Leibnizian Analysis in Metaphysics, Mathematics, Physics, Geology and Biology: From Fox Keller, back to Leibniz and on to Darwin

Emily R. Grosholz

I. Introduction

The world of classical physics proposed a view of nature where systems behaved like machines: they were reducible to their parts, governed by universal laws (which were moreover time-reversal invariant), and thus representable by an axiomatized discourse where predictable events could be deduced, given the correct boundary conditions. Thus, the philosophers of science of the early and mid-twentieth century happily offered the Deductive-Nomological Model of Explanation (and Prediction). It fit Newton's *Principia*, Book I, Proposition XI pretty well. However, it doesn't really account for Book III, the development of the theory and practice of differential equations, the *n*-body problem, electro-magnetic phenomena, thermodynamics, atoms, galaxies or the expanding universe, limitations that even Thomas Kuhn, author of the revolutionary book *The Structure of Scientific Revolutions*, (University of Chicago Press, 1962) played down.

But the philosophers did notice that the Deductive-Nomological Model of Explanation wasn't a very good fit for biology, as after Darwin it struggled to account for natural history with its attendant one-way temporality, the emergence of novelty, and the intentionality and nested downwards complexity of living things, that seemed so stubbornly un-machine-like. The discovery of DNA and the rise of a new kind of machine, the computer, briefly encouraged philosophers (and scientists) to think that biology might finally look like a real science, populated by tiny robots that lend themselves to axioms and predictions; but, alas. In 1907, Henri Bergson foresaw this philosophical conundrum in his theory of time and the *élan vital* presented in his book *Creative Evolution*: living things are temporal, indeed historical, and willfully unpredictable. In the past few decades, philosophers like Richard Lewontin, Stephen Jay Gould and Evelyn Fox Keller (inter alia) have done a good job of articulating in detail my ironic "alas" apropos modern biology. In this presentation, I take Fox Keller as an exemplary current philosopher of biology, and then turn back to the Early Modern period. I want to explain why Leibniz is especially helpful as a resource for contemporary philosophers, because of the way he understands science and mathematics and reason, and the relation between philosophy and other disciplines.

II. A Perspective on Contemporary Biology

In the Introduction to her book *Making Sense of Life* (Harvard University Press, 2002), Evelyn Fox Keller asks the questions, what do biological explanations aim at? What needs do various kinds of biological explanations meet? The model of explanation just noted, Hempel's Deductive-Nomological model, included premises that are pertinent principles and rules, along with boundary conditions or descriptions of an experimental set-up, and a conclusion that is the 'fact to be explained.' The usefulness of this model in physics and chemistry was sometimes accepted, occasionally questioned by philosophers, but its usefulness was doubted almost from the very beginning by philosophers of biology. In *Making Sense of Life*, Keller argues that explanations in biology are typically partial and provisional, because the epistemic diversity, heterogeneity and unpredictability of biology (corresponding to the diversity, heterogeneity, and willfulness or mentality of many of its objects) are more striking than its unity. The unity of an axiomatized theory, which provides a discursive 'home' for deductive explanations, is not an appropriate regulative ideal for biology, to use Kant's term.

The historical case studies in *Making Sense of Life* are drawn from the history of developmental biology, the study of how an organism develops from embryo to adult, a study related to the question of how life on earth emerged, from one-celled organisms in the primal soup to the present. The first two chapters deal with the kinds of explanations that were offered a hundred years or so ago, before the theoretical advent of the notion of gene in the context of the empirical annexation of Mendelian genetics to Darwin's theory of evolution. The next set of chapters examines the role that experimental genetics has played in developmental biology. In the mid-twentieth century, genetics was revolutionized by Watson and Crick's discovery that the genetic material, the 'units of selection' that underlie Mendelian genetics and are arrayed on chromosomes, consists of the double helix of DNA, and that triplets of the nucleotides in DNA code for amino acids, the building blocks of proteins. Their discovery gave rise to the highly reductionist dogma that genes are 'master molecules' installed in the control room of the nucleus, stable and continuous bits of chromosomes, linearly coding for linear proteins ("one gene – one protein").

Thus, scientists proclaimed that the organism could be "deduced" from the linear sequence of DNA, once it was known. Biological research over the past four decades has however complicated and undermined this picture in various ways. A stretch of genetic material that seems functional may be regulated by other sites on the genome that lie far from that stretch; moreover, within it only a few small patches of nucleotides may actively code for protein, patches that are interspersed with 'junk DNA.' When that stretch is recorded and transported out of the nucleus by a second stretch of messenger RNA, the mRNA must be edited and spliced by enzymes in order to be taken up by ribosomes to construct the protein; and that protein must be folded in a certain manner. There are many possible outcomes in this editing and splicing process, and there are many possible outcomes for the folding process; those outcomes are regulated by ribosomes and enzymes in the cytoplasm and therefore depend on the condition of the cell as a whole (which in turn is highly sensitive to its own local cellular environment). So what counts as a single gene, and what the causal outcome of that gene's activation may be, has changed dramatically in the minds and practice of biologists in the last half century.

The metaphysical dilemma for mid-century biologists, as Keller observes in her fourth chapter, was to reconcile the picture of genes as stable chemical units that account for the patterns of inheritance in genetic crosses, and the picture of genes as active, directive causal agents responsible for the determination of an organism's properties in the development from embryo to adult. These two roles seemed incompatible. One strategy was introduced by the pair of scientists, François Jacob and Jacques Monod in their investigation of the operon complex, a mechanism for the regulation of enzyme synthesis studied in the bacterium *E. coli*. Jacob and Monod discovered that one stretch of genetic material in *E. coli* only generated an enzyme when it was activated, or rather not blocked, by an enzyme produced by another stretch of genetic material; they dubbed the first stretch the 'structural gene' and the second the 'regulator gene.' Introducing the operon model to the scientific world, they suggested that it was like a computer program: "a coordinated program of protein synthesis and the means of controlling its execution." In her earlier book, *The Century of the Gene* (2000), Keller analyzed the conceptual inadequacies of this metaphor, but here she examines the features that made it attractive to biologists around 1960, its ambiguity. In particular, the notion of a computer program leaves the locus of agency ambiguous. A program is a plan or procedure, so one connotation suggests that the genome can direct development. But the development of an organism (and the operon complex) requires that genes be switched off and on, so that the gene is the object of activation, not its subject. Jacob and Monod's vocabulary of structural and regulator genes allowed for both passivity and agency, and calling the whole complex a computer program covered the issue of agency under a veil of subtle ambiguity, and moreover brought in as an adjunct the suggestive notion of 'information.'

In a sense, Keller argues, this ambiguity and metaphoricity at the time was useful. "Not only did it serve to fill the explanatory gap that had been left by the demise of gene action, by the inability of that discourse to account for development that new research had made manifest, but it also proved valuable on a more local level, and undeniably so: it helped to secure a framework for the hypotheses that early generations of molecular biologists needed to guide their day-to-day research. Indeed, the genetic program can be said to have consolidated the entire family of tropes that guided and gave meaning to virtually all of the discoveries that put molecular biology on the map—the finding not only of regulatory circuits, but also of messenger RNA, the genetic code, translation mechanisms, and even the central dogma of that new discipline." (p. 147)

However, the dogma of the 'master molecule as computer program' did *constrain* research as well. In the fifth chapter, Keller recounts the use of Norbert Wiener's conceptual model of feedback mechanism in the work of two developmental biologists, C.H. Waddington and F. E. Warburton, in the mid-1950s. They discovered that the synthesis of an amino acid could be inhibited by the end product of the metabolic pathway involved in the production of that amino acid—end-product inhibition. They hoped that their work could provide the theoretical outlook required to understand mechanisms of differentiation in the cell as a whole, despite the sameness of the genes in the nucleus of each cell. Around the same time, R. A. Yates and A. Pardee argued that in a cell, processes are controlled by one or more feedback loops that prevent any one phase of the process from being carried to an extreme: the cell regulates itself. However, when Monod and Jacob took over the notion of 'end-product inhibition,' they re-named it 'allosteric inhibition.' The renaming was significant, and polemical: for them, this kind of cellular regulation does not qualify as an explanation for differentiation—only genetic regulation can do that. The controlling mechanisms must be squarely located in the genes. While others took Wiener's vision to lie in the absence of centralized control, Jacob and Monod redefined both feedback and regulation to refer to *genetically* controlled processes.

There were also some standard questions in developmental biology that the 'master molecule as computer program' clearly would not be able to address, like the question of how a cell knows where it is within a developing embryo, as Keller notes in the sixth chapter. Lewis Wolpert first introduced the term 'positional information' in the late 1960s to answer this question, and his answer was given in terms of an abstract theoretical framework. A cell knows where it is, he argued, because of its position along an axis characterized by a chemical or physical gradient, which he hypothesized to be the variable concentration of a 'morphogen.' This model of explanation was not fashionable at the time. However, the work of C. Nuesslein-Volhard and Eric Wieshaus on the molecular biology of *Drosophila* embryos between 1975 and 1990 revealed that the cytoplasm in *Drosophila* eggs is not in fact homogeneous and exhibits an exponential gradient: positional information! Maternal effect genes establish the polarity and primary axes of the embryo, and cytoplasmic factors were important in early development. Experiments revealed that the cytoplasm of the egg is not homogeneous, but patterned by differential distribution of specific proteins and molecules of mRNA, preformed as products of maternal genes: they can diffuse across the egg. The combined effect of diffusion, degradation, and differential translation of the mRNA into protein is an exponential gradient in the concentration of bicoid protein. The nucleus divides many times, so the resultant nuclei are distributed along the inside of the cell membrane, and each set of genes encounters a different concentration of bicoid: the genes it activates are subject to different levels of activation. New gradients are generated, which activates or represses still other genes, producing a cascading sequence of signals and responses: bands, stripes, segments, laid out from head to tail. Thereafter, Lewis Wolpert's earlier explanatory strategy of 'positional information' became widely accepted and implemented.

In the physical sciences, empirical evidence is thought to play a significant explanatory role when it supports a theory. In the biological sciences, however, empirical evidence has always included description, reports on what is observed in the field, whether the field is a droplet under a microscope or the side of a mountain. Many advances in biology stem from advances in instrumentation that allow us to watch the activity of organisms at the molecular level, where we note an intersection between description and explanation. Techniques of imaging living cells, and the introduction of powerful computers that can refine and reconstruct visual images to produce four-dimensional representations have changed the nature of embryological research. Moreover, we can now introduce molecular markers, which serve as visual probes of the cell's internal dynamics, into living cells in a variety of ways. Even though these techniques are invasive, they allow us to observe *in vivo* processes with unprecedented clarity and precision. Biologists can now track the spatially and temporally specific dynamics of gene expression and protein function in developing embryos, by combining these techniques with video and confocal microscopy in conjunction with computer processing. One effect of all this is a growing sense among biologists that individuality and a kind of willfulness is as evident in the study of cells as in the study of wild animals. The team P. M. Kulesa and S. E. Fraser, writing about chick embryos in 1998, for example, report "The unpredictable cell trajectories, the mixing of neural crest cells between adjoining rhombomeres, and the diversity in cell migration behavior within any particular region imply that no single mechanism guides migration." (p. 228) Here we see that direct observation of living systems contributes to a move away from strict genetic determinism, and warns against premature theoretical generalization.

