avenel, NJ 07001.
Published by Kluwer Academic Publishers, Spuiboulevard 50, P.O. Box 17, 3300 AA Dordrecht, The Netherlands, and 101 Philip Drive, Norwell, MA 02061, U.S.A.
Postmaster: Please send all address corrections to: *Biology & Philosophy*, c/o Mercury Airfreight International Ltd., 2323 Randolph Ave., Avenel, NJ 07001, U.S.A.

Biology and Philosophy **13**: 311–339, 1998.

Aristotle's Anatomical Philosophy of Nature[1]

CHRISTOPHER E. COSANS
Department of Philosophy
George Washington University
801 22nd St., N.W., Suite T-525
Washington, DC 20052
U.S.A.

Abstract. This paper explores the anatomical foundations of Aristotle's natural philosophy. Rather than simply looking at the body, he contrives specific procedures for revealing unmanifest phenomena. In some cases, these interventions seem extensive enough to qualify as experiments. At the work bench, one can observe the parts of animals in the manner Aristotle describes, even if his descriptions seem at odds with 20th century textbooks. Manipulating animals allows us to recover his teleological thought more fully. This consideration of Aristotle as a sophisticated biologist helps our reading of his writings in other areas of philosophy.

Key words: anatomy, Aristotle, body, dissection, experiment, form, nature, soul, teleology, vivisection

The biological texts of Aristotle include the oldest extant references to systematic dissection and vivisection.[2] Throughout his writings on natural philosophy, he establishes points by declaring they are made clear from cutting-up (ἀνατέμνω or διαιρέω) an animal.[3] Aristotle's anatomical works go beyond offering detailed descriptions of how parts fit together; they examine how the parts' organization contributes to the processes by which an organism lives. The quest to capture such active processes requires carefully controlled observations of both living and deceased organisms. These operations, in turn, afford a more detailed understanding of the directiveness of natural organic activities.

In order to explore Aristotle's anatomy, I ventured to the Halsted Packing Company in Chicago. Down at the packing house, I was able to obtain something invaluable for reading Aristotle's biological texts: anatomical material. In an investigation into the epistemology of experimental science, Gooding (1990) argues that key aspects of science can only be understood as the result of human agency in the world. Touching and manipulating the matter of animals allows us to appreciate Aristotle's teleology not as ghostly words but as fully embodied science. Aristotle himself argues that the tangibles, the sense-objects of touch are "the differentia of body qua body" (*de An.* II.11, 423b27).[4] In a moment of unapologetic realism, he notes that if organisms that move around did not have touch, they would crash into things. If an organism did not perceive things that it touches "it would not be able to avoid some things and grab others" (*de An.* III.12, 434b16–17). Aristotle has a sophisticated notion of why bodily contact can contribute to our knowledge of nature. In *On Coming-to-be and Passing-away*, he describes the composition of earth, air, fire, and water – Greek science's traditional building blocks of the animal body – in terms of the two sets of tangible contraries of hot-cold and wet-dry:

> Firstly the potentially perceptible body, secondly the contraries (for example, hot and cold, and thirdly fire, water and the like, are sources. (*GC*, II.1, 329a33–35)

Since the principle of perceptible bodies is tangibility (ἁπτόν) and tangibility is the perceptible of touch (ἁφή), then "not all contraries constitute the form and sources of body, but only those answering to touch" (*GC*, II.2, 329b8–10). While the other senses perceive qualities accidentally associated with bodies, touch perceives the qualities which bodies possess in virtue of their embodiment. Of all the senses none grounds our knowledge of changing natural bodies, such as those studied by the anatomist, more than touch.

One might wonder to what extent can we accurately apply terms like 'biology' and 'anatomy' to Aristotle's writing. Although 'biology' is a modern word, it has such wide scope that it applies to any scientific investigation of living things. Scholars thus commonly designate Aristotle's writings about animals as "biological" (see for example Thompson 1913; Gotthelf and Lennox 1987). Anatomy, on the other hand, is a bit more interesting. Aristotle himself uses the term ἀνατομή (anatomy), but in a different sense than the English word. While 'anatomy' conveys the idea of knowing innumerable names of all the body's parts today, for Aristotle it has a much more active and observational meaning. The Greek noun 'ἀνατομή' literally means "a cutting up", and refers to both delicate vivisections, as well as intricate dissections. To the biologists of ancient Greece anatomy entails more than passively seeing and naming a dead animal's parts; it involves activity and carefully manipulating dead or living bodies to uncover the hidden nature of life.

The logic of anatomy

In the case of anatomy, although the natural philosopher operates on particular organisms, he searches for the universal organic form that an animal body shares with other members of the same kind. He probes and studies a particular

animal not merely to see its body, but in order to learn the nature of *the* body. The biologist's heavy reliance upon induction (ἐπαγωγή) from particular bodies makes the study of animals a somewhat fallen science. In the *Prior Analytics*, Aristotle says that in syllogisms which follow from induction scientists do not use the middle-term to connect the two extremes, but use the observed relation between one extreme and the middle term to establish the relation between the middle and the other extreme term. For example, someone might find that every long lived animal lacks bile or some kind of gall bladder. Aristotle says he could "let A stand for long lived, B stand for having no bile, and Γ stand for each long lived animal like man, horse and mule" (*APr.*, II.23, 68b19–21), so as draw the following inference:

1. A belongs to all Γ.
2. B belongs to all Γ.

\- - - - -

3. Therefore A belongs to B.

This syllogism uses the connection of proposition 2, which would be empirically observed, to support the more universal conclusion that a lack of bile contributes to longevity. Since the "particulars" of this demonstration are entire animal species, like horses, each case universally applies to many bodies. Aristotle concludes that the standard "syllogism through a middle is prior and more known by nature, but those through induction are more distinct to us" (*APr.*, II.23 68b35–37). Nonetheless, Aristotle the opens the *Physics* (*Ph.* I.1) by claiming that since natural philosophers are humans, they should indeed begin their inquiry with what is distinct to us and then proceed to what is naturally more knowable. So even if the Aristotelian natural philosopher ultimately justifies his theories with deductions, his experience still plays an important role in the earlier discovery phases of inquiry.

Aristotle frequently uses commonly experienced phenomena to unmask the anatomical forms that underlie bodily activity. For example, he supports his belief that males have their characteristic voice due to "strength in the sinews (νεύροις)" (Aristotle, *GA* V.7, 787b10–11) with the fact that castrated males have feminine voices. Aristotle reasons that the testes exist for the purpose of weighing down sinewy channels. These channels are seen to interconnect with the sinews of the body via blood vessels, and can thus concoct seed from blood. Aristotle refers to the general way weights pull on strings to illustrate both how the testes work and castration's effect:

> The loosening resembles the case if someone were to stretch a cord and make it taut by hanging some weight on to it, just as women do who weave at the loom; for they stretch the warp by attaching so-called stones. (*GA* V.7, 787b22–26)

Aristotle thus uses the machinery by which women weave their family tapestries as an analogy for the anatomical form of the male body. Both cases are particular instances of weights pulling on strings. When boys grow into men, their testes weigh down and tighten their sinewy reproductive systems not unlike the way that stones pull down the women's equipment into working order. The consequences of castration follow from this common mechanism. Just as the weaver's warp snaps up if its stones are removed, when the animal's testes are cut off the channels are pulled back into the body thereby slackening the whole sinew system. The resulting "loosening of sinewy strength" (Aristotle *GA* V.7, 787b20–21) causes the voice to change over to the more feminine tone.

We can reconstruct Aristotle's analysis of the relation between the body, voice and gender into a simple argument:

1. All string and weight systems have loose strings after their weights are removed. (illustrated with the warp example)
2. The sinews and testes are a string and weight system of the body. (from anatomical observation)

-----

3. Therefore: The body has loose sinews after its testes are removed.
4. The body has a feminine voice in virtue of loose sinews. (from anatomical theory)

-----

5. Therefore: The body has a feminine voice after its testes are removed. (observed result of castration)

Aristotle interweaves notions with different kinds of support into a coherent theory about the body that predicts the result of castration.[5] Proposition 3 follows from the application of mechanical principles to the body, as sinews and testes are observed to belong to the more general classes of weights and strings. Proposition 4 states Aristotle's general theory on the relation between the body's form and voice, and is closely wedded to the notion that tight sinews cause a masculine voice. It brings the bodies of castrated men, women and boys under a common class. Although not directly observable, it derives empirical support by building upon propositions 1, 2 and 3 to "predict" the result of castration (proposition 5). This type of thinking resembles the approaches that experimental scientists often take when they explore the material world. In his classic account of scientific discovery, Hanson (1958) argues that scientists often reason backwards from the results of experiments to abduct new conceptual patterns which explain or "predict" the results, just as Aristotle abducts proposition 4 from observable things. In a more recent exploration of discovery in biology, Schaffner (1993: 133–136) points out that experimenters test a hypothesis by using auxiliary hypotheses from background theories to deduce an observable conclusion. In the above argument the more empirical propositions 1 and 2 serve as auxiliary hypotheses that allow one to "test" the theory of proposition 4 by deducing the observed result of castration. Through his placing the common practice of castration in the context of his dissection of the male reproductive tract and his theory concerning the causal roles of the body's sinews, Aristotle thus incorporates folk observations into his search for an underlying bodily mechanism. The appropriation of castration for anatomical biology transforms the common agricultural practice into a thought experiment on the biological basis of sex and gender.

