Available online at www.sciencedirect.com
SCIENCE DIRECT®
Stud. Hist. Phil. Biol. & Biomed. Sci. 36 (2005) 245–260
Studies in History and Philosophy of Biological and Biomedical Sciences
www.elsevier.com/locate/shpsc

Mechanisms of life in the seventeenth century: Borelli, Perrault, Régis

Dennis Des Chene

Philosophy, Washington University in St. Louis, Campus Box 1073, St. Louis, MO 63130, USA

Abstract

In Descartes's reformulation of natural philosophy, two aspects of what came to be known as the mechanical philosophy were intimately joined: mechanism as an ontology of nature, according to which all natural things had only 'mechanical' properties; and mechanism as a method of explanation. One could, and many philosophers did, adopt mechanism as a method of explanation without adopting a mechanistic ontology. I examine two successors of Descartes who did just that, and one who did not. Giovanni Alfonso Borelli in his *De motu animalium* (1680) and Charles Perrault in his *Mécanique de animaux* (1680–1688, Vol. 3) propose and argue for a variety of mechanical accounts of the operations of animals, in particular of their muscles. They reject, however, the Cartesian reduction of animal souls to mechanical forces; the principle of animal motion for them remains a non-mechanical soul. Pierre Sylvain Régis in his *Cours entier de philosophie* (1690, 1691) follows Descartes in taking the 'physical cause' of motion in animals to be the fermentation of blood in the heart, and thus denies animal souls any role in his physiology. That he can do so while taking over, sometimes word for word, Perrault's accounts of animal motion shows that mechanistic explanation and mechanistic ontology could easily part company.

Keywords: Giovanni Alfonso Borelli; Charles Perrault; Pierre Sylvain Régis; Mechanism; Physiology

E-mail address: ddeschen@artsci.wustl.edu (D. Des Chene).

1369-8486/$ - see front matter
doi:10.1016/j.shpsc.2005.03.002

1. Introduction

The new science was almost immediately applied to the science of life, and for good reason. If mechanism was to become *the* form of explanation in natural philosophy, it would have to confront the Aristotelian alternative at its strong point. That strong point was the science of living things. Though corpuscular and microstructural hypotheses might be admitted to explain well enough the operations of inanimate things, the operations of plants and animals seemed to resist any reduction to mere mechanical causes. So the Aristotelians had argued at some length (Des Chene, 2000). Descartes's first comprehensive presentation of his natural philosophy included, therefore, not only chapters corresponding to Aristotle's *Physics*, *De generatione*, and *Meteores*, but also a counterpart to *De anima*—the *Treatise of man*. The mechanistic explanation of the phenomena of life was supposed to eliminate any need to attribute substantial forms or non-mechanical powers to creatures other than the human being, and thus to confirm a restrictive mechanistic ontology.

The use of mechanistic forms of explanation does not, however, require that nature should instance *only* those properties featuring in those explanations. After Descartes's death in 1650, mechanism and Cartesianism could and did part company. Aristotelian natural philosophers, following Aristotle himself, had made use of microstructural and corpuscular hypotheses without in the least being inclined to deny the existence of non-mechanical forms and qualities. There had never been an entire consensus concerning the restrictive ontology; what is new in the work of philosophers such as Borelli and Perrault is that an outright rejection of that ontology was combined with a thoroughgoing commitment to mechanism, and thus to a *non-restrictive* mechanism. The combination was made possible by emphasizing a traditional division of labor in which, contrary to the systematic claims of Cartesians, the study of the *transmission* and *determination* of active powers, which is the province of mechanics, could be undertaken separately from the study of those powers themselves and their principles. In the work of the Cartesian Régis, on the other hand, the science of living things must, in the interest of system, include not only the 'mechanical' but also the 'physical' causes of movement in animals. But Régis's defense of the Cartesian system, and of its restricted ontology, was by the time his *Cours* was published, a position that had, for the time being, exhausted its resources.

Much more than I say here could be said even on the narrow topic of the theory of the muscles and animal locomotion. My intention is simply to illustrate two points about mechanism in the science of life in the period here discussed. The first is that mechanism as a restrictive ontology of nature could be, and readily was, distinguished from mechanism as a method, or as *the* method, in the science of life. The second is that the pioneers—notably Descartes—put forward their hypotheses in a different context of persuasion than did those who employed mechanism as a method a generation or two later. Descartes had to show that a reasonably comprehensive mechanistic natural philosophy is possible (and desirable); a generation or so later, that much could be taken for granted. Indeed it was now humdrum common sense. One could, on the one hand, get on with the business of explanation, and, on the

other, acknowledge and even emphasize the limits of mechanism without calling into question its utility and propriety.

2. Aristotelian background

The immediate past for natural philosophers of Descartes's generation was the so-called philosophy of the Schools, or Aristotelianism, and in particular the Aristotelianism of the Jesuit commentators, whose monument is the series of commentaries that issued from the Jesuit college at Coimbra. Two standard questions in Aristotelian textbooks on physics, together with their offshoots, are of interest here.