Thus, Evelyn Fox Keller concludes at the end her book: "The central concern of this book has been with the de facto multiplicity of explanatory styles in scientific practice, reflecting the manifest diversity of epistemological goals which researchers bring to their task." (p. 300) And this, she adds, is a virtue: explanatory pluralism improves our ability to find out about the world. But she distinguishes herself from, e.g., John Dupré and Nancy Cartwright in the following terms: "The claims I put forth here are about the nature of the scientific pursuit and the essential diversity of interests that drive that pursuit. To the extent that I make a claim for how the world actually is, that claim is only for its irreducible complexity, not for an underlying incoherence." (p. 301)

My view is that the world is irreducibly complex, and that the things of this world are heterogeneous, of many, unlike kinds. That doesn't mean I believe that the world is incoherent. One of the things that I have learned from Leibniz, under the auspices of his Principle of Continuity, is that strongly unlike things can be brought into rational relation by both thought and practice. One such example is the way that the algorithms of the infinitesimal calculus bring the infinitesimal and the finite into rational relation. The use of molecular biology in genetics provides another example. Indeed, one of my quarrels with logic, modern predicate logic in particular, is the assumption of homogeneity that it imposes on the discourses that it pretends to formalize. The logicist model of theory reduction pretends that their differences can be erased, or at the least squashed into an isomorphism; and this assumption I contest. The reasoning that takes place in analytic geometry or modern genetics is not incoherent, but it does consist of two or three kinds of discourses, proper to two or three kinds of things, superimposed upon or set next to each other in carefully managed ways. The resultant ambiguity may sometimes be resolved, but sometimes we just have to live with it, as mathematicians must live with the incommensurability of the discrete and the continuous, or the finite and the infinite; chemists must tolerate the heterogeneity of the macroscopic and the microscopic; and biologists must accommodate the deterministic-cause, the function and the intentional action in the courtyard of their investigations.

III. A Brief Look Backward at Descartes and Gassendi

Recall what Fox Keller wrote about Jacob and Monod's operon model: the notion of a computer program leaves the locus of agency ambiguous. We can understand a computer program as part of a machine, or we can understand it as directions specifying functions, directions that stem from an agent. Thus as a middle term between the mechanical model which invokes only matter in motion and the biological organism which requires us to think about function and wonder about action, the term "computer program" may be thought to smuggle in functionality and agency. Fox Keller argues both that this ambiguity allows science to advance, with a flawed but serviceable model, but eventually impedes science, because the model is in fact flawed and the smuggling is illicet. We find the same ambiguity in the middle terms used by Descartes and Gassendi to save the mechanical modeling of organisms, "animal spirits," which was also an attempt to bring the dichotomized substances matter and spirit back into some kind of rational relation.

During the last two decades of his life, Pierre Gassendi aimed to promulgate Atomism, and to restore the philosophy of Epicurus, as St. Thomas Aquinas had restored the philosophy of Aristotle, making it consonant with Christian doctrine, for Gassendi was a priest as well as philosopher, scholar and empirical scientist. In his *Animadversiones* (1649), he published his Latin translation of Diogenes Laertius' Book X on Epicurus, and in his *Syntagma Philosophicum* (published posthumously in the *Opera Omnia* in 1658) he gave a more general and systematic treatment of Epicurean doctrine. Despite his allegiance to Atomism, he shared with Aristotle a firm empiricism: our access to the natural world depends on sense perception, and the accumulation of empirical data, pro and contra hypotheses. So for Gassendi, any account of what it is to be a human being must begin with sense perception, and what sense perception undeniably affords: one has a body as well as a soul. How then are they related?

In the *Meditations*, Descartes had suggested a middle term, just after he noted, midway through Meditation Two, "Yet I am a true thing and am truly existing; what kind of a thing? I have said it already: a thinking thing. What else am I? I will use my imagination to see if I am not something more. I am not that structure of limbs which is called a human body. I am not even some thin vapor which permeates the limbs – a wind, fire, air, breath, or whatever I depict to my imagination; for these are things which I have supposed to be nothing." (PWD v. II, p. 18) Animal spirits are characterized as matter so fine, rapidly moving and pure that it is aetherial (to use Aristotle's term for the fifth kind of (heavenly) matter): it is tempting to call animal spirits intelligent. They are a plausible candidtate for the middle term between mind and body, because they would be able to circulate throughout even the tiniest pores of the body, which brings in a further metaphor, the hydraulic engineering that the 16th century Italians were so good at, using it to animate their gardens with fountains and automata. But this supposition is rejected by Descartes as soon as entertained, because "It would indeed be a case of fictitious invention if I used my imagination to establish that I was something or other; for imagining is simply contemplating the shape or image of a corporeal thing." (Ibid., p. 19) To appeal to the faculty of imagination at this point in the thought experiment of the *Meditations* is, for Descartes, contradictory, indeed silly: the only appeal can be to the faculty of intellect.

Still, this is precisely the strategy that Gassendi recommends to Descartes. For Gassendi, the action of animal spirits is just the kind of empirical hypothesis that can offer "the point at which all the hard work begins." He repeatedly insists on the description of the soul which Descartes has just rejected: "You said that you did not know what the soul was, but imagined it to be merely 'something like a fire or wind or ether' which permeated the more solid parts of your body. This is worth remembering!" (Ibid., p. 181) And he goes on to observe, "...in this passage, you are regarding yourself not as a whole man but as an inner or hidden component – the kind of component which you had previously considered the soul to be. I ask you then, Soul, or whatever name you want me to address you by, have you by this time corrected the thought which previously led you to imagine that you were something like a wind diffused through the parts of the body? Certainly not. So why is it not possible that you are a wind, or rather a very thin vapour, given off when the heart heats up the purest type of blood, or produced by some other source, which is diffused through the parts of the body and gives them life? May it not be this vapor which sees with the eyes and hears with the ears and thinks with the brain and performs all the other functions which are commonly ascribed to you." (Ibid., pp. 181-182). Note that here the notion of function serves as a middle term between motion (ascribed to bodies) and action (ascribed to human beings); and the faculty of imagination serves as a middle term between the faculty of sense perception and the faculty of intellect.

Whatever we think of this proposed 'physiological' account of the soul, Gassendi has identified a real problem with Descartes' metaphysics: radical dualism. How can Descartes possibly bring thinking substance into rational relation with extended substance? What could possibly serve as a middle term? Two ironies follow. The first is that Gassendi seems blind to the problem inherent in the materialist monism of Epicureanism, which also seems so difficult to reconcile with his commitments as a Christian priest. He urges Descartes to locate middle terms, but to do that one must have prior terms which are strongly differentiated, distinguished within that discourse in meaningful ways. Otherwise, the proportion A : B :: B : C collapses to identity. Then no middle term remains, and the conceptual role of the middle term disappears.

Gassendi proposes the soul as a kind of middle term between mind and body, where the soul is diffused through the body and somehow also concentrated in the brain and heart. He suggests using the soul to refer to "the principle responsible for the vegetative and sensory functions in both us and the brutes... it is the vegetative and sensitive principle that is properly speaking said to 'animate' us," while the function of mind is to enable us to think." (Ibid., p. 184) But then, why not understand mind to be "the noblest part of the soul... so to speak, the flower, or the most refined and pure and active part of it?" Then mind would be "some pure, transparent, rarified substance like a wind, which pervades the whole body or at least the brain or some other part, and which animates you and performs your functions." (Ibid., p. 185) But notice how the vocabulary of function and action insinuates itself into this description of particles. How can a stream of particles organize or direct a living thing? The hydraulic metaphor (like the operon model) leaves out the human agents who design the fountain or automaton, and create the structure which directs the flow of water, and turn the water off and on. Without the hydraulic metaphor that smuggles in human agency, it seems as if Gassendi is left with atoms in the void; it is just a sandstorm, not an explanation.

The second irony is that in his physiological writings, *The Treatise of Man* and *Passions of the Soul*, Descartes employs precisely the same strategy that Gassendi suggests. Descartes like Gassendi is a materialist in his treatment of the body. His biological mechanics forms a kind of adjunct to his physics which, let us recall, consists of seven laws of motion governing the collision of particles (so that momentum, or rather bulk times speed, is conserved) and a rather imaginative theory of vortices in the plenum of material particles. His physiology, however, depends in unacknowledged ways on the medical tradition of Galen and on the classical theory of simple machines (where weight times distance is the pertinent invariant), and employs an imaginative set of similitudes unlike the rigorous deductions that the account of method as the order of reasons in the *Meditations* might lead one to expect. At the beginning of the *Treatise of Man,* he writes, "And truly one can well compare the nerves of the machine that I am describing to the tubes of the mechanisms of these fountains, its muscles and tendons to divers other engines and springs which serve to move these mechanisms, its animal spirits to the water which drives them, of the which the heart is the source and the brain's cavities the water main. Moreover, breathing and other such actions which are ordinary and natural to it, and which depend on the flow of spirits, are like the movements of a clock or mills which the ordinary flow of water can render continuous." (*Treatise of Man*, ed. T. S. Hall, Harvard University Press, 1972, p. 22). Not only does Descartes use an elaboration of this imaginative model to account for the functions, and actions, of animals; he also uses it to explain reflex action in a human beings, and to explain the way in which the perception of external objects acts on the brain. Indeed, the diverse and patterned flow of animal spirits through the fibers of the brain carries information, and may induce permanent configurations in the fibers; these 'folds' are corporeal memory, which in turn influences the subsequence flow of animal spirits. Descartes, like Gassendi, is exploiting an ambiguity in the concept of animal spirits: they are active and patterned, carrying information on the way into the pineal gland and directing the body's actions on the way out; they function as intelligence; and yet they are just flows of particles. The middle term of animal spirits brings the disparate terms of body and soul into relation, as the middle term of function brings motion and action into relation, and as the faculty of imagination brings sense perception and intellect into relation. And yet... we suspect that Gassendi has not escaped the traps of monism, and Descartes has not bridged the gap between *res extensa* and *res cogitans*.

IV. Spinoza and a Metaphysics that Opposes Dualism

From contemplating this debate between Descartes and Gassendi, I conclude that dualism is never going to provide a basis for explanation in biology. Materialism and its theory of machines cannot explain the emergence of function from motion and action from function, which is also to say the emergence of intentionality and mind in nature; nor can it explain the irreducible temporality and historicity of nature, which includes the eruption of novelty. (This is a recurring theme in the writings of Bergson.) Likewise Idealism's location of spirit in a transcendent reality disjunct from this material world (whose reality or meaningfulness is thus thrown into question) cannot inform biology: how would those angels ever interact with this messy, green, conflict-prone, erotic, surprising world?