In his effort to provide a foundation for a new modern science, Francis Bacon says some rather unflattering things about Aristotle's approach to science. Bacon portrays Aristotle as a one trick pony, "who utterly enslaved his natural philosophy to his logic" (1994, Aphorism I: 54). He considers this to be the most striking example of an *Idol of the Cave*, where an individual's particular nature and habits prevents him from seeing the true light of Nature. Aristotle's desire to ground science on a logical quest for universals so "tainted and corrupted" (1994, Aphorism I: 96) his natural philosophy that he cannot even use experience in the proper way. In a rebuff of not just of Aristotle, but all people who studied nature before the 17th century, Bacon claims that,

> Up to now, no search or collection has been made for a mass or store of particulars, suitable either in number or kind or certainty, nor in any way adequate to inform the understanding. (1994, Aphorism I: 98)

Bacon sees none of his predecessors as being systematic enough to adequately ground science with data. He contrasts the established approach to nature, which "flies from the senses and particulars to axioms of the most general kind", with his new method of calling "forth axioms from the senses and particulars by a gradual and continuous ascent, to arrive at the most general axioms last of all" (1994, Aphorism I: 19). Even if scientific knowledge addresses universals, the natural philosopher needs fully to engage and contemplate particulars before jumping to general conclusions. In order to properly ground our knowledge of nature the natural philosopher must use scientific observations not folk tales.

Bacon's critique raises serious questions about how Aristotle builds up his account of nature from experience. Each particular animal that someone might dissect usually varies in some way from the other members of its species, yet Aristotle fills his accounts of the body with universal propositions about what structures are present or absent in certain kinds of animals. Even when he recognizes that parts do indeed differ amongst animals in the opening of the *History of Animals* (I.1, 486a14–26), he focuses his account on the ways in which parts are the same. For example while human eyes have different colors, they are the same with respect to form (εἴδει). In searching for the organic form of the body, the Aristotelian ignores the features that that are unique to a particular cadaver's matter. Although he mentions the occurrence of rare cases where some animals have a liver on the left and spleen on the right, he emphasizes the general arrangement of the liver on the right and spleen on the left "in all having these parts according to nature and not monstrously (τερατωδῶς)" (*HA* I.17, 496b17–18). This focus on the common forms that occur by nature makes uncovering the extent to which Aristotle grounds his biology on particular dissections that he may have performed difficult. Making things worse, we no longer have his treatise *Anatomies*, which may have had his most explicit accounts of anatomical procedures and observations.

Nonetheless, Aristotle does make enough references to how one manipulates the matter of animals, so that we can tell he explored particular animal bodies with anatomical procedures. He especially does this in the *History of Animals* whose aim seems to be "to collect and analyze differentiae so that animal forms can be defined, and such definition will be able to be individual" (Balme 1987a: 19). Before anatomy, priests sacrificing animals or even cooks may have observed the general arrangement of reasonably large parts, such as the presence or absence of gall bladders in sheep (*HA* I.17, 496b24–29). However with dissection, one does not just cut animals open, but manipulates and pulls apart structures while removing fat and perhaps tracing them out. In comparing the cerebellum with the brain, for example, Aristotle claims that one can observe that the former "has a different form (μορφήν) by both touch and vision" (*HA* I.16 494b32–33). When considering the mole, he mentions "cutting away (ἀφαιρεθέντος) the skin" (*HA* I.9, 491b30–31) over the natural place of the eyes to observe that moles do have inner eye structures that were incapacitated in growth. In describing the form of the gizzard he claims that it contains a "strong skin that can be cut away from the fleshy part" (*HA* II.17, 508b33). Aristotle even shows some sensitivity to artifacts produced by dissection. He points out for example that the heart falls out of its true position in dissection (*HA* I.17, 496a11), and warns that blood runs from the lungs when they are removed from the body so quickly that some have incorrectly judged them to contain no blood naturally (*HA* I.17, 496b5–6). Although we take dissection for granted today, when it was first attempted by Aristotle and his predecessors it must have required its early practitioners to look at the body in a revolutionary way. Hacking points out that manipulations allow scientists to see the world anew; in one of the central examples of his book he notes that "you learn to see through a microscope by doing, not just by looking" (1983: 189). By exposing, touching and cutting away the various structures within the animals Aristotle would have learned to see the body anatomically.

Aristotle's account of the male reproductive structures of blooded animals (our vertebrates) in the *History of Animals* affords an example of the extent to which Aristotle's applies his laboratory vision systematically (see Figure 1). While the account of male reproductive anatomy, which we considered above, may seem fanciful at first, Aristotle's support of it in *History of Animals* seems to indicate that he arrived at it from observing the kinds of things that one could only see in careful dissections. Aristotle generally classifies blooded animals based upon whether they are oviparous or internally viviparous, and whether they are legless, biped, or quadruped. He claims the fish and snakes, both being legless and oviparous, lack proper testicles but have two ducts that run down from the midriff on each side of the body, converge into a common duct and empty into the body's posterior opening. If these ducts are pressed during breeding season white semen comes out. Aristotle cites his *Anatomies* as offering further descriptions of how these structures vary in different fishes. Oviparous quadrupeds and bipeds have passages similar to the fish, but they come off of an internal testicle and empty into a penis. Aristotle offers his most detailed description of the external testes found in viviparous footed animals. Two passages, one without blood from the aorta and one with blood from the kidney, run down to the head of each testicle. From the head a sinewy passage with a bloody liquid in it extends down the side, bends back at the base containing a white liquid, runs up to the head, and then proceeds to the penis. Since a common sheath envelops both passages on the side of the testicle, "the passages seem to be just one, unless someone would cut through (διέλῃ) the membrane" (*HA* III.1, 510a23). In addition to words, Aristotle includes a diagram to help the reader visualize what he observes in dissection. This seems to have been a common thing for him to do in the lost treatise, *Anatomies*, since he often cites it for diagrams (see for example *HA* I.17, 497a31–32). If we carefully dissect particular bodies of mammals like rats, rabbits, monkeys and men, we can see the structures as Aristotle describes them. The spermatic cord contains vessels and was probably what Aristotle saw coming down from the aorta and kidney, the passage from the kidneys could have been what we call the spermatic vein, since it comes off near the kidneys and would have much more blood than the spermatic arteries that come from the aorta. The passage going down the testicle could be construed as the epididymis and the returning passage as the vas deferens; both are enveloped by connective tissue which Aristotle could have easily seen as a membrane. These accounts of the different forms of reproductive structures in male blooded animals show Aristotle to be drawing his general conclusions quite carefully from the kinds of things that could only be observed in particular dissections.

Blooded Animals
- Oviparous and Legless: Males have no testicles but two passages running from the midriff to opening.
  - Fish: Study examples and differences in *Anatomies*.
  - Snakes
- Oviparous, and Biped or Quadruped: Males have internal testicles and a penis.
  - Birds
    - Ring-Dove: Testicles very hard to see except in breeding season.
    - Partridge: Testicles very hard to see except in breeding season.
    - Goose: Penis becomes more observable after copulation.
  - Lizards
  - Turtles and Tortoises
  - Crocodiles
- Internally Viviparous and Legless
  - Dolphin: Males have internal testicles.
- Internally Viviparous, and Biped or Quadruped
  - With internal testicles
    - Elephant
    - Hedgehog
  - With external testicles
    - Man: Testicles hang freely.
    - Pigs: Testicles do not hang freely.

Figure 1. The kinds of blooded animals and their forms that Aristotle reports upon in his account of male reproductive anatomy in *History of Animals* (*HA* III.1). Forms are listed under their kinds and are indented. Some anatomical facts or other comments that Aristotle reports follow a colon after the relevant categories.