The first is a question on 'nature and art'. Its usual form is: does art imitate nature? The pretext for the question is a passage in Aristotle's *Physics* in which he says that art imitates or perfects nature (*Phys*. 2c2). Human art imitates nature, but only to a degree. In the arts of depiction, human art mimics the outward appearance of things; in the arts of production, it imitates those things that 'ought to have pre-existed' and strives to fashion them as nature would have (Toletus, 1615–1616, *Phys*. 2c2q6, Vol. 4, f. 54v).[1] Nature did not give us claws or fur coats, but because we, unlike the animals, have a rational soul, we can produce those things for ourselves, imitating their counterparts. Even so, what we imitate remains the outward form of things, the sensible qualities by which we come to know their inward natures. Those inward natures, or forms, however, we are incapable of creating ourselves. The mark of our incapacity is the inertness or stolidity of artificial forms. They cannot possess, per se, the activity and spontaneity of life.

The second question is that of the origin of forms. Matter, though potentially all things, is entirely passive. The active powers of things, and especially those of living things, cannot come from matter, from the elements, or from mixtures. Questions on the 'eduction' of form from matter generally conclude that the forms of living things, and especially those of higher animals, are bestowed on matter by celestial intelligences—the mover of the Sun's sphere, for example—or, in the case of humans, by God himself. Human industry is secondary and subordinate to nature and to God. It cannot introduce new forms—forms with the active powers that we find in animals—into matter; instead it must content itself with rearranging already formed matter or with assisting natural processes.

What then of the famous automata of antiquity—the statues of Daedalus, the dove of Archytas, the animated tripods of Apollonius of Tyana? In every case, according to the Coimbrans, there is either fakery or else the redirection of natural forces. 'Neither art nor artificial form by its own power is capable of the work of nature' (Coimbra, 1594, 2c1q7a2, p. 218[118]). The claims of alchemy, on the other hand, fare better. The Coimbrans give a standard list of technological wonders (the compass, the printing press, flat glass…), taken perhaps from Jean Bodin's *Methodus ad facilem historiarum cognitionem* (1566). Given what human ingenuity has accomplished, it is

[1] All translations are my own.

possible that human art, they conclude, should be capable of understanding the conditions under which gold is produced in nature and of reproducing them. But that human art might go so far as to do the same for animals is impossible, because animal life requires more than the mere mixing and shaping of elements.

Life is divine art, evidence of the infinite power and understanding of the Creator. Animal life, in its higher forms at least, is *exclusively* divine art. Only God, or something superior to human beings, could produce a soul. The very idea of artificial life—not just the simulation of it, not just of magical means to make existing forms, like those of demons, do one's bidding—requires a certain amount of conceptual rearrangement. That rearrangement occurred, of course, in the seventeenth century with the rise of mechanistic natural philosophies, notably that of Descartes. Even when, as in the post-Cartesians Borelli and Perrault, mechanism is *combined* with the attribution of souls to animals, there is no simple reversion to Aristotelian conceptions of the soul. Once Aristotelian substance has been rejected from physics, the soul no longer has a role in explaining structure, nor even the transmission of force from one part of the body to another. It remains the source of the body's activity, of the spontaneous motion that the mechanics of the body does not pretend to explain.

3. The mechanics of living things

To an Aristotelian, then, the very idea of 'artificial life' would have suggested an impossibility. Descartes thought otherwise. He said that animals *are* machines. That we can't build one is owing to the crudeness of our tools and the limitations of our minds (see Gontier, 1998, pp. 207–209). In 1680, a generation after Descartes's death, there was no consensus on the matter. If anything, the tide was beginning to turn against Cartesian ontology: matter is not only *res extensa*, but at least impenetrable. Nevertheless, There was, among practitioners of the new science, a quite general agreement that much of what goes on in animals and plants can be explained mechanistically—*without* the reduction of animal souls to configurations of *res extensa*. Claude Perrault, in his *Mécanique des animaux*, begins his work with the following disclaimer: to avoid 'the bad effect' that his title might produce in those who have heard that 'most Animals are machines', Perrault affirms that

> by 'animal' I mean a being that has feeling and is capable of exercising the functions of life by a principle called the soul; that the soul makes use of the organs of the body, which are true machines... and that although the disposition of the pieces in the machine have with respect to each other does nothing other by way of the soul than what it does in pure machines, still the entire machine has need of being moved and driven by the soul... (Perrault, 1721, Vol. 1, p. 329)

Similarly Giovanni Alfonso Borelli, in the dedication to Queen Christina of his De motu animalium, echoes Galileo in holding that the 'idiom and characters with which the Creator of Things speaks in his operations are Geometrical Configurations and Demonstrations'. In particular, the science of animals and their movements will

be geometrical: 'the geometric perception' of animals is 'uniquely fitted' for reading 'the divine Codex inscribed in Animals' (Borelli, 1680, dedication, sig. a3). This even though it is evident that the 'principle and cause of the movement of animals is the soul' (ibid., p. 2).