Biological explanation requires a metaphysics that proposes a material world that is thoroughly animate, in which materiality and animation are not opposed but stem from the same source. The two great Rationalist opponents of Descartes immediately come to mind: Spinoza and Leibniz. My account of Spinoza here borrows from my colleague Elhanan Yakira, whose book *Spinoza and the Case for Philosophy* (Cambridge University Press, 2014) The book's main thesis is that Spinoza unifies the study of being and the study of intelligibility: they are exactly the same enterprise for him, and the figure for this identification is God. Spinoza's version of the principle of sufficient reason is completely general: it is the explicability or intelligibility of being: nothing happens without a cause, and causes are reasons that carry understanding or knowledge. Moreover, Spinoza does not distinguish between the principle of sufficient reason and the principle of identity but collapses them. *Sub specie aeternitatis*, every truth is a truth of fact with an existential import and also a necessity: its opposite would be a contradiction. There is no precedence of being over thought, and no precedence of thought over being: Spinoza rejects both idealism and materialism. The question is, how might this view of reality inform our understanding of biology?

The influence, I think, would not be as direct as some twentieth century commentators have proposed. Yakira has good reason to reject the materialist readings of Spinoza that we find Canguilhem, Deleuze and Foucault, for example, or the assimilation of his doctrine to "naturalized epistemology" that we find in interpretations offered by Michael Della Rocca and others. This understanding of Spinoza's account of normativity in "Stoic-medical" terms reduces *conatus* to the physical robustness of the organism; while it may seem plausible for passages in Part II and Part III, it cannot explain what Spinoza means when he comes to the account of beatitude in Part V, nor can it account for the intentionality that we find in the natural world, or the wonder it produces in us. The normativity of health or robustness does not make sense *sub specie aeternitatis*; the health of the organism can't be the key to beatitude, since after all the organism is one way or the other on its way to decline and death.

Yakira also criticizes Merleau-Ponty's phenomenological reading. He insists that we take Part II p 11 and p13 at face value, that we take them as straightforwardly and literally meant: the mind is an idea, and this idea is the idea of the body. Together they entail that the truth of the theory of substance in Part I is experienced here and now, in the body, and this experience (which is not subjective, or phenomenal, but if anything metaphysical) proves to be the key to beatitude and freedom. What was for Descartes a fact that needs to be explained (all five Meditations are used to explain it in Meditation VI!), that is, the union of body and soul, becomes for Spinoza a first principle, the ultimate condition of the intelligibility of everything else: the absolute unity and uniqueness of reality (and thus *pari passu* of the soul and body).

Pursuing this line of thought, we should also reject theological or mystical interpretations of Spinoza. Those who read too much into Spinoza's appropriation of Maimonides or neo-Scholasticism forget his implacable hostility not only toward religious institutions but also towards the predilection of religious metaphysics for transcendence: the transcendence of God vis à vis the world, of the soul vis à vis the body, of eternal afterlife vis à vis this life. Spinoza wants nothing to do with transcendence. His conception of the world and of human beings results in a doctrine of the absolute *value* of existence conceived as radically and solely *hic et nunc*, specifically the here and now of the private body. This is a realization of the fundamental intelligibility of existence: thus in a sense reason becomes the final arbiter of ethical judgment. Spinoza's project is an attempt to conceptualize, systematize and justify a normative stance based on the recognition of the irreducible seriousness, importance and value of existence, which includes human existence. Thus, the ultimate achievement of the philosophical journey Spinoza expounds is what he calls the "soul's intellectual love which is God's love in which he loves himself" (Part V p 36). This realization is not simply happiness or joy, which the Spinozistic sage possesses as a personal asset, but also a fulfillment and recognition of the intrinsic, objective importance and value of being, *sub specie aeternitatis*.

This is a strange doctrine. Some scholars, like those noted above, have tried to normalize it (while avoiding both materialist and idealist readings) by treating it as a solution to Descartes' mind-body problem: Spinoza's mind-body 'parallelism' is supposed to prefigure the modern scientific theorizations of neuroscience and cognitive science. The key passage is *Ethics* Part II p 7: "the same order and connection that holds among ideas, also holds among things." This proposition seems to assert an "isomorphism" (as modern commentators often anachronistically call it) between ideas and their relations and bodies and their relations. However, asYakira points out, it is not Spinoza but rather Leibniz who first uses the term 'parallelism' in order to characterize his own strategy based on the metaphysical notion of harmony. According to Leibniz, it makes no sense to think that spirit and body are the same thing, only expressed in two different manners, or that thinking substance and extended substance are one and the same substance. Leibniz adds that it is completely unreasonable to say that the soul is an idea, for ideas are abstract, like numbers or figures, and so cannot act. Thus these commentators misread Spinoza in terms of Leibniz's coinage of 'parallelism' to describe his own solution to the mind-body problem, along with his figure of the synchronized clocks.

Indeed, the philosopher who first speculates that formal structure (the kind of structure implicit in the notion of isomorphism) might be used to bring terms that are metaphysically separate into intelligible relation is Leibniz: that is the work done by his principle of continuity. Leibniz revels in and appreciates the power of formal structure; Spinoza does not. Furthermore, Descartes never affirmed that the mind-body union could be fully conceptualized; Gueroult reminds us that the ideas of sense have only infinitesimal reality for Descartes. For Spinoza, by contrast, the experience of one's body—experience itself—is fully transparent, and metaphysical: it is the paradigm of rationality, of adequate knowledge, where being experiences itself and the 'distance' between agent and object is obliterated. By 'order,' Spinoza often means precisely the givenness or factuality of experience. This is not phenomenology, or the report of an internal experience that could be studied by scientists; it is metaphysics: the recognition and acceptance of the fundamental unity and intelligibility of reality. The body is not external to the soul. There is no room for hyperbolic doubt in Spinoza's philosophy, or for the dissociation of body and soul in Meditation I.

But does this move us towards a science of biology? Yes and no. Yes, because if we understand Spinoza's doctrine of adequate ideas in terms of the identity of being and intelligibility, we see that there is metaphysical room for two kinds of necessitation. There is the necessity of that which acts and exists by its own nature (Part I def. 7), as distinguished from the necessity of that which is determined to act or exist by something alien or external to it. In the case of bondage, my idea is externally caused and my activity is reduced; I merely know *that*. When I am free, however, I affirm my idea because of reasons, which explicate the inner meaning or intelligibility of the thought, and my activity is enhanced; I understand *why*. This is what motivates science as well as metaphysics. Spinoza not only rejects Cartesian dualism, he rejects both Christian and Hebrew doctrines of the soul as somehow opposed to the body, and the conduit for things of the spirit. He links the body and soul, the world and God, necessity and freedom, directly. No, precisely because what Spinoza aims at here is beatitude, not science. We need to turn to Leibniz to see what kind of science a metaphysics deeply influenced by Spinoza might lead to. Finally, on to Leibniz!

V. Leibniz and Metaphysics

Leibniz's theory of knowledge does not eschew but makes use of metaphysics; it accounts for both discovery and justification, and thus for the historicity of knowledge as well as the timeless necessity that emerges in history; and it is not dogmatic but avoids totalization without abandoning reason. The key insight is that for Leibniz the actual infinite is not a whole and not one: it cannot be totalized. As Herbert Breger writes, "Das Aktual Unendlich der Leibnizschen Metaphysik ist kein Ganzes und keine Einheit, es ist lediglich die aktual existierende Vielheit von mehr Dingen als sich mit irgendeiner Zahl angeben lässt. (GP II, 304-5; GP III, 535) Eine Ausnahme (die einzige) bildet natürlich Gott: er ist sowohl aktualunendlich als auch eine Ganzheit." (Breger 1990, 63) Thus the infinitary nature of things insures both that they are "open" and that they are intelligible; in the case of human beings, it insures that we are creative and free as well as rational. The human activity of analysis is the search for and expression of conditions of intelligibility and requires the use of characteristics; at the same time, it is somehow analogous to God's creation of the world. Leibniz's created world is progressive, for its intelligibility increases. God's creation of the world brings actuality into rational relation with what is intelligible (the possibles), and the rationality of that relation is always increasing as the created world increases in perfection, or, perfects itself. Likewise, our analytic understanding contributes to and increases the intelligibility of things by discovering their conditions of intelligibility.

At the beginning of the *Discourse on Metaphysics*, Leibniz announces not that to understand human knowledge, freedom, and goodness properly, we must first study how these attributes are manifest in God, and in particular what divine perfection is. (Spinoza begins the *Ethics* with an account of God.) Section I presents God as an infinite existing thing that is really one, and so is unlike infinite things – e. g. numbers – which cannot be totalized. Leibniz tells us that natures which are not capable of a highest degree are not perfections, "Car le nombre le plus grand de tous (ou bien le nombre de tous les nombres), aussi bien que la plus grande de toutes les figures, impliquent contradiction, mais la plus grande science et la toute-puissance n'enferment point d'impossibilité. Par consequent la puissance et la science sont des perfections, et en tant qu'elle appartiennent à Dieu, elles n'ont point de bornes." (GP IV, 427) This introduces a moment of difference within the unity of God, for it means that God as an awareness, existent and creator is an actually infinite whole, but that the contents of his thought, the possibles, cannot be totalized and considered as a whole. As Breger observes, "Der springende Punkt ist nun, dass der Beweis einer zufälligen Wahrheit nie vollendet werden kann; Leibniz betont ausdrücklich, dass selbst für Gott der Beweis einer zufälligen Wahrheit unmöglich ist (wenngleich Gott eine solche Wahrheit "infallibili visione"erkennen kann)." (Breger 1990, 64)

Section II intensifies this moment of difference: God's will must accede to the rational structure of what he knows. Thus, divine perfection exemplifies both of the great principles, the Principle of Contradiction, which treats the identity or self-sameness of things, and the Principle of Sufficient Reason; indeed, the two principles implicate each other. For anything to be intelligible, or thinkable, or as the logicians say, for A=A, some moment of difference must exist in A's identity expressed by the repetition of "A" in the equation just given. Thus, God's being cannot be expressed in a sheer act of will with no content: this would be to say "qu'il n'y a point de regles de bonté et de perfection dans la nature des choses, ou dans les idées que Dieu en a; et que les ouvrages de Dieu ne sont bons que par cette raison formelle que Dieu les a faits." (GP IV, 427) God, the One, confronts the contents of his thought, that is the infinite, articulate, heterogeneous, many of the possibles, as a moment of difference, for their rational relations of contradiction and congruity are something which he must recognize. Besides, if God were nothing but a sheer despotic will, an uninflected identity, he would constitute another counter-example to the Principle of Sufficient Reason: “qu’il semble que toute volonté suppose quelque raison de vouloir et que cette raison est naturellement anterieure à la volonté.” (GP IV, 428) God is the supreme agent; his mode of acting is first of all thought, which requires differentiation; the moment of difference is constitutive of thought. God doesn’t just think, he thinks what is possible, what is thinkable. Moreover, his agency – all the more so when extended from thought to creation – is unthinkable without reasons.