By grounding his account of animals on dissection and vivisection, Aristotle introduces a new anatomical way of thinking about the body. Anatomical thinking focuses upon those aspects of the body rendered manifest in dissection and vivisection. In the *Timaeus*, Plato argues that the body's structure gives rise to its various physiological functions. While giving a likely account on how invisible structures might contribute to physiological processes, Plato often fails to identify the exact structures involved in particular functions (see Cosans 1995). After systematically dissecting organisms, Aristotle can offer a more detailed account of which specific structures can or cannot perform some function. He then redefines older common experiences and observations of the body. Aristotle's criticism of various folk observations illustrates the scope of this redefinition. For example, in *Generation of Animals*, he tells us of fishermen who saw female fish eat white stuff coming from male fish. Based on this observation, the fishermen reported that in these fish the females are fertilized by eating milt. From their pre-anatomical perspective, the fishermen see the body as a black box in which substances can readily move from one area of the body to another. After dissecting fish Aristotle dismisses this interpretation "because the passage whose entrance is through the mouth passes down into the bowels, but not into the uterus" (*GA*, III.5, 756b8–10). As we discussed above, instead simply gutting fish as cooks did, Aristotle's text indicate that he manipulated and examined their inner part, which would involve tracing out the path and connections of the reproductive and digestive tracts. Since the body uses whatever goes into the belly as nourishment, swallowed semen cannot possibly fertilize eggs. Anatomically speaking, the mouth simply does not serve as an inlet for the reproductive system. By exploring the body to obtain understanding of the role structure plays for activity, Aristotle thus observes that organisms are not black boxes, but contain parts that are organized into wholes. Rather than accepting common sense, he deliberately controls experience in order to discover nature's universal principles. With this epistemological shift, Aristotle goes beyond traditional craft and explores animals as an anatomist.

Does Aristotle do experiments?

Although Aristotle occasionally grounds his claims about animals on dissection and vivisection, one may still question the extent to which his anatomical method measures up to what we expect from modern laboratory science. Bacon regards Aristotle's approach as entirely inadequate for discovering the hidden aspects of animals. In discussing Aristotle's *History of Animals*, he claims that it:

> contains only the variety of natural species and no experiments of the mechanical arts. And just as in ordinary life the true personality of a person and his hidden thoughts and motives show themselves more clearly when he is under stress than at other times, so things in Nature that are hidden reveal themselves more readily under the vexations of art than when they follow their own course. (1994, Aphorism I: 98)

According to Bacon, Aristotle's desire to base biology on knowledge about the different types of animals, prevents him from giving it an experimental foundation. For one does not do an experiment on a whole species, but only on a particular animal. Rather than passively looking for the forms of animals, Bacon argues that the natural philosopher must use mechanical instruments to create unnatural situations. Nature's inner chambers are only seen when "by the art and intervention of man, she is forced out of her natural state and is pressed and moulded" (1994: 25).

Today, many philosophers of science concur with Bacon's verdict on ancient science. In his call for philosophers to pay more attention to experiments, Hacking designates Bacon as "the first philosopher of experimental science" (1983: 246). Likewise, Kuhn distinguishes the "Baconian" experimental movement from earlier uses of observation by claiming that:

> When its practitioners, men like Gilbert, Boyle, and Hooke, performed experiments, they seldom aimed to demonstrate what was already known or to determine a detail required for the extension of existing theory. Rather they wished to see how nature would behave under previously unobserved, often previously nonexistent circumstances. (1977: 43)

According to Kuhn, 17th century scientists begin to use experiments to discover new things about the world, and thus need to draw a sharp distinction between thought experiments and ones that they actually perform. Kuhn also claims that 17th century experiments are novel because they exhibit nature "under conditions it could never have attained without the forceful intervention of man" (1977: 44). Tiles builds upon Kuhn's argument in a detailed comparison of Aristotelian and Baconian attitudes towards experience, and offers careful philosophical analysis of why Aristotle would not fully value experimental intervention. Tiles sees Aristotle's interest in the formal nature of things as erecting a metaphysical barrier to him grounding inquiry on the unnatural situations created in experiments:

> An Aristotelian nature will manifest itself spontaneously, providing conditions are not unfavorable and providing there is no other natural body acting in such a way as to thwart it's realization. (1993: 467)

Intervening with and altering natural events would thus obscure or distort the world's underlying reality on this interpretation of Aristotle. According to Tiles it is only with Bacon's discovery that nature has hidden "depths of unrealized potential which needed the manipulation of phenomena, the 'vexations of art' to bring to the surface of actuality" (1993: 468), that truly experimental science could begin.

Do Aristotle's anatomical manipulations vex animals enough to qualify him as a laboratory scientists, or are they just demonstrations of whatever ideas he previously theorized about? Today, dissection has become so common that we think of it as merely showing the way things are naturally, without even recognizing that it requires the intervening hand of man. In evaluating Aristotle's science, I think Bacon seriously underestimates the active and revolutionary nature of his use of anatomical procedures. With the above example of male reproductive anatomy, we see Aristotle thinking very mechanically about the body, as Bacon insists an experimental biologist should. However, to be an experimental philosopher, one must not just talk the talk, but walk the walk. In order to consider Aristotle as a proper laboratory biologist, we must find evidence that he goes beyond passively looking at animals as one might naturally find them to actively altering their natural state so as to uncover previously unknown facts. Until his time, no one seems to have even had the idea to dissect animals systematically. By first breaking the skin, Aristotle takes the first, and perhaps most important step, in

the development of experimental biology. In the following examples we will consider three levels of progressively unnatural states that Aristotle creates under the aegis anatomy: the special preparation of specimens for dissection, the cutting open of a chameleon while alive, and the cutting out of the heart in a tortoise to see the effect on the rest of the animal.

Aristotle's argument that the system of blood vessels originates from the heart shows him vexing animals with mechanical manipulations in order to learn the truth about the body. By comparing this account with those of his predecessors, we can see the extent to which even mere dissection can reveal previously unknown things about the body. In the *History of Animals*, Aristotle argues that no previous investigator has given a sufficient account of cardio-vascular anatomy because of "the difficulties of observation" (τὸ δυσθεώρητον αὐτῶν) (*HA* III.2, 511b13–14). Previous investigators had based their accounts on what could be observed by dissecting dead animals or in living "humans that had grown extremely emaciated" (*HA* III.2, 511b22). Both procedures are inadequate for discovering the origin of the blood vessels. Because animals were typically bled to death, their major vessels would collapse and be difficult to dissect in cadavers, while the external examination of living organisms reveals little about the major vessels "because their nature is internal" (*HA* III.2, 511b19–20). Aristotle illustrates the consequences of such an approach by quoting passages from texts of the physicians Syennesis and Polybus, as well as that of the Pre-Socratic philosopher Diogenes, to serve as representatives of the most detailed descriptions written about vessel anatomy (*HA* III.3, 513a8–12). All three show signs of *not* being based upon the kinds of detailed manipulations that one performs when dissecting and tracing out the blood vessels: they all describe most vessels as having *no* connection to the heart. The passages from Syennesis and Polybus both focus on course of vessels close to body's exterior with vague references to how they might connect some internal organ like the liver or kidney. Such information would be important to blood-letting, when physicians attempt to relieve some bodily disease by removing blood from a superficial vessel; Peck (in Aristotle 1979: 164–5 and 169) points out that both passages also appear in Hippocratic works. Neither physician makes any mention of the heart. Diogenes provides the most detailed report with more focus within the body, but again gives no account of how all the vessels fit together as one system or of their origin. In order to observe the vascular system properly and discover its origin, Aristotle argues the investigator must *deliberately* prepare the subjects for dissection. He combines aspects of his predecessors approaches and dissects organisms first made lean and then strangled to death. The starvation reduces the amount of fat which could obscure vessels, while choking the animal keeps the blood in the vessels.[6]

The full impact of Aristotle's approach can be shown by comparing the details of his account with Plato's description of heart and vessel anatomy. Aristotle's teacher gives us an account of vessels that is intermediate between Aristotle's theory and the earlier medical accounts he quotes. In his discussion of the organization of the body, Plato describes the heart as "a knot of vessels and fount of blood that moves vigorously about all the parts" (*Ti.*, 70b). In this context he thus seems to view the heart as the center of a blood vessel system. According to his account of how the body works, however, vessels not only convey blood, but also sensation and other substances around the body (see *Ti.*, 77c–81e). Plato mentions two great vessels that run on the left and right side of the body cavity, but indicates nothing about whether or not they are connected to the heart (*Ti.*, 77c–d). This vagueness allows him to represent vessels as all purpose conduits in his account of how the body works, and indicates that like Syennesis, Polybus and Diogenes, Plato seems to have not systematically dissected and traced out the anatomy of the vessels. While the *Timaeus* associates some vessels with the heart, Plato does not advance the concept of a centralized cardio-vascular system.

