Leibniz, Organic Matter and Astrobiology

Richard T.W. Arthur*

1 Introduction

In this chapter I discuss some of the leading ideas in Leibniz's philosophy of biology with an eye to their relevance to modern astrobiology. Leibniz's views make for an interesting contrast with the modern synthesis in biology, since although he posited the encoding of genetic information in each individual as a programme for its structure and development, his biological philosophy

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R.T.W. Arthur (✉)
Department of Philosophy, McMaster University, Ontario, Canada
e-mail: rarthur@mcmaster.ca

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was developmental rather than evolutionary. But he had interesting and still topical views on (among other things) the compatibility of teleological explanation with mechanism, on what constitutes a living organism, on what a biological individual is, and on organic matter being more fundamental than inorganic. In what follows we will see that many of his insights and distinctions have been rediscovered by contemporary biologists working in the modern synthesis of evolution, natural selection, mutation, molecular biology and speciation, anatomy, physiology and homeostasis, developmental biology and reproduction, ecology and geochemistry.

2 Other Worlds

In the relatively new science of astrobiology there are several deep questions that inevitably confront researchers. In looking for the possibility of life on other planets, one needs to know what the conditions for life are, and in order to determine this, one needs to know as much as possible about how many planets there are, how life arose on our own planet, and, indeed, what differentiates living from non-living matter.[1] On these matters, as I hope to show, Gottfried Leibniz offered some interesting reflections which, despite the gulf that separates his philosophy from the modern evolutionary perspective, are of surprising contemporary relevance and profundity.

To begin, it will be worth setting the cosmological context. Leibniz developed his views on the matters we will be discussing in the late 1670s and early 1680s, after the end of his four-year sojourn in Paris. There he had made himself acquainted with the views of leading physicists such as Giovanni Borelli (1608–79), Ignace-Gaston Pardies (1636–73), Claude Perrault (1613–88), and especially Christiaan Huygens (1629–95), the leading astrophysicist of the time, who acted as a mentor to the young German in mathematics and physics. Here is a part of Leibniz's summary of what he took to be established in cosmology, written in 1685—two years before the publication of Newton's *Principia Mathematica Philosophiae Naturalis*:

[1] In his final essay, *What Makes Biology Unique?*, Ernst Mayr expresses profound scepticism about the principles on which SETI (the search for intelligent life) is based, and stresses the probable ubiquity of non-intelligent life in the cosmos.

> Stars either shine by themselves, in which case they are called *Suns*, or they are illuminated, in which case they may be called *Earths*.
>
> Stars are also either fixed or free. And the fixed stars do indeed stay in one place, or at least they have not till now changed place sufficiently for this to be observable; the free ones either complete periodic orbits, in which case they are called *Planets*, or they follow trajectories in the mundane space according to an as yet unknown law and along lines that are practically straight, in which case we call them *Comets*.[2]
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> Indeed, up till now it has been observed that the fixed stars are suns, whereas the planets are earths which move around their own sun, so that a fixed star with its planets is said to compose a *great orb*. It is also believed that there are perhaps as many great orbs or planetary systems as there are fixed stars. Meanwhile there is nothing to prevent there being both wandering suns and fixed earths …[3]
>
> Whether in fact the planets came from suns or fixed stars that had been gradually enveloped with crust, or whether, conversely, suns came out of planets that had burst into flames, and whether these things are subject to any change, or whether they all turned into their present form immediately at the beginning or a very short time afterwards, we do not presume to say solely on the basis of reason. However, it seems to me to be acknowledged by many arguments that the whole surface of our earthly globe was once in flames.[4]

But what about these other earths? Did Leibniz imagine the other worlds or earths contained in our universe to be necessarily inferior to ours? Did he imagine them as unable to sustain life? Far from it. For even our own planet, according to Leibniz, is teeming with previously unimagined life-forms on all scales. This is what he wrote to his friend and champion, the Swiss mathematician and teacher of Euler, Johann Bernoulli (1667–1748), in a letter of 18 November 1698:

> Furthermore, I am not joking, but freely profess, that there are animals in the world as much larger than ours as ours are larger than the animalcules

[2] A VI 4, 1508/LC 289.
[3] A VI 4, 1509/LC 289.
[4] A VI 4, 1513/LC 295.

> of the microscopists, for nature knows no bound. And again, there could be—indeed must be—worlds in the smallest motes of dust, even in tiny atoms, that are not inferior to ours in beauty or variety; and (what could be considered even more amazing) nothing prevents animals from being transported to such worlds by dying, for I think that death is nothing but the contraction of an animal, just as generation is nothing but its unfolding.[5]

These remarks take us right into the heart of Leibniz's views about "life, the universe and everything". Note the comment about the animalcules observed with the microscope. Such observations had already influenced him as a young man through his reading of Robert Hooke (1635–1703), Marcello Malpighi (1628–94) and Athanasius Kircher (1602–80), and by 1670 he had extrapolated these micro-worlds to infinity in his *Hypothesis Physica Nova* [New physical hypothesis] (published 1671):

> For it should be recognized, as those celebrated Micrographers Kircher and Hooke have observed, that most of the qualities that we can sense in larger things the keen-eyed observer will detect in proportion in smaller things. And if this proceeds to infinity—which is certainly possible, since the continuum is divisible to infinity—any atom will be of infinite species, like a kind of world, and there will be worlds within worlds to infinity.[6]

What Leibniz observed first-hand through the microscopes of his contemporaries seemed only to confirm this vision in his mind. For when he visited Holland in December 1676 he made certain to visit not only Baruch Spinoza in The Hague, but also Antoni van Leeuwenhoek (1632–1723)—now feted as the "father of microbiology"—in Delft, and Jan Swammerdam (1637–80), another celebrated microscopist, in Amsterdam. We find a reference to Leeuwenhoek's famous discoveries of

[5] GM 3, 553. In his reply of 6 December 1698, Bernoulli says he is "not surprised that you agree with me when I conjecture that there are animals in the world as much bigger than ours as ours are bigger than the animalcules of the microscopists. For to you the whole universe is a congeries of animals." But Bernoulli thinks those animals would be "animals in the usual sense, having bodies and members similar to ours, or something analogous instead; and that among those animals there would also be intelligent ones or ones using reason, i.e. people" (GM 3, 557). To this Leibniz replies on 17 December: "I too would readily admit that there are animals in the usual sense incomparably greater than ours; and I once said as a joke, that there could be some system similar to ours that would be the pocket watch of a huge giant" (GM 3, 560).