Possible things as well as actual things do not exist singly: they exist in suites or networks that are actually infinite (and not totalizable) because their conditions of intelligibility, their reasons and causes, link them to other things. Thus, when God wants to create a world, he must create something that is infinite in space and time (which, as Gueroult observes, express the logical relations of compossibility and incompatibility that exist among intelligible things) and even downwardly in composition, without closure; and it must be brought into rational relation with the boundless possibles that will never be actualized. What makes this world the best and God’s act of creation perfect? It cannot be the perfection of the world, since the world cannot be summed up, but must rather be our infinite capacity for perfectibility, the ability of creatures to lend themselves to perfection. (See also Rutherford 1995, Ch. 3) In Sections V and VI, Leibniz explains the Principle of Perfection (the Principle of Sufficient Reason vis à vis God and his creation) in a cascade of metaphors. The metaphors must be read in both directions; on the one hand, they serve “crayonner quelque ressemblance imparfaite de la sagesse divine, et pour dire ce qui puisse au moins elever nostre esprit à concevoir en quelque façon ce qu’on ne scauroit exprimer assez.” (GP IV, 431) On the other hand, they exhibit, “Pour ce qui est de la simplicité des voyes de Dieu, elle a lieu proprement à l’égard des moyens, comme au contraire la varieté, richesse ou abondance y a lieu à l’égard des fins ou effects. Et l’un doit estre en balance avec l’autre...” (GP IV, 430) Thus human creativity is to be understood as an expression of God’s creation, for the geometer, the architect, the machinist, the author, are all engaged in the *imitatio dei*. The problem with Leibniz’s conviction that our being, acting, making and knowing are an *imitatio dei* is the involvement of so much infinity, like clouds or nebulae, in his metaphysics: what are we to do with it all? In his essay “Infinity and Life: The Role of Infinity in Leibniz’s Theory of Living Beings,” (*The Life Sciences in Early Modern Philosophy*, ed. O. Nachtomy and J. Smith, Oxford UP, 2014) Ohad Nachtomy argues that it is precisely the centrality of infinity in Leibniz’s metaphysics that allows him to develop a philosophy of biology that inspires Goethe and Darwin. I agree with many of his arguments, to which we will return later in this presentation, and add that Leibniz’s metaphysics also allows him to develop a positive account of temporality and the emergence of novelty: but of course, the topical threads of life, time, intentionality and the unexpected are interwoven, as Bergson understood. (However, I think Bergson misunderstood Leibniz, perhaps because at that point in time, the reading of Leibniz by Russell and … was so influential.)

Leibniz’s doctrine of time, to which we will turn next, is often taken to be a scientific doctrine, a relationalism opposed to Newton’s doctrine of absolute time. However, this underplays the depth and complexity of Leibniz's treatment of the topic of time: there is a tension between Leibniz's tendency to lead temporal succession back to causal consequence and thence to logical consequence (which works against the reality of time) and his emphasis on development and discovery in both the natural world and human culture, the aspects of his thought that make him the harbinger of evolutionary theories. Leibniz views the created world not just as a logical order but also as a moral order; a perfect logical order would not exhibit temporality at all. In Leibniz's second letter to Samuel Clarke (the spokesman for Newton in their famous debate), he argues that mathematics alone cannot construct principles that will successfully oppose materialism. Mathematics requires the aid of metaphysics: the Principle of Contradiction must be supplemented by the Principle of Sufficient Reason, for there must always be a reason why things are as they are, rather than otherwise. Since observed facts under-determine theory, a true physics will combine mathematics and empirical observation under the guidance of metaphysics. The world must be explained as the product not just of God's power, but also of His wisdom and perfection. (GP VII: 355-9). Leibniz's conception of method, dependent on his metaphysics, tends to make the study of history scientific and the scientific study of nature historical. This notable effect of his method indicates that both his method and metaphysics are intimately related to time; that is, his treatment of temporality should provide an important key to his method and metaphysics.

A Leibnizian savant must engage in analysis, the search for the conditions of intelligibility, the requisites, of what exists; this search is ampliative, leading from the simple schema 'S is P' to series and networks of relations. The doctrine of pre-established harmony, and conversely the doctrine of monadic expression, underwrites the movement from 'S is P' to relational idioms, like algebraic formulas, infinite series, differential equations, and combinatorial schemes, or deductive inference forms, probabilities and trees, which apply to a variety of different kinds of objects and operations. The method of analysis, uncovering a condition of intelligibility P of an existent, S, is ampliative; it discovers what is primitive, or fundamental, or 'simple' in the investigation of a complex thing, and this investigation, by making the implicit explicit, uncovers the general or canonical form of the thing, the general formula according to which it can be treated systematically. Things that exist are not just non-contradictory, but completely – indeed infinitely – conditioned, governed both by the Principle of Contradiction and the Principle of Sufficient Reason; so the systematicity uncovered by analysis is not illusory or superficial but rather well-founded.

To understand something, a Leibnizian savant must not only witness its internal consistency, but also investigate the processes that determine it to be what it is, and therefore what it expresses. Unlike Spinoza, Leibniz believes that determinations of nature and of human culture cannot be understood purely in terms of logic. The conditioning of S by P is not merely logical or even causal, but also historical, because the created world is the result of the intelligible and moral choice of a rational and benevolent God, the progressive expression of sentient and self-conscious, perceptive and apperceptive, creatures. Progress must be temporal; indeed, it must take place in history as well as in time. Explanation requires narrative as well as argument.

There remains, however, a tension between Leibniz's insistence on the importance of development in both the natural world and human culture, and his tendency to read temporal succession back to causal consequence and thence to logical consequence, which works against the reality of time. The latter tendency is the result of his debt to Spinoza and his love of logic and mathematics; the former stems from his interest in British empiricism and the Royal Society, and his own inexhaustible curiosity: it made him not only the harbinger of the Theory of Evolution but also of modern scientific cosmology. For Leibniz, natural science includes natural history, but it also includes mathematical physics. Another tension exists within Leibniz's evocation of narrative: for Leibniz, time is the expression in the created world of the logical incompatibility of concepts (possibles) as space is the expression of their logical compossibility; the conditions are prior to the conditioned, and what we choose excludes the unactualized possibles we did not choose. Thus, time is not illusory or indifferent, as it is for Spinoza, but rather an aspect of the orderliness and morality of the created world. However, Leibniz sometimes writes as if the time of the created world will come to an end, following the *Book of Revelations*, and sometimes as if it will go on forever, in this best of all possible worlds which is continually perfecting itself. History requires narrative, the recounting of the free acts of human beings which always include reference to the actions that were not chosen, the unactualized possibles that frame and give meaning to realized action. Leibniz hesitates between the closed moral order of *Revelations* and Dante's *Divine Comedy*, where all the stories are told in retrospect, and the open moral order of lived history.

Leibniz produced a wide range of historical writings. Lessing, Kant and Herder were indirectly inspired, through Wolff and his school, by Leibniz's metaphysics and historical writings; one might observe that not only did Leibniz inspire the Enlightenment, but the Romantic turn against it, with his notion of the monad and the dynamic development of the created world. In his celebrated book *Die Entstehung des Historismus*, Friedrich Meinecke traced twentieth century historicism back from Herder to Leibniz,[1] and Ernst Troeltsch, somewhat tendentiously, argued that Romanticism sprang from the mysticism of Eckhart and the philosophy of Leibniz.[2]

VI. Leibniz, Mathematics and Physics

Leibniz believed that mathematics has a special place in the human search for wisdom, knowledge of the 'most sublime principles of order and perfection,' because the things of mathematics are so determinate, and exhibit their determinate inter- relations so clearly. However, the proper use of mathematics requires careful philosophical reflection. The reason why materialism has seemed attractive to serious thinkers, he argues in the *Tentamen Anagogicum* (1696), is because it lends itself well to mathematical representation, and thus to

[1] Munich 1946.
[2] "The Ideas of Natural Law and Humanity," in O. Gierke (ed.), *Natural Law and the Theory of Society, 1500-1800*, Cambridge 1934, p. 212.

calculation and rigorous inference. [3] However, we should not over-estimate the extent to which the material world lends itself to mathematics, for all mathematical 'models' are a finitary representation of an infinitary reality; and we should not forget that other aspects of reality also lend themselves similarly to mathematization. The materialist illusion is not only a mathematical mistake (which should be addressed by yet more mathematics) but also a metaphysical mistake. The alleged materialist universe is a mirage, for it violates the principle of sufficient reason, which along with the principle of contradiction governs the created world; it is thus after all not thinkable, like the mirage of the 'greatest speed.' The world's beings are not only material, but thoroughly sentient and endowed with force or conatus, a striving for perfection; and in that striving they express their Maker, as well as the intelligibility for which mathematics is apt.

Leibniz writes that "the ancients who recognized nothing in the universe but a concourse of corpuscles," as well as the modern philosophers who are inspired by them, find materialism plausible,

> because they believe that they need to use only mathematical principles, without having any need either for metaphysical principles, which they treat as illusory, or for principles of the good, which they reduce to human morals; as if perfection and the good were only a particular result of our thinking and not to be found in universal nature… It is rather easy to fall into this error, especially when one's thinking stops at what imagination alone can supply, namely, at magnitudes and figures and their modifications. But when one pushes forward his inquiry after reasons, it is found that the laws of motion cannot be explained through purely geometric principles or by imagination alone. (GP VII, pp. 271) [4]

Moreover, he adds, there is no reason to suppose that other phenomena which in that era had eluded mathematical formulation (he mentions light, weight, and elastic force) will not sooner or later prove to lie within the expressive powers of mathematics. But all such representation will be provisional, because while finitary models can express the infinitary things of nature well, they can never express them completely; and the formulation of increasingly accurate stages of representation must be governed, like nature itself, by the two great principles of contradiction and sufficient reason.

Leibniz recognizes that different sciences require different methodologies, but no matter what special features different domains exhibit, he believes that all scientific investigation must move between mathematics

---

[3] Leibniz, G. W. *Philosophische Schriften*, C. I. Gerhardt, ed. Vol. VII, pp. 270-279.