With his greater willingness to vex and alter animals, Aristotle cuts Plato's Gordian knot. He systematically describes a single vascular system in which all major vessels have the heart as their origin (ἀρχή). Although he seeks to offer an account "concerning the origins and greatest of blood vessels" (*HA* III.4, 515a16–17) that applies to all blooded animals, he recognizes that there is significant variation in the lesser vessels and that the general pattern may not be very evident in small organisms. His account of cardio-vascular anatomy fits especially well with mammals. The heart contains three cavities (κοιλίαι): a large one on the right, the smallest one to the left, and third medium sized one in between. A vessel traditionally called the "great vessel" goes into the largest cavity and comes out another part "as though the cavity were a part of the vessel in which blood forms a lake" (*HA* III.3, 513b3–4). This vessel has two branches that come off above the heart, one extends to the lungs, while the other goes "towards the backbone and the last vertebra of the neck" (*HA* III.3, 513b15–16). A third branch extends off below the large cavity that travels along the back next to the aorta. The only vascular attachments that Aristotle mentions for the left chamber are connections with the lungs (*HA* I.17, 496a22–24) – presumably this connection would be what 20th century anatomists call the pulmonary vein. The aorta (ἀορτή) originates from the middle chamber and gives off branches that follow those of the great vessel. All vessels that go to other parts of the body ultimately branch off of either the great vessel or the aorta. Aristotle's account captures many intricacies that would make the 20th century practitioners of his tradition proud. For example, he describes the tree like branching of the pulmonary artery into the

substance of the lung (*HA* III.3, 513b16–23). Although remarkably detailed, Aristotle's account of the vessels' branches also contains some stumbles: he entirely misses what we call the celiac trunk and asserts that "not one blood vessel runs from the aorta to the liver or spleen" (*HA* III.4, 514b27–28). A realist philosophy of science would predict exactly this. Aristotle enjoys the most success with large structures such as the attachments of the vena cava and aorta to the heart, but fails with the smaller more obscured details such as the fat and fascia covered celiac trunk. While his early dissections of carefully prepared specimens enable Aristotle to observe more details than Plato, Western biology still has long a way to go before *Gray's Anatomy*.

Aristotle's description of the heart as having three cavities has been discussed a great deal in classical scholarship. Some criticize the above account as being contaminated by unempirical beliefs. For example, G. E. R. Lloyd (1975: 128) cites Aristotle's description of the heart's three chambers as evidence that:

> Certainly some surprising and gross errors and confusions remain in his anatomical descriptions, due either to a failure to observe or more often to his observations being hasty or coloured by theoretical interests and preconceptions.

Lloyd thus views Aristotle's observation of only three cavities in the heart as more coloured by theory than the modern anatomist's observation of four chambers. Along with Bacon, he sees significant limitations in Aristotle as an empirical scientist. One traditional way of rescuing Aristotle's observations takes him to be construing the right atrium as part of the vena cava rather than as part of the heart's cavities, thus leaving our right ventricle, left ventricle and left atrium his three cavities (Huxley 1879: 2; Ogle 1911: 666b footnote 3; Shaw 1972: 375–378). Huxley relies upon an artifact of strangulation, which can cause blood to build up in and expand in the right ventricle, to make the right ventricle appear larger than the left ventricle (1879: 2).

A problem that both the critics and apologists of Aristotle's numbering share is looking for a strict correspondence between his cavities and structures that have become clearly defined by latter anatomists. If we sweep away our preconceptions and consider what a heart looks like afresh, we can see how Aristotle's "theory" adequately describes "experience." Aristotle indicates that he examined hearts so as to find bones in the hearts of horses and oxen (*HA* II.15, 506a7–10), to see creases on the surface of a pigs heart (*PA* III.4, 667a10–11), as well as the relative sizes of the hearts found in hares, deer, mice, hyenas, asses, leopards, and martens (*PA* III.4, 667a19–22). In the laboratory we can easily construe a large mammal heart, such as that of a pig, as having three chambers with much of our right atrium forming a single cavity with our right ventricle. Since the right ventricle only needs to pump the blood into the lungs, its wall is not much thicker than the right atrium, and the three cusps of the right atrio-ventricular valve offer a wide opening in a dissected heart. Taking these two cavities as one would explain why Aristotle's right cavity is larger than our left ventricle without relying on artifacts, and derives further support from his assertion that there are sinews, (which correspond to our atrio-ventricular valves) within the heart's largest cavity (*HA* III.5, 515a28–29) rather than at its edge. In contrast to the right ventricle, the left ventricle must pump blood to the entire body and is distinguished from the left atrium by its much thicker wall, while the two cusps of the mitiral valve provide a more defined boundary between the two cavities (see Figure 2). The fact that Aristotle's text so closely corresponds to something that we can only experience with dissection affords us clear evidence that he did some exploration as a laboratory scientist.

While few would object to considering dissection a laboratory science, its degree of intervention still falls short of what most people expect from experiments. After all, even cooks cut open dead animals, but "to experiment is to create, produce, refine and stabilize phenomena" (Hacking 1983: 230), which are regular and reproducible. Yet it is clear from the texts that Aristotle moves beyond dissection to perform vivisections, interventions that alter the course of natural processes to discover stable phenomena, "effects," in Hacking's terms (Hacking 1983: 224). In his account of the chameleon, for example, Aristotle reports that

> It is actually active with breath for a long time after being cut open completely, there being still a very slight movement in it about the heart, and while contraction takes place particularly round the ribs, it affects the remaining parts of the body as well. (*HA* II.11, 503b22–26)

This procedure clearly indicates an experimental intent. Rather than simply looking at the lizard, Aristotle somehow restrains it and the manipulates it with a knife or some other instrument in order to reveal some hidden aspect, just as Bacon insists a natural philosopher should do. In order to keep the animal alive for such observations, he would have to be quite careful to cut away the layers of the thoracic wall without damaging the heart or lungs. When manipulating living organisms this precisely, the anatomist must use artisanship to its fullest extent in order to alter nature's course exactly enough to reveal the interesting effect. Presumably Aristotle cuts a live lizard open, not to see it squirm, but so that he can observe the causes of life that are normally hidden within the organism. Hence, he characterizes the observed motion in terms of breath ($\pi\nu\varepsilon\tilde{\upsilon}\mu\alpha$), a phenomenon which distinguishes the living from the dead.

Aristotle refers to even more involved procedures throughout his works in *Parva Naturalia*. For example in *On Youth and Old Age; On Life and Death*

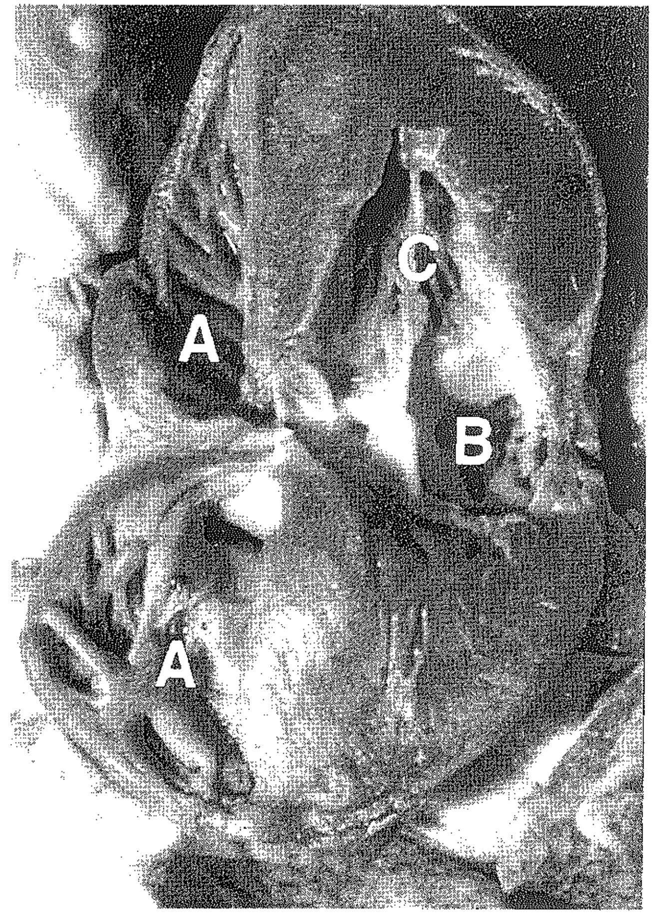

Figure 2. A pig heart cut in half with the front section lifted up so as to show Aristotle's three cavities. Above and below left (the pig's right), the largest cavity that connects to the great vessel (our "vena cava"), A. Center right, the left and smallest cavity that recedes back through the shadows to the lungs, B. Above right, the thick walled middle cavity that connects to the aorta, C. This heart was generously donated by the Halsted Packing Company.

(in Aristotle 1975), he cites several vivisections when attempting to localize an organism's metabolic power of sustaining itself with external material. All organisms must possess three basic parts: one that accepts nourishment, one that discards waste products, and a third in the middle. Aristotle considers manipulations on three different kinds of organisms in exploring how levels of complexity relate to metabolic capacity. In plants, which Aristotle considers the simplest life forms, "the metabolic soul in those having it is actually one, but potentially many" (*Juv.* II, 468b3–4). His evidence is the fact that some plants can be cut into numerous sections each of which gives rise to a new organism. Animals manifest a higher degree of complexity with the middle part being necessary for life. If one cuts off the heads or abdomens of insects like wasps and bees, "they live afterwards if the middle part remains attached" (Aristotle, *Juv.* II, 468a25). Although the middle enables the parts to retain life for some time, unlike plants they are not able "to preserve their nature (σώζεσθαι τήν φύσιν)" (Aristotle, *Juv.* II, 468b5–6) without the full body. Because the organization of complex animals distributes powers to different parts, each part depends upon its relation to the whole for its continued subsistence.

