

Leibniz and *The Logic of Life*

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Résumé

Le présent article compare la compréhension contemporaine de la vie avec sa conception leibnizienne, dont elle partage certains traits, en particulier depuis l'émergence de la génétique moléculaire dans les années 1950. Ma principale source pour notre appréhension contemporaine de la notion de vie est l'ouvrage influent de François Jacob: *La logique du vivant* (1970). Je développerai l'analogie en m'attachant à trois questions: 1) l'usage que fait Leibniz de la forme substantielle, fonctionnant comme un programme constitutif pour le développement des individus, que je comparerai à la notion contemporaine de programme génétique; 2) la notion d'un tel programme de développement comme le signe distinctif des êtres vivants, que ce soit pour Leibniz ou les biologistes actuels; 3) la définition leibnizienne des individus possibles (*via* leur notion complète) et la notion d'«espace séquentiel» dans la théorie du génome. Cette étude comparative contribuera, je crois, à montrer que la conception leibnizienne de la vie, même si elle est dépassée sous bien des aspects, est une source influente (bien que méconnue) de notre conception contemporaine de la vie. Dans le même temps, une telle comparaison servira aussi à montrer combien le concept de vie utilisé dans la biologie actuelle diffère radicalement de celui développé par Leibniz.

1. Introduction

In her article “Leibniz and the Logic of Life”, Catherine Wilson argues against “an influential teaching in the history of science that biology did not exist as a science before 1750, and that there was no concept of life before that date which might have justified the establishment of such a branch of study” (p. 237)¹. In contrast to this view, Wilson shows that Leibniz “had a sharp and well defined concept of life which had both an empirical and a metaphysical face” (p. 252). In the present article, I compare Leibniz’s concept of life not with that of his contemporaries but with that of ours. This comparison will contribute, I believe, in showing that Leibniz’s conception of life, while outdated in many respects, is an influential (but under recognized) source for our contemporary concept of life.

I will first highlight some facets of Leibniz’s metaphysical concept of life and then compare them to facets of the current concept of life, that is, the way in which the concept of life is understood by some notable contemporary biologists and, in particular, to the way in which it was understood during the rise of molecular biology in second half of the 20th century. Such a comparison will show that some of Leibniz’s insights regarding the question of life not only contributed

1 Catherine Wilson: “Leibniz and the Logic of Life”, in: *Revue internationale de philosophie* 48/188 (1994), pp. 237-253.

to the formation of biology as a science in the 18th century but also that some of his insights remain current today. At the same time, such a comparison will also serve to show in which respects the concept of life used in current biology radically differs from that of Leibniz's.

An assumption underlying this comparison is that both Leibniz and contemporary biologists consider living beings to be individuals (an assumption that goes back at least to Aristotle)². On the basis of this assumption, I develop an analogy between the Leibnizian and the current biological concepts of individuality. While there may not be at present a shared biological concept of individuality, the features I focus on here are broadly speaking non-controversial as contenders for characterizing living things as individuals.

My main source for the contemporary notion of life is François Jacob's influential study *La logique du vivant* (1970, 1973 in English). Comparing Leibniz's work with Jacob's shows that Leibniz's insights regarding the notions of individuality, life, and possibility are interestingly related to what Jacob calls, *la logique du vivant*. Thus, the title of this article, Leibniz and *The Logic of Life*, makes a threefold reference: to Jacob's book, to its main theme, and to Wilson's article (1994), mentioned above. Jacob's text was published in the early 1970s. The major principles of genetics, on which I focus here, however, are still current and fully confirmed by further developments in biology. I bring that point out mainly through the recent writings of the historian and philosopher of biology, Evelyn Fox Keller³.

I will develop three points of analogy: (1) Leibniz's usage of a substantial form functioning as a constitutive program for the development of individuals and the contemporary notion of a genetic program; (2) the notion of such a developmental program as a distinct mark of living beings for both Leibniz and contemporary biologists; and (3) Leibniz's definition of possible individuals (through their complete concepts) and the notion of "sequence space" in contemporary genomic theory.

Before addressing the comparison directly, a few words of caution regarding the methodology I adapt here. Clearly, comparing the views of a 17th century philosopher with contemporary biology is a delicate task. Indeed, any comparison between Leibnizian metaphysical notions and current biological notions reveals many points of difference. I would like to call attention at the outset to a number of these. (1) The difference between the fixed nature of Leibnizian individuals, which are seen as God's creation, and the evolving nature of individuals in contemporary theory of evolution; (2) the difference between a Leibnizian world without causal interaction among individuals and the world of contemporary

2 As David Hull writes, "[T]he first thing a biologist does in arguing that an entity can or cannot function as a unit of selection is to argue that it is or is not an individual" (David Hull: "Individuality and selection", in: *Annual Review of Ecology and Systematics* 11 (1980), pp. 311-332, p. 314).