[4] "Parce qu'ils croyent de n'avoir à employer que des principes de mathematique, sans avoir besoin ny de ceux de metaphysique qu'ils traitent de chimeres, ny de ceux du bien qu'ils renvoyent à la morale des hommes, comme si la perfection et le bien n'estoient qu'un effect particulier de nos pensées, sans se trouver dans la nature universelle… il est assez aisé de tomber dans cette erreur, et par tout quand on s'arreste en meditant à ce que l'imagination seule peut fournir, c'est à dire aux grandeurs et figures, et à leurs modifications. Mais quand on pousse la recherche des raisons, il se trouve que les loix du mouvement ne scauroient estre expliquées par des principes purement geometriques, ou de la seule imagination." (GP, VII, 271)

and metaphysics. Mechanics, in particular, is best viewed as a middle term between mathematics and metaphysics, and so too Leibniz's account of time. Of all the parameters involved in mechanics, time is the least tied to any specific content, even though it presents a determinate topic for scientific investigation. Thus, a closer look at Leibniz's account of time presents an especially 'pure' version of the interaction of mathematics and philosophy in the service of progressive knowledge.

As Yvon Belaval, Gilles-Gaston Granger, François Duchesneau, and Daniel Garber have variously argued on the basis of a wide range of texts, Leibniz's novel conception of scientific method has two dimensions (Belaval 1960, Granger 1981, Duchesneau 1993, Garber 2009). His account of method is informed by that of Bacon and Descartes but diverges from both in significant ways and combines aspects of each. He borrows from Bacon the project of collecting empirical samples from the laboratory and field, inductively, and compiling tables, taxonomies and encyclopediae, always with the expectation of discovering harmonies and analogies, deeper systematic organization in the things of nature. He borrows from Descartes the assurance that the indefinite presentations of sense can be associated with precise mathematical concepts, and thus by analogy be re-organized as ordered series, which can then be subject to deductive inference.

In the *Tentamen Anagogicum*, Leibniz mentions the use of geometry in the "analysis of the laws of nature," and goes on in that essay to develop the ideas of Fermat, Descartes, and Snell in optics using a series of geometrical diagrams, as well as the ideas of maximal and minimal quantities developed in his infinitesimal calculus. In an earlier, more general essay, "Projet d'un art d'inventer," (1686), he invokes arithmetic as a source of formulations apt for analysis considered as the art of invention, "which would have the same effect in other subject matters, like that which algebra has on arithmetic. I have even found an astonishing thing, which is that one can represent all kinds of truths and inferences by means of numbers." (C 175) [5] The idea is to locate nominal definitions, involving a finite number of requisites, and then reason on the basis of them:

> I found that there are certain primitive terms—if not absolutely primitive then at least primitive for us—which once having been consituted, all our reasonings could be made determinate in the same way as arithmetical calculations; and even in the case of those reasonings where the data, or given conditions, don't suffice to determine the question completely, one could nevertheless determine [metaphysically] mathematically the degree of probability. (C176) [6]

[5] "qui feroit quelque chose de semblable en d'autres matieres, à ce que l'Algebre fait dans les Nombres. J'ay même trouvé une chose estonnante, c'est qu'on peut representer par les Nombres, toutes sortes de verités et consequences." (C 175)

[6] "Je trouva donc qu'il y a des certains Termes primitifs si non absolument, au moins à nostre egard, les quels estant constitués, tous les raisonnements se pourroient determiner à la façon des nombres et meme à l'egard de ceux ou les circonstances données, ou data, ne suffisent pas à la determination de la question, on pourroit neantmoins determiner [Metaphysiquement] mathematiquement le degré de la probabilité." (C 176) (Couturat indicates by brackets a word or phrase that Leibniz has crossed out.)

The clarity and determinacy of mathematical things is crucial to this method of analysis. “The only way to improve our reasonings is to make them as salient as those of mathematicians, so that one can spot an error clearly and quickly, and when there is a dispute, one need only say: let us compute, without further ado, to see who is right.” (C176) [7]

Early modern mechanics begins by exploiting an already existing trove of empirical records, the precise tables left by centuries of astronomers tracking the movements of the moon, the planet, certain stars and the named constellations which culminate in the careful data of Tycho Brahe, so important to Kepler, and which are soon thereafter improved by the measurements of astronomers equipped with telescopes. Luckily for human science, the solar system is both an exemplary mechanical system (just a few moving parts, isolated, and so almost closed despite the occasional comet) and a very precise clock; so, its study richly repaid the efforts of early modern physicists.

How shall these two occupations, empirical compilation and theoretical analysis, be combined? Leibniz calls on metaphysics, in particular the principle of sufficient reason in the guise of the principle of continuity, to regulate a science that must be (due to the infinite complexity of individual substances) both empirical and rationalist. The correlation of precise empirical description with the abstract conception of science *more geometrico* is guaranteed by the thoroughgoing intelligibility and perfection of the created world, and encourages us to work out our sciences through successive stages, moving back and forth between a concrete taxonomy and abstract systematization. Empirical research furnishes nominalist definitions—finite lists of requisites for the thing defined—which can set up the possibility of provisionally correct deductions, though every such definition due to its finitude can be corrected and amplified; mathematics provides the rule of the series.

At the beginning of Ch. 6, “La philosophie de l’histoire” of his book *Leibniz historien*, Louis Davillé writes:

> From the metaphysical point of view, Leibniz, contemplating together the diversity and uniformity of things and beings, also follows two opposed principles, recognized earlier by scholastic philosophers, the principle of individuation and the principle of analogy, which he expresses by two phrases, in French: “l’individualité enveloppe l’infini” and “c’est tout comme ici.” But this is only an appearance. Always seeking to reconcile opposites, he unites these two points of view in “la conception d’un développement à la fois spontané et régulier des êtres,” through the contemplation of the universal harmony, principle of things persisting in diversity balanced by identity. This powerful and original synthesis he calls the law of continuity… The notion

[7] “L’unique moyen de redresser nos raisonnemens est de les rendre aussi sensibles que le sont ceux des Mathematiciens, en sorte qu’on puisse trouver son erreur à veue d’oeil, et quand il y a des disputes entre les gens, on puisse dire seulement: contons, sans autre ceremonie, pour voir lequel a raison.” (C 176)

> of continuity plays a leading role in Leibniz's philosophy, differentiating it sharply from that of Descartes. One might call the law of continuity the "general method" of Leibniz, and this expression doesn't seem to be an exaggeration. (Davillé 1909, pp. 667-68)

Davillé notes three formulations of the principle of continuity: 1) Time and space are divisible to infinity. 2) The order of the input terms ('principes') is expressed in the order of the output values ('consequences') and vice versa. (I use the anachronistic vocabulary of functions here, to capture the generality of Leibniz's words.) This principle, 'of harmony,' is a corollary of the principle of reason. It can also be understood as the principle of induction, that the cause can always be retrieved from the effect; the principle of differentials (ratios between finite magnitudes persist even when the magnitudes are reduced to infinitesimals, as in the 'characteristic triangle'); and the principle of analogy. 3) Change never occurs in jumps, but always by degrees. Leibniz also calls this the principle of transition; like the principle of the identity of indiscernibles, Leibniz deduces it from the principle of sufficient reason. The principle of continuity, taken as a principle governing *history*, corresponds to a conception of historical evolution, slow and successive change due to natural and immanent causes. (Davillé 1909, pp. 668-70)

This model of scientific inquiry accords very well with Leibniz's own investigations into mechanics and planetary motion, and so too his mathematical-metaphysical account of time. Given the subtlety of his conception of method, I will argue that his account of time is deeper and more multivalent than that of Newton, which explains why it has proved to be more suggestive for physicists in succeeding eras and especially during the last century.

Descartes' definition of motion in the *Principles* is "the transfer of one piece of matter, or one body, from the vicinity of those bodies which are in immediate contact with it, and which are regarded as being at rest, to the vicinity of other bodies." (AT viii 53). Thus, motion and rest can be interpreted only as a difference in velocity or acceleration established with respect to a reference frame of other bodies; no absolute determination of motion or rest is possible. This definition of motion and rest is so radically relativistic that, strictly speaking, the Cartesian observer, by choosing different reference frames, may not only shift from judging that a given particle is at rest to judging that it is in inertial motion (rectilinear motion at a constant speed), but also to judging that its trajectory should be considered accelerated (and perhaps curvilinear). Descartes himself never seems to have considered this consequence of his relativism, nor its inconsistency with his invocation of inertial motion in the first two rules of motion given at the beginning of the *Principles*. Perhaps the inconsistency escaped his notice because in his mechanics there is no accelerated motion: the inherent motion of corpuscles is rectilinear and constant in speed (that is, inertial) and the transfer of momenta (defined for each contributing corpuscle as bulk times constant speed) in a collision is instantaneous. His mechanics is thus undynamical and atemporal; its laws are not only time-reversal invariant, they do not involve time as an independent variable: nothing in Descartes' mechanics varies continuously with respect to time.

Newton, however, saw and criticized this outcome, precisely because it entails that Descartes is not entitled to his own definition of inertial motion. In *De Gravitatione* (unpublished in his lifetime) Newton argues that since in Cartesian vortex mechanics all bodies are constantly shifting their relative positions with time, "Cartesian motion is not motion, for it has not velocity, nor definition, and there is no space or distance traversed by it. So it is necessary that the definition of places, and hence of local motion, be referred to some motionless thing such as extension alone or space in so far as it is seen to be truly distinct from bodies" (Newton 1962, p. 131). That is, Descartes cannot give empirical procedures in his mechanics that allow him to distinguish inertial motion from accelerated motion.

Newton responds with his well known thought experiment about the revolving bucket, arguing that the presence of forces is the sign of true (accelerated) motion; forces are real and measurable. But he goes beyond that claim: in Book III of the *Principia*, he writes,

> Hypothesis I: The center of the system of the world is at rest.
>
> Proposition 11, Theorem 11: The common center of gravity of the earth, the sun, and all the planets is at rest. (Newton 1999, p. 816)

Taken together, these claims offer an absolutist conception of space that makes not only accelerated motion, but even uniform motion, definable with respect to a Euclidean space that has been provided with a center and axes. By countering so strongly Descartes' relativism and subsequent loss of the distinction between inertial motion and accelerated (straight or curvilinear) motion, Newton has sacrificed the equivalence of inertial reference frames and thus his own first law. He has also postulated a spatio-temporal structure that cannot be empirically verified, a set of Cartesian coordinates for the Euclidean space of his planetary mechanics, which violates his methodological principle of not invoking merely metaphysical hypotheses. Newton is not entitled to the equivalence of rest and inertial motion, which is just as essential to his system as Descartes' concept of inertial motion is to his system. (Grosholz 2011)

Leibniz acknowledged but was not troubled by the consequences of Descartes' relativism, and extended it to time. Thus in a commentary on the *Principles*, "Critical Thoughts on the General Part of the Principles of Descartes," (unpublished in his lifetime), Leibniz writes about *Principles* II, Articles 25 and 26:

> If motion is nothing but the change of contact or of immediate vicinity, it follows that we can never define which thing is moved. For just as the same phenomena may be interpreted by different hypotheses in astronomy, so it will always be possible to attribute the real motion to either one or the other of the two bodies which change their mutual vicinity or position. Hence, since one of them is arbitrarily chosen to be at rest or moving at a given rate in a given line, we may define geometrically what motion or rest is to be ascribed to the