Animals, in short, are sufficiently machine-like to fall within the scope of mechanics. Perrault even states, and Borelli implies, that 'if one knew an Animal as one knows a clock, one would know it perfectly' (1721, Vol. 2, p. 514). But, as Perrault argues, we don't:

> One cannot say that we are as assured of knowing how the organs of an Animal act, in the way that it is certain that one knows how a counterweight or a spring make a watch run; we do not know what causes a Dog who has lost its Master to stop eating, even though we are quite sure that it is not chagrin that stops a watch from running. (Ibid.)

It may be surprising that a philosopher should both offer a 'mechanics of animals' *and* hold that animals have souls. But seventeenth-century mechanism was not a monolith. The bundle of metaphysical presumptions, methodological precepts, and models of understanding that is comprised under that label was, like many such bundles, loosely bound.

Descartes did his best to bind the pieces together. For him the thesis that animals are machines is a consequence of conceiving body to be nothing other than *res extensa*. Conversely, to show that animals are machines, all of whose properties are modes of extension, is to confirm the ontology of *res extensa*. Descartes's physiology is of a piece with his physics, and that is in turn of a piece with his 'first philosophy' (Des Chene, 2001). Pierre Sylvain Régis, for his part, sets great store by system. The hypotheses he proposes, rather than being purely arbitrary and ad hoc, 'depend in such a way on one another, and all of them together on first truths, that they form a single System' (Régis, 1691, Vol. 1, p. 278), here echoing similar statements by Descartes in the Principles.

But even as Régis was, in the 1680s, writing his *Cours entier de philosophie*, the bundle was coming apart. System was beginning to look like dogma; the 'sect of Cartesians', as Leibniz called them, was starting to be described in terms like those formerly reserved for the School philosophers. What succeeded in the later seventeenth century was not the ambitious program of Descartes but something more modest. Mechanism as ontology failed, but mechanism as method succeeded.

Let me clarify this distinction. When Descartes and Régis hold that animals are machines, they mean that animals are machines and *nothing else*, and by 'machine' they mean at least an object every property of which is a mode of extension (or else one of the modes—duration, for example—that are common to all substances). 'Mechanism as ontology' more generally is the claim that the only properties animals have are those attributed to them in mechanical explanations, whatever those may be. Mechanism as ontology typically is thought to entail the sufficiency of mechanical explanations for all the phenomena of nature. But it is itself a claim about what kinds of substances or properties exist: taken positively, it claims that things in nature have mechanical properties (but perhaps others as well); taken restrictively, it

claims that things in nature have *only* those properties. Cartesian natural philosophy was restrictive.

Mechanism as method is more circumspect. Aristotle himself is not averse to appealing to mechanisms in explaining natural phenomena; in commentaries on *De generatione et corruptione* and the *Meteora* there are instances of explanation in terms of pores and corpuscles that could easily be imported into a Cartesian framework. From the actual situation—the animal's bones, joints, muscles, and tendons, awash in blood, sheathed in skin, threaded with nerves—mechanism as method abstracts a schema to which the rules of mechanics, for example the principle of the lever, can be applied. That abstraction is evident in the figures of Borelli (see Figure 1 below): the drawings themselves exhibit what is to be counted as part of the schema, and by implication what is not. The figures are not fictions. What they exhibit is part of what actually exists in the organism. But it is clearly not the whole. Ideally one might offer a series of pictures, in ever finer detail, exhibiting a nested series of mechanisms capable of explaining all that occurs in the organism (Duchesneau, 1998, p. 276). The limit at which mechanical explanation ends can be deferred, but it cannot be removed altogether.

Perrault's preformationist theory of generation illustrates this point: the 'development' of the embryo is 'not a formation, but only an augmentation of parts already

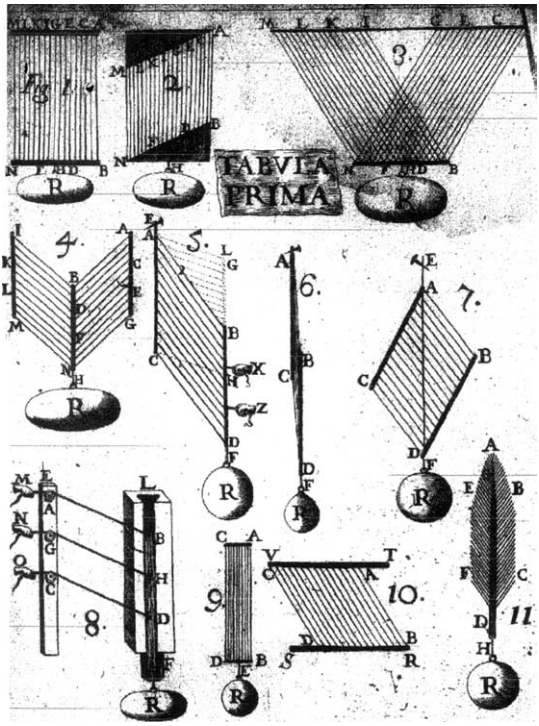

Fig. 1. Mechanical models of bone and muscle (from Borelli, 1680, Table 1).

formed, although imperceptible in small bodies, uncountable in number, just as their smallness is almost infinite' (Perrault, 1721, Vol. 2, p. 506). Those parts were created by God; here mechanical explanation ceases.