[6] A VI 2, 241/LC 338.

micro-organisms in pepper water in Leibniz's letter to Antoine Arnauld (1612–94) of 30 April 1687:

> We find that there is a prodigious number of animals in a drop of pepper water … If these animals have souls, we will have to say of their souls what we can probably say of the animals themselves, namely that they have been alive since the creation of the world …[7]

Arnauld was deeply sceptical of such claims about the indestructibility of animals and their souls, scoffing: "If fire took hold of one of those houses where they keep a hundred thousand silkworms, what would become of those hundred thousand indestructible souls?"[8] But Leibniz was unperturbed. He had his reasons for believing that there are everywhere in matter principles analogous to souls in certain respects, whose material casings simply transform rather than vanish.[9] "You suppose that there remains no organized body in the ashes," he replied, "whereas I suppose instead that naturally there is no soul without an animated body, and no animated body without organs; and neither ashes nor other masses seem to me incapable of containing organized bodies".[10]

In this response he appeals to the necessity for matter to consist in organized bodies, and as I have said he had strong theoretical arguments for this. But we should not underestimate his attention to available empirical evidence that supported this thesis.[11] His familiarity with Swammerdam's work had convinced him that the body of a silkworm could be sloughed off in a drastic transformation of its material form, with an apparently different creature unfolding from within a small part of that body: "the silkworm and the butterfly are the same animal … the parts of the butterfly are already enveloped

[7] GP II, 99/WFT 125–6.

[8] GP II, 87-8/WFT 121.

[9] Among Leibniz's reasons for considering there to be such indestructible principles in bodies everywhere was his conviction that a purely material body would be incapable of acting or of being the same thing through time; and in the case of humans, a commitment to the Lutheran interpretation of the soul as remaining in a state of sleep until resurrection. See Arthur, *Leibniz*, 60–76.

[10] GP II, 124/WFT 134.

[11] See Smith, *Divine Machines*, especially 151 ff., for an account of Leibniz's knowledge of contemporary empirical evidence for micro-organisms.

in the caterpillar".[12] As for the indestructibility that Arnauld made fun of, we do not know everything that Leibniz might have learned from the observations of Leeuwenhoek (with whom he was to have a friendly correspondence decades later). It is not inconceivable, for example, that he might have gleaned some knowledge of waterbears (tardigrades), since these together with nematodes and rotifers constitute the "animalcules" Leeuwenhoek studied.[13] These tiny creatures (about the size of a poppy seed) are commonly found in ponds and in tree bark, and can survive the kind of fire that Arnauld thought would destroy all such animalcules.[14]

Leibniz was also familiar with Francisco Redi's experiments refuting spontaneous generation, published in 1668. This would have served to confirm him in his belief that living things can only be engendered by other living beings. Like Gassendi, Leibniz believed that animate or organic matter could only be generated from matter that was already itself organized or preformed, not from inanimate matter lacking any soul or principle of organization. One can see him articulating this belief, as well as its connection with the kind of transformation shown him by Swammerdam, in the following quotation from unpublished manuscripts dating from the early 1680s:

> If we imagine some animal similar to a butterfly that is made out of a worm, and prior to that was of such a kind that the worm, in turn, was made from something else that till then was very small, and thus again back to the beginning of the world, or … pushed back into some nonsensible animalcule, … with the soul likewise remaining in all of them, there will be not mere Metempsychosis in this soul, but in fact transformation, and indeed it will always be not just the soul that remains, but the corporeal substance itself.[15]

[12] Smith, *Divine Machines*, 189.

[13] Kinchin, *Biology of Tardigrades*, 2.

[14] Tardigrades were first described in detail by Johann Goeze in 1773. They have been shown recently to be able to survive fire, drought, freezing, intense pressure and near vacuum, and even irradiation by cosmic rays in outer space! If Leibniz knew anything of such creatures' durability, it would help explain his insouciance in the face of Arnauld's scorn.

[15] Smith, *Divine Machines*, 188.

3 Mechanism vs. Vitalism

By 1678 Leibniz had already begun to write about the necessity of matter's containing principles or forms analogous to souls in order to account for the composition of matter from unities in the face of the paradoxes of the continuum.[16] In numerous manuscripts from the period between his arrival in Hanover in 1677 and his letters to Arnauld a decade later, he expressed this in terms of matter's being fundamentally *organic*. Inorganic matter simply consists in agglomerations of organic units, perhaps even machines that are mechanical systems of parts, but whose unity is provided by their being perceived as one or perceived as moving as a system: a unity that is ephemeral, but not substantial. The organic units, on the other hand, are bodies each containing a substantial form: the form is a substantial and enduring unity, even while the matter constituting its envelope undergoes continual change; and the form together with this continually transforming matter constitutes a corporeal substance or living thing.