Aristotle cites a third set of vivisection procedures, in order to consider further the psychic function of the middle part. He reports that the outer parts of tortoises and turtles (χελῶναι) retain some capacities for sensation and locomotion after the removal of the heart. Thus, while the powers of the soul originate in the heart, they animate the rest of body. These manipulations of tortoises and turtles indicate a significant degree of sophistication. One might commonly cut apart plants and bugs, but the heart of the living turtle lies walled off from everyday experience by a hard shell; it is not something that would be observed by a common craftsman. Aristotle offers a fuller reference to this deliberately created experience in *On Respiration*:

> Some animals have potentially many sources of life, but not actually. This is why some insects live when divided, and why some among blooded animals that are not very active, live a long time after the heart has been excised (ἐξῃρημένης), for example tortoises even move with their feet if the shells are left on, because their nature is not organized in a complex fashion, as it also is in insects. (*Resp.* XVII, 479a3–7)

Rather than simply cutting apart tortoises and turtles as he does with insects, Aristotle contrives further manipulations in order to tease apart the contributions of the heart and body to the whole organism's life. His qualification about leaving the shell on not only indicates that he varied his procedure in order to discover the precise circumstances in which the body retains the power of life, but also gives the reader the specific conditions necessary for observing the same thing. The comparison with insects further shows that Aristotle employs vivisection in a systematic investigation of how specific parts maintain life in different animals. Once one starts anatomical manipulation, the observations from even simple procedures can easily lead the natural philosopher to devise and execute more sophisticated follow up experiments. The anatomist's perception of these phenomena with particular members of a species, enables him to observe a universal relation between a species' complexity and the primacy of its heart.

The fact that decardiated tortoises wiggle their legs can be viewed as a surprising experimental effect which the anatomist can only discover by breaking the body down. I have attempted to perform Aristotle's procedure on the common pond turtle *Pseudemys*,[7] and observed that its legs do indeed retain some power of motion after one removes its heart. Since the legs are attached to the plastron, Aristotle would have needed to be quite careful in removing just enough of the lower shell to expose and remove the heart without disturbing the limbs. Given the great difficulty of doing this with a 20th century power saw, I suspect Aristotle must have been quite clever, if not ingenious, at finding proper instruments. Aristotle's reference to his vivisection procedures on plants, insects, turtles and tortoises shows him to be an experimental biologist in the material sense: he deliberately manipulates different organisms in special ways so as to reveal and isolate hidden aspects of life.

Teleology naturalized

With his new methodology for acquiring anatomical experience, Aristotle advances the enterprise of teleological theory. After making observations of the body's inner structures, he provides a much more detailed account than Plato of how particular parts within the organism work together. In the narrative of the *Timaeus*, the Demiurge (literally Craftsman) fashions the cosmic order by ensouling that which comes about by necessity with mind; Plato speaks of reason as persuading necessity to do what is best. On this external view of teleology, the directivenss of organic activities ultimately comes from outside of the animal (Lennox 1992: 325). After attributing the body's organization to apparently external intelligence, Plato presents a strikingly mechanical account of how bodily functions arise by necessity from the structure the parts and the molecular particles that make it up (*Ti.*, 77c–81e). At times he talks as if the body were a passive machine whose functional organization depends upon the agency of gods who fashioned it. Aristotle, on the other hand, sees necessity as controlled by formal natures that are intrinsic to the organisms themselves. In *On the Parts of Animals*, he maintains a Platonic like dichotomy between directiveness and necessity. Throughout the entire work he contrasts explaining a part in terms of necessity (ἀνάγκη) with describing its final cause – "that for the sake of which (τὸ οὗ ἕνεκα)" the part comes-to-be. In the realm of biology, Aristotle uses the concept of necessity in the hypothetical sense of a material constituent. If a saw cuts through wood, then it must be made of something hard like iron. Knowing everything about iron, however, will not yield a full account of the saw. In order to understand fully why its material constituents came to be arranged into a structurally organized entity, one must also know the saw's active function. Aristotle argues that this principle applies no less to anatomy: just as a saw exists for cutting, "in some way the body exists for the sake of the soul, and its parts for the sake of those tasks for which each grew" (*PA* I.5, 645b19–20). Aristotle identifies an animal's soul with its organic form, and uses these concepts to grasp the way in which an organism's interrelated parts contribute to the complex process of life. Aristotle simply observes that "it is evident that the body as a whole has come together for the sake of some multifaceted action" (*PA* I.5, 645b16–17). In order to explain life the anatomist must focus not upon static shapes but on active processes.

With his search for how teleological activity arises from the animal's internal organic form Aristotle sees significant limitations in a mechanical analysis of the body. The living organism is more than the shape of its parts: "the corpse has the same shape of its figure, and yet it is not a man" (*PA* I.1, 640b34–35). Despite having the same structure as a living person, the cadaver cannot perform any of the life processes such as eating, moving, perceiving, or thinking. Aristotle discuses the limitations of structural understanding further in book II of the *Physics*. There he contrasts the approach of the mathematician (ὁ μαθηματικός) with that of the natural philosopher (ὁ φυσικός). When a mathematician considers things, he abstracts out planes, solids, lines, and points from natural bodies. He treats these abstractions neither as limits nor as attributes of natural bodies, but separates them entirely from natural change. In an oblique reference to Plato, Aristotle accuses "those speaking of the Forms" (*Ph.* II.1, 193b36) of doing the same thing. While such an approach might be good exercise for the imagination, it has significant limits in contributing to our understanding of natural bodies. One can consider "number, line and figure without reference to change (κινήσεως), but not so in the case of flesh, bone and a man" (*Ph.* II.2, 194a4–6). In order to explore functional processes, a natural philosopher must go beyond being and examine the way particular material objects naturally come-to-be. Insofar as an object's nature involves both its form and matter, the natural philosopher must consider objects "neither without matter nor only with respect to matter" (*Ph.* II.2, 194a14–15). A strict account of an organism's structure will explain neither the processes by which it lives, nor those by which it comes-to-be. In contrast to static geometrical shape, organic form involves a dynamic achievement of the animal maintaining its nature amidst assaults of the changing outside world (White 1994: 27–28). During the course of differentiation, numerous parts develop in the precise manner that actualizes the unified form of an adult (Gotthelf 1987: 213). Organisms are not mere machines, but entities which originate and live by their own internally directed processes.

There is some controversy in the scholarship over how to interpret Aristotle's teleology. Nussbaum has composed a dialogue between an Aristotle and a Democritus versed in 20th century arguments for reductionism, in which they discuss reconciling teleological causation with the mechanical causes that follow from the structure of matter (1978: 59–99). Nussbaum's Aristotle concedes a great deal to her Democritus' materialism, including that an animal's form "is something material, a functional state of matter" (Nussbaum 1978: 72). Since he grants that "functions are realized in some material efficient causal sequence that goes through without causal gaps according to the necessary laws of matter" (Nussbaum 1978: 92), he would seem to give no significant ontological status to organic forms. Indeed, Nussbaum's Aristotle sees nothing unique about the living body that would prevent "a creature made of string and wood who performed all the functions mentioned in our formal account of what it is to be human" (1978: 72) from being a real boy. He seems to embrace teleological explanation for mere convenience since they are "more general than efficient-causal accounts, and, because they take account of plasticity, more economical" (Nussbaum 1978: 85). Balme characterizes Nussbaum's reading as treating final cause as something that, although of some heuristic value, "does not actually exist" (1987b: 280–281). He argues, by contrast, that material causes might be necessary for the genesis of organisms, but they are not sufficient because "when the elements act without being used by nature or soul, they do not impose limit and definition upon themselves" (1987b: 281). Balme defines an animal's soul or nature synonymously as "a self-limiting complex of physiological interactions or 'movements' which control the body's development in conformity with the inherited parental forms" (1987b: 282). Insofar as the soul involves activities that arise from the animal living as a whole, the motion of its material elements "is not an automatic interaction reducible to the primary actions of the elements, but is imposed upon them by the pre-established soul-movements" (Balme 1987b: 285).