Like the Cartesians, Perrault and Borelli explain the operations of animals mechanically. Once they have specified that by calling animals machines they do not intend to deprive animals of their souls or their sentiments, they proceed in very much the same manner as Descartes and Régis. Borelli even presents his theory *more geometrico*, stating his main propositions as theorems, and adducing mechanical lemmata in support of them. Perrault and Borelli embrace mechanism as method. Indeed they make a virtue of doing so.

They embrace also the positive ontology of mechanism: animal bodies really do include particles and springs, those parts really do exert force, and so forth. Their mechanism is in no way instrumentalist. But they do not accept the restrictions imposed by the Cartesians. On their view, mechanistic explanations provide us with as complete an explanation as we are likely to have of what lies within their scope; but beyond that, mechanism as method has no authority. In particular it cannot decide the question of animal souls. The Cartesian bundle is undone.

4. Borelli

Borelli's *De motu animalium* was published posthumously in 1680 and 1681. The preface to the work, which is dedicated to Queen Christina, sets forth the apologetic aim of exhibiting the 'perfect Goodness' of God by way of eliciting our admiration for the 'works and machines which Nature has elaborated with such great art' (Borelli, 1680, sig. a2r). The 'idiom and characters' with which the Creator has inscribed his conceptions in the 'Codex' of nature consist in 'Geometric Configurations and Demonstrations'. Borelli here echoes Galileo. Since 'animals are bodies, and their vital operations are either motions or cannot occur without motion, and [since] bodies and motions are the subject of Mathematics, the scientific contemplation of them will be Geometrical' (ibid., sig. a3r).

It is evident, moreover, that the principle and effective cause of motion in animals is the soul—evident enough that Borelli offers only cursory support for the claim. It is by way of 'a certain natural appetite' in the soul that the motions of animals are caused. The 'active instrument' of the soul is the animal spirits; the corresponding 'organic, and merely passive' instrument is the muscles and bones (ibid., p. 3). By that distinction Borelli makes possible a division of labor: the mechanics of motion, which includes both statics and dynamics, treats the active and passive instruments of the soul; the consideration of the soul itself is implicitly referred to another branch of the study of living things, a 'psychology' properly speaking.

Introducing his description of the muscles and their use, Borelli writes that 'just as in other Physico-mathematical sciences it is customary so too will we attempt to set forth the science of the movement of animals starting from the phenomena, considered as foundations' (ibid., p. 4). Hence the first task is to describe the structure and

operations of the muscles. What follows is a series of propositions, including various lemmas from mechanics, the purpose of which is to show that the muscles can and do exert the force necessary to move the body.

The description of muscle emphasizes that it consists not of tubes but of spongy fibers, properly white in color (*in situ* they look red, but that is only because they are suffused with blood) (ibid., p. 6). After showing that the 'action of the muscle is contraction' (ibid., Table 1, Figures 1–4; see my Fig. 1), Borelli presents what he calls a 'new notion [discovered] in recent years of the true form of the muscles and their mechanical mode of operations', which in service to his love of truth he will explain. The problem is to explain how the muscle, in contracting, thickens without the addition of new matter (ibid., p. 10). Borelli's predecessors had explained this by supposing that the muscle is a rhomboid composed of fibres all running in the same direction.

> They suppose, that in Animals there are muscles whose shape is that of a simple rhomboid, so that ABCD [see Table 1, Figure 5], whose tendon is affixed to the solid bone EAC or to the terminus E; and the opposite tendon BD is equidistant from AC, and they are separated from each other; then let two contrary powers, of which one is the weight R pulling down the tendon BD from B toward F, and the other is that contractive force [*vis contractiva*] of the fibers, which acts by drawing obliquely upward the weight R from B toward A, and from D toward C.

If the fibers neither grow nor shrink in volume, then the fibers must become thicker as they shorten, and so

> necessarily the obliquity of the prism ABDC will diminish, and will approach more closely the straight line AGHC; likewise the acute angle BAC will grow to the size of GAC; and thus the weight R will be drawn upward. (Ibid.)

The entire 'speculation' just laid out rests 'on the trvial proposition of Euclid, that two prisms ABDC and AGHC on the same base between two parallel planes are equal to each other and conversely' (ibid.).