Leibniz often compared his own view with the views of atomists like Gassendi and the Neo-Cartesian atomist Gerauld Cordemoy, who also sought to account for the perdurance of matter in terms of enduring and indestructible substantial units underlying the various combinations and changes of texture, shape and so forth. Atomists had thus followed the Aristotelians in adopting a distinction between *per se* unities (their atoms) and accidental ones (agglomerations of atoms), but had no account of how atoms could remain self-identical or cohesive. Leibniz insisted that a substantial form (under his new interpretation) was necessary in order to supply this self-identity through material change. Thus in his criticisms of Cordemoy in 1685, Leibniz opposed his own view: "All organic bodies are animate, and all bodies are either organic or collections of organic bodies."[17] He amplified on this in another fragment from the same year: "Bodies that lack a substantial form are merely aggregates, like a woodpile or a heap of stones, and consequently do not possess cognition or appetite."[18]

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[16] See *Arthur*, *Leibniz*, for a detailed account of the origination of Leibniz's philosophy in relation to his scientific interests.

[17] A VI 4, 1798/LC 277.

[18] A VI 4, 1508/LC 287.

By "cognition" Leibniz did not mean conscious knowledge, which would only be available to creatures with the requisite organs, while self-consciousness would only be found in beings with minds, capable of reflection ("acting on themselves"). Rather, by this he meant a *perception* or state encompassing a kind of relation to all other things in the universe, a conception that owed much to his youthful enthusiasm for the philosophy of Bisterfeld. In the *Monadology* of 1714 perception is defined as "a representation of external things in a certain individual thing", and *appetition* as "an internal principle which brings about the passage from one perception to another" in accordance with a law internal to the substance.[19]

Now Leibniz's idea that all substances in the universe have perception and appetition is often labelled *panpsychism*. In a sense it is: according to him all substances do contain cognition of all others, although this is a kind of tacit knowledge, a confused cognition. They contain this information in the sense that it could be read off from their representation of it, although their own use of this information will normally be drastically limited by their own resources, according to how it is utilized in their own actions as agents. In fact, Leibniz's conception of *representation* or *expression* is very general, not specifically psychic:

> One thing is said to *express* another when the relationships that hold in it correspond to the relationships of the thing to be expressed. But there are various types of expression: for example, a model of a machine expresses the machine itself, a projective delineation of a thing onto a plane expresses a solid, speech expresses thoughts and truths, characters express numbers, and an algebraic equation expresses a circle or some other figure. What they all have in common is that solely from a consideration of the relationships of the expression we can arrive at a knowledge of the corresponding properties of the thing to be expressed. Hence it is clear that it is not necessary for that which expresses to be similar to the thing expressed, so long as a certain analogy is preserved between the relationships.[20]

[19] GP VI, 600/PPL 644.

[20] A VI 4, 1370/PPL 207.

Thus as Leibniz tells Arnauld in October 1687, “expression is common to all forms. It is a genus of which natural perception, animal feeling and intellectual knowledge are species”.[21] Still, Leibniz insists that perception is not reducible to mere mechanism. It is one thing for information to be represented or encoded in a perception; it is another for it to be acted upon, and that requires something to do the interpreting. In the *Monadology* of 1714 he famously argues for the impossibility of an explanation of perception solely in terms of shapes and motions:

> Imagine a machine which by its structure produced thought, feeling, and perception. We can imagine it as being enlarged while retaining the same relative proportions to the point where we could go inside it, as we would go into a mill. But if that were so, we would find nothing but pieces pushing against one another, and never anything to account for a perception.[22]

He concludes that perception cannot be found in a composite body like a machine. In order to account for it, he believes, we must posit some entities in things that are doing the interpreting of their representations, in such a way that they are moved to perform certain actions. These are the unities in things that he calls *monads*, which he models on the human soul, conceived as immaterial. This is no more an idealism, however, than is Aristotle’s philosophy, to which Leibniz owes a profound and explicitly acknowledged debt. For monads are always embodied, the organic body being a “machine of nature”. A monad with its body is a living organism: “each monad, with its particular body, makes a living substance”.[23] There is, of course, a huge element of Aristotelianism in this conception. Moreover, the monad is often described by Leibniz as an *entelechy*, which for Aristotle was a kind of vital principle responsible for actualizing a substance’s actions, actions that would be directed towards certain ends.[24]

[21] GP II, 112/PPL 339.

[22] GP VI, 609/PPL 644.

[23] GP VI, 599/PPL 637.

[24] For a lyrical and highly readable account of Aristotle’s science of life, I recommend Leroi, *The Lagoon*.

This is perhaps reminiscent of the vitalism of Hans Driesch (1867–1941), who proposed Aristotelian entelechies as a corrective to a purely mechanical view of nature. Similarly Henri Bergson (1859–1941) was an outspoken opponent of mechanism, arguing for an *élan vital* as permeating the universe. But Leibniz was not an opponent of the mechanical philosophy. In fact, he was perhaps one of its most forceful advocates. He adopted it with enthusiasm in his youthful *Hypothesis physica nova*, and this was still his position even as he recognized the need for substantial forms. In his correspondence with Herman Conring (1606–81) in 1678, he responded to the latter's scorn for mechanism with one of the most eloquent declarations of the mechanist creed ever made:

> I recognize nothing in the world but bodies and minds, and nothing in mind but intellect and will, nor anything else in bodies insofar as they are separated from mind but magnitude, figure, situation, and changes in these, whether partial or total. Everything else is merely said, not understood.[25]

This was written in precisely the year in which Leibniz committed himself to the thesis that there is some perception and appetition in all living beings. But despite his commitment to that thesis from this time onwards, Leibniz consistently opposes the idea of a vital force as a causal agent, as in this passage from the *New Essays* of 1704:

> I attribute to mechanism everything that happens in the bodies of plants and animals, except for their initial formation. Thus I agree that the movements of what are called 'sensitive' plants result from mechanism, and I do not approve of recourse to the soul when it is a matter of explaining the details of the phenomena of plants and animals.[26]

In fact, he explicitly rejects the vitalism of his contemporaries Ralph Cudworth (1617–88), and Georg Stahl (1659–1734), who insisted that some kind of "plastic" or "vital force" was necessary in addition to matter, a force governing the growth and development of organisms—analogous

[25] GP I, 197-8/PPL 189.

