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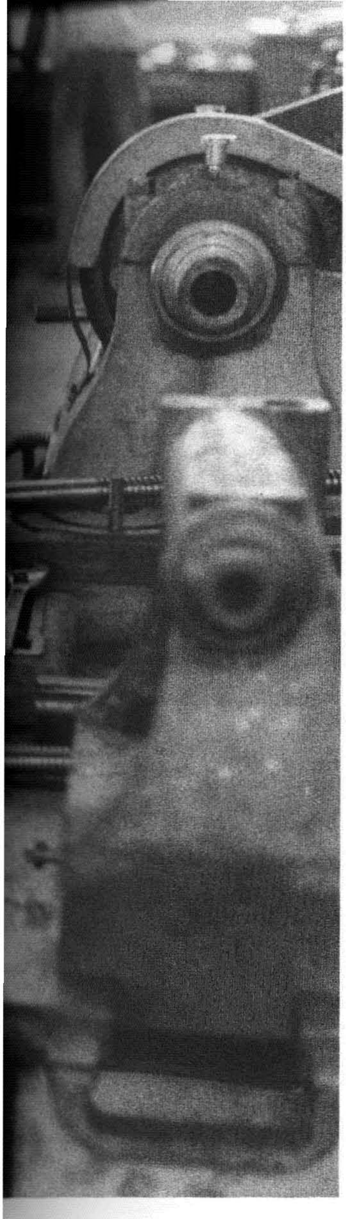

Machine and Organism

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The relationship between machine and organism has generally been studied in only one way. Nearly always, the organism has been explained on the basis of a preconceived idea of the structure and functioning of the machine; but only rarely have the structure and function of the organism been used to make the construction of the machine itself more understandable. Even though mechanistic theory sparked some very impressive technical research, the fact remained that the very notion of an "organology," as well as its basic premises and methodology, remained undeveloped.[1]

Philosophers and mechanistic biologists approached the machine as a set of data, or else made it into a problem that they could solve purely through mental application. To do this, they called on the engineer, who was for them a scientist in the truest sense. Misled by the ambiguities of their view of mechanics, they saw machines only as theorems in concrete form. The operations necessary to construct machines were only secondary considerations when compared with the all-important idea that the machine revealed their theories *in concreto*. To see this, one needed only to acknowledge what science could accomplish, and from there it was simply a matter of the confident application of that knowledge. However, I do not believe that it is possible to treat the biological problem of the "living machine" by separating it from the technological problem it supposedly resolves — namely, the problem of the relationship between technology and science. This problem is normally resolved by starting with the idea that, logically and chronologically, knowledge precedes application. What I want to show is that the construction of machines can indeed be understood by virtue of certain truly biological principles, without having at the same time to examine how technology relates to science.

I shall address the following topics in successive order: what it means to compare an organism to a machine; the relationship between mechanical processes, and the results that might be achieved by using them; and the historical reversal of the traditional relationship between the machine and the organism and the philosophical consequences of this reversal.

For those who have carefully studied living beings and the forms they take, it is rare — and only in the case of the vertebrates — that one notices any truly mechanical attributes, at least in the sense that the term is commonly understood by scientists. In *La Pensée technique*, for example, Julien Pacotte notes that movements of the joints and the eyeball can be paralleled with what mathematicians call a "mechanism."[2] A machine can be defined as a man-made, artificial construction, which essentially functions by virtue of mechanical operations. A mechanism is made of a group of mobile solid parts that work together in such a way that their movement does not threaten the integrity of the unit as a whole. A mechanism therefore consists of movable parts that work together and periodically return to a set relation with respect to each other. It consists of interlinking parts, each of which has a determinable degree of freedom of movement: for example, both a pendulum and a cam valve have one degree of freedom of movement, whereas a threaded screw has two. The fact that these varying degrees of freedom of movement can be quantified means that they can serve as tangible guides for measuring, for setting limits on the amount of movement that can be expected between any two interacting solid objects. In every machine, then, movement is a function, first, of the way the parts interact and, second, of the mechanical operations of the overall unit.[3]

Mechanics is governed by the principle that every movement of a machine is geometric and measurable. What is more, every such movement regulates and transforms the forces and energy imparted to it. Mechanics, though, does not work in the same way that a motor does: in mechanics, movements are simply propagated, not created. A rather simple example of how this transformation of movement takes place can be seen in several devices — a wheel crank or an eccentric crank, for example — that are set into motion by an initial lateral movement but eventually produce reciprocating, rotary movement. Of course, mechanical operations can be combined, either by superimposing them or adding them together. It is even possible to take a basic mechanical device, modify it and make it capable of performing a variety of other mechanical operations. This is exactly what happens when a bicycle freewheel clutch is released or stopped.[4]

What constitutes the rule in human industry is the exception in the structure of organisms and the exception in nature, and I must add here that in the history of technology and the inventions of man *assembled* configurations are not the most primitive. The oldest known tools are made of a single piece. The construction of axes or of arrows made by assembling a flint and a handle, or the construction of nets or fabrics, are so many signs that the primitive stage has been passed.

This brief overview of some elementary principles of kinematics helps to give a fuller sense of the problem without losing sight of a central paradox: Why was it necessary to turn to the theory of mechanism, as outlined above, in order to explain the living organism? The answer can be found, it seems, in the fact that this mechanical model of living organisms does not rely on kinematics alone. A machine, as defined above, is not totally self-sufficient: it must receive and then transform energy imparted to it from an outside source. To be represented in movement it must be associated with an energy source.[5]

For a long time, kinematic mechanisms were powered by humans or animals. During this stage, it was an obvious tautology to compare the movement of bodies to the movement of a machine, when the machine itself depended on humans or animals to run it. Consequently, it has been shown that mechanistic theory has depended, historically, on the assumption that it is possible to construct an automaton, meaning a mechanism that is miraculous in and of itself and does not rely on human or animal muscle power.

This is the general idea put forth in the following well-known text:

> Examine carefully the physical economy of man: What do you find? The jaws are armed with teeth, which are no more than pincers. This stomach is nothing but a retort, or heat chamber; the veins, the arteries and indeed the entire vascular system are simply hydraulic tubes; the heart, a pump; the viscera, nothing but filters and sieves; the lungs, a pair of bellows; and what are muscles if not a system of cables and ropes. What is the oculomotor nerve, if not a pulley? And so on. Try as they will, chemists cannot explain nature and set up a separate philosophy simply by coining a new vocabulary around words like "fusion," "sublimation" and "precipitation"; for this does not at all address either the incontrovertible laws of equilibrium or the laws governing the workings of the wedge, cables, pumps as elements of mechanical theory.

This text is not where we might think to find it, but in fact comes from the *Praxis medica*, written by Baglivi in 1696, an Italian doctor belonging to the iatromechanical school. This school, founded by Borelli, had apparently been influenced by Descartes, although for reasons of national prestige, the Italians prefer to attribute it to Galileo.[6] This text is interesting because it treats the wedge, the rope, the cable and the pump as if they could be seen in the same terms for formulating explanatory principles. It is clear, however, that from the mechanistic point of view there is a difference between these devices: a cable essentially transmits a given movement, whereas a pump transforms a given movement and is also a motor — admittedly, a motor that returns whatever energy it receives; but, at certain intervals, it apparently has a degree of independence of movement. In Baglivi's text, the heart is the *primum movens* — the central pump that serves as the motor for the whole body.