3 See Evelyn Fox Keller: *The Century of the Gene*, Cambridge, Mass. 2000, and Evelyn Fox Keller: *Making Sense of Life: Explaining Biological Development with Models, Metaphors, and Machines*, Cambridge, Mass. 2002.

biology that focuses on the chemical interactions between genes, proteins, cells, organisms; (3) the fundamental role Leibniz ascribes to God is obviously not to be found in contemporary biology. Despite these (and other) dissimilarities between the Leibnizian concept of individuality and the current one in biology, I will attempt to show that a comparison between them is instructive for understanding Leibniz as well as his contribution to the history of the life sciences. In fact, for this purpose, the dissimilarities are no less instructive than the similarities. As we shall see, the perspective of molecular biology reveals that some of Leibniz's insights were profound and far-reaching. It remains equally possible that some of Leibniz's insights were not only of pure historical interest but that they may still be pertinent to questions that puzzle philosophers of biology today. This point concerns, in particular, two questions: (1) how to characterize life and distinguish living from non-living beings, which is my main topic below, and (2) how to define biological individuality, especially in the context of the debate over the units of selection, which I will not discuss here⁴.

The first section presents Leibniz's mature view of living things as a reconciliation of the Aristotelian and the Cartesian models for understanding them; the second section suggests that Leibniz's notion of a complete concept, which functions as a program for its development and self-regulation is, in a way, comparable to Jacob's genetic program; the third section suggests that this notion of an internal program has various features that make it an attractive candidate for characterizing organic unity and life. The fourth section suggests that the Leibnizian notion of individuality and the contemporary biological one are both related to combinations of simple elements and exemplify similar connections between possibility, complexity, and variability. In this way, each section develops one point of analogy between Leibniz's and the contemporary concepts of life. In order not to lose sight of the significant conceptual and historical gaps, I conclude with a reminder of some of the dissimilarities between Leibniz's view of living things and the contemporary one.

2. Some Features of Leibniz's View of Life

First, I would like to draw a brief sketch of Leibniz's view of life as it develops in the context of his own philosophy. To present Leibniz's view of life merits a book-length treatment, and one that is still missing from the current literature⁵. Here I will only indicate a few general features of the way in which Leibniz characterizes living beings. In my view, Leibniz's view of living beings

- 4 In this connection, see Ohad Nachtomy, Justin Smith, and Ayelet Shavit: "Leibnizian Individuals, Organisms, and Units of Selection", in: *Theory in Biosciences* 121 (2002), pp. 205-230.
- 5 In effect, other than the groundbreaking work of François Duchesneau: *Les modèles du vivant de Descartes à Leibniz*, Paris 1998, and the forthcoming book by Justin Smith (*Divine Machines*, Princeton University Press) this topic is certainly under treated in Leibniz's scholarship, especially in English.

can be best presented by reference to the two chief models of living beings in the early modern period, viz. the Aristotelian model and the Cartesian one. Typically, Leibniz produces a brilliant and original synthesis between these two models. To be more precise, Leibniz is showing a special interest in the living world in the period of writing his *New System of Nature* in 1695. At this time, he is using the Aristotelian concept of *entéléchy* in his rehabilitation of substantial forms, which he uses to characterize a substance by an internal principle of activity and life. At the same time, Leibniz holds this metaphysical principle to be consistent with a mechanical description of living things at the physical level.

According to Aristotle, any being or substance is a hylomorphic compound of form and matter. The form is an active principle that determines and organizes passive matter. In living things, the form is a dynamic and active principle, the *anima* or *psyche*, which defines the thing's nature by virtue of its internal nature and *telos*. The soul or the entelechy fixes the thing's nature by informing its development through the actualization of its inherent potential. By virtue of similarity and reproduction, the substance's form also places each particular thing within a larger system of species, subspecies, etc. For Aristotle, there are three main general types of animating forms, the vegetative, the sensitive, and the rational, which divide living things accordingly (*De Anima*, Book II section 2).

Descartes' program, as is well known, was to replace the Aristotelian model of living beings with a new one. As Garry Hatfield puts this, "Descartes' aim was to mechanize virtually all of the functions that had traditionally been assigned to the vegetative and sensitive souls"⁶. Descartes' aimed at showing that all living phenomena can be explained mechanistically without any reference to substantial forms. This program was very clear and straightforward. At the same time, his argumentative strategy was rather subtle and sophisticated. Descartes' strategy for executing his program and his powerful rhetorical device can be described in two moves: first to conceive of all natural animals (as well as the human body) as *machines* and, second, once the body of an animal has been referred to as a machine, Descartes used the comparison between a machine manufactured by humans and a machine created by God in order to minimize the differences between them. Roughly stated, Descartes' strategy was to model natural machines on artificial ones. More precisely, he argued that the differences between the works of a complex artificial machine, such as a horologe or a fountain, and those of animal bodies are only apparent and turn on the degree of subtlety of their internal mechanism. Descartes attempted to show that, in essence, complex machines and animal bodies are of the same type and that the only differences between them reduce to degrees of complexity and subtlety of their parts. Thus, just as there is no need to invoke an occult agency in a horologe

6 Garry Hatfield: "Descartes' Physiology and Its Relation to His Psychology", in: *The Cambridge Companion to Descartes*, ed. by John Cottingham, Cambridge 1992, pp. 335-370, p. 343.

that *shows* the hour, so there is no need to invoke such agency in our body other than the disposition of organs and parts (AT IX, 321-322)⁷.