Borelli presents four arguments against this arrangement of the fibers, of which the strongest is the 'mechanical' argument that it is quite inept to the task of lifting any weight (p. 12). Given that force is exerted by the fibres through contraction along their long axis, the arrangement in Figures 5 or 7 will not do the job, even though (as Borelli notes) the rhomboidal arrangement does explain what we see when a muscle grows longer or shorter: 'what is most important in this affair is the mechanical reason according to which the force of the muscle moves a resisting [body] by means of the organ [i.e. the muscle]'; the rhomboidal arrangement provides no such reason. Although it is possible, by means of the arrangement shown in Figure 8, to lift a body by means of forces exerted in the same direction as those exerted by the fibers in Figure 5, nevertheless we do not see any such arrangement in the body:

> It is true that in a certain case the proposition [i.e. that the fibers are arranged as in Figure 5] can be verified, as when the fibers are joined to the fixed bone

> EAC and the side BD of the rhomboid is restricted to a channel LF hollowed out of a column... But this hypothesis has no place in animals, in whom are found no muscles having a simple rhomboidal form nor any whose tendon or mobile side BD runs through a channel. (Ibid., p. 12)

The 'true figures' of muscles are seen in Figures 9, 10, 11. The difference between Borelli's figures and those illustrating the false opinion is that the line to which the ends of the fibres are attached is either perpendicular to the force exerted, or else the line itself along which force is exerted. Mechanical reasons alone suffice to show that this must be the case.

I will mention one other proposition in which Borelli claims to differ from his predecessors—not only Aristotle, Lucretius, and Galen, but also Gassendi. Those philosophers held that in animals a small force or power must be capable of moving a great mass. Borelli for his part holds that the force of the muscles can be 'immensa', and must be:

> I will show that machines are applied to the motions of animals, and that they are multiple and various; but that it is not true that a great weight is lifted by a small force, but rather a great force and effort of the animal faculty holds up a small weight; so that the motive force [of the muscles] exceeds by a hundredfold or a thousandfold the weight of the bones... and is never less than [their weight]. (Ibid., Prop. 8, p. 18)

What follows is a series of propositions on the shape and configuration of various muscles, and then a chapter consisting of lemmas concerning levers and weights. Borelli then shows what the force of various muscles must be: for example, the force exerted by the biceps when a weight of 28 pounds is being held by the hand with the arm extended horizontally is 560 pounds. The calculation is based on the known places of attachment of the muscles, and the use of the forearm (in this case) as a lever, the fulcrum being the elbow. In the flight of birds, the proportion of force to weight must be much greater; it is for this reason that humans will not be able to fly by their own power alone.

Three things are to be considered: (i) the 'motive faculty' by which the body of an Animal can be suspended in air; (ii) suitable Instruments, that is, wings; (iii) the resistance of the weight of the body of the Animal. Borelli thinks he has shown than in birds the motive force of the wings is ten thousand times greater than the resistance of their weight (ibid., prop. 193, p. 303).

> When, therefore, it is asked, whether men by their own force can fly, one must see whether the motive force of the pectoral muscles... exceeds the resistance of the weight of the whole human body, together with wings, by the same amount [as in birds], namely ten thousand. It is plain that the motive forces of the pectoral muscles in men are much less than is required for flight, because in birds the mass and weight of the muscles that flex the wings is not less than one-sixth of the weight of the whole body. Therefore it is necessary that the pectoral muscles of a man should weight at least one-sixth the weight of the whole body. (Ibid., p. 323).

But in fact those muscles weigh less than a hundredth part of the weight of the whole body. From this it can be deduced that 'the artifice of Icarus was entirely fabulous', and that no machine can increase the speed or momentum of the wings sufficiently to allow flight.

The animal, or at least its muscular and skeletal structure, is a machine, the effects of which can be calculated on mechanical principles (see Balaguer Perigüell, 1974, pp. 94–121 for further examples and analysis). What mechanics cannot explain is the source of the motive power by which the muscles exert themselves in lifting weights and locomotion. Borelli here continues a traditional division of labor between mechanics, which deals mathematically with the distribution of forces in machines, and physics, to which alone belong questions of the origin of force. Descartes likewise distinguished mechanics, one of the three branches of the tree of knowledge, from physics proper, which is the trunk of the tree (Gabbey, 1993, p. 320). Among other things, mechanics takes weight for granted, and measures or calculates its effects; the explanation of weight belongs to physics. In the traditional division of labor, the use of mechanical explanations typically carries the positive implication that the things figuring in those explanations have mechanical properties. Descartes, in adopting a restrictive mechanism-as-ontology, takes over into physics the procedure of abstraction proper to mechanics, and makes it a criterion of the real.

5. Perrault

Claude Perrault (1613–1688) is best known for his architectural work, which included the eastern façade of the Louvre and an edition of Vitruvius (1673, 1684). He was trained as a physician, and after entering the Académie des Sciences at its founding in 1666 spent his last twenty years working on two monumental volumes of natural history (*Mémoires pour servir à l'histoire naturelle des animaux*, 1671, 1676) and on the *Essais de physique*, the third volume of which is the *Mécanique des animaux* I discuss here. The *Essais*, as their title implies, do not purport to offer a systematic, orderly treatment of natural philosophy. Knowing that the taste for 'philosophical physics' is rare, and yet hoping to satisfy the curiosity of 'those who ordinarily have little of it' in these matters (Perrault, 1680–1688, Vol. 1, Preface, sig. avi), Perrault not only writes in the vernacular but also promises to define all the terms of art he uses. Instead of the geometrical style of Borelli we have the easy style of Descartes's *Discourse* and Mersenne's *Questions*.