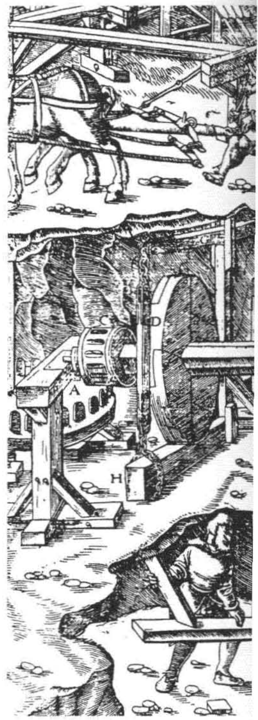
Therefore, a crucial element behind the mechanical explanation of bodily movement is that, in addition to machines that perform as kinematic devices, there are also machines that act as motors, deriving their energy, at the moment it is utilized, from a source other than animal muscle. And this is why, although Baglivi's text seems linked to Descartes, the idea of the body-as-machine actually goes back to Aristotle. When dealing with the Cartesian theory of the animal-machine, it is often difficult to decide whether or not Descartes had any precursors for this idea. Those who look for Descartes's predecessors here usually cite Gomez Pereira, a Spanish doctor of the second half of the sixteenth century: Pereira suggested, before Descartes, that he could demonstrate that animals were wholly machines and that they do not possess that sensitive soul so frequently attributed to them.[7] But in other respects, it is unquestionably Aristotle who saw the congruity between animal movements and automatic mechanical movements, like those observed in instruments of war, especially catapults. This idea is treated rather extensively by Alfred Espinas, who discusses the connection between the problems dealt with by Aristotle in *De Motu animalium* and those in his compilation of *Quaestiones mechanicae*.[8] Aristotle draws a clear parallel between the organs of animal movement and "*organa*," or parts of war machines, like the arm of a catapult about to launch a projectile. Thus catapults, typical automatic machines of the period, seemed to be articulated like a human limb, as they were poised and made to release their great stores of pent-up energy. In the same work, Aristotle carries the analogy even further by comparing the movement of our limbs to mechanisms; and he makes his case in much the same way that Plato did when, in the *Timaeus*, he compared the movement of vertebrates to hinges or pivots.

It is true that in Aristotle the theory of movement is somewhat different from what it would become in Descartes. According to Aristotle, the soul is the principle of all movement. All movement first presupposes immobility and then requires a prime mover or some motivating force. Desire moves the body, and desire is explained by the soul, just as potentiality is explained by an act. Despite their differing explanations of movement, for Aristotle as for Descartes later, the comparison of the body with a machine presupposes that man is composed of automated mechanical parts reliant on an energy source that produces motor effects over time and continue to do so well after the original (human or animal) energy has dissipated. It is this discrepancy between the storage of energy to be released by the mechanism and the moment of release that allows us to forget the relation of dependence between the effects of the mechanism and the actions of a body. When Descartes looks to machines to explain how organisms work, he invokes spring-operated and hydraulic automata. As a result, he owes a great intellectual debt to the ideas behind the technical creations of his own time, including clocks and watches, water mills and church organs of the early seventeenth century. We can say, then, that as long as the concept of the human and animal body is inextricably "tied" to the machine, it is not possible to offer an explanation of the body in terms of the machine. Historically, it was not possible to conceive of such an explanation until the day that human ingenuity created mechanical devices that not only imitated organic movements — as in the launching of a projectile or the back-and-forth movement of a saw — but also required no human intervention except to construct them and set them going.

In two instances, I have asserted that an explanation cannot be formulated without the existence of certain conditions. Is this tantamount to attributing a historical necessity to scientific explanation? How do I explain the abrupt appearance in Descartes of a lucid mechanistic interpretation of biological phenomena? This theory is clearly related to modifications that occurred in the economic and political structure of Western society, but the nature of this relation remains obscure.

This problem has been treated in depth by P.-M. Schuhl, who has shown that in ancient philosophy the opposition of science and technique paralleled the opposition of freedom and servitude and, at a deeper level, of art and nature.[9] Schuhl supports this parallel with Aristotle's assertion that natural and violent movement are opposed — a violent movement occurs when mechanisms are used against nature, and its characteristics are that it exhausts itself rapidly and never becomes habitual — which is to say, a permanent tendency to reproduce itself never obtains.

Here I must turn to the difficult problem of the history of civilization and the philosophy of history. With Aristotle, the hierarchy of freedom and servility, of theory and practice, of nature and art, is paralleled by an economic and political hierarchy in the cities, namely, the relations of freemen and slaves. The slave, according to Aristotle in the *Politics*, is an animated machine.[10] This is the crux of the problem to which Schuhl only alludes in passing: Did the Greek conception of the dignity of science lead to their disdain for technique and the resultant paucity of inventions? And did this in turn lead to the difficulty of applying the results of technical activity to the explanation of nature? Or, rather, did the Greeks' high regard for purely speculative science and detached contemplation explain the absence of technical invention? Did their disregard for work cause slavery, or did the abundance of slaves due to military supremacy explain their low regard for work? Are we obliged to explain the ideology in terms of the socioeconomic structure or, rather, the socioeconomic structure in terms of the ideology? Did the ease of exploiting human beings make it easier to disdain the techniques that would allow them to exploit nature? Does the arduousness of exploiting nature justify the exploitation of man by man? Is there a causal relationship at work here? And if so, in which direction does it go? Or are we dealing with



a global structure having reciprocal relations and influences?

A similar problem is presented by Father Lucien Laberthonnière, who contrasts the physics of an artist or an aesthete to that of an engineer and an artisan.[11] Laberthonnière suggests that the determining factor here is ideas, given that the Cartesian transformation in the philosophy of technique presupposes Christianity. It was necessary to conceive of man as a being who transcends nature and matter in order to then uphold his right and his duty to exploit matter ruthlessly. In other words, man had to be valorized so that nature could be devalorized. Next it was necessary to conceive of men as being radically and originally equal so that, as the exploitation of humans by each other was condemned on political grounds, there were increased technical means to exploit nature and a growing sense of duty to do so. This analysis permits Laberthonnière to speak of a Christian origin for Cartesian physics. However, he qualifies his own claim: the physics and technique supposedly made possible by Christianity came, for Descartes, well after Christianity had been founded as a religion. Moreover, humanist philosophy, which saw man as master and proprietor of nature, was in direct opposition to Christianity as humanists saw it: the religion of salvation, of escape into the hereafter, inspired by a contempt for the things of this life and unconcerned with whatever fruits technology might win for mankind in this world below. Laberthonnière asserts that "time does not enter into the question," but this is by no means certain. In any case, several classic texts have demonstrated that certain technical inventions that transformed the use of animal motor power — for example, the horseshoe and the shoulder harness — accomplished more for the emancipation of slaves than did the countless preachings of abolitionists.

In *Der Übergang vom feudalem zum bürgerlichen Weltbild*, Franz Borkenau argues that there is a causal relationship between mechanistic philosophy and the totality of social and economic conditions in which it arises.[12] He claims that at the start of the seventeenth century the qualitative philosophy of antiquity and the Middle Ages was eclipsed by mechanistic ideas. The success of these new ideas was, on the level of ideology, an effect of the economic fact of the new organization and expansion of manufacturing. For Borkenau, the division of artisanal labor into separate, simplified operations requiring little skill produced the concept of abstract social labor. Once labor had been decomposed into simple, identical and easily repeatable movements, price and wages could be determined simply by comparing the hours worked — and the result was a process that, previously qualitative, had become quantifiable.[13] Calculating work in purely quantitative terms that can be treated mathematically is claimed to be the basis and the starting point for a mechanistic conception of the life world. It is therefore by reducing all value to economic value, "to cold hard cash," as Marx puts it in *The Communist Manifesto*, that the mechanistic view of the universe is supposed to be fundamentally a Weltanschauung of the bourgeoisie. Finally, Borkenau claims that the animal-machine gives rise to the norms of the nascent capitalist economy. Descartes, Galileo and Hobbes are thus the unwitting heralds of this economic revolution.