It is mainly to this powerful and influential attempt to reduce natural machines to artificial ones – and, more broadly, to reduce living things to non-living machines – that Leibniz responds to in his *New System of Nature* in 1695. Leibniz, however, does not object to Descartes' claim that living things are subtle machines. Rather, he attempts to draw a distinction between living and non-living things as two *kinds* of machines – one artificial, and the other natural. Leibniz's formulation of the distinction is that, while both are said to be machines, a natural machine, unlike an artificial one, “remains machine to the least of its parts, and what is more, it always remains the same machine” (GP IV, 482; my translation). The unity of such natural machine is due to the activity and presence of the Soul or Form inhering in it. Leibniz states explicitly that natural machines have something substantial – *Soul or Form* – that makes them one and the same thing in the *least of their parts*. This characterization constitutes the main difference between these two *types* of machines. Furthermore, this characterization applies both to the internal structure of a natural machine, in that all its parts are machines, and to its development, in that it remains the same machine through its various states.

Leibniz's view concerning the unity and identity of a natural machine, in contrast to an artificial one, is confirmed in the sequel to the passage cited above:

“In addition, by means of the soul or form there is a true unity corresponding to what is called *the self* [*moy*] in us. Such a unity could not occur in the machines made by a craftsman or in a simple mass of matter, however organized it may be; such a mass can only be considered as an army or a herd, or a pond full of fish, or like a watch composed of springs and wheels”⁸.

An artificial machine, then, is classed under things that lack true unity, namely, aggregates. By contrast, a natural machine is classed under things that

- 7 “[Je] ne reconnois aucune difference entre les machines que font les artisans et les diuers corps que la nature seule compose, sinon que les effets des machines ne dependent que de l'agencement de certains tuyaux, ou ressorts, ou autres instrumens, qui, deuant auoir quelque proportion avec les mains de ceux qui les font, sont tousjours si grands que leurs figures et mouuements se peuuent voir, au lieu que les tuyaux ou ressorts qui causent les effets des corps naturels sont ordinairement trop petits pour etre apperceus de nos sens. Et il est certain que toutes les regles des Mechaniques appartiennent à la Physique ..., en sorte que toutes les choses qui sont artificielles, sont avec cela naturelles. Car, par exemple, lors qu'une montre marque les heures par le moyen des roues dont elle est faite, cela ne lui est pas moins naturel qu'il est à vn arbre ... de produire ses fruits” (*Œuvres de Descartes*, ed. by Charles Adam and Paul Tannery, 13 vols., Paris 1897-1913 (hereafter: AT), tom. IX, pp. 321-322).
- 8 *G. W. Leibniz: Philosophical Essays*, ed. and transl. by Roger Ariew and Daniel Garber, Indianapolis – Cambridge 1989 (hereafter: Ariew/Garber), p. 142; “De plus, par le moyen de l'âme ou forme, il y a une veritable unité qui repond à ce qu'on appelle moy en nous; ce qui ne scauroit auoir lieu ny dans les machines de l'art, ny dans la simple masse de la matiere, quelque organisée qu'elle puisse estre, qu'on ne peut considerer que comme une armée ou un troupeau, ou comme un estang plein de poissons, ou comme une montre composée de ressorts et de roues” (GP IV, 482).

have true unity, namely, substances. As on the Aristotelian model, things that have unity by virtue of their soul or form have life and activity. It is for this reason that Leibniz invokes and rehabilitates the Aristotelian forms in this context. Even if it involves infinitely many states and infinitely many machines, a natural machine has (or is) a true unity. By 1695 Leibniz is well equipped with the fundamental distinction between substances and aggregates, which he develops and defends in the second part of his correspondence with Arnauld (1686-87)⁹. While a substance has a true unity, an aggregate, which is a collection of substances, does not. The unity of an aggregate is not a natural one in the sense that it requires a mental act, i. e., the very aggregation of its constituents into a single group (such as sheep into a herd, stones into a pile, soldiers into an army, birds into a flock).