Perrault is not a promoter of novelties. Of those recently introduced into philosophy he writes that they are mostly just the 'explication of ancient opinions that modern authors have pushed a little further than their first authors did' (ibid., sig. eij). His own opinion, for example, concerning the movement of the muscles was 'furnished' to him 'by Galen', and his preformationist theory of generation is credited to Hippocrates.

The *Mécanique des animaux* begins by disclaiming the implication of its ambiguous title. An animal, says Perrault, 'is a being which has sensation and which is capable of exercising the functions of life by a principle called the Soul'. The soul 'makes use of

the organs of the body, which are truly machines, by way of being the principal cause of the action of each piece of the machine'. This even though 'the disposition of those pieces with respect to one another' in the machine does almost nothing that it would not do 'in pure machines' (ibid., Vol. 3, 'Avertissement', sig. A). For Perrault as for Borelli, mechanism in the study of the movements of animals does not preclude supposing them to have souls. What it does preclude, in Perrault's case, is any appeal to 'occult qualities or formal faculties' (Duchesneau, 1998, p. 278)—any return, that is, to the Aristotelian soul, endowed as it was with special powers of sensation, locomotion, and so forth.

Despite the opposition to Cartesianism evident in the preface to the *Essais* and in the 'Avertissement' to the *Mécanique*, Perrault's explanation of the action of the muscles proceeds in a manner not unlike that of Descartes in the *Treatise of man*. The chief difficulty in explaining their action is that the 'fibres of the flesh of the muscle' are aligned transversely, and thus do not seem to be responsible for the contraction of the muscle. To explain the action of the fibres, Perrault introduces a number of suppositions:

> that the 'fibres that compose the membrane that covers each muscle have a natural spring', and thus tend to return to their natural state after being stretched—thus do the claws of lions withdraw of themselves (Perrault, 1680–1688, Vol. 3, p. 74; see his Plate 3, Figure 1);
>
> that the fibres are ordinarily stretched because each muscle has an antagonist; the 'equilibrium' position of a limb is that in which the fibres of protagonist and antagonist are in equal tension (ibid., p. 75);
>
> that since both the protagonist and antagonist are in tension, the relaxation of one will lead to bending in the direction of the other, just as a ship's mast will bend in the direction of the tighest guy-wire (see his Plate 3, Figure 2);
>
> that the relaxation of the fibres occurs by way of the 'introduction of the spirituous substance brought by the nerves from the brain', which 'corrupts and relaxes' their spring (ibid., p. 76).

It follows (this is Perrault's principal claim) that the so-called animal spirits operate to relax the muscles and not to tighten or shorten them. They shorten of their own accord after being stretched. Among the opponents here is Descartes. The *Treatise of man*, as we have seen, argues that the entry of the animal spirits into a muscle shortens it (AT 11:135).[2]

As with Borelli, we see a definite demarcation between the 'mechanics' of animals and what we might call their 'energetics'. The source of active power is the soul, about which very little is said. What remains is to explain the transmission and application of that power to the end of locomotion, and that is a matter of applying mechanical knowledge. Perrault acknowledges that the animal-machine resembles 'pure machines' in the manner of its operation. But every machine requires a mover, and this the mechanism itself is incapable of supplying.

[2] Descartes, 1996. I use the standard Adam–Tannery page numbers, denoted by 'AT'.

Rather than seeing Perrault's and Borelli's admission of animal souls as a withdrawal from the more forthright mechanism of the Cartesians, it might be fruitful to regard it instead as a division of labor not unlike the division Descartes, drawing on precedents in optics, himself proposes in the *Dioptrique*. He sets aside questions concerning the nature of light in favor of a few assumptions about its action (e.g. that it travels in straight lines unless interfered with) that will allow him to get on with the business of applying geometry to the description of its behavior when reflected or refracted. So in the study of animals the vexing question of the soul, like analogous questions about other causes and powers, can be set aside in favor of investigating the 'instruments we can see and whose manner of acting we know by *expériences*', in particular by the dissections which show all the pieces of the animal machine 'distinctly and separately' (Perrault, 1680–1688, Vol. 3, pp. 8–9).

6. Régis

Like Perrault (from whom he borrows copiously), Régis takes the muscles to consist of fibres, and to have a natural spring. This is confirmed, as in the other authors, by the observation that when the antagonist of a muscle is cut, the protagonist pulls the limb in its direction much further than usual. In their 'natural state' the muscles are in tension (Régis, 1691, Vol. 2, p. 534).