Borkenau's theses have been analyzed and criticized more forcefully by Henryk Grossmann.[14] According to him, Borkenau ignores five hundred years of economic and ideological history by seeing mechanistic theory as coinciding with the rise of manufacturing at the beginning of the seventeenth century: Borkenau writes as if Leonardo da Vinci had never existed. Referring to Pierre Duhem's *Les Origines de la statique* (1905), and the publication of Leonardo's manuscripts (Herzfeld, 1904; Gabriel Séailles, 1906; Péladan, 1907), Grossmann agrees with Séailles that with the publication of Leonardo's manuscripts it became clear that the origins of modern science could be pushed back by more than a century. The quantification of the notion of work occurs first within mathematics, well before its economic rationalization. The norms of the capitalist evaluation of production, moreover, had been defined by the Italian bankers even in the thirteenth century. Relying on Marx, Grossmann reminds us that although in general there was no division of labor in manufacturing properly speaking, manufacturing at its inception meant the gathering together in the same place of skilled artisans who had previously worked independently. According to Grossmann, then, it is not the calculation of cost per hour of work, but the evolution of mechanization that is the real cause of the mechanical view of the universe. The development of mechanization begins during the Renaissance.[15] It is, therefore, more accurate to say that Descartes had consciously rationalized a mechanistic technique than that he had unconsciously expressed the imperatives of a capitalist economy. For Descartes, mechanics is a *theory of machines* that presupposes a spontaneous invention which science must then consciously promote and develop.

Which machines did the most to modify the relationship between man and nature before the time of Descartes, far beyond the wildest imaginations of the ancients — and did most to justify and rationalize the hopes men had vested in machines? Above all there were firearms, which hardly interested Descartes except in terms of the problem of the projectile.[16] On the other hand, Descartes was very interested in clocks and watches, in lifting machines, in water-driven machines and other related devices. As a result, one should say that Descartes made a human phenomenon — the construction of machines — into an integral part of his philosophy; and one should avoid saying that he transposed the social phenomena of capitalist production into ideology. The key question becomes: How does Cartesianism account for an internal principle of goal-directed activity in mechanisms, as is implied in the comparison of a machine with an organism?

The theory of the animal-machine is inseparable from "I think therefore I am." The radical distinction between the soul and the body, between thought and extension, requires the affirmation that matter, whatever form it adopts, and thought, whatever function it fulfills, are each an undivided substance.[17] Because the only function of the soul is judgment, it is impossible to admit the existence of a soul in animals, since we have no proof that animals judge, incapable as they are of language or invention.[18]

For Descartes, though, the refusal to attribute a soul — that is, reason — to animals, does not necessarily lead to the conclusion that animals are not alive (since not much more than a warm, beating heart is at issue); nor must animals be denied sensibility, to the extent that such sensibility is solely a function of their organs.[19]

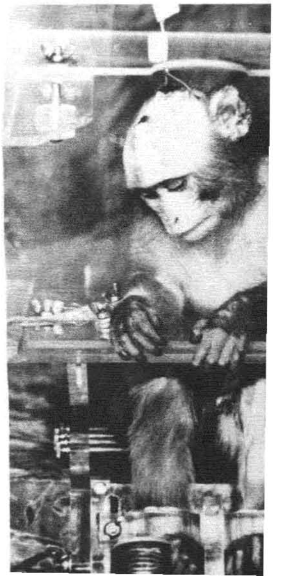
In the same discussion, a moral foundation for the animal-machine theory comes to light. Descartes views the animal as Aristotle had viewed the slave, devalorizing it in order to justify man's using it to serve his own purposes: "My opinion is no more cruel to animals than it is overly pious toward men, freed from the superstitions of the Pythagorians, because it absolves them of the hint of crime whenever they eat or kill animals."[20] And it comes as no small surprise to find the same argument in reverse in a passage of Leibniz: "if we are compelled to view the animal as being more than a machine, we would have to become Pythagorians and renounce our domination of animals."[21] And so we confront an attitude typical of Western thought. On the theoretical level, the mechanization of life only considers animals to the extent that they serve man's technological ends. Man can only make himself the master and proprietor of nature if he denies any natural finality or purpose; and he must consider the whole of nature, including all life forms other than himself, as solely a means to serve his purposes.

This is how the mechanical model of the living organism, including the human body, was legitimized; for already in Descartes the human body, if not man's entire self, is seen as a machine. As I have already noted, Descartes based his mechanical model on automata, that is, on moving machines.[22]

In order to see the full implications of Descartes's theory, I now intend to look at the beginning of his "Treatise on Man," which was published for the first time in Leyden in 1662. He wrote there:

> These men will be composed, as we are, of a soul and a body. First I must describe the body on its own, then the soul, again on its own; and finally I must show how these two natures would have to be joined and united in order to constitute men who resemble us.
>
> I suppose the body to be nothing but a statue or machine made of earth, which God forms with the explicit intention of making it as much as possible like us. Thus God not only gives it externally the colors and shapes of all the parts of our

Animal testing, c. 1970.



> bodies, but also places inside it all the parts required to make it walk, eat, breathe, enabling it to imitate all those functions which seem to proceed from matter and to depend solely on the interacting movements of our organs.
>
> We see clocks, artificial fountains, water mills and other such machines which, although only man-made, seem to move of their own accord in various ways; but I am supposing this machine to be made by the hands of God, and so I think you may reasonably think it capable of a greater variety of movements than I could possibly imagine in it, and of exhibiting more artistry than I could possibly ascribe to it.[23]

Were we to read this text as naively as possible, the theory of the animal-machine would seem to make sense only if we put forward two important and often-neglected postulates. The first is the existence of a God who builds things, and the second that living bodies are given in essence before machines are constructed. In other words, to understand the machine-animal, it is necessary to see it as being preceded, logically and chronologically, by God, who is an efficient cause, and by a preexisting living model after which it is to be modeled or imitated, which is a formal and final cause. With all this in mind, I propose to take the animal-machine theory, which is usually seen as a departure from the Aristotelian concept of causality, and show how all of Aristotle's types of causality are nonetheless found in it, but not always in the same place or simultaneously.

If we read the text more closely, we see that in order to construct the living machine[24] it is necessary to imitate a preexisting living model. The construction of a mechanical model presupposes a living original (Descartes is perhaps closer here to Plato than to Aristotle). The platonic Demiurge copies the ideas, and the Idea is the model of which the natural object is a copy. The Cartesian God, the *Artifex maximus*, works to produce something equivalent to the living body itself. The model for the living machine is that body itself. Divine art imitates the Idea — but the Idea is the living body. What is more, in the same way that a regular polygon is inscribed in a circle, and that one must pass an infinite distance to deduce one from the other, there is something of the machine in every aspect of life; but to pass from one to the other would require crossing over an infinite gap, one that only God can close. This is the idea brought out at the end of the text: "but I am supposing this machine to be made by the hands of God, and so I think you may reasonably think it capable of a greater variety of movements than I could possibly imagine in it, and of exhibiting more artistry than I could possibly ascribe to it." The theory of the animal-machine would, therefore, have the same relation to life that a set of axioms has to geometry, that is, nothing more than a rational reconstruction. Thus, the theory operates by deception: it pretends to ignore the concrete existence of what it must represent, and it denies that what it actually produces comes only after it has been rationally legitimized.

This aspect of Cartesian theory, moreover, was accurately assessed by a contemporary anatomist, the noted Nicolaus Steno, in the *Dissertation on the Anatomy of the Brain* delivered in Paris in 1665, a year after the "Treatise on Man" had appeared. While paying homage to Descartes (which was remarkable, since anatomists had not always been very accepting of Cartesian anatomy), he notes that Descartes's man was man reconstituted by Descartes with God as a foil, but that this was not man as the anatomist understands him. One can therefore say that by substituting the body for the machine, Descartes removed teleology from life, but in appearance only, because he has concentrated it in its entirety at the point at which life begins. A dynamic structure is replaced by an anatomical one; but since this form is produced by technique, all possible sense of teleology has been confined to the technique of production. In fact, it appears that mechanical theory and purposiveness cannot be placed in opposition, nor can mechanism and anthropomorphism. If the functioning of a machine can be explained by relations of pure causality, the construction of a machine cannot be understood without taking two things into consideration: a specific goal-directed activity and man himself. A machine is made by man and for man, to achieve specific ends, to produce a given series of effects.[25]

The positive element, then, in Descartes's attempt to explain life mechanically is that he eliminates the need to tie mechanism to finality in its anthropomorphic aspect. However, it seems that in doing this, one anthropomorphism has been substituted for another. A technological anthropomorphism has been substituted for a political anthropomorphism.