Most importantly for my purposes here is that being a single unity implies having an internal source of activity. It is this inherent activity and having primitive force that makes a natural machine both a true unity and a living being. In his writings following *The New System of Nature* (1695), Leibniz is integrating Aristotelian and Cartesian insights by reintroducing inherent force and *telos* into natural beings. While maintaining their status as machines, Leibniz explicitly designates such machines as machines of nature, distinct from artificial machines or mere mechanisms. This is not a difference in degree of complexity, as in Descartes, but a difference of type. The natural machine is indeed a peculiar type of mechanism – one that involves machines within machines *ad infinitum*. It is the natural machine that Leibniz would later qualify by the term “organism”, a term he would coin a few years later (cf. Duchesneau: *Les modèles du vivant de Descartes à Leibniz*, 1998, pp. 339-340). Unlike artificial machines, natural machines remain machines to the least of their parts, that is, they remain machines to infinity and are identified with living bodies. As Leibniz says in the *Monadology*: “Machines of Nature, that is to say, living bodies, are still Machines in the least of their parts, all the way to infinity” (*Monadology* § 64). The infinity of natural machines is both structural and functional: it is structural in that natural machines have a fractal like structure that unfolds to infinity¹⁰, and it is functional in that each of its organs serves another function and is thus a part of an infinite chain (or more precisely a circle) of such functions (*Monadology* § 64). Above

9 “[L]a substance demande une véritable unité [...] tout être par agrégation suppose des êtres doués d’une véritable unité parce qu’il ne tient sa réalité que de celle de ceux dont il est composé, de sorte qu’il n’en aura point du tout si chaque être dont il est composé est encore un être par agrégation [...] s’il y a des agrégés de substances, il faut bien qu’il y ait aussi des véritables substances dont tous les agrégés soient faits. [...] il n’y a point de multitude sans des véritables unités. Pour trancher court, je tiens pour un axiome cette proposition identique qui n’est diversifiée que par l’accent: *que ce qui n’est pas véritablement un être n’est pas non plus véritablement un être*” (*Lettres de Leibniz à Arnauld. D’après un manuscrit inédit*, with an introd. and notes by Geneviève Lewis, Paris 1952, pp. 68-69 (GP II, 164-165).

10 See letter to Des Bosses 11-17 March, 1706; GP II, 305-306; *The Leibniz – Des Bosses Correspondence*, transl., ed. and with an introd. by Brandon C. Look and Donald Rutherford, New Haven, Conn. 2007, p. 35).

all, the infinity of natural machines indicates that, unlike artificially fabricated machines, natural machines are divine *creations* that cannot be produced by a composition of parts. Rather, natural machines are unique and infinitely complex active beings created by an infinite creator. In creating natural machines, God gives each one of them an inherent force and an internal source of activity. As Leibniz writes in *On Nature Itself*: “And so, we must add a soul or a form analogous to a soul, or a first entelechy, that is, a certain urge (*nisus*) or primitive force of acting, which itself is an inherent law, impressed by divine decree” (Ariew/Garber, pp. 162–3). Leibniz often uses the model of a law of a series to describe this. For example, he suggests that: “The law of order [...] constitutes the individuality of each particular substance” (GP IV, 518; Loemker, p. 493). The model of an internal law for the individual’s development stresses the causal self-sufficiency of each one of them (see for example Ariew/Garber, p. 144).

By virtue of its inherent source of activity, for which Leibniz employs the Aristotelian notion of entelechy¹¹, a natural machine is given not only power of action but also a law of action – a law that functions as an internal program for the development and self-regulation of an individual substance. In this respect, each natural machine has its own developmental program, prescribed from within as a constitutive part of its unique nature. Thus, for Leibniz, an internal program of action and an internal law of development are essential features of a natural machine, which serves to distinguish it from artificial one. An artificial machine does not have an internal purpose or end but only an external one (for which it is produced by humans). For this reason, an artificial machine does not have an internal source of unity, activity, and life. Furthermore, it is for this same reason that an artificial machine may be seen as a collection of living beings but not itself a living being.

Thus, by using the notion of a natural machine, Leibniz articulates a distinct model of living beings. To this end, Leibniz is reconciling the Aristotelian model with the Cartesian one and the result is an original and most influential model. In this model, each living being or animal has its own source of activity (primitive force) and its own developmental program (inherent law): “For why should God be unable to give substance, from the beginning, a nature or an internal force that can produce in it, in an orderly way (as would happen in a *spiritual or formal automaton*, but *free* in the case where it has a share of reason), everything that will happen to it, that is, all the appearances or expressions it will have, without the help of any created being?” (Ariew/Garber, p. 144).

11 “Aristote les appelle *entelechies premieres*, je les appelle peutestre plus intelligiblement *forces primitives*, qui ne contiennent pas seulement l’acte ou le complement de la possibilité, mais encore une *activité originale*” (GP IV, 479). As Fichant remarks, “From 1691, Leibniz does not hesitate to rehabilitate the Aristotelian term entéléchie [and use it] as quasi-equivalent to substantial form” (Michel Fichant: “Leibniz et les machines de la nature”, in: *Studia Leibnitiana* XXXV/1 (2003), pp. 1-28, p. 17). As Fichant also notes (in footnote 35) “one observes a progressive reception of Aristotle’s Entelechy identified with a substantial Form” in A VI, 4 A, 400, 559, 597.