Nussbaum's Aristotle indulges the metaphysical speculations of atomists more, I think, than we would expect from one of the pioneers of laboratory observation. In absence of the experimental procedures of modern chemistry, ancient reductionists had even less empirical evidence than their 20th century counterparts (Cooper 1987: 270–1). Nussbaum's interpretation seems to give ontological priority to highly theoretical chains of mechanical causality, but from an anatomical point of view organic forms are no less empirical than bodily mechanism.[8] Indeed, Aristotle observes the directiveness of natures towards ends all around us:

> So if it is both by nature and for the sake of something that the swallow makes its nest and the spider its web, and that plants grow their leaves

> for the sake of fruit and send their roots not up but down for the sake of food, then it is evident that there exists such a cause in the things that come-to-be or exist by nature. (*Ph.* II.8, 199a26–30)

A natural philosopher should study end-directed processes not just in the context of human consciousness, but also as other organic processes manifest it. Quite literally, Aristotle naturalizes teleology. He studies organic beings as moving towards ends and goals without attributing self-consciousness to them (Preus 1975: 105–107). In *On the Soul*, he explicitly states that "just as intellect acts for the sake of something, so does nature, and this is its end" (*de An.* II.4, 415b16–17). By accepting teleology as perfectly natural, the anatomist enables his eyes to focus upon it wherever it may interact with necessity. Aristotle's reference to the downward growth of roots appears to be a reply to Empedocles. In *On the Soul*, Aristotle criticizes Empedocles' claim that roots grow down because they contain earth while stems grow upward because the have fire, as failing to explain why the parts of organisms would not then simply fly apart. The fact that parts with such different elements are held together in a whole indicates the presence of what Aristotle calls the soul (*de An.* II.4, 416a1–9). In order to help define what he means by soul, Aristotle coins the term ἐντέλχεια (*de An.* II.1, 412a27), from the Greek words 'in (ἐν)', 'end (τέλος)' from which we get our word teleology, and the verb 'hold (ἔχω)'. When stressed and vexed by inorganic material forces, Aristotle believes that the natural philosopher can observe that the organism maintains its organic form by literally "holding its end within itself." In the laboratory final causes can be seen simply as empirically observed properties of organisms.

Teleological activity becomes especially prominent when one studies the development of organisms. The seed's (σπέρμα)[9] change towards a complete organism strikes Aristotle as an obvious case of an end-directed process. In justifying his belief in formal natures as causally potent, he observes: "in fact we do not find any chance creature being formed from a particular seed, but this from this, nor does any chance seed come from any chance body" (*PA* I.1, 641b26–28). Each chicken hatches from an egg which had been laid by another chicken. Although the egg may seem to come first, "nevertheless, logically prior to the seed stands that of which it is the seed, because the seed is but a beginning, but the end is a substance (οὐσία)" (*PA* I.1, 641b30–32). Before the egg comes the substantial form of a chicken. In a parallel passage of *On the Parts of Animals* book II, Aristotle explicitly acknowledges that "matter and generation come first in time, but logically (τῷ λόγῳ) the substance and the form (μορφήν) of the thing come first" (*PA* II.1, 646b1–2). As the formation of the animal proceeds, the substantial form drives the animal's matter to takes on one arrangement after another as the

embryo advances from an undifferentiated mass to a fully articulated adult (Preus 1975: 95–98). The final adult form is so complex, that it must develop gradually as initial parts work to impart the proper form to the matter of latter parts. From this perspective, matter exists within a hierarchy of organization in which each part exists as material for the sake of its whole. Some flesh exists for the sake of its muscle which in turn exists for the sake of its limb, etc. Unfortunately for Pinocchio, this intimate relation between an animal's form and its matter would make it virtually impossible, from Aristotle's point of view, for a human form being embodied by anything as radically different from human blood and flesh as wood and strings.

In the case of organisms, Aristotle uses facts about how parts yield to the anatomist's blade to distinguish between nonuniform-parts (ἀνομοιομερῆ) such as a wing, and their component uniform-parts (ὁμοιομερῆ) such as flesh or bone. In contrast to nonuniform-parts, the pieces of a uniform part come out the same way no matter how the anatomist slices it up on the dissection table. One piece of flesh looks like another, while a piece of wing which includes the tip looks quite differently from a piece cut from around the shoulder. Since the developing organism ultimately fashions uniform-parts into nonuniform-parts, Aristotle analyzes uniform-parts as existing for the sake of nonuniform-parts, just as the nonuniform-parts might exist for the sake of the whole organism. He even extends teleological analysis to any of the elements which have been brought within the organism: "the matter of the elements must exist for the sake of the uniform-parts, because these come later in generation than the elements" (*PA* II.1, 646b5–8). The particles of food may behave mechanistically, but the organism harvests this necessity for the sake of its nourishment by converting the matter from food into blood and moving it to the right part at the proper time. Aristotle would thus view the efforts of 20th century Democritean biologists to explain organic beings in terms of genetic mechanisms, as an effort to explain how the tail wags the dog. He would see genes as working for the sake of the whole animal no less than any other part.

With his focus on what present anatomical experience indicates about the internal dynamics of life, Aristotle shies away from an account that seeks to explain the organization of animals without teleology. A few years before Aristotle, Empedocles attempted to account for the incorporation of parts within animals in terms of necessity. According to Empedocles:

> whenever all the parts came together as if generated for the sake of something, the wholes which by chance were serviceably composed were saved, but those which came together not in this manner, like the man-faced offspring of oxen mentioned by Empedocles, perished and still do so. (*Ph.* II.8, 198b29–31)

Although this account has been likened to Darwin's theory, Charlton points out that since Darwin's theory considers how *whole* organisms evolve new structures that are better for the sake of the entire animal, the *Origin of Species* has a distinct "Aristotelian ring" (1992: 122). Empedocles analyzes an organism's parts as only the result of many chance causes, which appear to have been formed as part of a whole only because poor arrangements perished. He thus evokes distant chance events in order to explain present structural organization. Aristotle on the other hand, seeks to examine directly the very source of organic powers as it operates in the present. In contrast to the mythic time of Empedocles, Aristotle focuses his consideration of life's generation on experimentally observable time. Whenever an anatomist observes the development of a part or some other natural process it " comes-to-be either always or for the most part in a given way" (*Ph.* II.8, 198b35–36). If they came about by chance, then a natural philosopher should not expect such regularity. In the case of organisms, numerous parts develop into a living whole with a specific nature; the anatomist rarely observes anything like human-faced cows or olive-faced vines that are implied by Empedocles' theory. Aristotle describes as arising by nature "whatever having started from some principle within itself, finally arrives by a continuous motion at a certain end" (*Ph.* II.9, 199b15–17). At the heart of his notion of organic nature lies the concept of internal self direction, which grapples with and limits the whims of chance and necessity.

In advancing an organic philosophy of nature, Aristotle expresses some normative concerns. Learning about teleology justifies overcoming any distaste someone might have for the gore of anatomical procedures. Before the advent of systematic dissection and vivisection, natural philosophers like Empedocles had dismissed organisms as hodgepodge arrangements of chance parts. Plato countered such accounts with a more detailed and likely account on how organisms manifest mind as well as necessity. With his anatomical approach to biology, Aristotle brings the teleological project of his teacher into the realm of experience. Throughout his anatomical works he provides numerous descriptions on how countless parts are organized together for some function. In pagan Greece, such a earthly activity could take on spiritual dimensions. Aristotle argues that "for the student who is naturally of a philosophic spirit and can discern the causes of things, the crafting (δημιουργήσασα) nature provides joys which cannot be measured" (*PA* I.5, 645a9–10). Even the most ornate woodcut pales in comparison to the simplest worm. In imploring natural philosophers to explore the innards of organisms, Aristotle invokes Heracleitus' statement "for there are gods even here" (*PA* I.5, 645a21). The anatomist should study not only cute mammals but also the "less honored" organisms such as bugs since "in all there is some

nature and beauty" (*PA* I.5, 645a22–23). At the heart of Aristotle's anatomical quest to observe teleological organization, lies the intellectual excitement of witnessing and contemplating different animals' formal natures.

Politics of the body

With his internally focused teleology, Aristotle advances an even more unified account of the body than Plato. By explaining how soul manifests mind within organisms, Plato offers some consideration of how organic powers arise in the life of the whole animal. Yet his account still disperses powers about the body; at times he even describes conflicts between the rational, spirited, and desirous souls and their associated activities of the head, chest and belly regions (*Ti.*, 70a). Aristotle, on the other hand, seeks to avoid civil strife within the organism. His biology describes how the body's parts all work together and arise from a single center. Aristotle distinguishes a natural object from man-made artifacts by virtue of the fact that it has "a principle (ἀρχήν) of motion and of standstill, whether with respect to place or increase or decrease or alteration" (*Ph.* II.1, 192b14–16). It is in a rock's nature to fall, an embryo's nature to grow into an adult, but a bed just lies there. The bed itself simply "has no natural tendency in itself for changing (μεταβολῆς)" (*Ph.* II.1, *192b18–19) which would enable it to preserve its being as a bed naturally.* Any artifacts possess natural properties only by coincidence. Beds fall to the ground because they happen to be built with materials that contain a great deal of earth. There is nothing about the definition of beds which prevents a clever person from making them largely of water. Aristotle's analysis of principles plays an important role in the focus of his anatomical research program. As one complex but unified natural body, a given organism should have a principle from which its various parts and powers emanate.