In "Description of the Human Body and All of Its Functions," a short treatise written in 1648, Descartes addresses the question of voluntary movement in man: he offers, in terms so lucid that they were to dominate the entire theory of reflex and automatic movements up until the nineteenth century, the explanation that the body obeys the soul only on condition that the body is primed mechanically to do so. For the soul to decide to move is not a sufficient condition to induce the body to move. "The soul," writes Descartes "cannot produce any movement without the appropriate disposition of the bodily organs which are required for making the movement. On the contrary, when all the bodily organs are appropriately disposed for some movement, the body has no need of the soul in order to produce that movement."[26] Descartes means that when the soul moves the body it does not act like a king or a general commanding his subjects or his troops as is popularly conceived. Rather, by viewing the body as a clock mechanism he envisions each organ driving the other like interlocking cogwheels. So Descartes substitutes for the image of the political chain of command — where commands are passed by signals or spoken orders, through a type of magical causality — the technological image of "control," in which a desired series of operations is activated by a controlling device or coordinated by a series of mechanical linkups.

Descartes takes the exact opposite position of Claude Bernard who, in his critique of vitalism, in *Leçons sur les phénomènes de la vie communs aux animaux et aux végétaux*, refuses to admit that a vital force could have a separate existence because it "cannot do anything" — but he does admit, surprisingly, that it can "direct phenomena that it does not produce."[27] In other words, Bernard replaces the notion of a vital-force-as-worker with the idea of vital-force-as-legislator or guide. This is a way of admitting that one can direct events without taking action — which borders on a kind of magical concept of direction, implying that the overall operation transcends the execution of individual operations. On the contrary, according to Descartes, a mechanical operation replaces the power of direction and command, but God has fixed the direction once and for all: the constructor includes the guide-controls within the mechanical process itself.

In short, with the Cartesian explanation, it might appear that we have not moved beyond the idea of finality or inner purposiveness. The reason for this is that if we limit ourselves to the workings of the machine, everything can be explained by the theory of mechanism; but the theory cannot account for the construction of the machine itself. Machines do not construct other machines, and it could even be said that, in a sense, explaining organs or organisms through mechanical models amounts to explaining the organ by means of itself. At bottom, then, we are dealing with a tautology; for it can be shown — and I shall indeed try to justify this view — that *machines can be considered as organs of the human species*.[28] A tool or a machine is an organ, and organs are tools or machines. And so it is hard to see how mechanism can be distinguished from purposiveness. No one doubts that a mechanism is needed to ensure that a given operation is carried out successfully; and, conversely, every mechanism must follow a precisely determined sequence toward performing some particular task, since a mechanism cannot depend on randomness or chance. Therefore, the opposition would be between those mechanisms whose purpose is manifest and those whose purpose remains latent. In the case of a lock or a watch, their function is apparent, while the pincers of the crab, often considered a marvel of adaptation, have a latent purpose. As a result, it seems impossible to deny that certain biological mechanisms serve a set purpose. Let us consider an oft-cited example, which mechanistic biologists use to argue their case; namely, that of the woman's pelvis, which enlarges just before she gives birth. To deny that this enlargement might not in someway be the fulfillment of a fundamental, purposive activity, we need only view the question in another way: given that the largest-sized fetus exceeds the maximum size of the pelvis by 1 or 1.5 cm, it would be impossible to give birth were it not for a loosening of the symphyses and a gradual rocking movement toward the sacrococcygien bone which increases the diameter ever so slightly beyond its maximum. It is understandable that one would not want to believe that an act with such a specific biological purpose is allowed to occur only by virtue of a mechanism with no real biological function. And "allow" is indeed the word that applies here, since without this mechanism the act simply could not take place. It is well known that, when dealing with an unknown mechanism, we have to make certain that it is in fact a mechanism — that is, we have to know what ultimate purpose or function it is intended to serve. We can come to no conclusions about how it is to be used, simply on the basis of its form or its structure, unless we already know how the machine or similar machines are used. As a result, it is necessary first to see the machine at work before attempting to deduce the function from the structure.

We are now at the point where we can see the historical reversal of the Cartesian relationship between the machine and the organism. It is a well-known fact — and so need not be belabored — that in all organisms we observe the phenomena of autoconstruction, automaintenance, autoregulation and autorepair. In the case of the machine, its construction is beyond its power and depends on the skill of the mechanic. Its maintenance requires the constant attention and watchfulness of the machinist; for we all know how the complex workings of a machine can be irremediably damaged due to inattention and carelessness. As for maintenance and repair, they demand the same periodic intervention of human action. While there are machines that are self-regulating, these are in fact machines that man has grafted onto another machine. The construction of servomechanisms or electronic automata merely displaces the question of the man–machine relationship without changing it in any fundamental way.

Further, in the case of the machine there is a strict adherence to rational, economical rules. The whole is rigorously the sum of its parts. The final effect depends on the ordering of the causes. What is more, a machine functions within narrowly defined limits, and these limits become all the more rigid with the practice of standardization. Standardization leads to the simplification of basic models and spare parts, and to unified standards of measurement and quality, which allows for the interchangeability of parts. Any individual part can be exchanged for any other part meant for the same place — within, of course, a margin of tolerance determined by manufacturing constraints.

Now that the properties of a machine have been defined in relation to those of an organism, can one say that there is more or less purposiveness in a machine than in an organism?

One would surely agree that there is more purposiveness in machines than in organisms, since a machine seems to move uniformly, unidirectionally toward completing a particular activity. A machine cannot replace another machine. The more specific the end-result desired, the more the margin of tolerance is reduced, and the more the machine's directiveness seems concentrated, focused on a particular end. It is well known that functions in the organism are substitutable, organs are polyvalent. Although this substitutability of functions and polyvalence of organs is not absolute, in comparison with the same qualities in the machine, it is so considerable that any comparison is quite obviously absurd.[29] As an example of the substitutability of functions, I can give a very simple and well-known case, that of aphasia in children. A hemiplegia on the right side of the child's brain is almost never accompanied by aphasia, because the other areas of the brain ensure the continuance of the linguistic functions. In the case of the child who is less than nine months old, any existing aphasia disappears very quickly.[30] As for the problem of the polyvalent organs, I need simply note the fact that for a majority of organs, which we have traditionally believed to serve some definite function, the truth is that we have no idea what other functions they might indeed fulfill. This is the reason that the stomach is said to be, in principle at least, an organ of digestion. However, it is a fact that after a gastrectomy performed to treat an ulcer, there are fewer problems with digestion than with those we observe with hematopoiesis. It was finally discovered that the stomach behaves like an internal secretive gland. And I might also cite yet another example — and not at all to be taken as some sort of miracle — which came to light during a recent experiment performed by the biologist Courrier, at the Collège de France. Courrier made an incision in the uterus of a pregnant rabbit, extracted a placenta from the uterus and placed it in the peritoneal cavity. This placenta grafted itself onto the intestine and fed itself normally. When the graft was performed, the rabbit's ovaries were ablated — meaning that the function fulfilled by the corpus luteum during pregnancy was suppressed. At that moment, all the placentas present in the uterus were aborted and only the placenta situated in the peritoneal cavity came to term. Here is an example of the intestine behaving like a uterus, and perhaps, one might even say, more successfully.