In earlier writing Leibniz defines an individual through its complete concept, that is, a concept that includes all its predicates – past, present, and future (*Discourse on Metaphysics* §§ 8 and 13). The complete concept, however, defines the individual as a mere possibility. To be a real living individual, such a possibility has to be actualized or created by God. According to Leibniz, God realizes such a possibility by giving it power of action – entelechy or primitive force, which would actualize the program and results in the individual’s development. Thus, according to Leibniz, a living individual is defined by having an active principle that realizes the program inscribed in its concept.

Following Aristotle, Leibniz calls this active principle entelechy and identifies it with a substantial form (roughly since 1691). Such a principle functions both as motivating force as well as a prescription for action – realizing the individual’s properties from within and bringing about its development¹². In rehabilitating Aristotle’s substantial forms, Leibniz invokes an internal dynamic principle that accounts for the individual’s change of states in realizing its end and nature. According to Leibniz, then, the individual’s nature is intrinsically related to its end in the sense that its development realizes its unique *telos*. Unlike Descartes, who wished to avoid final causes in explaining natural phenomena, Leibniz seeks to reconcile final causes (at the metaphysical level) with efficient ones (at the physical level). In this sense, we can say that Leibniz articulates a notion of an internal program – a program that defines the individual’s nature and informs its development.

3. A Program for Action and a Genetic Program

At this point an analogy with François Jacob’s notion of a genetic program may be developed. The analogy concerns the individual’s developmental program. Following their discovery of regulatory genes in 1961, Jacob and Monod argued that:

“The discovery of regulator and operator genes [...] reveals that the genome contains not only a series of blue-prints, but a coordinated program of protein synthesis and the means of controlling its execution”¹³.

In *The Logic of Life* Jacob developed the idea that we should view genetic material as a program or as instructions for the organism’s development:

“At the level of the individual – the bacterial cell – one observes the recopying, with extreme rigour, of a programme which prescribes not only the detailed plan of each molecular structure but the means of executing the plan and of coordinating the activities of the structures”¹⁴.

12 “[F]orms are for me nothing but activities and or entelechies, and substantial forms are primitive entelechies” (to Bernoulli, 18 November 1698, Ariew/Garber, p. 168). See also Letter to De Volder, 21 January 1704: GP II, 262; *G. W. Leibniz: Philosophical Papers and Letters*, transl. and ed. by Leroy E. Loemker, Dordrecht ²1969 (hereafter: Loemker), p. 533. See also Michel Fichant: *Science et métaphysique dans Descartes et Leibniz*, Paris 1998.

13 François Jacob and Jacques Monod: “Genetic Regulatory Mechanisms in the Synthesis of Proteins”, in: *Journal of Molecular Biology* 3 (1961), pp. 318-356, p. 354.

14 François Jacob: *The Logic of Life. A History of Heredity*, New York 1973, p. 292.

Jacob thus argued that the notion of a genetic program, written in the DNA, plays a defining role in the logic of heredity:

“It [deoxyribonucleic acid] is a long polymer formed by the alignment of four sub-units, the four organic bases, repeated by millions and permuted along the chain, like the letters of the alphabet in a text. It is the order of these four sub-units that directs the order of the twenty sub-units in proteins. Everything then leads one to regard the sequence contained in genetic material as a series of instructions specifying molecular structures, and hence the properties of the cell; to consider the plan of an organism as a message transmitted from generation to generation; to see the combinative system of the four chemical radicals as a system of numeration to the base four. In short, everything urges one to compare the logic of heredity to that of a computer”¹⁵.

While it is controversial whether a computer program provides the best model for illustrating the notion of instructions embedded in the genetic material, the thrust of Jacob’s point does not depend on this analogy. A computer program seems to presuppose a programmer and it is not self-regulative in the same sense as a genetic program. Nonetheless, it is significant that the development of these notions in biology, computer science, and cybernetics are closely intertwined¹⁶. In any event, it is beyond doubt that viewing the genetic material as a developmental program has proved very useful, perhaps indispensable, in explaining heredity, development and evolution. According to Jacob, the notion of a program is necessary for an adequate description of the mechanisms of development, regulation, heredity and evolution¹⁷.

Furthermore, Jacob argues that understanding a program chemically allows us, finally, to reconcile chemical analysis with functional organization as well as with the end of an organism (which he identifies with reproduction). Jacob, in addressing the paradox formulated by Claude Bernard between physico-chemical manifestations and a “kind of pre-established design for each being and each organ”, claims: “[W]hen heredity is described as a coded programme in a sequence of chemical radicals, the paradox disappears”¹⁸. He remarks that, “the concept of a programme has made an honest woman of teleology”¹⁹. What made teleology “honest” is the observation that the developmental program is inscribed and transmitted as a sequence of chemical radicals. According to Jacob, the notion of a genetic program is not only appropriate for describing the development of living organisms but also resolves such anomalies within the scientific description of living beings.