Aristotle attributes particular importance to the heart for the life-principle of blooded animals (our vertebrates) in his account of embryology. In the *Generation of Animals*, he advances a theory of development that would later be dubbed epigenesis. All the parts of organisms do not come-to-be at once, but in a specific order of succession. As the animal differentiates, its matter proceeds up "a hierarchy of forms" (Preus 1975: 94), where a product of one generation acts as the matter for formation of the next level of organization. For example, the father's seed and material from the mother can take on the forms of flesh and bone, which in turn can be formed into a hand. Given the fact that females must receive seed (σπέρμα) from males in order to produce new organisms, Aristotle argues that the father's seed effects a critical change in the material supplied by the mother. Since the seed imparts its motion in one shot, "not by being in contact with it anywhere now, but by having at one time been in contact" (*GA* II.1, 734b13–14). After the male's seed imparts the heat of pneuma to set the mother's seed in motion, the father's influence is complete. The new organism becomes an autonomous entity using nourishment acquired from its mother for its own sustenance. Later on, Aristotle characterizes this separation from the parent's organic powers with a socio-political metaphor: "the generated animal must manage for itself, just like a son who has set up a house of his own independently of his father" (*GA*, III.4, 740a6–7). As a distinct organism, the new life must flourish by its own principle. In the case of blooded animals, this principle part would be the heart – the very fount of blood.

Aristotle justifies his centralization of power in the heart with his anatomical approach to natural philosophy. After dissecting starved and strangled animals, he is able to trace systematically how the vessels growing out from the heart interconnect it with the rest of the body. Further observations of birds eggs at various stages, reveal the heart as the first discernible part. In the *History of Animals*, Aristotle reports the appearance of the heart in a 72 hour old chicken egg:

> This spot beats and moves as though it were ensouled, and from it, as it grows, two vein-like passages with blood in them lead on a twisted course to each of the two surrounding tunics. (*HA* VI.3, 561a12–15)

Soon, the vascular system conveys the nourishing matter of blood from the yolk to the heart, and sends out blood to the rest of body. As in his dissection of the adult vascular system, Aristotle carefully focuses his observations with theoretical reflections. In *Generation of Animals* he explicitly uses the lungs to control for the possibility that the heart is first evident only because of its large size:

> As for simultaneous formation of the parts, our senses tell us plainly that this does not happen: some of the parts are clearly to be seen present in the embryo while others are not. And our failure to see them is not because the are too small; this is certain, because although the lung is larger in size than the heart it makes its appearance later in the original process or formation. (*GA* II.4, 734a22–25)

While Plato views the marrow as the foundation around which the organism forms (*Ti.*, 73b–d), Aristotle likens the cardio-centered vascular system equivalent to the body's version of "frameworks (καvάβους) traced within walls" (*GA* II.4, 743a2). Shortly after the appearance of the vascular system, Aristotle observes the genesis of the cold eyes and brain. In a fascinating section of *Generation of Animals* (*GA* II.4–II.6, 743a1–745b20), he describes how the living animal uses the effects of hot and cold to help generate various uniform-parts of the body from the material of the blood. Throughout the

organism's development, the heart maintains a position of primacy as the fount of blood and heat; the other parts of the body come-to-be around it. As death approaches, this primacy still manifests itself as the heart's last beat marks the organism's final spark (Aristotle, *GA* II.5, 741b18–24).

In a sense, the heart serves as the capital from which soul's activities originate. Although Aristotle often states that all parts of a living organism must have soul (see *GA* II.1, 734b24–27, for example), he seems to view their connection with the heart as especially critical to this ensoulment. Aristotle speaks of the soul in political terms:

> For when order is once established in a city there is no need of a special ruler with arbitrary powers to be present at every activity, but each individual performs his own task as he is ordered, and one act succeeds another because of custom. And in the animals the same process goes on because of nature, and because each part of them, since they are so constituted, is naturally suited to perform its own function; so that there is no need of soul in each part, but since it is situated in a central origin of authority over the body, the other parts live by having grown upon it and perform their own functions in the course of nature. (*IA* X, 703a30–703b2)[10]

If Plato views the body as a republic in which a rational soul centered in the head governs the spirted and desirous souls associated with the chest and belly, Aristotle sees it as a monarchy ruled from the heart. As sensing beings, Aristotle analyzes the animal body as having a spatial presence defined by the three axis of up-down, left-right, and front-back (White 1994: 25–26). From its central location, the heart reigns over the body. Indeed, in *Parts of Animals*, Aristotle describes the heart's location as a "more honorable" and "commanding place" (*PA* III.4, 665b17–18). With the vessel's delivery of blood, the heart serves as the source of the nutritive soul's fodder. Aristotle also associates the heart with the sensitive powers of soul. In the case of smell and hearing he claims that their organs have passages which "end at little vessels about the brain that extend from the heart" (*GA* II.6, 744a3–5). The heart's rise to power over the brain even corresponds with Aristotle's emphasis of touch over vision. Of all the sense organs, Aristotle associates the eyes most closely with the brain. He embodies touch, on the other hand, in flesh (σάρξ), the very tissue of which the heart most consists.[11]

Interestingly enough, in his political philosophy, Aristotle himself links biology with politics. He argues both that "the state exists by nature, and that man is by nature a political animal" (*Pol.* I.2, 1253a2–3). Hence man's political and biological nature are not at odds (see also Thompson 1913: 24–26). In the *History of Animals*, Aristotle defines political animals, which include bees, ants and cranes, as "those which have some one common activity" (*HA* I.1, 488a7–8). Just as the face and brain work for the sake of the whole organism, individual political animals work for their whole social community. By nature each human body has the power of speech, which allows us to organize extremely complicated activities with other humans. Although a polity may not have a soul, it can be seen as a natural entity that works towards a good end (Sedley 1991: 193). Aristotle uses anatomical language to characterize the polity as prior to any individual:

> The whole is of necessity prior to each of its parts. For if the whole [man] ceases to exist, his foot or hand will exist only equivocally, and such a hand will then be like a hand made of stone. Indeed every part, such as [a hand or a foot], is defined by its function or power, so if the [power and the function] are lacking, one should not say that what remains is the same as a hand unless one uses the term "hand" equivocally. It is clear then that the state exists by nature and is prior to each [of its parts]: for if each man is not self-sufficient when existing apart from a state, he will be like a part separated from the whole; and one who cannot associate with others or does not need association with others because of self-sufficiency is no part of a state, but is either a beast or a god. (*Pol.* I.2, 1253a20–29)

Both anatomical and political organization arise from the directiveness of nature. In addition to acquiring his anatomical form, the individual must also take on the form of a political being whose activity extends beyond his body. The unique combination of divine reason with an animal body gives man special capacities that can only be properly developed by a polity. Humans rely on their interactions with their polity, just as hands depend upon their connection to the rest of the body for their existence. Severed from his political community an individual cannot even become a fully actualized human being.

Dissection and vivisection are perhaps Aristotle's most enduring modes of inquiry; today, many students are introduced to biology by cutting open animals just as Aristotle did. Out of a theoretical commitment to the importance of touch, Aristotle pioneered empirical practices and procedures which have become "obvious" for us. With anatomical procedures the philosopher uses his very body to explore aspects of what it is to be a body. Anatomy shows animals to consist of parts that are organized into wholes in virtue of dynamic forms. Manipulating the bodies of animals gives the natural philosopher a technique for a limitless study of organic form. This inquiry not only reveals the order within organisms, but naturally led to Aristotle's quest to understand the order amongst organisms. Indeed, much of his "nonbiological" work can be understood as contributing to his investigation of the organism that puzzled him the most: man.

Acknowledgments

I would like to thank the many people who have discussed the various ideas of this paper. R. Richards, E. Asmis, W. Wimsatt, M. Forster, K. Schaffner, J. White, M. Frampton, D. Millett, A. Melzer, P. Sereno, A. Cosans, and two anonymous referees from this journal have read previous drafts and offered many helpful suggestions.

Notes

[1] The following paper is part of a larger inquiry into how anatomy began. Other papers from this study include "The Platonic Origins of Anatomy" (Cosans 1995), "Galen's Critique of Rationalist and Empiricist Anatomy" (Cosans 1997) and "The Expermental Foundations of Galen's Teleology" (Cosans, forthcoming).

[2] G. E. R. Lloyd (1975: 113–147) argues that Aristotle was the first person to use dissection systematically. He indicates that no pre-Aristotelian medical work or philosophical fragment contains evidence of systematic dissection for its own sake. Lloyd insightfully relates Aristotle's "fully worked out epistemology and methodology" (142) with his use of dissection. However, he does not give any role to Plato's theories of the body as an intermediary between Aristotle's approach with that of pre-anatomical physicians and philosophers. For an excellent comprehensive analysis of Aristotle's biological thought see Preus (1975).