The springiness of the muscles he explains in the usual Cartesian manner:

> we are quite reasonably brought to believe that it depends on the fact that the lengthening of their fibres diminishes the pores [of those fibres] enough that instead of being round or square they become lozenges or spindles…; and this causes the subtle matter that no longer passes so easily through these pores to make an effort to enlarge them, and thus to shorten the Muscle that has been lengthened. (Ibid., pp. 534–535)

To this he adds a condensation of Perrault's account of the shortening of the muscles by the animal spirits. The visible fibres of the muscles are composed of 'other fibres, as a rope is composed of the threads of which it is made'. When those smaller fibres are forced apart by the animal spirits, they pull apart from one another, thus shortening the muscle in the same way that water shortens a rope when it soaks into the fibres of the rope (ibid., p. 535).

It is in the chapter that Régis devotes to the uses of the nerves and muscles that he departs from the agnosticism of Borelli and Perrault concerning the ultimate causes of movement in animals. He divides the causes in general into 'mechanical' and 'physical' causes. The mechanical are just those described by Borelli and Perrault, and adopted in turn by Régis. The 'physical' cause, on the other hand, is the movement of the animal spirits, whose force is provided by the fermentation of the blood, which Régis has described earlier. Régis's primary concern in the present is to show how the movement of the animal spirits is *determined*. In the case of the heart, it is 'so disposed that it cannot be contracted by the effort of the animal Spirits that inflate its fibres unless the auricles are dilated by their proper springiness and by the

impulsion of the blood that comes from the vena cava; nor can it be dilated by its elastic virtue and by the effusion of the blood that falls into its ventricles unless the auricles are contracted by the effort of the animal Spirits'. This renders the heart's movement, like that of a pair of antagonistic muscles, 'absolutely necessary' (ibid., p. 607).

The 'contingent' movements of animals are caused by the senses according to 'the place of the object that acts on the organ of movement, the quality of its action, the disposition of the fibres of the brain, and the diverse situations of the exterior members [of the body]' (ibid., p. 607). Régis goes on to describe the action of the senses on the pores of the brain, and thus on the organs of movement, in a manner quite similar to that of Descartes in the *Treatise of man*. When a dog 'pursues a hare, its regulated movement depends only on the fact that its brain, a mechanical organ, is so disturbed by the insensible particles that issue continually from the body of the Hare, that it determines the animal spirits to flow precisely in the muscles that serve, according to the order of nature, to make the movements necessary to the pursuit' (ibid., p. 609).

That last sentence exhibits the kind of vacuity that mechanistic discourse is capable of—a vacuity easily matching that of the Scholastic 'dormitive virtue' explanations that mechanists made fun of (see Gabbey, 1990). In particular the 'order of nature' has no independent grounding; Régis appeals to a teleology that Descartes himself rejected. Nevertheless what Régis is proposing is that in principle mechanics can explain everything that goes on in animals, even the origin of force. Its domain is not, as in Perrault and Borelli, restricted to the explanation of motion, given the active powers that initiate it. Those active powers themselves require explanation and an eventual reduction to the motion with which God endowed matter at its creation.

7. Conclusion

Descartes was faced with the task of offering a comprehensive alternative to the natural philosophy of the Schools. The alternative was his version of mechanism. Its differences with the School philosophy were fundamental, and the objections to it likewise fundamental. Is the universe furnished with forms and qualities of the Aristotelian sort, or is it nothing other than Cartesian bodies in motion? In offering accounts of particular phenomena, such as the self-movement of living things, the disputational context is one in which the issue is not which mechanism, but whether any mechanism, can explain the phenomena. Can any machine respond to its surroundings and act appropriately in the way that animals do? Can any machine reproduce itself? In that context what one needs to explain is not how the body actually works but how it is *possible* that in a mechanical universe there could be things that resemble the animals of this world.

Descartes was aware of the distinction. Already in the concluding paragraphs of the *Treatise of man*, Descartes asserts, on the one hand, after a lengthy list of the functions that the man-machine is capable of performing, that his reader should

consider that 'these functions all follow naturally, in this Machine, from the disposition of its organs alone, neither less nor more than do the movements of a clock or some other automaton', and so there is no reason to assume in the Machine any sort of vegetative or sensitive soul. On the other hand, he also holds that 'knowing that Nature acts always by the easiest and simplest means of all', the reader will perhaps judge that it is not possible to find means 'more similar to those that [Nature] uses, than the ones here proposed' (AT 11:201–202).

The first claim requires only that the means proposed in the *Treatise* be possible; the emphasis is on their agreement with Cartesian principles, and on the superfluity of other means such as vegetative or sensitive souls. The least one can say is that the man-machine simulates the human body very well, showing thereby how it is possible that a machine could resemble a human not only in outward aspect but also in its operations. The second claim, on the other hand, urges that the mechanisms proposed in the *Treatise* are the most similar one could think of to those employed by Nature: which is to say, they provide the best explanation of the operations of the human body that we can have—not only do we see how Nature could have done so, but how she does.

The how-possible account suffices in the context of a foundational dispute, where the other side doubts that your principles can even begin to explain the phenomena. In *De anima* commentaries, Aristotelian authors argued that even in the case of the vegetative soul, what we would call merely physical or chemical properties were insufficient; *a fortiori* they could not explain the operations of the sensitive soul. In that context, working with an even shorter list of properties than the Aristotelians had in mind, Descartes had first of all to show that some mechanical explanation or other could do the job.