Although Jacob’s vision has been revolutionary, filling in the details of the genetic program of the development of an organism has proven to be far more complicated than he expected²⁰. Even if Jacob’s view of the program might seem a bit naïve today, it is clear that his focusing on the notion of a program is very insightful. Not only does the notion of a molecular genetic program and the

15 Ibid., pp. 264-265.

16 See Fox Keller: *The Century of the Gene* (see note 3), chapter 3.

17 On the DNA as chemical instructions see Jacob: *The Logic of Life* (see note 14), p. 278.

18 Ibid., p. 4.

19 Ibid., pp. 8-9.

20 Fox Keller: *The Century of the Gene* (see note 3), chapter 3, for more details.

mechanism of its inheritance constitute one of the significant events in the transition from classical to molecular genetics but, as Fox Keller remarks: the notion of a “genetic program has come to be widely regarded as a fundamental explanatory concept for biological development – if not *the* fundamental concept”²¹.

The theory of evolution can appeal to an internal genetic program without appeal to a “programmer”. As Jacob notes:

“The genetic message, the programme of the present-day organism, therefore, resembles a text without an author, that a proof-reader has been correcting for more than two billion years, continually improving, refining and completing it, gradually eliminating all imperfections”²².

The chemical character of a program, which includes both the instructions as well as some of their means of execution, may be seen as informing the organism’s development, as well as itself a product of natural selection. In addition, the structure of the DNA explains both its replication in future generations as well as its liability for mutations and variations. Thus, the remarkable explanatory power of the genetic material derives from its ability to account for stability and variability in the contexts of inheritance and development, both of which are essential for explaining evolution.

It should be stressed, however, that the use of the notion of a program for describing and explaining the development of living creatures is far from new. In some sense, it is certainly as old as Aristotle’s identification of the nature of the individual with its *telos*. For Leibniz, as we have seen above, the power to act together with the instructions for action are essential for a created living individual²³. The Leibnizian notion of a program can be characterized through a rule producing a unique structure of predicates (i. e., the complete concept of the individual), which, upon creation, informs the individual’s development²⁴. Such a program is an essential part of the individual. In prescribing and regulating the individual’s activity from within, the program is constitutive of its individuality, identity and unity over time. The program is the very source of the individual’s end and it orders the individual’s constituents into unified and organized whole.

Moreover, the Leibnizian notion of an internal program of action and his principle of causal self-sufficiency of created substances (i. e., that there is no causal interaction among substances) imply that each individual substance has all the information needed for its development. In other words, the individual’s activity is internally regulated and it is self-organized in this sense. A self-organized being (which later came to be associated with that of an organism),

21 Ibid., p. 74. According to Mayr, the typical structure of the DNA in the cellular nucleus can be considered as “encoded and preordered information capable of controlling a process (or behavior) in guiding it towards a determined end” (Ernest Mayr: *The Growth of Biological Thought*, Cambridge, Mass. 1982, pp. 48, 102; see also, F. Duchesneau: *Philosophie de la biologie*, Paris 1997, p. 99).

22 Jacob: *The Logic of Life* (see note 14), p. 282.

23 See Ohad Nachtomy: *Possibility, Agency, and Individuality in Leibniz’s Metaphysics* (= *The New Synthese Historical Library* 61), Dordrecht 2007, chapter 5.

24 For details, see *ibid.*, chapters 2 and 5.

as it turns out, is one of the forming concepts of modern biology. Fox Keller argues that, the question ‘What is an organism’? may be taken as marking the beginning of biology as a separate science²⁵. Furthermore, this question has set “the obvious task for biology in the years ahead [...] [namely], to try to understand the character of this special type of organization, or self-organization”²⁶.

Fox Keller claims that one of the early articulations of this point appears in Kant. For example, Kant has written that, “An organized product of nature is that in which everything is an end and reciprocally a means as well. Nothing in it is in vain, purposeless, or to be ascribed to a blind mechanism of nature”²⁷. At the same time, it is worth noting that Leibniz appropriated the word “organism” for organic bodies in the first years of the 18th century²⁸. One could even argue that Leibniz coined the term for this very usage. We must note, however, that Leibniz’s characterization of an organism involves a very subtle nuance that distinguishes it from a mechanism. He writes, for example, that, “[...] the organism of living things (*organismus viventium*) is nothing other than a more divine mechanism, progressing to infinity in its subtlety”²⁹. The divine source and the progression to infinity are extremely important in Leibniz’s characterization of natural things as distinct from artificial ones³⁰. As I noted in the first section, these features also distinguish between living and non-living things. Likewise, the notion of infinity indicates that such living beings are defined through an internal law or a program of development³¹. Thus, in addition to the significance of the notion of a program, Leibniz’s contribution to the employment of the related notions of internal program, self-organization, and organism for describing living beings should not be neglected. At the same time, Leibniz’s characterization of organic

