DRAFT

Abstracting from the soul: the mechanics of locomotion

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Life was art before it was artificial. It was divine art, evidence of the infinite power and understanding of the Creator. More to the point, animal life, in its higher forms at least, was *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—required 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. What is striking to me as I begin to examine the later history of the mechanistic philosophy of life is that in some authors—today's guinea pigs are Borelli and Perrault—there is a kind of reversion to the pre-Cartesian conceptual situation. A reversion, however, that did not inhibit the treatment of animals as machines: it would seem, rather (here I speculate) that the general direction of thought after (say) 1700 is to regard "matter" itself as already, in some low degree, living. Creating life would be impossible, not because it was beyond our powers, but because it was already there…[1]

The topic of this paper belongs rather to the parahistory of artificial life than to its history. With the possible exception of Descartes, the natural philosophers I am look-

1. Threefold distinction among enterprises claiming to produce life: (i) "primeval soup" experiments (Urey, etc.)—doing it God's way; (ii) mechanical, including hydraulic, automata, or "Cartesian" artificial life; (iii) computer simulations of self-reproducing automata (in the sense of automaton theory), which is to say the functional simulation of life, parallel to the functional simulation of the mind in AI.

ing at did not attempt to produce living things from nonliving materials. They studied living things *as if* they were artificial, that is, as machines; but since (after Descartes) the distinction between art and nature no longer sets machines on the side of nature, it might be better to say simply that they studied machines, some of which were already made without human labor.

1. Outline of the Aristotelian background

The "past" for the natural philosophers of Descartes' 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 of the 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 imitate those things that "ought to have pre-existed" and strive to fashion them as nature would have (Toletus 1615-1616, *Phys.* 2c2q6; 4:54v). 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.

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, and so incapable of introducing new forms—forms with the active powers 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 stools 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; 218[118]). The works of alchemy, on the other hand, fare somewhat better. The Coimbrans, after giving a standard list of technological wonders (the compass, the printing press, flat glass…), conclude that it is possible that human art 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 of elements.

2. Cartesianism

The very idea, then, of “artificial life” would have suggested an impossibility. Descartes, as we all know, thought otherwise. The principles upon which his physiology is based should be familiar. What I want to emphasize here is the role of simulation and the machine in the elimination from his natural philosophy of the sensitive and vegetative souls, and thus of animal souls altogether.

The *Traité de l’homme* is an exercise in simulation. The Simulator is God, not us. God has made soulless machines that resemble us in every way possible. Descartes shows that, using only the mechanistic principles put forward in *Le Monde*, he can explain all those functions of the animal that in the Schools were explained by supposing a sensitive and vegetative soul. In fact the *Traité* does not explain generation. That lacuna was filled when Descartes returned to physiology near the end of his life. The *Description du corps humain* includes an account of the formation of the fetus, beginning with the mingled male and female seeds in the womb. That account is likewise

presented as conforming to the principles of Cartesian physics—it mentions nothing but the sizes, shapes, and motions of various corpuscles, and (in principle) derives their movements and configurations in the developing animal from the laws of nature.

Setting aside the wild card Descartes deals himself—the already-existing seed—the *Description*, unlike the *Treatise*, offers not a simulation of the human body and its processes but the thing itself. The pretence of the *Treatise* that the objects described are automata made in imitation of the body is dropped. The body is not like a machine, it *is* a machine.

How then do animal-machines, which are of divine origin, differ from the machines we are capable of building? The only difference is that God is a far better engineer than we are: more knowledgeable, more delicate, no doubt more patient too. But human industry is no longer subordinate to that of nature or to divine industry: it is not limited to imitation, nor is it confined to the reshaping of already-existing natural materials. In principle we could configure matter down to whatever dimensions are required and give it the appropriate motions; the machines we made would *be* animals. The question of building animals is one of feasibility alone.