In this case, then, it is tempting to reverse one of Aristotle's formulations in his *Politics*: "For nature is not stingy, like the smith who fashions the Delphian knife for many uses; she makes each thing for a single use, and every instrument is best made when intended for one and not for many uses."[31] On the contrary, it seems that this definition of finality or purposiveness would be more applicable to a machine than to an organism. One must be willing to acknowledge, ultimately, that in an organism, a given organ can accommodate a diversity of functions. Clearly, an organism has a greater range of activity than a machine. It is less bound by purposiveness and more open to potentialities.[32] Every aspect and every movement of the machine is calculated; and the working of the machine confirms how each calculation holds up to certain norms, measures or estimates; whereas the living body functions according to experience. Life is experience, meaning improvisation, acting as circumstances permit; life is tentative in every respect. Hence the overwhelming but often misunderstood fact that life permits monstrosities. There are no monstrous machines. There is no mechanical pathology, as Xavier Bichat noted in 1801 in his *General Anatomy, Applied to Physiology and Medicine*.[33] Whereas monsters are still living things, there is no way to distinguish between the normal and the pathological in physics and mechanics. Only among living beings is there a distinction between the normal and the pathological.

Above all, it is work in experimental embryology that has led to the abandoning of such mechanistic representations when interpreting living phenomena, *primarily by demonstrating that once the embryo starts to develop, it* does not contain any kind of "specific mechanism" intended to produce automatically one organ or another. There can be no doubt that this was Descartes's conception as well. In his "Description of the Human Body," he wrote: "If we had a good knowledge of what makes up the semen of some species of animal in particular, for example man, then we would be able to deduce from this alone, using certain and mathematical reasoning, the complete shape and conformation of each of its members, and likewise, reciprocally, if we knew many particularities about this conformation, it would be possible to deduce from that what the semen is."[34] However, as Paul Guillaume remarks, it seems that the more we compare living beings to automatic machines, the more we seem to understand their functions but the less we understand their genesis.[35] If the Cartesian conception were accurate, that is, if the living organism were both preformed in the embryo and developed mechanistically, any modification made in the earliest stages would tend to disrupt the development of the egg or prevent development altogether.

However, this is hardly the case. According to a study in potential egg development, based on research by Driesch, Hörstadius, Speman and Mangold, it was shown that embryonic development cannot be reduced to a mechanical model without running into anomalies. Let us take the example of the experiments conducted by Hörstadius on the egg of a sea urchin. He cut an egg A from a sea urchin at stage sixteen so that each part of the egg maintained a horizontal symmetry, and then he cut egg B, with each part being vertically symmetrical. He joined half of A with half of B and the egg developed normally. Driesch took the sea urchin egg at stage sixteen and pressed the egg between two thin layers of cells, while modifying the reciprocal position of the cells at the two poles; still, the egg developed normally. The results of these two studies allow us to conclude that the same effect is achieved regardless of how conditions are varied.

There is an even more striking experiment, in which Driesch took blastomeres from the sea urchin egg at stage two. By removing the blastomeres, either mechanically or chemically in sea water lacking calcium salts, the result was that each of the blastomeres gave birth to a larva which was perfectly normal down to the smallest detail. Here, then, the result is the same regardless of how the characteristics of a factor are changed. The quantitative change in a given factor does not lead to a qualitative change in the result. Conversely, when two sea urchin eggs are joined they result in a single larva that is larger than normal. This is yet another confirmation that the result is unaffected by the quantitative change in one of the factors. Whether the factors are multiplied or divided, the experiment yields the same results.

I should add that the development of all eggs cannot be reduced to this schema. For quite some time there was a problem in knowing whether there were two different kinds of eggs at issue: regulated eggs, like the eggs of sea urchins, and mosaic eggs, like those of frogs, whose first blastomeres develop in exactly the same way, whether they are dissociated or remain together. Most biologists have recently come around to admitting that what distinguishes the two phenomena is simply that determination occurs earlier in the so-called mosaic eggs. On the one hand, the regulated egg starts to act like a mosaic egg at a certain stage; on the other hand, at stage two the blastomere of the frog egg yields a complete embryo, as does a regulated egg, if it is reversed.[36]

Thus, it is illusory to deny the idea of purposiveness in organisms and to attribute it to automatic functions, however complex we might imagine these to be. As long as a machine cannot construct itself, and as long as an organism is not equal to the sum of its parts, it might seem legitimate to think that biological organization is the basis and the necessary condition for the existence and purpose of a machine. From the philosophical point of view, it is less important to explain the operation of a machine than to understand it. And to understand it means to inscribe it in human history by inscribing human history in life — not overlooking the fact that with the advent of man there appeared a culture that was no longer entirely reducible to natural causes. And so we arrive at the point where the machine is seen as a *fact of culture,* expressed in mechanisms that are themselves nothing more than *an explainable fact of nature.* In a celebrated text in "Principles of Philosophy," Descartes writes, "It is certain that all the rules of mechanics belong to physics, *to the extent that all artificial things are thereby natural.* Since, for example, when a watch counts the hours, by using the cogs from which it is made, this is no less natural for it than it is for a tree to produce fruit."[37] But, from our point of view, we can and must reverse the relationship of the watch to the tree and say that the cogs and generally all the components that make up a watch are designed to produce a desired effect: all the parts of the mechanism are products of imagination, each piece fulfilling some final purpose or design that at one time was only imagined or dreamed of; they are thus the direct or indirect products of a technical activity that is as authentically organic as the flowering of trees. And, on a more fundamental level, the process works with great efficiency even though there is no more conscious observance of the rules and laws of physics than there might be within vegetal life. Although the construction of a machine might presuppose at some stage the understanding of the logics of physics, it should not and cannot be forgotten that, as a matter of chronology and biology, construction of machines took place well before there was any understanding of physics.

However, another author has asserted, contrary to Descartes, that living organisms cannot be reduced to a machine and, similarly, art cannot be reduced to science. The author in question is Kant, in his *Critique of Judgment*. While it is true that the French have not tended to look to Kant as a philosopher of technique, it is no less true that German authors greatly interested in this question, especially after 1870, *have* done so.

In the "Critique of Teleological Judgment," Kant distinguishes between the machine and the organism, while drawing on Descartes's favorite example of the watch. In a machine, he states, each part exists for the other but not because of the other: no part produces another part; no one part is produced by the entire unit; nor does one part produce another part of similar kind. There is no watch that makes other watches. No part can replace itself. And no machine can replace one of its own missing parts. And so, while a machine possesses motor power, it has no transformational energy that might propagate itself or be transmitted to an object outside the machine itself. Kant draws a distinction between human skill and technology, which are marked by intentionality, as opposed to involuntary life processes. But in an important passage of the "Critique of Aesthetic Judgment," Kant defines the originality of human skill as it relates to knowledge:

> Art, regarded as human skill, differs from science (as ability differs from knowledge) in the same way that a practical aptitude differs from a theoretical faculty, as technique differs from theory. What one is capable of doing, as soon as we merely know what ought to be done and therefore are sufficiently cognizant of the desired effect, is not called art. Only that which a man, even if he knows it completely, may not therefore have the skill to accomplish belongs to art. Camper describes very exactly how the best shoes must be made, but he certainly could not make one.[38]

This text is cited by Paul Krannhals in *Der Weltsinn der Technik*, and, following Kant, he acknowledges that all technique is essentially primordial, meaning that it cannot be reduced to a simple question of rationality.[39] Indeed, we tend to see the skilled hand that adjusts a machine or the mind that carefully orchestrates a production process as examples of "ingenuity," having their basis in instinct; but these are in fact as difficult to explain as the production of mammalian eggs outside the ovary, even in the event that the physiochemical composition of protoplasm and of sexual hormones had been made entirely clear to us.