> other, so as to produce the given phenomena. Hence if there is nothing more in motion than this reciprocal change, it follows that there is no reason in nature to ascribe motion to one thing rather than to others. The consequence of this will be that there is no real motion. (GP IV, 369) [8]

This is just what Newton says! But for Leibniz, it is not a problem, certainly not a problem to be banished by postulating absolute space and time as the arena for motion. Rather, he makes the following claim: "Thus, in order to say that something is moving, we will require not only that it change its position with respect to other things but also that there be within itself a cause of change, a force, an action." [9] Newton proposes that whenever acceleration occurs, it is due to the action of forces; Leibniz proposes that whenever any motion occurs, it is due to the action of forces. This doesn't mean that he has reverted to Aristotelianism, but is instead an expression of his pan-animism. What Leibniz means by force is not Newtonian force, but something more like energy, internal to the body. Leibniz believes that no body is ever truly at rest, for all bodies are ensouled: motion thus becomes an expression of *conatus*, as individual substances jostle each other for a place within the Cartesian plenum at all times. (GP IV, pp. 354-92)

In this picture of the universe, we see the principle of sufficient reason at work, fashioning Lebniz's mechanics along with mathematics. The universe must be a plenum, and the individual substances in that plenum are jostling each other in an effort to attain perfection: everything strives. Indeed for Leibniz even unactualized possibles strive: essences strive for existence. In the realm of ideas, this striving sorts ideas out into an infinity of possible worlds, and (with the beneficent cooperation of God) precipitates one world into creation; in the created world, it induces vortical motion in the plenum as well as temporality. Time is the expression of the incompatibility of things; because creation involves plurality, mentality, and mutual limitation, all things are active, passive and intentional. This is the best of all possible worlds because it is continually becoming more perfect, on into the infinite open future: creation is a continuous temporal process. In the law of the series, the independent variable is always time. Thus matter is not merely extended, but involves resistance and action; and it develops: Leibniz's science will also be a natural history.

Having invented a supple and powerful notation for his version of the infinitesimal calculus during his sojourn in Paris (1672-76), Leibniz proceeded to work out a theory and practice of differential equations, in which

---

[8] Si motus nihil aliud est quam mutatio contactus seu viciniae immediatae, sequitur nunquam posse definiri, quaenam res moveatur. Ut enim in Astronomicis eadem phaenomena diversis hypothesibus praestantur, ita semper licebit, motum realem vel uni vel alteri eorum tribuere quae viciniam aut situm inter se mutant; adeo ut uno ex ipsis pro arbitrio electo, tanquam quiescente, aut data ratione in data linea moto geometrice definiri queat, quid motus quietisve reliquis tribuendum sit, ut data phaenomena prodeant. Unde si nihil aliud inest in motu, quam haec respectiva mutatio, sequitur nullam in natura rationem dari cur uni rei potius quam aliis ascribi motum oporteat. Cujus consequens erit, motum realem esse nullum. (GP IV, 369)

[9] "Itaque ad hoc, ut moveri aliquid dicatur, requiremus non tantum ut mutet situm respectu aliorum, sed etiam ut causa mutationis, vis, actio, sit in ipso." (GP IV, 369)

the dependence of different forms of accelerated motion on time could be clearly expressed by the term ‘d*t*’. One application of this method was to planetary motion. While in Vienna on his way to Rome in 1688, Leibniz read Newton’s *Principia*, took extensive notes and then wrote a series of papers that culminated in the *Tentamen de Motuum Coelestium Causis* (*Acta Eruditorum*, Feb. 1689), where he proposed differential equations that would characterize planetary motion. Leibniz combined Cartesian vortex theory with Newton’s reformulation of Kepler’s laws, locating the planets in ‘fluid orbs’rather than empty space, in order to derive the laws governing central forces while avoiding the problem of action at a distance. Whereas Newton calculates the deviation from the tangent to the curve, Leibniz expresses the situation with a single differential equation, by calculating the variation of the distance from the center, comparing the distances at different times by a rotation of the radius. The upshot of his calculation is that the effect of gravity is $[(2h^2) / (ar^2)]\, dt^2$, so that the ‘solicitation of gravity’ (conceptualized in Cartesian terms as the action of a vortex) is inversely proportional to the square of the distance, which was of course the result Leibniz was trying to reproduce. (Aiton 1985, Ch. 6; Bertoloni Meli 1993, Ch. 4)

For Leibniz, space is the expression in the created world of the logical order of compossibility among individual substances, and time is the logical order of incompatability among individual substances. [10] Thus, space and time only come into being with the creation of this material universe, the best of all possible worlds, and have only a secondary ontological status, because they are constituted as relational structures of the things with primary ontological status, individual substances. This is the basis of Leibniz’s relationalism; but we must recall that his relationalism is deployed on the basis of a method which is two-tiered, both mathematical (seeking a precise mathematical correlate for the law of the series) and metaphysical while at the same time empirical (examining and tabulating evidence in an ongoing search for the systematic organization of things). The true scientist will find ways to put the mutual adjustment of nominalistic form with the investigation of the infinitely complex, infinitely ordered world of individual substances, in the service of the progress of knowledge; this process requires both mathematics and metaphysics.

To correlate time with precise mathematical concepts, Leibniz chooses as the correct representation the straight Euclidean line, endowed with directionality by Descartes’ analytic geometry, which assigns positive and negative numbers—real numbers we would say—to the line. In some texts, it appears that Leibniz holds time to be a half-line, given what he writes to Clarke in the fifth letter of the Leibniz-Clarke correspondence (GP VII, pp. 389-420). Since this is the best of all possible worlds, created by God, the universe must constantly increase in perfection, and so has a temporal beginning point but no end. Thus it is metaphysically important that the number-line is both geometrical and arithmetical. As arithmetical, it expresses the fact that time is asymmetric; time may be counted out in units, like seconds or years, and the numbers increase in a unidirectional order without bound to infinity. The asymmetry of time follows from the metaphysical ground that everything strives. As geometrical, the number-line expresses the fact that time is a continuum; units of time like seconds are not atoms, but

[10] See, for example, GP II, pp. 248-53.

conventionally established, constant measures of time, as the inch is a measure of continuous length. An instant is only the marker of a boundary of a stretch of time, not what time is composed of; we misunderstand what an instant is, Leibniz observes, if we conceive of it as an atom of time. Time must be both measured and counted.

This duality of time is not however without conundrums. Analysis in arithmetic leads us to the unit; but in geometry it leads us to the point. Whole numbers are composed of units, but lines are bounded by points, not composed of them; Cartesian reductionism is useful as an approach to arithmetic, but not to geometry. In a letter to Louis Bourguet, written just before the correspondence with Clarke, in August 1715, Leibniz writes,

> As for the nature of succession, where you seem to hold that we must think of a first, fundamental instant, just as unity is the foundation of numbers and the point is the foundation of extension, I could reply to this that the instant is indeed the foundation of time but that since there is no one point whatsoever in nature which is fundamental with respect to all other points and which is therefore the seat of God, so to speak, I likewise see no necessity whatever of conceiving a primary instant. I admit, however, that there is this difference between instants and points—one point of the universe has no advantage of priority over another, while a preceding instant always has the advantage of priority, not merely in time but in nature, over following instants. But this does not make it necessary for there to be a first instant. There is involved here the difference between the analysis of necessities and the analysis of contingents. The analysis of necessities, which is that of essences, proceeds *from the posterior by nature to the prior by nature*, and it is in this sense that numbers are analyzed into unities. But in contingents or existents, this analysis *from the posterior by nature to the prior by nature* proceeds to infinity without ever being reduced to primitive elements. Thus the analogy of numbers to instants does not at all apply here. It is true that the concept of number is finally resolvable into the concept of unity, which is not further analyzable and can be considered the primitive number. But it does not follow that the concepts of different instants can be resolved finally into a primitive instant. (GP III, pp. 580-83) [11]

[11] " Pour ce qui est de la succession, où vous semblés juger, Monsieur, qu'il faut concevoir un premier instant fondamental, comme l'unité est le fondement des nombres, et comme le point est aussi le fondement de l'etendue: à cela je pourrois repondre, que l'instant est aussi le fondement du temps, mais comme il n'y a point de point dans la nature, qui soit fondamental à l'egard de tous les autres points, et pour ainsi dire le siege de Dieu, de meme je ne vois point qu'il soit necessaire de concevoir un instant principal. J'avoue cependant qu'il y a cette difference entre les instans et les points, qu'un point de l'Univers n'a point l'avantage de priorité de nature sur l'autre, au lieu que l'instant precedent a tousjours l'avantage de priorité non seulement de temps, mais encor de nature sur l'instant suivant. Mais il n'est point necessaire pour cela qu'il y ait un premier instant. Il y a de la difference en cela entre l'analyse des necessaires, et l'analyse des contingens: l'analyse des necessaires, qui est celle des essences, allant a *natura posterioribus* ad *natura priora*, se termine dans les notions primitives, et c'est ainsi que les nombres se resolvent en unités. Mais dans les contingens ou existences cette analyse a *natura posterioribus* ad *natura priora* va à l'infini, sans qu'on puisse jamais la reduire à des elemens primitifs. Ainsi l'analogie des nombres aux instans ne procede point icy. Il est vray que la notion des nombres est resoluble enfin dans la notion de l'unité qui n'est plus resoluble, et qu'on peut considere comme le nombre primitif. Mais il ne s'ensuit point qu e les notions des differens instans se resolvent enfin dans un instant primitif." (GP III, 581-82)

The analysis of time requires the scientist to proceed both by the analysis of necessities, using the line whose continuity is the best expression mathematics provides for infinite complexity; and by the analysis of contingents, using the natural numbers whose linear ordering and asymmetry is the best mathematical expression of irrevocability. Leibniz goes on to observe that the use of mathematics does not solve the metaphysical question whether time has a beginning, which leads one to suppose that more metaphysics and more empirical research are required. He writes:

> Yet I do not venture to deny that there may be a first instant. Two hypotheses can be formed—one that nature is always equally perfect, the other that it always increases in perfection. If it is always equally perfect, though in variable ways, it is more probable that it had no beginning. But if it always increases in perfection (assuming that it is impossible to give its whole perfection at once), there would still be two ways of explaining the matter, namely, by the ordinates of the hyperbola B or by that of the triangle C. [i]

Here Leibniz gives the following figures:

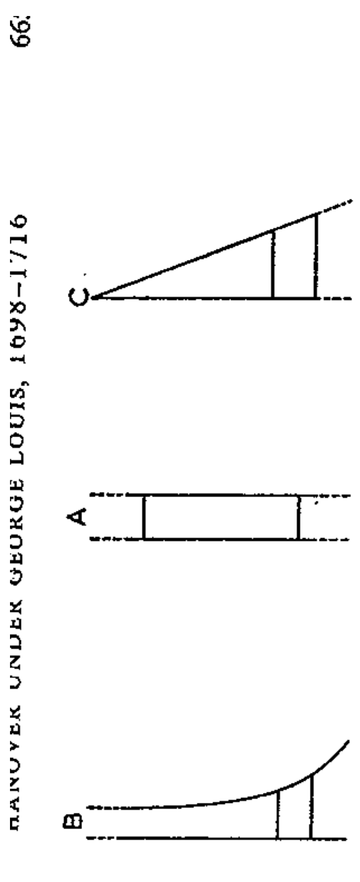

Fig. 38.