25 Fox Keller: *Making Sense of Life* (see note 3), p. 16.

26 Fox Keller: *The Century of the Gene* (see note 3), p. 108.

27 Immanuel Kant: *Critique of the Power of Judgment*, ed. by Paul Guyer, transl. by Paul Guyer and Eric Matthews, Cambridge 2000, section 66; A 5: 376, pp. 247-248. See also: “In such a product of nature each part is conceived as if it exists only through all the others, thus as if existing for the sake of the others and on account of the whole, i. e., as an instrument (organ), which is, however, not sufficient (for it could also be an instrument of art, and thus represented as possible at all only as an end); rather it must be thought of as an organ that produces the other parts (consequently each produces the others reciprocally), which cannot be the case in any instrument of art, but only of nature, which provides all the matter for instruments (even those of art): only then and on that account can such a product, as an organized and self-organizing being, be called a natural end” (ibid., section 65; A 5: 374, p. 245).

28 See Duchesneau: *Les modèles du vivant* (see note 5), pp. 316 and 336-337.

29 C, 16 (my translation).

30 On Leibniz’s subtle distinction between artificial and natural machines, see Fichant: “Leibniz et les machines de la nature” (see note 11), and my own “On Leibniz’s Distinction between Artificial and Natural Machines”, in: *Machines of Nature and Corporeal Substances in Leibniz*, ed. by Justin Smith and Ohad Nachtomy, Dordrecht 2011.

31 The reason for this, in brief, is that Leibniz rules out infinite number and magnitudes. His way of characterizing infinite series and concepts is through the law of the series or the rule producing such series or concepts. For an explanation of this issue, see Nachtomy: *Possibility, Agency, and Individuality* (see note 23), chapter 2.

unity as infinite brings out the sharp difference between it and the conception of a genetic program and the DNA sequence: a genetic program is based on a finite number of bases and a long but finite sequences of base pairs.

The related concepts of a program and self-organization evidently played a central role in biological thought after Kant. For example, roughly a hundred years after Kant, Claude Bernard continued to characterize a program as having both legislative and executive aspects. Likewise, in his classical study of 1944, *What is Life*, Erwin Schrödinger echoes this point, applying it to the chromosomes (the structure of the DNA was, of course, unknown at the time). He wrote that chromosomes are “law-code and executive power – or to use another simile, they are architect’s plan and builder’s craft, all in one”³². I have already noted Crick and Jacob’s views regarding the DNA as a genetic program. While such views have been recently criticized for playing down the role of environmental conditions in the execution of the program as well as being gene centric, the notion of a program, as we noted above, remains useful, and perhaps inevitable in explaining the stability of development of individuals of the same species.

In the context of the 20th century synthesis between genetics and evolution, we see the program of development as being reproduced and transmitted to future generations and thus as playing an essential role in our understanding of species and their evolution. As it turns out, one of the most remarkable points of stability is the similarity of developmental patterns between organisms of the same species. Variation among organisms as well as mutation at the genotypic level can be clearly detected by reference to this remarkable similarity at the phenotypic level³³.

In addition, conceiving of DNA as encoded instructions for an organism’s development requires many qualifications and reservations. While we now possess very specific and concrete mapping of the genome, the transition from the genotypic level (the coded instructions) to the phenotypic ones is only vaguely understood³⁴. Bearing this in mind, the notion of an intrinsic/natural program stands in contrast to an extrinsic/artificial program, such as the plan for a house or a machine in which the designer, the design and the execution are separable. Both the Leibnizian program and Jacob’s notion of a genetic program are seen

32 Erwin Schrödinger: *What is Life. The Physical Aspect of the Living Cell*, Cambridge 1944, pp. 18-19.

33 As Fox Keller writes, “Because a given phenotype can often be produced by a variety of different developmental and molecular pathways, phenotypic stability might even be said to exceed genotypic stability” (Fox Keller: *Making Sense of Life* (see note 3), p. 105).

34 As Lewontin notes, “[...] the forward mapping of genotypic description into phenotypic description is not possible except in special cases” (R. Lewontin: “Genotype and Phenotype”, in: *Keywords in Evolutionary Biology*, ed. by Evelyn Fox Keller and Elisabeth A. Lloyd, Cambridge, Mass. 1992, pp. 137-144, p. 140). As Ian Stewart observes, “Another feature of DNA is that it can encode instructions [...] DNA codes, in the first instance, are instructions for making proteins; proteins are the molecular building blocks of organisms. After this, our understanding of how organisms get constructed rapidly fades” (Ian Stewart: *Life’s Other Secret. The New Mathematics of the Living World*, New York 1998, pp. 238-239).

as regulating the organism's development as an intrinsic part of it or as part of its nature. Hence Leibniz's phrase of a natural machine might be adequate for both.

Contrary to Leibniz's view, in current biology, an organism development depends on many contingent conditions. According to Leibniz, no additional information is needed for the individual's development. Rather, since its creation it has in it every bit of information required for its development. Our contemporary model of living beings involves, by contrast, substantial dependency on the environment. The new synthesis between the theory of evolution and molecular genetics has strongly inclined contemporary biology towards an epigenetic model of living things, stressing the role of the environment in development. Leibniz's model of living things, on the other hand, given both his metaphysical commitments as well as the biological knowledge available at the time, was essentially a preformationist model of development.