This is why the work of anthropologists (and not engineers) seems to shed more light, however faint, on the question of the construction of machines.[40] Currently in France, ethnologists have come closest to creating a philosophy of technique in which the philosophers themselves seem to have lost interest, their main concern having been chiefly the philosophy of science. On the contrary, the ethnographers have generally focused their attention on the relationship between the production of the earliest tools, the first instruments that were used to act upon and modify nature, and the ways these tools were assembled or grouped together. The only philosopher in France I know to have posed these questions is Alfred Espinas, in his classic text on *Les Origines de la technologie*.[41] This work includes an appendix, the outline for a course taught at the Faculté des Lettres at Bordeaux around 1890, which dealt with the will, and in which Espinas addressed, under the guise of will, the question of practical human behavior and especially the invention of tools. By borrowing the theory of organic extension from the German writer Ernst Kapp, Espinas was able to explain the construction of the first tools. Kapp first made his theories known in 1877.[42] According to the theory of extension, whose philosophical bases go back to Hartmann's *The Philosophy of the Unconscious* and further back still to Schopenhauer, the earliest tools were simply extensions of moving human organs. The flint, the club and the lever extend and magnify the organic movement of the arm and its ability to strike. This theory, like all theories, has its limits and runs into certain stumbling blocks, especially when it is used to explain fundamental inventions, such as fire and the wheel. In these cases, we would search in vain for the body movements and the organs that fire and the wheel are supposed to prolong or extend; but the explanation certainly works for instruments like the hammer or the lever and all such related tools. In France, then, it was the ethnographers who sought out and compiled not only the facts but also the hypotheses from which a biological philosophy of technique could be constituted. The philosophical path was laid out by the Germans[43] — for example, the theory of the development of inventions based on the Darwinian notion of variation and natural selection, as advanced by Alard Du Bois-Reymond in his *Erfindung und Erfinder* (1906), or again, by Oswald Spengler in *Der Mensch und die Technik*, which presented the theory that machines are constructed as a "life tactic"[44] — and is taken up again, independently it seems, by André Leroi-Gourhan in his book *Milieu et techniques*. Leroi-Gourhan attempts to explain the phenomenon of the construction of tools by comparing it to the movement of the amoeba, which extends substances out beyond its mass so that it might seize and capture an object it wishes to digest:

> If we are drawn to view the act of percussion as the fundamental technical activity, it is because we witness an act of touch or contact in almost every technological process; but even though the amoeba's expansion always leads its prey through the same digestive process, there is no one way of explaining the working of that process — whether we view the material being digested or whether we approach the question from any given view of technology — since our view must change according to the circumstances, just as the digestive process itself might be like the various specialized grasping or striking organs.[45]

In the last chapters of this work one finds a theory of machine that is altogether different from the traditional theories that, for lack of a better term, I shall classify as Cartesian — where technical invention amounted to the application of a given system of knowledge.

Traditionally, the locomotive is presented as a classic example of a "marvel of science." However, the construction of the steam engine is only understandable when placed in light of theoretical knowledge that preceded it, as the culmination of an age-old problem, and a specifically technological one at that — how to pump water out of mines. And so it would be necessary to understand the natural history of the development of the pump, and to know about the fire pump (which at first did not rely at all on vapor but produced a vacuum via condensation under the pistons, thereby allowing the atmospheric pressure acting as a motor to lower the piston) in order to see that the essential "organ" in a locomotive is a cylinder and a piston.[46]

Tracing a similar progression of ideas, Leroi-Gourhan goes even further, pointing back to the wheel as one of the locomotive's ancestors, in the biological sense of the word. "It is machines like the wheel," he states, "that gave rise to steam engines and modern-day motors. All of the highest technological achievements of the most inventive minds of our time can be grouped around the circular movements of the crank, the pedal, the drive belt."[47] He then goes on to add: "The way inventions influenced each other has not been studied sufficiently and we don't seem to take note of the fact that, without the wheel, we would not have the locomotive."[48] Further on:

> At the beginning of the nineteenth century no one had yet recognized how to make use of the elemental forms that would later give birth to the locomotive, the automobile and the airplane. The underlying principles of mechanics were spread throughout twenty applications which had been known for many centuries. It is here we find the principle that explains invention, but the defining characteristic is that it in someway manifests itself spontaneously.[49]

In light of these remarks, we see how science and technique must be considered as two separate areas; that is, they do not graft onto each other but, rather, each takes from the other either its solutions or its problems. It is the rationalizing and ordering imposed by technology that makes us forget that machines have their origin in the irrational. In this area as in all others, it is necessary to know how to accommodate the irrational, even when — and especially when — we want to defend rationalism.[50]

It must be added that the reversal of the relationship between the machine and the organism, brought about by a systematic understanding of technical inventions as if they were extensions of human behavior or life processes, is in someway confirmed by the belief that the generalized use of machines has slowly imposed contemporary industrialized society on man. George Friedmann has shown very clearly the steps by which "body" gradually became a first-order term in the human machine-body equation.[51] With Frederick Taylor and the first technicians to make scientific studies of work-task movements, the human body was measured as if it functioned like a machine. If we see their aim as the elimination of all unnecessary movement and their view of output as being expressed only in terms of a certain number of mathematically determined factors, then rationalization was, for all intents and purposes, a mechanization of the body. But the realization that technologically superfluous movements were biologically necessary movements was the first stumbling block to be encountered by those who insisted on viewing the problem of human-body-as-machine in exclusively technological terms. From here on, the systematic examination of certain physiological, psychotechnological and even some psychological conditions (since a consideration of values leads inevitably to questions at the very center of the origin of human personality) finally culminated in a reversal, called an inevitable revolution by Friedmann, in which technology would adapt machines to the human body. As Friedmann saw it, this industrial technology appeared to take the form of a scientific rediscovery of the same entirely empirical procedures through which primitive peoples had always sought to have their tools meet the highest organic norms: that is, their tools had to carry out a given action effectively while maintaining a biological economy; and this occurred at the optimum level, when it most closely approximated the movement of the body at work, as when the body defends itself spontaneously from becoming exclusively subordinate to the mechanical.[52] In this way, Friedmann could speak, without irony or paradox, of the legitimacy of considering the industrial development of the West from an ethnographic point of view.[53]

In summary, by considering technology as a universal biological phenomenon[54] and no longer simply as an intellectual operation to be carried out by man, I am led to the following conclusions: on the one hand, the creative autonomy of the arts and skilled crafts in relation to all forms of knowledge that are capable of annexing them or expanding on them; and, on the other hand, to inscribe the mechanical into the organic. It is no longer then, a question of determining the extent to which an organism can be thought of as a machine, whether by virtue of its structure or of its functions. But it is necessary to find the reasons that gave rise to the opposite view, the Cartesian one. I have attempted to shed light on this problem, suggesting that the mechanistic conception of the body was no less anthropomorphic, despite appearances, than a teleological conception of the physical world. The answer I am tempted to offer would insist on showing that technology allows man to live in continuity with life, as opposed to a solution that would see humankind as living in a state of rupture for which we ourselves are responsible because of science. There is no doubt that this answer appears to lend credence to the list of accusations that all too many writers have offered up nostalgically from time to time, with no apparent regard to their lack of originality, as they point out the faults of technology and progress. I have no intention of rushing to support their cause. It is clear that if human society has embraced the idea of a technology based on a mechanistic model, the implications are enormous, and the whole question cannot easily be treated lightly or recalled on demand. But that model is *altogether different* from the one just examined.

Notes

1. After having been dogmatically accepted by biologists for many years, the mechanistic theory of the organism is now considered narrow and inadequate by those scientists who call themselves dialectical materialists. But the fact that they still concern themselves with formulating a philosophical position could easily support the rather widespread idea that philosophy does not possess its own domain, that it is a poor relation of speculation, and must clothe itself in the hand-me-downs scientists have used and then discarded. It will be my aim to show that the problem of machine and organism is much broader in scope and more philosophically important than is commonly thought; and that it is far more than a theoretical and methodological dispute among biologists.

2. Julien Pacotte, *La Pensée technique* (Paris: Alcan, 1931).

3. One example of the fundamental principles of a general theory of mechanisms understood in this way can be found in Franz Reuleaux's *Theoretische Kinematik: Grundzüge einer Theorie des Maschinwesen* (Braunschweig: Vieweg, 1875).