[26] A VI 6, 139/NE 139.

to what Henri Bergson and Hans Driesch proposed in the twentieth century. He agrees with Cudworth that "matter arranged by divine wisdom must be essentially organized throughout", but for him this means that "there are machines in the parts of a natural machine to infinity, so many envelopes and organic bodies enveloped one within another, that one can never produce any organic body entirely anew and without any preformation".[27] He therefore dismisses Cudworth's "immaterial plastic natures" with the comment: "*Non mi bisogna*, *e non mi basta* [I do not need them, nor are they enough for me], for the very reason that this infinitely complex organism provides me with material plastic natures sufficient for the need."[28] Against Georg Stahl, dubbed "the father of phlogiston theory", Leibniz insists that organism is really a mechanism, although "a more exquisite one".[29] This is entirely analogous to Ernst Mayr's rejection of the vitalism of Hans Driesch and Henri Bergson.

4 Organic Bodies

How then does Leibniz account for the difference between organic and inorganic matter? In a fragment from 1680–2 published by Enrico Pasini, he writes:

> The human body, like the body of each and every animal, is a sort of machine. Every machine, however, is best defined in terms of its final cause, so that in the explanation of its parts it is therefore apparent how each of them is coordinated for its intended use.[30]

The best way to describe a clock, for example, is as "a machine made to indicate equal divisions of time, so it is necessary for the clock-hand to undergo uniform motion for some period of time".[31] Such an artificial machine cannot move itself, however, or sustain itself in existence: it requires an

[27] GP VI, 544/PPL 589.
[28] Ibid.
[29] Stahl, *Negotium otiosum*, 6–7.
[30] Smith, *Divine Machines*, 290.
[31] Ibid.

external agent to set it in motion, and once it has used up its stored energy, it stops. The body of an animal is a "superior kind of machine" in that it has organs for nutrition and excretion which enable it to nourish itself, importing through its interaction with its environment the energy[32] necessary to sustain itself. Also, it has reproductive organs: "since it is not able easily to conserve the individual, at least it conserves the species of the machine and of its mechanical motion as much as possible", he writes, and "contrives a way in which machines of this kind are able to produce other machines similar to themselves".[33] Thus a *living body* is a machine sustaining itself and producing ones similar to itself. Leibniz writes:

> The *bodies of animals* are *machines of perpetual motion*, or, to put it more clearly, they are machines comparable to a certain fixed and singular species of perpetual organic motion that is always maintained in the world. Thus for as long as there are spiders there will be weaving machines, for as long as there are bees there will be honey-producing machines, and for as long as there are squirrels there will be leaping machines.[34]

"And so, through nature's end, we have at once the origin of three *functions*: namely, *vital*, *animal* and *genital*."[35] Thus organic bodies are self-moving and self-sustaining machines, able to replicate other machines of the same kind.

This anticipates the *autopoesis* of Maturana and Varela,[36] and Stuart Kauffman's idea of organisms as emergent systems that can "act on their

[32] I should stress that the use of the term "energy" is not anachronistic here. One of Leibniz's greatest contributions was his identification of it as a central concept in physics and biology, with the correct measure, as well as proposing its universal conservation as a basic law of physics. See Arthur, *Leibniz*, for details.

[33] Smith, *Divine Machines*, 292.

[34] Ibid., 290–1.

[35] Ibid., 292.

[36] "Autopoiesis" is the term introduced in 1972 by Chilean biologists Humberto Maturana and Francisco Varela to define the self-maintaining chemistry of living cells. In a later work they write: "An autopoietic machine is a machine organized (defined as a unity) as a network of processes of production (transformation and destruction) of components which: (i) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and (ii) constitute it (the machine) as a concrete unity in space in which they (the components) exist by specifying the topological domain of its realization as such a network." Maturana and Varela, *Autopoiesis and Cognition*, 78.

own behalf".[37] But for Leibniz, replication applies to *kinds* of bodies: individual organisms radically *transform*, but they do not have an origin except with the origin of the world. As Leibniz writes in his *New System* of 1695:

> It must be recognized that the machines of nature have an infinity of organs, and are so well apportioned and resistant to all accidents that it is impossible to destroy them. A natural machine remains a machine in its least parts, and what is more, it remains the same machine that it always was, being merely transformed by the different folds it receives, now extended, now contracted, and as it were concentrated when we think it has been destroyed.[38]

Thus we can make an artificial machine like a clock, building it up out of inorganic bodies like its metal cogs, pendulum and hands; but these parts are not themselves machines contributing to its function by their own self-directed actions, as is the case with an organic body. To make an organic body we would have to be able to make machines within machines to infinity, with all their actions coordinating to produce the actions of that body. For Leibniz what makes a natural machine "the same machine in its least parts" is its possession of a substantial form or monad. It does not have to have the same parts from one instant to another, so long as the parts it does have contribute to its own functions and end. For this it needs to be the source of its own actions, and also to have a law or "programme" for the development and unfolding of these actions.

For Leibniz, the substantial form of an individual substance incorporates the whole series of its states, and each of these reflects (however confusedly) everything that is occurring in the universe simultaneously with it. The law governing this series of the substance's states corresponds, in his view, to the fact that the complete concept of an individual substance contains all the information necessary for the development of that individual. The germ of this idea was worked out by Leibniz in his MA

[37] See Kauffman, *At Home in The Universe*, for a readable account of his ideas about life beginning with the evolution of collectively autocatalytic systems.