His explanation of these diagrams shows that, despite what he would shortly write to Clarke, he was perhaps not convinced that time has a beginning:

> According to the hypothesis of the hyperbola, there would be no beginning, and the instants or states of the world would have been increasing in perfection from all eternity. But, according to the hypothesis of the triangle, there would have been a beginning. The hypothesis of equal perfection would be that of rectangle A. I do not yet see any way of demonstrating by pure reason which of these we should choose. But though the state of the world could never be absolutely perfect at any particular instant whatever according to the hypothesis of increase, nevertheless the whole actual sequence would always be the most perfect of all possible sequences, because God always chooses the best possible. (GP III, 582-83) [ii]

In any case, Leibniz's conception of method requires that time be investigated not solely by pure reason or pure mathematics, which he admits here to being inconclusive; time must also be investigated empirically. It must be considered as the relational structure of the individual substances that exist, insofar as they are not logically compatible with each other. This means that we may have to revisit the formal structures we have just been discussing, in light of what we discover about the physical universe. The principle of sufficient reason governs the created world; not only does it entail that everything is determinate and intelligible (which for Leibniz means, thinkable), it also entails that everything strives for perfection. Thus, the essences that are ideas in the mind of God strive for existence, but only those that constitute this best of all possible worlds succeed; and in the created world, the essences continue to jostle each other, to interfere with each other, as they all strive. This dynamic quality of ideas produces time, as their harmonies produce space; creation entails plurality and mutual limitation, activity and passivity. And the time that is produced is asymmetrical, as creation tends towards greater perfection, a harmonious dissention among the sentient, active individual substances.

What Leibniz heralds is the now received belief that matter is not passive and inert, or dead: even a molecule is mobile, active, forceful, and sensitive. As he writes in the *Monadology*, sec. 66-69:

> 66. (…) there is a world of creatures, of living beings, of animals, of entelechies, of souls in the least part of matter.
> 67. Each portion of matter can be conceived as a garden full of plants, and as a pond full of fish. But each branch of a plant, each limb of an animal, each drop of its humors, is still another such garden or pond.
> 68. And although the earth and air lying between the garden plants, or the water lying between the fish of the pond, are neither plant nor fish, they contain yet more of them, though of a subtleness imperceptible to us, most often.

69. Thus there is nothing fallow, sterile, or dead in the universe, no chaos and no confusion except in appearance (…). (GP IV, p. 618-619) [iii]

VII. Leibniz, Geology and Biology

In the writings of Fox Keller, we see a useful history of the development of biology from the late 19th century on, and a useful articulation of issues that distinguished the life sciences from physics: the role of mathematics and mathematical models, the relation of material causes and teleology, the seemingly endless complexity and unpredictability of living systems, the odd fact that living things includes us, the scientific discovery that the earth and living things have a history. I have tried to show that Leibniz's conception of method, combining mathematics and a metaphysics that asserts that 'everything strives,' often chimes with the issues raised by Fox Keller, and also seems to be a harbinger of Darwin. Thus, the next part of my project is a very much a work in progress: I am trying to find out more about the line of succession between Leibniz and Darwin. I'd also like to propose that earlier twentieth century philosophers of the life sciences, like Bergson and Merleau-Ponty, may have misunderstood or misread Leibniz, who could have been more helpful to them; and that it might also be the case for contemporary philosophers like Fox Keller and Lewontin.

To make the first argument, I need to find out more about last 17th and 18th century figures investigating geological and biological systems, who were linked to Leibniz and transmitted his ideas to Kant and the German Romantics, and so to England. Here is the beginning of a timeline:

Leibniz (1646-1716) and friends (who are the most important friends and correspondents?)
Friedrich Hoffmann (1660-1742), physician and chemist, Halle
Christian Wolff (1679-1754), Halle and Marburg
Anton W Amo (1703-1757), Halle and Jena
James Hutton (1726-1797), *Theory of the Earth* (1788)
John Playfair (1748-1819), who wrote about Hutton
J.-B. Lamarck (1744-1829), theorized evolution in *Philosophia zoologique* (1809)
Johann Friedrich Blumenbach (1752-1840), at Goettingen, physician and naturalist
Charles Lyell (1797-1875), *Principles of Geology* (1830): major influence on Darwin
Richard Owen (1804-18920, biologist and paleontologist

What role does Leibniz's controversy with Stahl over the theory of chemistry play here? The exchange was translated into English and edited, with an introduction, by François Duchesneau and Justin Smith (Yale University Press, 2016). They discuss the order of nature, and the relation of causality and teleology.

How influential, during this long period, was the *Protogaea*, where Leibniz applies his conception of method to the study of geology. (Ed. C. Cohen and A. Wakefield, University of Chicago Press, 2008.) Leibniz worked in the mines of the Harz Mountains, for the Duke of Hannover, and became very interested in fossils. To understand them, he read Descartes, Nicolaus Steno / Niels Stenson, Burnet, Scilla, Agricola, Kircher, and Becherd, as he tried to find a balance between the universal and particular, global and local. How important was Steno to Leibniz: Troels Kardel and Paul Maquet edited Nicolaus Steno: Biography and Original Papers of a 17th C. Scientist (Springer 2013). Helmut Hoelder wrote a doctoral dissertation on Stensen's Bedeutung fuer die Begruendung des Geologie und Palaeontologie, and published Geologie und Palaeontogie in Texten und ihre Geschichte (Munich 1960), and an article in Studia Leibniziana Sonderheft 1 (105-125), "Leibniz's erdgeschichtliche Konzeptionen."

After Leibniz's Preamble, he speculates that the first formation of the earth was through fire, using the Principle of Sufficient Reason, and traces of atomism (without atoms: matter is divisible all the way down). He examines different opinions concerning the creation of the globe: fire, water, earth, and considers various kinds of material evidence: sea salt, fires, precipitation of sediment. Then he revisits the ancient stories of the great floods and brings them into relation with the depositing of sediments in layers; the distinction between igneous rock and sedimentary rock. A new science: geology! He asks, what was the sources of the water that covered the earth? Where did it go? Why do we find seashells on mountaintops, and shark's teeth here and there. He also wonders where the shapes of various fish imprinted on slate come from, and argues that they are not "games of nature." Some are fresh water fish, and some are sea fish: we find them with the finest details of their fins and scales; we find many different kinds of fish enclosed in the same space; we find them in 'hanging veins.' (We need to keep in mind that Leibniz couldn't have known about the theory of continents colliding and creating the great mountain chains.) So, he goes on investigating fossils: marine shells: nautilus, urchin, snails, other fish teeth; parts of real (still existing) animals. He notes the distinction of fossils from crystals (and fairy tales) and re-emphasizes the empirical importance of shark's teeth. He also notes traces of huge animals (mammoths?) but he doesn't seem to think about the possibility of extinction.

Apropos these questions, a book I've found helpful is the collection *The Life Sciences in Early Modern Philosophy*, edited by Ohad Nachtomy and Justin Smith. Ohad Nachtomy offers the essay "Infinity and Life: The Role of Infinity in Leibniz's Theory of Living Beings," where he first refers us to the pertinence of Alexander Koyré's *From the Closed World to the Infinite Universe* (1957) and the changes that arrive in our understanding of the cosmos from Copernicus to Newton and Leibniz. He also reminds of us of the importance of the early microscope observers: Malighi, Hook and Leeuwenhoek. Philosophically, we recall Pascal's famous passage: Man in between the two infinities. Pascal and Descartes saw an irreconcilable gap between the infinite creator and the finite creatures. Leibniz, however, begins working on the infinitesimal calculus in Paris, with Huygens: infinitesimals can be used effectively in calculations! You can deal with infinity without falling into paradox.

Leibniz's metaphysics is very infinitary, both in the large and the small and… sideways (the realm of the possibles). Actual infinity expresses the perfection of God.

But what is the link between infinity and life? Leibniz claims, every particle of the universe contains an infinity of creatures (matter is infinitely divisible). All bodies are body-souls, even 'primitive entelechies,' so the animated machines of nature are very different from the machines that we ourselves construct. Infinity is a defining feature of living things – and everything is alive. (Here, 'The New System of Nature,' and also *The Discourse on Method, the Monadology* and *Principles of Nature and Grace, Based on Reason* are particularly important.) The downward infinity posited by Leibniz cannot be empirically verified. And it is not just a matter of infinite organs, for living machines are not aggregates or composites: they are active, perceptive, unified structures, regulated by law, intelligible. This infinity is not divine absolute infinity, nor mathematical quantitative infinity. Infinity and perfection, being, life. What is capable of perfection? (Wisdom, power). What is not? (Number and figure). Perfection as a degree of essence. God realizes the best of all possible worlds, the most perfect.

In the same volume, Lea Schweitz reminds us, in "On the Continuity of Nature and the Uniqueness of Human Life," of the importance of theomorphic rationality. Rational souls and other souls: we are capable of reflection, and imitate the divine; we are mirrors of the divine. How does this claim cohere with Leibniz's account of natural machines: nature is full of natural machines; and God is immanent in nature. Here we also find Leibniz's account of the definition of species in terms of line of generation: this prefigures the origin of species. Human beings are natural machines: Leibniz agrees with Descartes (note quotations from Descartes) that organisms are machines, but he claims that the machines of nature are organized, infinitely, all the way down: we find infinite complexity in the nested structure of living organisms. "Nature's machines have a truly infinite number of organic parts." All the components have their own entelechies, and the soul unifies them all.

Worrying about classification of organisms, Leibniz claims that species are defined by generation: species are not based on arbitrary classification, but on the objective fact that all the members of the same species have the same origin. (Thus, we don't need a miracle from God, or Malebranche's occasionalism.) Leibniz's sacramental view of nature includes nested individuality: nature that is teeming with life. We discover this with the help of a microscope! Every substance in a sense is an imago dei: every substance expresses the universe, past, present and future, however confusedly, and God is present in every place. Human beings however have reason. We rise from function to action to moral action. We have a social relation with God: we are citizens in the City of God. So, she concludes, Leibniz is not a fully modern thinker, nor is he a pre-modern thinker.