4. For everything concerning machines and mechanisms, see Pacotte, *La Pensée technique*, ch. 3.

5. According to Marx, a tool is moved by human power while the machine is moved by a natural force; see his *Capital*, trans. Samuel Moore and Edward Aveling (New York: International Publishers, 1967), vol. 1, pp. 374–79.

6. For more on this, see Charles Victor Daremberg, *Histoire des sciences médicales* (Paris: Baillière, 1870), vol. 2, p. 879.

7. Gomez Pereira, *Antoniana Margarita: Opus physicis, medicis ac theologis non minus utile quam necessarium* (Medina del Campo, 1555–58).

8. Alfred Espinas, "L'Organisation ou la machine vivante en Grèce au IVe siècle avant J.-C.," *Revue de métaphysique et de morale* (1903), pp. 702–15.

9. P.-M. Schuhl, *Machinisme et philosophie* (Paris: Alcan, 1938).

10. *Aristotle's Politics*, trans. Hippocrates G. Apostle and Lloyd P. Gerson (Grinnel, Iowa: Peripatetic Press, 1986), bk. 1, ch. 2, secs. 4–7.

11. Lucien Laberthonnière, *Les Etudes sur Descartes* (Paris: Vrin, 1935), especially the appendix to volume 2: "La Physique de Descartes et la physique d'Aristote."

12. Franz Borkenau, *Der Übergang vom feudalem zum bürgerlichen Weltbild* (Paris: Alcan, 1934).

13. Jean de la Fontaine's fable, "The Cobbler and the Businessman" (in *La Fontaine: Selected Fables*, trans. Jamie Michie [New York: Viking, 1979], pp. 188–91) is an excellent illustration of the two different conceptions of work and its remuneration.

14. Henryk Grossmann, "Die gesellschaftlichen Grundlagen der mechanistischen Philosophie und die Manufaktur," *Zeitschrift für Sozialforschung*, 4th ser., vol. 2 (1935), pp. 161–231.

15. "Mechanization" here means the generalized use of machines to replace human labor. However, it was also used to describe Descartes's theory of animals as machines before the nineteenth century when the above usage was in force — TRANS.

16. In Descartes's "Principles of Philosophy" (4.187 [AT 8A.314], *Descartes: Selected Philosophical Writings*, trans. John Cottingham, Robert Stoothoff and Dugald Murdoch [New York: Cambridge University Press, 1988], pp. 199–200), there are a few passages that reveal Descartes to be equally interested in gunpowder, but he did not look for an analogous explanatory principle for the animal organism in the explosion of gunpowder as a source of energy. It was an English doctor, Thomas Willis, who explicitly formulated a theory of muscular movement based on the analogy with what occurs when the powder explodes in a harquebus. In the seventeenth century, Willis compared the nerves to powder lines in a manner that remains valid today in some quarters — most notably, W. M. Bayliss comes to mind. Nerves are a sort of Bickford cord. They produce a spark that will set off, in the muscle, an explosion that, in Willis's view, is the only thing capable of accounting for the phenomena of spasm and prolonged contraction observed by the doctor.

17. "For there is within us but one soul, and this soul has within it no diversity of parts: it is at once sensitive and rational too, and all its appetites are volitions" ("The Passions of the Soul" 47, in *Selected Philosophical Writings*, p. 236).

18. "Discourse on Method" 5 (AT 6.56ff.), in ibid., p. 44ff. Letter to the Marquis of Newcastle, Nov. 23, 1646.

19. Letter to Morus, Feb. 21, 1649, in Descartes, *Correspondance*, ed. Charles Adam and Gérard Milhaud (Paris: P.U.F., 1963), vol. 8, pp. 121–39. In order to understand

adequately the relationship of sensibility to the arrangement of the organs, we must be familiar with the Cartesian theory of the degrees of sense; on this subject, see Descartes, "Author's Replies to the Sixth Objections" 9 (AT 7.436–39), in *The Philosophical Writings of Descartes*, trans. John Cottingham, Robert Stoothoff and Dugald Murdoch (Cambridge, Eng.: Cambridge University Press, 1984), vol. 2, pp. 294–96.

20. Descartes, Letter to Morus, Feb. 21, 1649, in *Correspondance*, vol. 8, p. 138.

21. Letter to Conring, March 19, 1678, in *Gottfried Wilhelm Leibniz: Sämtliche Schriften und Briefe* (Darmstadt: Reichl, 1926), 2d ser., vol. 1, pp. 397–401. Leibniz's outline of criteria in particular, which would allow us to distinguish an animal from an automaton, should be compared to the analogous arguments adduced by Descartes, and also the profound reflections of Edgar Allan Poe on the same subject in his "Maelzel's Chessplayer." On the Leibnizian distinction between the machine and the organism, see "A New System of the Nature and the Communication of Substances" 10, in *Leibniz: Philosophical Papers and Letters*, trans. and ed. Leroy Loemker (Chicago: University of Chicago Press, 1956), vol. 2; and "Monadology" 63–66, in *Monadology and Other Philosophical Essays*, trans. Paul Schrecker and Anne Martin Schrecker (New York: Macmillan, 1985).

22. It is important to point out that Leibniz was no less interested than Descartes in the invention and construction of machines, as well as in the problem of automatons. See especially his correspondence with Duke John of Hanover (1676–1679) in the *Sämtliche Schriften und Briefe* (Darmstadt: Reichl, 1927), 1st ser., vol. 2. In a text of 1671, *Bedenken von Aufrichtung einer Academie oder Societät in Deutschland zu Aufnehmen der Kunste und Wissenschaften*, Leibniz exalts the superiority of German art, which has always strived to produce works that move (watches, clocks, hydraulic machines, and so on), over Italian art, which has always attached itself exclusively to the fabrication of lifeless objects made to be contemplated from without (ibid. [Darmstadt: Reichl, 1931], 4th ser., vol. 1, p. 544). This passage is cited by Jacques Maritain in his *Art and Scholasticism and the Frontiers of Poetry*, trans. Joseph W. Evans (New York: Scribners, 1962), p. 156.

23. "Treatise on Man" (AT XI. 119–20), in *The Philosophical Writings of Descartes*, trans. John Cottingham, Robert Stoothoff and Dugald Murdoch (Cambridge, Eng.: Cambridge University Press, 1985), vol. 1, p. 99.

24. This phrase is a traditional equivalent of "the human body," especially in the eighteenth century — TRANS.

25. Moreover, Descartes can only express the meaning of God's construction of animal-machines in terms of finality: "considering the machine of the human body as having been formed by God in order to have in itself all the movements usually manifested there" ("Sixth Meditation," in *Philosophical Works of Descartes* [1913], trans. Elizabeth S. Haldane and G. R. T. Ross [New York: Cambridge University Press, 1967], vol. 1, p. 83). [Here the wording of the older translation is more literal than is the translation of Cottingham et al., *Philosophical Writings of Descartes*, vol. 2, pp. 50–62 — TRANS.]

26. "Description of the Human Body and All of Its Functions" 1 (AT II. 225), in *Philosophical Writings of Descartes*, vol. 1, p. 315.

27. Claude Bernard, *Leçons sur les phénomènes de la vie communes aux animaux et aux végétaux: 1878–1879* (Paris: Masson, 1936).

28. For more on this idea, see Raymond Ruyer, *Eléments de psycho-biologie* (Paris: P.U.F., 1946), pp. 46–47.

29. "Artificial means what is aimed at a definite goal. And is opposed therefore to *living*. Artificial or human or anthropomorphic are distinguished from whatever is only living or vital. Anything that succeeds in appearing in the form of a clear and finite goal becomes artificial and this is what tends to happen as consciousness grows. It is also true of man's work when it is intended to imitate an object or a spontaneous phenomenon as closely as possible. Thought that is conscious of itself makes itself into an artificial system.... If life had a goal, it would no longer be life" (Paul Valéry, *Cahier B* [Paris: Gallimard, 1910]).