[38] GP IV, 482/PPL 456.

thesis which he completed before he was 20, which contained a theory of permutations and combinations that showed how an amazing variety of different complex concepts can be produced combinatorially from only a small set of primitive ones. The complete concept of an individual living being, known in its infinite complexity only to God, corresponds to the law of that substance's containing all the information necessary for its development and functioning, through all the changes its body undergoes.[39]

The analogy of this view with modern genetics should be obvious, where the information necessary for a living being's development is contained in the genetic code. A nucleotide consists of a base of one of A, T, G or C (the four chemicals: adenine, thymine, guanine, and cytosine) plus a molecule of sugar and one of phosphoric acid, and a codon is a triple (a "con3ation" in Leibniz's playful nomenclature) of these DNA or RNA nucleotides, yielding 64 distinct codons, each corresponding to a specific amino acid or stop signal during protein synthesis. The resulting proteins are those necessary for life, as well as (under suitable conditions) for the development and functions of the organism. Of course, there are some salient and obvious disanalogies. Leibniz was not an evolutionist. He believed that in order to account for divine predetermination, the states of each substance would have to be predetermined in all their detail in the law of the substance, which consequently would have to incorporate an infinitely ramified sequence of states during any time, and that each state, in order to represent all things occurring simultaneously with it in the whole universe, would also have to contain infinite information.

Leibniz's characterization of organic bodies is also of interest in connection with a deeper issue in modern biology concerning what constitutes a biological individual. Geneticists treat the individual organism as simply the means by which the genes influence the probability of their replication. But genes are not agents: it is the chemistry of an organism's body that draws energy from the environment required for doing the work of reproducing.[40] This raises the further question: if biological individuals

[39] For an account of these aspects of Leibniz's thought see Arthur, *Leibniz*, chaps. 2 and 5.

[40] Cf. Terence Deacon: "For Dawkins, the organism is the medium through which genes influence their probability of being replicated. But as many critics have pointed out, this inverts the location of agency and dynamics. Genes are passively involved in the process while the chemistry of organi[c] bodies does the work of acquiring resources and reproducing." Deacon, *Incomplete Nature*, 132. See

are simply organisms, how does one characterize an organism? As Frédéric Bouchard notes, there are particular difficulties when one looks at cases involving symbiosis: how do you construe individuality when there are many unrelated organisms that nevertheless live as one entity?[41]

Consider the case of the parasitic crustacean *Cymothoa exigua*. The female *Cymothoa* works its way through the gills into a fish's mouth, then eats the fish's tongue and replaces it with itself! The parasite continues to function as the animal's tongue, conferring certain adaptive benefits for the fish which I will not go into here. Another example of an organism one of whose essential organic functions is carried out by another would in fact be *us*: an individual human being has a flora of gut bacteria necessary for our digestion that are not coded for in our DNA. Thus one of the basic functions of our organic body is carried out by unrelated organisms, each bacterium with its own DNA. And concerning DNA, as Addy Pross has noted, "the cellular mass that we characterize as an individual human being (you, me, or the girl next door) actually consists of significantly more bacterial cells than human cells (~10^{14} compared to ~10^{13}) … all working together in a symbiotic relationship to establish a dynamic kinetically stable system".[42]

These examples would not constitute difficulties for Leibniz's account of organic bodies, but would rather be the norm. On his view, organisms are individuated by their own substantial form, but their bodies contain the bodies of other organisms in any of their parts. Each of these organisms is animated by its own form, governing the actions and development of its organic body in turn. These are the subordinate forms; although each is the substantial form of the organic body to which it belongs, its actions will be necessary to the functioning of the larger organic body of which they are part, the body possessing the dominant form. But it will only be necessary to the functioning of the dominant organism for a time, as that body is undergoing continuous change, with parts of its biomass being added and parts discarded. As we have seen, one of the

Chap. 8 ("Selection") in Mayr, *What Makes Biology Unique?*, for a good overview of this topic, as well as the references for the criticisms of Dawkins (by Mayr himself, Wimsatt, Sober and Lewontin) that Deacon alludes to here.

[41] Bouchard, "What Is a Symbiotic Superindividual", 248.

[42] Pross, "Toward a general theory of evolution", 12.

paradigms on which Leibniz based his view is the transformation of a caterpillar into a butterfly. The organic body of the organism is, for a time, the caterpillar body. After the apparent death of the caterpillar, this body is mostly discarded, and there emerges from the biomass a different organism, which Swammerdam had shown could be seen folded up in the body before this development. Leibniz thought that the same thing happens on the death of any organism: on its death the apparent body of the substance contracts to a smaller biomass—possibly, and perhaps usually, a microscopically small mass, from which another macroscopic creature might not emerge for a very long time. As we saw him writing to Bernoulli, "nothing prevents animals from being transported to such worlds by dying, for I think that death is nothing but the contraction of an animal, just as generation is nothing but its unfolding".[43]

Thus cases of symbiosis like *Cymothoa exigua* present no difficulty in principle for Leibniz. All that is necessary is that the states coded for in the form of the parasite, whose sequence performs the functions necessary for the parasite's survival, are compatible throughout with the sequence of states of the fish, and the functions for which this sequence codes. Although Leibniz regarded such codes—the individual "laws" governing the series of states of each substance—as coeval with the created universe, it is clear that the functions they code for at different stages of the animal's existence will correspond to different organs, as those of a tadpole differ from those of a frog. Analogously in modern genetics, the same DNA sequence codes for very different bodily forms and transformations between them depending on when these sequences are activated. In cases of symbiosis, or even more exotic cases, such as the whole system of a colony of termites and the mound they build from fungi that acts as a lung for the colony as a whole, the genetic information is so modified during evolution that essential functions are performed by other creatures.[44] It does not particularly matter what is regarded as a true individual so long as these systems, together with their environments (that is, the whole ecosystems), are preserved by

[43] GM 3, 553.