Descartes was reputed to have built or planned several automata. But details are lacking. I will mention instead one example from the *Dioptrique*—a prosthetic addition to the human eye. Descartes is considering ways to improve vision. One way would be to move the point of convergence of light rays entering the eye as far forward from the retina as possible. To do this, Descartes imagines affixing to the front of the eye a tube of water whose outward end has the same shape as the cornea. “Vision will occur”, Descartes writes, “in the same manner as if Nature had made the eye longer than it is”—as long as the tube, in fact. Moreover the natural pupil of the eye will become “not only useless but even deleterious, insofar as it excludes, by its smallness, rays that could otherwise proceed toward the edges of the back of the eye” (*Dioptrique* 7, AT 6:156–157). If the pupil were excised, we would have a hybrid, a fusion of machine and organ, superseding the eye God gave us, but no less “natural”. To go from this to the construction of an artificial eye might require feats of engineering. But the conceptual barrier has been removed.

3. Interlude: the animal souls debate

[A bit of discussion is needed here to understand why Perrault and Borelli insist on the need for an animal soul to supply *force motrice* to the animal-machine. In Borelli's case, the question would be whether he felt any pressure to give up animal souls.]

4. Borelli and the mechanics of locomotion

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" (a2r). The "idiom and characters" with which the Creator has inscribed his conceptions in the "Codex" of nature consist in "Geometric Configurations and Demonstrations". Because animals are bodies, and their operations either are motions or else have motion as a necessary condition, we can see God's geometry at work in their organs, using our own geometry to describe them and to measure their effects.

The first part of Borelli's work is devoted to locomotion on earth and in water and air. Borelli says that in his inquiry he will suppose certain things that are "shown by the evidence of the senses" (2). The first of these, surprisingly enough, is that the "principal and effective cause of the movement of animals is the soul". This everyone knows, because "once the animal has expired, that is, once the soul no longer is operating, the animal machine is left entirely inert and immobile" (2). The soul, moreover, does not move the body *per se*, but by way of an instrument, namely, the power or faculty of local motion, "which is commonly held to reside in the animal spirits" (2). The animal spirits in turn move the body by acting on the muscles, communicating their active power to them by way of the nerves (3).

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

tions 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.

After showing that the "action of the muscle is contraction" (Tab. 1, fig. 1–4), 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 by his love of truth he will explain. The problem seems to be to explain how the muscle, in contracting, thickens without the addition of new matter (10). Borelli's predecessors had explained this by supposing that the muscle is a rhomboid composed of fibres all running in the same direction (Prop. 5). Borelli argues that this arrangement is quite inept to the task of lifting any weight (12). Given that force is exerted by the fibres through contraction along their long axis, the arrangement in Tab. 1, figs. 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 by 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.

The "true figures" of muscles are seen in Tabula 1, fig. 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 differs 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] (Prop. 8, p18).

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 (322ff).

The animal, or at least its muscular and skeletal structure, is a machine, the effects of which can be calculated on mechanical principles. What mechanics cannot explain is the source of the motive power by which the muscles exert themselves in lifting weights and locomotion. Borelli is here continuing a traditional division of labor (see Gabbey in Voss) 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 in Voss 320). Among other things, mechanics takes weight for granted, and measures or calculates its effects; the explanation of weight belongs to physics.

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, ^{2}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 physiques*, the third volume of which is the *Mécanique des animaux* that 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, he 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' *Discourse* and Mersenne's *Questions.*

Perrault is not a promoter of novelties. Of those which have been 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" (1, "Preface" e ij). 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 equivocal and 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" (3, "Avertissement", A). For Perrault as for Borelli, mechanism in the study of the movements of animals does not preclude supposing them to have souls.

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 his *Essais.* 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:

(i) 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 (74; see Plate 3, fig. 1);

(ii) 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 (75);

(iii) that since both the protagonist and antagonist are in tension, the relaxation of one will lead to bending in the direction of the other (see Plate 3, fig. 2);

(iv) 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 (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. The opponent here is Descartes, whose *Traité de l'homme* argues that the entry of the animal spirits into a muscle shortens it (AT 11:135).

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.

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 that proposed by Descartes himself in the *Dioptrique*. There 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" (3:8, 9).

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, or rather—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 intelligibility". 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.