In "The Organism-Mechanism Relationship: An Issue in the Leibniz-Stahl Controversy,' François Duchesneau that the natural of the relationship between mechanism and organism lies at the heart of this famous controversy. He begins with an exposition of Friedrich Hoffman's use of the novel term 'organism.' Hoffmann was a correspondent of Leibniz's, and a professor of medicine at Halle, as was Stahl. How should nature be understood in relation to the preservation of life and the formation of organic bodies? Against Descartes, Hoffmann argues that bodies have a real active force of their own; he goes to far as to conceive of bodies as 'extended forces.' Organic bodies differ from inanimate bodies by a higher degree of structural complexity; but the mechanism of the body depends on necessary laws, physical and chemical processes. He appeals to the Leibnizian notion of the 'machines of nature' whose immense (indeed, infinite) complexity is not found in the finite artificial machines: a harmonious organization of active and passive components. So too, the machines of nature have the power of reproduction, according to a 'seminal principle.' When Leibniz approves his dissertation in 1699, he sees a convergence between Hoffmann's understanding of the machine of the body, in opposition to that of Stahl. Moreover, Leibniz refers to and depends upon Hoffmann's understanding of 'organism' in the dispute with Stahl. In these alternative frameworks, Stahl tends to oppose mechanism and organism, while Leibniz brings them into relation, transforming both.

To go back to Davillé, and conclude: the Principle of Continuity, Davillé observes, has obvious applications in Leibniz's mathematical and scientific research, and he clearly makes use of it in natural history (geology, botany, zoology) and human history, as we have seen in the *Protogaea*. In Leibniz's monadology, there is both an internal and external continuity: each monad contains within itself the series of its own development; and it expresses the world, made up of other, equally expressive monads, whose points of view differ from those of their neighbors "par des transitions insensibles." Thus, the present is always pregnant with the future, as Jean-Pascal Anfray stresses in an essay, and wears the traces of the past, for those who know how to read them; and the least event reverberates throughout the world. Leibniz as historian is very sensitive to the ways in which the past prolongs itself, expressing itself in the present. Inspired by the Principle of Continuity, Albert Sorel wrote *L'Europe et la révolution française*, which shows in eight volumes that the French Revolution was not a revolution—a discontinuity in history—after all.

Not only does Leibniz's principle indicate that all historical development is an evolution, reminding us of the continuities of geography, of chronology, of genealogy; it also confers special importance on the details of culture, Davillé argues, for even the smallest thing is expressive of the whole. Thus, Leibniz is always preoccupied with origins, pursues hidden causes and distant consequences, loves to digress, and explores analogy wherever he can. So too Leibniz always studies the languages of the cultures he investigates, tracing etymologies, borrowings, and branchings on the great tree of Adam's language. Overall, the Principle of Continuity acts as a regulative, chastening guide, to keep historical hypotheses from veering off into improbability, and imprints on Leibniz's historical works their defining characteristics: determinism (but not fatalism), optimism, and the idea of progress.

Leibniz understands that productive scientific and mathematical discourse must carry out distinct tasks in tandem: a more abstract search for conditions of intelligibility or solvability, and a more concrete strategy for achieving successful reference, the clear and public indication of what we are talking about. The texts characteristic of successful scientific research will thus be heterogeneous and multivalent. This fact that has been missed by philosophers who begin from the view of logic, where rationality is often equated with strict discursive homogeneity and method is construed as the rewriting of science and mathematics in a formal, axiomatized language; and it has led scholars influenced by logicism, among them Louis Couturat and Bertrand Russell, to misread Leibniz. While deductive argument is important (since its forms guarantee the transmission of truth from premises to conclusion) as a guide to effective mathematical and scientific reasoning, it does not exhaust method, for Leibniz. As we have seen, Leibnizian method has two dimensions, empirical and rational, and both require analysis, whose logical structure includes abduction and induction, as well as deduction. Moreover, analysis, the search for conditions of intelligibility, is more than logic; it is a compendium of research and problem-solving procedures, which vary among investigations of different kinds of things.

An unswerving focus on logic diverts attention from other forms of rationality and demonstration. Human awareness is both receptive and active, an accomodating construal and an explanatory construction. Some empiricist or naturalist philosophers of science demand that true knowledge be an accurate construal of the way things are, but then they deny the obvious fact that all representation is distortion, however informative it is, and that representation itself changes the way things are. And explanatory analysis goes far ‘beyond’ the things that invoked it, and thus often sacrifices concrete, descriptive accuracy. Other logicist or anti-realist philosophers of science want to suppose that all knowledge, and indeed all reality, is a human construction, but then they deny the obvious fact that the world is the way it is whether we like it or not, and that it has depths that elude our construals and constructions altogether. Many an explanatory analysis has shipwrecked on the hidden shoals of reality. A more reasonable view of human knowledge is to regard it with Leibniz as a combination of focussed awareness and theoretical elaboration; thus when we combine multiple modes of representation in our scientific work we may in fact have a better chance of doing justice to what we are investigating. Such representational combination and multivocality is just what we find in Leibniz’s most important pronouncements on the nature of time.

References

Aiton, E. J. (1972) *The Vortex Theory of Planetary Motion*. London: MacDonald.

Aiton, E. (1985) *Leibniz. A Biography*. Bristol and Boston: Adam Hilger.

Belaval, Y. (1960) *Leibniz critique de Descartes*. Paris: Gallimard.

Bertoloni-Meli, D. (1993) *Equivalence and Priority*. *Newton versus Leibniz*. Oxford: Oxford University Press.

Breger, H. (1990) "Das Kontinuum bei Leibniz." *L'infinito in Leibniz: Problemi e terminologia*. Roma: Edizioni dell'Ateneo, 53-67.

Davillé, L. (1909) *Leibniz historien. Essai sur l'activité et la méthodes historiques de Leibniz*. Paris: Félix Alcan

.
Descartes, R. (1964-74) *Oeuvres*, vols. I-XII. Ed. C. Adam and P. Tannery. Paris: Vrin.

Duschesneau, F. (1993) *Leibniz et la méthode de la science*. Paris: PUF.

Duchesneau, F. (1994) *La dynamique de Leibniz*. Paris: VRIN (Mathesis Series).

Echeverría, J., ed., and Parmentier, M., tr. (1995) *La caractéristique géométrique*. Paris: VRIN (Mathesis Series).

Fichant, M. (1994a) *La réforme de la dynamique*. Paris: VRIN (Mathesis Series).

Fichant, M. (1994b) "Les axiomes de l'identité et la démonstration des formules arithmétiques '2 + 2 = 4'". *Revue international de Philosophie* 188 (1994), 175-211.

Garber, D. (2009) *Leibniz: Body, Substance, Monad*. New York: Oxford University Press.

Granger, G.-G. (1981) "Philosophie et mathématique leibniziennes," *Revue de Métaphysique et de Morale*, 86, pp. 1-37.

Grosholz, E. (1999) L'analogie dans la pensée mathématique de Leibniz." *L'Actualité de Leibniz: Les deux labyrinths*." Stuttgart: Franz Steiner Verlag (*Studia Leibnitiana* Supplementa, Vol. 34), 511-22.

Grosholz, E. (2011) "Space and Time." *The Oxford Handbook of Philosophy in Early Modern Europe*. Ed. D. Clarke and C. Wilson. Oxford: Oxford University Press, 51-70.

Grosholz, E. and Yakira, E. (1998) *Leibniz's Science of the Rational*. Stuttgart: Franz Steiner Verlag (*Studia Leibnitiana* Sonderheft 26).

Leibniz, G. W. (1960/61) *Die Philosophischen Schriften*, vols. I-VII. Ed. C. I. Gerhardt. Hildesheim: Georg Olms.

Leibniz, G. W. (1966) *Opuscules et fragments inédits*. Ed. L. Couturat. Hildesheim: Georg Olms.

Newton, I. (1962) *Unpublished Scientific Papers of Isaac Newton*. A Selection from the Portsmouth Collection in the University Library, Cambridge. Ed. A. R. Hall and M. B. Hall. Cambridge: Cambridge University Press.

Newton, I. (1999) *The PRINCIPIA. Mathematical Principles of Natural Philosophy*. [3rd Edition, 1726.] Trans. I. B. Cohen and A. Whitman. Berkeley and Los Angeles: University of California Press.

Parmentier, M. (1989) *La naissance du calcul différentiel*. Paris: VRIN (Mathesis Series)

Rutherford, D. (1995) *Leibniz and the Rational Order of Nature*. Cambridge: Cambridge University Press.

Sinaceur, H. (1988) "*Ars inveniendi* et théorie des modèles." *Dialogue* XXVII (1988), 591-613.

Yakira, E. (1989) *Contrainte, nécessité, choix: La métaphysique de la liberté chez Spinoza et chez Leibniz.*

---

[i] "Cependant je n'ose point nier qu'il y ait eu un instant premier. On peut former deux hypotheses, l'une que la nature est tousjours egalement parfait, l'autre qu'elle croit tousjours en perfection. Si elle est tousjours egalement parfait, mais variablement, il est plus vraisemblable qu'il n'y ait point de commencement. Mais si elle croissoit tousjours en perfection (supposé qu'il ne soit point possible de luy donner toute la perfection tout à la fois) la chose se pourroit encor expliquer de deux façons, savoir par les ordonnées de l'Hyperbole B ou par celle du triangle C. (GP III, 582)

[ii] "Suivant l'hypothese de l'Hyperbole, il n'y auroit point de commencement, et les instans or etats du Monde seroient crûs en perfection depuis toute l'eternité; mais suivant l'hypothese du Triangle, il y auroit eu un commencement. L'hypothese de la perfection egale seroit celle d'un Rectangle A. Je ne vois pas encor le moyen de faire voir demonstrativement ce qu'on doit choisir par la pure raison. Ceendant quoyque suivant l'hypothese de l'accroissement, l'etat du Monde ne pourroit jamais etre parfait absolument, etant pris dans quelque instant que ce soit; neanmoins toute la suite actuelle ne laisseroit pas d'etre la plus parfaite de toutes les suites possibles, par la raison que Dieu choisit tousjours le meilleur possible." (GP III, 582-83)

[iii] "66. … il y a un Monde de Creatures, de vivans, d'Animaux, d'Entelechies, d'Ames dans la moindre partie de la matiere. 67. Chaque portion de la matiere peut être conçue comme un jardin plein de plantes, et comme un étang plein de poissons. Mais chaque rameau de la plante, chaque membre de l'Animal, chaque goutte de ses humeurs est encor un tel jardin ou un tel étang. 68. Et quoyque la terre et l'air interceptés entre les plantes du jardin, ou l'‘eau interceptée entre les poissons de l'étang, ne soit point plante, ny poisson, ils en contiennent pourtant encor, mais le plus souvent d'une subtilité à nous imperceptible. 69. Ainsi il n'y a rien d'inculte, de sterile, de mort dans l'univers, point de Chaos, point de confusions qu'en apparence;" (GP VI, 618-619)