30. See Ed. Pichon, *Le Développement psychique de l'enfant et de l'adolescent* (Paris: Masson, 1936), p. 126; and Paul Cossa, *Physiopathologie du système nerveux* (Paris: Masson, 1936), p. 845.

31. *Politics*, bk. 1, ch. 1 (1252b), in *The Basic Works of Aristotle*, ed. Richard McKeon (New York: Random House, 1941), p. 1128.

32. Max Scheler, in his *Man's Place in Nature* [1928] (trans. Hans Meyerhoff [Boston: Beacon, 1961], pp. 75–81), has remarked that it is those living things that are the least specialized that are the most difficult to explain by the mechanistic idea, *pace* the mechanists, because in their case all functions are carried out by the whole organism. It is only with the growing differentiation of functions and the increased complexity of the nervous system that structures which resemble a *machine in some fashion tend to appear.*

33. *General Anatomy, Applied to Physiology and Medicine*, trans. George Hayward (Boston: Richardson and Lord, 1822).

34. "Description du corps humain" 1 (AT II. 225), in Charles Adam and Paul Tannery, eds., *Ouevres de Descartes* (Paris: Vrin, 1974), vol. 11, p. 225. [This pasage is omitted from the English translation of "Description of the Human Body and of All of Its Functions" — TRANS.]

35. Paul Guillaume, *La Psychologie de la forme* (Paris: Flammarion, 1937), p. 131.

36. Pierre Grassé and Max Aron, *Précis de biologie animale* (2d ed., Paris: Flammarion, 1947), p. 647ff.

37. 4.203, in *Philosophical Writings of Descartes*, p. 288. See also my study "Descartes et la technique," *Travaux du Congrès International de Philosophie*, vol. 2: Etudes cartesiennes (Paris: Hermann, 1937), p. 77ff.

38. "An organized being is not a mere machine, for that has merely moving *power*, but it possesses in itself formative power of a self-propagating kind which it communicates to its materials though they have it not of themselves; it organizes them, in fact, and this cannot be explained by the mere mechanical faculty of motion" (*Critique of Judgment*, trans. J. H. Bernard [New York: Hafner, 1951], p. 22).

39. Krannhals, *Der Weltsin der Technik* (Munich and Berlin: Oldenbourg, 1932), p. 68.

40. The starting point for these works must be sought in Darwin, *The Descent of Man* — whose ideas Marx saw clearly as immensely significant.

41. Alfred Espinas, *Les Origines de la technologie* (Paris: Alcan, 1897).

42. Ernst Kapp, *Grundlinien einer Philosophie der Technik* (Braunschweig: Westermann, 1877). This work, which was a classic in Germany, has remained so misunderstood in France that certain psychologists who took up the problem of how animals utilize tools, and animal intelligence, and who took the research of Köhler and Guillaume as their starting point, attributed this theory of projection to Espinas himself, without noting that Espinas states explicitly, at numerous junctures, that he borrowed it from Kapp. I am alluding here to the excellent little book by Gaston Viaud, *L'Intelligence: Son evolution et ses formes* (Paris: P.U.F., 1946).

43. See Eberhard Zschimmer's *Deutsche Philosophen der Technik* (Stuttgart: Enke, 1937).

44. Alard Du Bois-Reymond, *Erfindung und Erfinder* (Berlin: Springer, 1906); and Oswald Spengler, *Der Mensch und die Technik* (Munich: Beck, 1931). Alain outlined a Darwinian interpretation of technical constructions in a fine remark (*Les Propos d'Alain* [Paris: N.R.F., 1920], vol. 1, p. 60), preceded and followed by some others that are most pertinent to our problem. The same idea is referred to many times in the *Système des Beaux-Arts*, concerning the making of the violin (4.5), furniture (6.5), houses in the countryside (6.3, 6.8).

45. André Leroi-Gourhan, *Evolution et technique*, vol. 2: *Milieu et techniques* (Paris: Michel, 1945).

46. The double-acting engine, in which the steam acted on the upper and lower sides of the piston alternately, was perfected by Watt in 1784. Sadi Carnot's *Réflexions sur la puissance motrice du feu* dates from 1824, and we know that it was ignored until the middle of the nineteenth century. On this subject, see Pierre Ducasse, *Histoires des techniques* (Paris: P.U.F., 1945), which stresses that technique precedes theory.

On the subject of the empirical succession of the various organs and uses of the steam engine, consult Arthur Vierendeel's *Esquisse d'une histoire de la technique* (Brussels and Paris: Vromant, 1921), which summarizes Thurston's extensive work, *History of the Steam Engine*. For more about the history of Watt's work as an engineer read the chapter entitled "James Watt ou Ariel ingénieur," in Pierre Devaux's *Les Aventures de la science* (Paris: Gallimard, 1943).

47. Leroi-Gourhan, *Milieu et techniques*, p. 100. The same view can be found in an article by A. Hadricourt on "Les Moteurs animés en agriculture" (*Revue de botanique appliquée et d'agriculture tropicale* 20 [1940], p. 762): "We must not forget that we owe our inanimate motors to irrigation: the noria is at the origin of the hydraulic mill, just as the pump is at the origin of the steam engine." This excellent study sets out the principles for explaining tools from the perspective of their relationship to organic commodities and the traditional ways they were used.

48. Leroi-Gourhan, *Milieu et techniques*, p. 104.

49. Ibid., p. 406.

50. In his *The Two Sources of Morality and Religion* (trans. R. Ashley Andra and Cloudesley Brereton [New York: Holt, 1949]), Henri Bergson thinks very explicitly that the spirit of mechanical invention, although it is fed by science, remains distinct from it and can even, if necessary, be separated from it (pp. 329–30). The fact is that Bergson is also one of the rare French philosophers, if not the only one, who has considered mechanical invention as a biological function, an aspect of the organization of matter by life: *Creative Evolution* (trans. Arthur Mitchell [New York: Modern Library, 1944) is, in some sense, a treatise of general organology.

On the subject of the relationship between explanation and action see also Paul Valéry, "L'Homme et la coquille" and "Discours aux chirurgiens," in *Variété V* (Paris: Gallimard, 1945), and his description of boat building in *Eupalinos*.

And, finally, read the admirable "In Praise of Hands" in Henri Focillon, *The Life of Forms in Art* (New York: Zone Books, 1989), pp. 157–84.

51. George Friedmann, *Problèmes humains du machinisme industrielle* (Paris: Gallimard, 1946).

52. Ibid., p. 96, note.

53. Ibid., p. 369.

54. This attitude is one that has begun to be familiar among biologists. In particular, see L. Cuénot, *Invention et finalité en biologie* (Paris: Flammarion, 1941); and Andrée Tétry, *Les Outils chez les êtres vivants* (Paris: Gallimard, 1948) — especially the latter's reflections on "Adaptation and Invention" (p. 120ff.). It is impossible to mistake the impetus given to these treatments by the ideas of Teilhard de Chardin.

A new discipline, Bionics, which emerged around ten years ago in the United States, studies biological structures and systems able to be utilized as models or analogues by technology, notably by builders of systems for detection, direction and equilibration meant for equipping planes or missiles. Bionics is the extremely subtle art of information that has taken a leaf from natural life. The frog, with its eye capable of selecting information that is instantly usable, the rattlesnake, with its thermoceptor which traces the blood of its prey at night, the common fly, balancing itself in flight by means of two vibratile filaments, have all furnished models for this new breed of engineers. In many American universities, special training in Bioengineering is available, for which the Massachusetts Institute of Technology seems to have been the instigator. See the article by J. Dufrenoy, "Systèmes biologiques servant de modèles à la technologie," *Cahiers des ingénieurs agronomes* (June–July, 1962), p. 21.

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