[44] Cf. Deacon: "And even those [parts of organisms] that biologists believe to have originated independently, like the mitochondria of eukaryotic cells, are no longer fully separable cell components. … much of the genetic information necessary for their maintenance has been relocated outside of the mitochondrion, in the cell's nucleus." Deacon, *Incomplete Nature*, 135.

the reproducing creatures involved, so that all the functions are performed that are necessary for the survival of them all.

The upshot of this is well summarized by Terence Deacon, who writes that:

> The life of an organism is not resident in its parts. It is embodied in the global organization of the living process. Moreover, the so-called parts that analysis produces—the individual molecules, organelles, cells, tissue types, and organs—are not parts in the sense that machine parts are.[45]

This corresponds well with Leibniz's view. It is not at all essential to the existence or preservation of a living being that it maintain the same material parts, nor even equivalent machinic ones, such as when we replace the wheel of a wagon. A living being depends for its functioning at any given stage of its development on the functioning of other living beings inside it (as we depend on the well functioning of our stomach bacteria), as well as outside it (as do our stomach bacteria on the environments provided by our stomachs). What is important is the global organization of all these functionalities and their material requisites, and the harmony among them, and it is this that enables the successful continuance of these enfolded organisms.

Also, many modern scientists agree with Leibniz that there must be some principle of organization in living organisms, something that is absent from inanimate matter, and that the self-organizing capacity of living things (as in the *autopoesis* of Maturana and Varela) requires some notion of self. To quote Terence Deacon again:

> But self is not merely *associated* with life and mind, it is what defines the very individuation that characterizes an organism and is the most fundamental organizing principle. Only living organisms are truly individual in the sense that all aspects of their constitution are organized around the maintenance and perpetuation of this form of organization. It is the circularity of this consequential architecture—teleodynamics—that both delineates and creates the individuality that is organism self.[46]

[45] Deacon, *Incomplete Nature*, 135.
[46] Ibid., 465.

Deacon's first statement echoes Leibniz's claim that

> By means of the soul or form there is a true unity corresponding to what is called "I" in us. Such a unity could not occur in artificial machines or in a simple mass of matter, however organized it might be.[47]

The idea is that an artificial machine has no capacity for maintaining and perpetuating itself, precisely because only something that is properly a *self* can maintain or perpetuate it*self*. In an artificial machine there is nothing corresponding to the "self" in "itself". While Prigogine's notions of order arising from chaos in far-from-equilibrium processes provided a new paradigm for imagining how certain processes that required an intake of energy from their surroundings could become stable for a time, these instances were initiated by the environment, not self-initiated. By contrast:

> Living organisms are integrated and bounded *wholes*, constituted by processes that maintain persistent *self-similarity*. These processes are *functions*, not merely chemical reactions, because they exist to promote *self-promoting* physical consequences. These functions are *adaptive* and have evolved with respect to certain requirements in their environment that may or may not obtain. And these adaptations exist *for the sake of* preserving the integrity and persistence of these integrated systems and the unbroken chain of ancestral forms for which they are the defining links.[48]

Similarly, Stuart Kauffman has claimed that "living systems are autonomous agents—they act on their own behalf".[49] Commenting on this claim of Kauffman's in a recent article, Addy Pross adds: "In contrast to non-living things, all life forms appear to follow an agenda."[50] These considerations invite further examination of the notion of function, and with it the whole question of the place of final cause reasoning in biology.

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[47] GP IV, 482/PPL 456.

[48] Deacon, *Incomplete Nature*, 273.

[49] Kauffman, *Investigations*; Pross, "Toward a general theory of evolution", 9.

[50] Pross, "Toward a general theory of evolution", 9.

5 Life, Function and Final Causes

It is a widely accepted dogma among contemporary biologists that *function* must absolutely not be interpreted in terms of end-directed behaviour. It is not that there are no end-directed behaviours in the biological sphere, such as plants turning their leaves to face the light. Rather, the explanation for such end-directed behaviour must, ultimately, be given in terms of natural selection. Plants have this disposition as part of their genetic inheritance, and it operates purely mechanically, given the correct functioning of the genes in coding for the right chemicals in the right environments, and in the right order.[51]

From this perspective Leibniz is apt to seem a throwback to pre-Enlightenment conceptions of nature as purposive, and as carrying out God's plan in exhaustive detail. This is the portrait Voltaire paints of the doctrine of the best of all possible worlds in his satire *Candide*, where every single thing that happens is as a result of optimal design: "Observe," says Pangloss, "that the nose is formed for spectacles, and therefore we come to wear spectacles; the legs are visibly designed for stockings, and therefore we come to wear stockings!"[52]

As Eric Palmer has shown, however, although this satire certainly hits its mark if its target is taken to be the kind of quietist philosophy advocated by Noël Antoine Pluche in his 1750 *Spectacle de la Nature*, it does not if its target is Leibniz's natural philosophy.[53] For Leibniz's views on teleology are considerably more sophisticated. He was perfectly familiar with Descartes' attempt to banish final causes from philosophy,[54] and also with Spinoza's related criticisms of such reasoning.[55] But he completely disagreed with these advocates of the mechanical philosophy that considerations of final causes are incompatible with mechanism. To the contrary, as we have

[51] Ernst Mayr distinguishes between function in the sense of the physiological functioning of an organ or other biological feature, "which can be largely translated into physiochemical explanations" (*What Makes Biology Unique?*, 50), and function in the sense of a biological role that such a feature might (contingently) have.

[52] Voltaire, *Candide*, 48.

[53] See Eric Palmer's introduction to his edition of Voltaire, *Candide*.

[54] Descartes, *The Philosophical Writings of Descartes*, 202–3 (*Principles of Philosophy*, I §28).