By 1680 the situation was different. Once the new science took hold, its participants, agreeing more or less on principles, were arguing within the general context of mechanism. The proponents of mechanical explanation no longer have to argue its legitimacy; instead they observe its limits. Mechanism as method no longer needs the backing of mechanism as ontology, or at least not universally: it suffices that muscles, bones, and nerves be mechanical in certain respects. Borelli and Perrault instead take their task to be that of judging the merits of various mechanical explanations of animal motion, of choosing among models. How-possible explanations no longer suffice; their polemical function lapses; and so begins the twofold task of finding means by which to distinguish the experimental consequences of competing mechanical explanations and of devising experiments to increase the store of *expériences* on the basis of which disputes may be settled.

There is a science of the movements of animals, of which Borelli's *De motu* and the second part of Perrault's *Mécanique* are illustrations. There may also be a science of the souls of animals, though it would seem that Perrault thinks it is beyond our capacities. Only in the latter will the source of animal power be explained, if anywhere. The upshot is that the scientific treatment of the animal-machine, considered as an object of mechanics, and that of the animal-automaton, the self-mover, should part company. There will be two sorts of 'artificial life': that which simulates the operations of animals without going so far as to aim at self-motion, and that which

does, or that which, without attempting to make something that looks like an animal, is a self-mover.

To put the point another way: Descartes succeeded in introducing mechanism into the study of living things—more specifically, the new mechanism and the new mechanics put forward by Galileo, Descartes himself, and others in the first half of the seventeenth century. Not only that, but to a large degree he and his contemporaries succeeded in making the machine a model of understanding. By that I mean that to understand something as a machine, or to understand that it is a machine, was to understand it sufficiently well—well enough that no further requirement of clarity or demonstrative certainty was in order. Borelli and Perrault do not dispute that. But Descartes sought to unify the science of life under the mechanistic model, and that included a reduction of the active powers of living things to mechanical forces. That reduction is rejected by Borelli and Perrault. The result is a science of animal movement in which the soul is assumed only to be left behind, not because it can be eliminated but because it cannot be mechanized—nor is there any need to do so.

Acknowledgements

Thanks to Carl Craver for conversations preceding, and comments following, the presentation of this paper at the Mechanisms Conference.

References

Balaguer Perigüell, E. (1974). La introducción del modelo físico-matemático en la medicina moderna. Análisis de la obra de G. A. Borelli (1608–1679), De motu animalium. Cuadernos hispánicos de historia de la medicina y de la ciencia, 14. Serie A: Monografías. Valencia [Cátedra de Historia de la Medicina. Facultad de Medicina].

Borelli, G. A. (1680). *De motu animalium Giovanni Alphonsi Borelli*.... Rome: Angelo Bernarbo.

Coimbra [Collegium Conimbricensis] (1594). *Commentarii Collegii Conimbricensis*...*in octo libros physicorum Aristotelis*. Coimbra. (Facsimile repr. Hildesheim: Olms, 1984).

Des Chene, D. (2000). *Life's form*. Ithaca, NY: Cornell University Press.

Des Chene, D. (2001). *Spirits & clocks*. Ithaca, NY: Cornell University Press.

Descartes, R. (1996) *Le monde*, *l'homme* (A. Bitbol-Hespériès, & J.-P. Verdet, Eds.). Paris: Seuil. (First published 1661).

Duchesneau, F. (1998). *Les modèles du vivant de Descartes à Leibniz*. Paris: Vrin.

Gabbey, A. (1990). Explanatory structures and models in Descartes' physics. In G. Belgioioso, et al. (Eds.), *Descartes: il metodo e i saggi* (2 vols.) (Vol. 1, pp. 273–286) Rome: Istituto della Enciclopedia Italiana.

Gabbey, A. (1993). Descartes' physics and Descartes' mechanics: Chicken and egg?. In S. Voss (Ed.), *Essays on the philosophy and science of René Descartes* (pp. 311–323). Oxford: Oxford University Press.

Gontier, T. (1998). *De l'homme à l'animal. Montaigne et Descartes ou les paradoxes de la philosophie moderne sur la nature des animaux*. Paris: Vrin.

Perrault, C. (1680–1688). *Essais de physique ou recueil de plusieurs traitez touchant les choses naturelles* (4 vols.). Paris: J.-B. Coignard.

Perrault, C. (1721). *Oeuvres diverses de physique et de mechanique de Mrs. C. & P. Perrault* (2 vols.). Leiden: Peter van der Aa.

Régis, P. S. (1691). *Cours entier de philosophie, ou systeme general selon les principes de M. Descartes*… (3 vols.). Amersterdam: Huguetan (First published 1690).

Toletus, F. (1615–1616). *Commentaria unà cum quæstionibus in octo libros Aristotelis De physica ascultatione*. In idem, *Opera omnia philosophica* (Vol. 4). Cologne: Birckmann. (Fascimile repr. with intro. by W. Risse. Hildesheim: Olms, 1985.).