[3] Aristotle explicitly uses διαιρέω to refer to the physical division of animals in the *History of Animals* (for example HA I.1 486a5–6, HA I.17 496a11, and HA III.2 511b20).

[4] English translations will be taken with occasional modifications from Apostle's *de Anima*, *Physics*, and *Politics*, Peck's *History of Animals*, *Parts of Animals* and *Generation of Animals*, Forster's *Generation and Corruption* and *Movement of Animals*, and Hett's *Respiration*.

[5] For an account of the logical grounding of Aristotle's biological texts see Lennox (1987). Loeck (1991) provides rich formal analysis of Aristotle's use of gear wheels as technical simulation for the embryo. She argues that his analysis uses a causal calculus of relations that is ultimately unsound. In the case of the warp, Aristotle's reasoning works on a less abstract level. While the analogy between the testes and stone weights does not prove how the body works, it helps to focus our attention on mechanical aspects of the organism which can be explored by material manipulation. For excellent analysis of Aristotle's use of analogies between art and nature see Preus (1975: 11–13).

[6] For more on Aristotle's approach to studying cardio-vascular structure see Shaw (1972: 361–370).

[7] In order to minimize suffering, the turtles were first put in hibernation and then decapitated.

[8] Nussbaum's interpretation puts her at odds with Charlton who claims that "the form of a thing is for Aristotle very much of a reality – is, indeed, what has the best claim to the title of 'reality'." (1992: 121)

[9] Σπέρμα, the cognate of the English 'sperm', refers to seed in its widest sense; it can describe the seed of Abraham as well as the seeds that farmers scatter upon the ground. Mistranslating this term as semen unfairly makes Aristotle seem politically incorrect when he refers to women as producing "semen".

[10] M. Frampton analyzes (1991) the heart's role in Aristotle's theory of locomotion. His exploration of Aristotle's theory shows how Aristotle used detailed methods to explain locomotion, while leaving fruitful problems for his successors. In particular, Frampton argues that since Aristotle claimed the heart's sinews were discontinuous with the sinews that moved the limb, Aristotle's centralization of locomotion in the heart is incomplete.

[11] Aristotle discusses the nature flesh at *Parts of Animals* 653b19–654a31. He uses the term 'flesh' to generally refer to a soft tissue including the innards of bloodless-animals (i.e. our "invertebrates"). At *History of Animals* 496a12, he explicitly refers to the heart as being fleshy (σαρκῶδες).

References

Apostle, H.: 1981, *Aristotle's On the Soul (de Anima)*, Peripatetic Press, Grinnell.
Apostle, H.: 1980, *Aristotle's Physics*, Peripatetic Press, Grinnell.
Apostle, H.: 1986, *Aristotle's Politics*, Peripatetic Press, Grinnell.
Aristotelis: 1960, *Opera*, volumes I and II (Greek text edited by I. Bekker), Walter de Gruyter & Co, Berlin.
Aristotle: 1922, *On Coming-to-Be and Passing-Away* (a revised Greek text with introduction and commentary by H. H. Joachim), Clarendon Press, Oxford.
Aristotle: 1955, *On Sophistical Refutations, On Coming-to-Be and Passing-Away* (Greek text and English translation by E. S. Forster), Harvard University Press, Cambridge.
Aristotle: 1957, *Politica* (Greek text edited by W. D. Ross), Clarendon Press, Oxford.
Aristotle: 1960, *Aristotle's Physics*, (edited with a commentary by W. D. Ross), Clarendon Press, Oxford.
Aristotle: 1975, *On the Soul, Parva Naturalia, and On Breath* (Greek text and English translation by W. S. Hett), Harvard University Press, Cambridge.
Aristotle: 1979, *Historia Animalium I* (Greek text with an English translation, edited by A. L. Peck), Harvard University Press, Cambridge.
Aristotle: 1983, *Parts of Animals, Movement of Animals* (Greek text with an English translation, edited by A. L. Peck and E. S. Forster), Harvard University Press, Cambridge.
Aristotle: 1984, *Historia Animalium II* (Greek text with an English translation, edited by A. L. Peck), Harvard University Press, Cambridge.
Aristotle: 1989, *Analytica Priora et Posteriora* (Greek text edited by W. D. Ross), Clarendon Press, Oxford.
Aristotle: 1990, *Generation of Animals* (Greek text with an English translation by A. L.Peck), Harvard University Press, Cambridge.
Aristotle: 1990, *Nicomachean Ethics* (Greek text with an English translation by H. Rackham), Harvard University Press, Cambridge.
Balme, D.: 1987a, 'The Place of Biology in Aristotle's Philosophy', in A. Gotthelf and J. G. Lennox (eds.), *Philosophical Issues in Aristotle's Biology*, Cambridge University Press, Cambridge, pp. 9–20.
Balme, D.: 1987b, 'Teleology and Necessity', in A. Gotthelf and J. G. Lennox (eds.), *Philosophical Issues in Aristotle's Biology*, Cambridge University Press, Cambridge, pp. 275–285.
Bacon, F.: 1994, *Novum Organum* (translated and edited by P. Urbach and J. Gibson), Open Court Publishing Company, Chicago.
Charlton, W.: 1992, *Aristotle's Physics Books I and II*, Clarendon Press, Oxford.
Cooper, J.: 1987, 'Hypothetical Necessity and Natural Teleology', in A. Gotthelf and J. G. Lennox (eds.), *Philosophical Issues in Aristotle's Biology*, Cambridge University Press, Cambridge, pp. 275–285.
Cosans, C.: 1995, 'The Platonic Origins of Anatomy', *Perspectives in Biology and Medicine* **38**, 581–596.
Cosans, C.: 1997, 'Galen's Critique of Rationalist and Empiricist Anatomy', *Journal of the History of Biology* **30**, 35–54.
Cosans, C.: Forthcoming, 'The Experimental Foundations of Galen's Teleology', *Studies in the History and Philosophy of Science*.

Frampton, M.F.: 1991, 'Aristotle's Cardiocentric Model of Animal Locomotion', *Journal of the History of Biology* **24**, 291–330.
Gooding, D.: 1990, *Experiment and the Making of Meaning*, Kluwer Academic Publishes, Dordrecht.
Gotthelf, A.: 1987, 'Aristotle's Conception of Final Causality', in A. Gotthelf and J. G. Lennox (eds.), *Philosophical Issues in Aristotle's Biology*, Cambridge University Press, Cambridge.
Hanson, N.R.: 1958, *Patterns of Discovery*, Cambridge University Press, Cambridge.
Huxley, T. H.: 1879, 'On Certain Errors Respecting the Structure of the Heart Attributed to Aristotle', Nature **21**(523), 1–5.
Kuhn, T.S.: 1977, 'Mathematical versus Experimental Traditions', in *The Essential Tension*, University of Chicago Press, Chicago.
Lennox, J.G.: 1987, 'Divide and Explain: The *Posterior Analytics* in Practice', in A. Gotthelf and J. G. Lennox (eds.), *Philosophical Issues in Aristotle's Biology*, Cambridge University Press, Cambridge.
Lennox, J.G.: 1992, 'Teleology' in E. Fox Keller and E. A. Lloyd (eds.), *Keywords in Evolutionary Biology*, Harvard University Press, Cambridge, pp. 324–333.
Lloyd, G.E.R.: 1975, 'Alcmaeon and the Early History of Dissection', *Sudhoffs Archiv* **59**, 113–147.
Loeck, G.: 1991, 'Aristotle's Technical Simulation and its Logic of Causal Relations', *History and Philosophy of Life Sciences* **13**, 3–32.
Nussbaum, M.: 1978, *Aristotle's De Motu Animalium: Text with Translation, Commentary, and Interpretive Essays*, Princeton University Press, Princeton.
Ogle, W.: 1911, *De Partibus Animalium* (English translation with footnotes), Clarendon Press, Oxford.
Plato: 1903, *Timaeus*, in *Platonis Opera IV* (Greek text edited by J. Burnet), Clarendon Press, Oxford.
Preus, A.: 1975, *Science and Philosophy in Aristotle's Biological Works*, Hildesheim, New York.
Sedley, D.: 1991, 'Is Aristotle's Teleology Anthropocentric?', *Phronesis* **36**, 179–195.
Schaffner, K.: 1993, *Discovery and Explanation in Biology and Medicine*, University of Chicago Press, Chicago.
Shaw, J.R.: 1972, 'Models for Cardiac Structure and Function in Aristotle', *Journal of the History of Biology* **5**, 355–388.
Ross, W.D.: 1949, *Prior and Posterior Analytics with Commentary*, Clarendon Press, Oxford.
Thompson, D.W.: 1913, *On Aristotle as a Biologist*, Clarendon Press, Oxford.
Tiles, J.E.: 1993, 'Experiment as Intervention', *British Journal of the Philosophy of Science* **44**, 463–475.
White, J.: 1994, 'A Biological Theme in Aristotle's Ethics', *St. John's Review* **42**, 17–43.