[55] Spinoza, *Ethics*, Appendix to Part 1.

seen, he thought machines are best *defined* in terms of final cause: "Every machine … is best defined in terms of its final cause, so that in the description of its parts it is therefore apparent in what way each of them is coordinated with the others for its intended use."[56] Indeed, Leibniz had shown in his work in optics that it is possible to construe end-directed actions in such a way that no reference is implied to any intentions or knowledge on the part of the systems involved. The optimal path of a reflected or refracted light ray will be such as to make it the "most determinate", which will be either a maximum or a minimum. There is no assumption here that the ray "knows" this best path. As he wrote in 1678–9:

> it is not the ray itself, but the founding nature of optical laws that is endowed with cognition, and foresees what is best and most fitting.[57]

Such an attitude to telic processes is now deeply entrenched in modern physics, although with little recognition of its origin in Leibniz's philosophy. The idea of end-directed optimization is the basis of Hamilton's formulation of classical mechanics, and also the variational formulation in quantum mechanics and field theory. It is recognized that this often provides a computationally quicker and more efficient method of finding a solution than a forward-running mechanistic method.[58] But in Leibniz there is a deeper connection between the appeal to optimization and his philosophy of efficient causation. According to his Principle of the Equipollence of Cause and Effect, "any full effect, if the opportunity presents itself, can perfectly reproduce its cause, that is, has sufficient forces to bring itself back into the same state as it was in previously, or into an equivalent state".[59] In 1678 he gave an argument for this principle based on minimax principles:

> *The entire effect is assimilated to the full cause to the extent that this can occur*. For the entire effect is only a certain change of the full cause, and indeed as small a change as possible. For example, the present state of the world

[56] Pasini, *Corpo e Funzioni Cognitive in Leibniz*, 217; Smith, *Divine Machines*, 290.
[57] A VI 4, 1405/LC 257.
[58] I am indebted to Erik Vynckier for some of the wording here.
[59] Hess, "G.W. Leibniz aus der Zeit seines Parisaufenhaltes", 204.

> differs as little as possible from its entire cause, namely, its preceding state. Of course, the effect and cause only differ in some formal particular, in sum, they agree.[60]

From this, together with Leibniz's idea that the "forces" in question are a measure of the system's ability to do work (namely what he called *vis viva* and we call its internal energy), it follows that in an isolated system energy will be conserved. Leibniz did not hesitate to draw this conclusion, giving this very argument for what we now call the First Law of Thermodynamics:

> The same quantity of forces always remains in the same machine, that is, in the same aggregate of however many bodies constituting it by their action and passion. Any external body, though, is excluded, or at least, not considered. There is always the same quantity of forces in the world, because the whole world is a machine.[61]

Thus any given machine, insofar as it remains the same machine, will operate in such a way as to minimize the difference between the force of a preceding state (the cause) and that of the following state (the effect). This is the basis for the conservation of energy in any isolated system, and also *a fortiori* for the whole universe, since there is nothing outside it. It is because of this that we are able to determine certain things about the behaviour of systems when we know only the initial and final states, and know nothing of the detailed efficient causal processes and mechanisms taking us from one to the other. Thus, although we may in certain circumstances be able to explain the workings or effects of a machine in terms of efficient causes, this will often not be the case, especially in biology. In such cases, Leibniz tells Stahl, "since the internal parts are unknown to us, it may be easier to understand [the effects] from the final causes rather than the efficient ones".[62]

So teleological explanation *complements* explanation in terms of efficient cause and effect, the actions of bodies on one another through their motions. It relates to the function or purpose of the machine, and thus,

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[60] Fichant, *La réforme de la dynamique*, 145.

[61] Ibid., 146.

[62] Smith, *Divine Machines*, 92.

for Leibniz, to the soul or form. Considered in itself, the form or soul "tends through final causes to the goal that the corporeal machine, considered in itself, attains through efficient causes".[63]

For Leibniz a machine is identified by its function. For an artefact, that is its intended use. For an organism, functions will be produced by such causes as allow the establishment of a machine of nature, a self-sustaining machine taking energy from its environment to preserve and facilitate its continued existence as an individual.

Again, this can fruitfully be compared to modern thinking on teleology in the natural sciences. Like Leibniz, Ernst Mayr distinguishes forms of teleology involving no reference to an individual's intentions from teleology in the intentional sense. But he distinguishes two kinds of the former: those that "are end-directed only in an automatic way", by following natural laws—teleomatic processes, like a stone falling to the ground—and those that "owe [their] goal-directedness to the influence of an evolved program"—teleonomic processes. These "occur in cellular development processes, and are most conspicuous in the behaviour of organisms".[64] This distinction would correspond, in Leibniz's thinking, to the distinction between those inanimate processes (like the path of a light ray) that embody optimization because they are part of the optimal world that God has created, and those which are agents actively seeking optimal behaviours. Both of these are distinguished by him from the intentional behaviour of rational agents, which involve the ability to conceptualize possible consequences of one's actions, and thus require a recognition of self. Likewise, Mayr distinguishes teleonomic process from purposive behaviour in thinking organisms, although he includes mammals and birds among the latter; and also from the adaptive features resulting from natural selection which "are, so to speak executive organs for teleonomic programs".[65] Another difference, though, is that for Leibniz, even in the

[63] Stahl, *Negotium otiosum*, 176.

[64] Mayr, *What Makes Biology Unique?*, 50–2.

[65] Ibid., 58–9. Mayr also distinguishes these four types of process, teleomatic, teleonomic, functional and adaptive, from the "cosmic teleology" implicit in the kind of orthogenetic worldview endorsed by Leibniz. As he rightly points out, this has been refuted by the evolutionary synthesis of the 1930s and 1940s (*ibid.*, 60). But, I have argued here, Leibniz's interpretation of divine predestination is full of insight, and not to be equated with the kind of naïve finalism one finds in La Pluche, where every single function is supposed to have been divinely selected for the purpose it happens to serve.

case of simple organisms that are incapable of conscious *recognition* of self, there must still be some self in terms of which the organism and its behaviours are defined, an embodied form that "preserve[s] *real, physical identity*".[66] Here Terence Deacon seems to make a similar point. He argues that Mayr's notion of teleonomy provides an insufficiently robust notion of teleology on which to base evolution. In keeping with John Collier's views on information,[67] he argues that:

> Something physical must be generated and multiplied for evolution to be possible, and this process is necessarily dependent on a special kind of dynamical system: an organism. The form that gets replicated must be embodied, and because generating embodied form is a process that runs counter to the second law of thermodynamics, work must be done to accomplish this.[68]

In addition to "programs controlling teleonomic activities [which] initially were thought of exclusively in terms of the DNA of the genome", Mayr argued, additional "somatic programs" were also required.[69] But he still conceived all such programmes as in some sense equivalent to the programmes of information theory. Deacon, however, suggests that the process of evolution "not only requires reproduction of information in the form of a pattern but also reproduction of a system capable of utilizing and copying that pattern, and, not incidentally, building a replica of itself".[70] It has to generate the means to avoid thermodynamic degradation, and this is a prerequisite for the process of natural selection even to begin. Consequently, he argues:

[66] A VI 6, 236/NE 236.

[67] Collier, "Hierarchical Dynamical Information Systems With a Focus on Biology".

[68] Deacon, *Incomplete Nature*.

[69] Mayr, *What Makes Biology Unique?*, 55.

[70] Deacon, *Incomplete Nature*, 136. This builds on Kauffman's claim: "But evolution requires more than simply the ability to change, to undergo heritable variation. To engage in the Darwinian saga, a living system must first be able to strike an *internal* compromise between malleability and stability. To survive in a variable environment, it must be stable, but not so stable that it remains forever static." Kauffman, *At Home In The Universe*, 73.

> Natural selection could not have produced the conditions that made natural selection possible. These conditions that enable an individuated dynamical system—an organism—to defeat the second law of thermodynamics locally, by repairing and replicating its parts and by producing replicas of itself, are prerequisites to natural selection.[71]

Deacon coins the word "ententional" for processes "that are intrinsically incomplete in the sense of being in relationship to, constituted by, or organized to achieve, something non-intrinsic. This includes function, information, meaning, reference, representation, agency, purpose, sentience, and value."[72] He concludes:

> [T]eleonomy has been used to legitimize explanations employing end-directed accounts while presuming to deny that this has any ententional implications. But as I have gone to great pains to demonstrate, organisms aren't merely mechanisms that mimic teleological tendencies; they are entirely organized around a central goal-directedness, self-generation, and perpetuation. End-directedness is an intrinsic defining characteristic of an organism, not something only assessed from outside and extrinsically or accidentally imposed.[73]

6 Conclusion

The last paragraph, it seems to me, could have been written by Leibniz himself—even though Deacon himself does not seem to be aware of his views on these matters. Of course, I am not trying to claim that Leibniz anticipated everything of interest in modern biological research. The contexts are much too different. Leibniz would surely have revelled in all the detailed science that has been learned since his time, particularly organic chemistry and molecular theory, and would have had much to say on the theoretical links that have been forged between thermodynamics and probability theory, and between these theories, information theory and

[71] Deacon, *Incomplete Nature*, 136.
[72] Ibid., 549.
[73] Ibid., 467.

the science of life, and how this all fits together into a coherent picture—although he would, of course, have deplored the exclusion of God from the foundations of the world. Nor am I claiming that Deacon's views on the non-reducibility of ententional processes are widely shared.

But the extraordinary consilience of some of Leibniz's leading ideas with the novel theoretical ideas of relevance to modern astrobiology shows, I believe, amazing prescience. Among these ideas are the following: (1) that genetic information can be combinatorially encoded, but that this is not sufficient without the existence of a materially embodied, dynamic and stable vehicle for that information; (2) that this requires organic bodies, defined as self-moving and self-sustaining machines, able to replicate other machines of the same kind; (3) that although organisms are mechanisms, they must be understood in terms of mutual functioning and hierarchies of dominance, the lower supporting the functions of the higher, and sometimes the other way round; (4) that the nested structure of the organic bodies of living beings, and their mutually supporting functionalities, means that individuals cannot be defined merely as spatiotemporal continuants, but must be defined in terms of function and agency; (5) that biological function must be characterized in terms of teleology; (6) that the teleology concerned does not necessarily connote any awareness, but that it does involve optimization to achieve a certain end; and (7) that the integrity and unity of living things requires a robust notion of "self", without which there can be no proper account of agency.

The need for matter that can self-organize and replicate itself is now seen as a prerequisite for natural selection even to get started, and Leibniz realized the need for organic matter of this kind over three centuries ago. Thus although Leibniz's philosophy is not evolutionary, it anticipates recent trends in biological thinking in emphasizing life as a process, involving symbiotically linked, dynamic and self-sustaining systems. It is only with the prior establishment of autogenic, self-replicative systems by teleodynamic processes that natural selection can begin to operate, producing designs that Leibniz attributed to a wise creator. And it is only when living organisms have been established that one can talk in terms of agency and intention.

Addy Pross has suggested that the continual transformation of "regular" matter into replicative matter by drawing energy from the outside, in much the way Leibniz proposed in defining his "machines of nature", suggests "that in some fundamental manner replicative matter is the more 'stable' form".[74] This in turn suggests that this is what we should expect to find on other planets and star-systems. There is already evidence of an abundance of extra-terrestrial organic matter, at least in our solar system. So, as our understanding of the cosmos progresses in astrobiology, we may come to see that Leibniz's vision of matter as fundamentally made up of self-sustaining replicating machines is not so very far from the truth.

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