4. A Program as a Mark of Living Beings

In light of the fundamental explanatory role a genetic program plays in contemporary biology, it is not surprising that it has been seen as the key for characterizing the phenomena of life. As Jacob stated: "For the biologist, life begins with what could constitute a genetic programme"³⁵. A genetic program written in the language of DNA thus serves (both chemically and functionally) as a mark of living things³⁶.

Seeing a development program as the distinct mark of living beings has a long history. The most obvious source of this idea can be traced back to Aristotle's notion of the soul as the dynamic principle that gives living things their final form. Another important ancient source is the tradition (from the Stoics to Augustine) of the invisible and rational seeds (*seminalis rationis*) that animate and inform the development of living things. These notions were held, developed, and modified in various forms up to the modern period. Descartes, as we noted, marks the commencement of the attempt of modern science to reduce teleological notions to mechanistic ones and likewise to view "living things" (apart from human souls) as subtle mechanisms. As noted in the first section, Leibniz revives the Aristotelian notions of entelechy and substantial form as a reaction to Descartes' reductive program and attempts to reconcile them with a mechanistic view of non-living things.

It is fairly clear that Leibniz's definition of *living beings* coincides with his definition of *beings*. As he writes in the *Principles of Nature and Grace* (§4), for example, "each Monad, with its particular body, makes a living substance".

35 Jacob: *The Logic of Life* (see note 14), p. 304. "Pour le biologiste, le vivant ne commence qu'avec ce qui pu constituer un programme génétique" (François Jacob: *La logique du vivant. Une histoire de l'hérédité*, Paris 1970, p. 325).

36 See also James Bonner: *The Molecular Biology of Development*, Oxford 1965, cited in Fox Keller: *The Century of the Gene* (see note 3), p. 73.

According to Leibniz, true beings must have unity, individuality, internal activity, and self-organization. In turn, these features are explained through the existence of an intrinsic program and power of action. In his mature writings, Leibniz captures these roles with the notions of entelechy and primitive force, which he tends to identify³⁷. Leibniz's view thus provides a crucial background for the tradition of identifying living beings with self-organized beings or organisms, which Kant has made famous. Kant held that the very essence of life is the execution of a program. Among modern biologists, Claude Bernard has identified life with the existence of a program. Among our contemporaries, in addition to Jacob, there are Mayr, Duchesneau, and Fox Keller who argue that the notion of a program is essential in characterizing living things.

If one agrees then with Jacob, Mayr, Duchesneau, and Fox Keller that the notion of a program plays an indispensable role in biology, there are several points of remarkable similarity between the contemporary notion of a program and the Leibnizian one. Here are some of these points articulated in somewhat greater detail:

1. As understood by some contemporary biologists, the notion of a program integrates a chemical mechanism with a built-in *telos*. This is consistent with both mechanical explanations that are based on efficient causation as well as functional ones. Leibniz passionately argues in favor of using both types of explanation together with their underlying disciplines (physics and metaphysics, as in, e. g., *Discourse on Metaphysics* § 22). Therefore, in this way, the notion of a program allows us to understand living beings as compatible with both mechanistic and functional explanations, while not taking recourse in mysterious vital forces, as Leibniz holds in his controversy with Stahl.

2. A genetic program integrates a legislative aspect – its program of action or its possible course of action – with an executive aspect (i. e., power for its realization) as a Leibnizian individual does. The distinction between legislative and executive aspects is clearly applicable to living beings. As Claude Bernard has noted, while the mechanisms of life may be fully described in chemical terms, they are insufficient for a full description of living beings. Such a description also requires the legislative aspect of the program (such as the regulation of a fixed body temperature).

While many of an organism's properties may vary overtime, its program remains relatively fixed throughout the organism's life. While we may consider the legislative aspect of the program as invariable and as expressing the essence or the concept of an individual, we may consider the executive aspect of the program as temporal and changeable. Likewise, while the DNA sequence is relatively fixed, the way it is expressed and activated varies significantly. This contrast echoes Leibniz's distinction between the principle of action (which is fixed and also has the same measure of force) and the individual's actions, which are temporal

37 As Fichant notes, "L'entéléchie primitive d'une monade est alors [in the *System Nouveau*] identifiée à sa 'force active primitive'" (Fichant: "Leibniz et les machines de la nature" (see note 11), p. 17).

and variable. Going back to contemporary biology, we may compare Leibniz's notion of an individual realizing its program to the transition from the relatively fixed level of the genotype to the varying level of the phenotype (more on this analogy in the next section)³⁸.

3. An additional feature of a program is its capacity to entail many sub-programs as proper constituents. Since the notion of a program implies an end, it may be useful in accounting for the internal organization and functional relations among the constituents of an organism. This feature enables us to account for the notion of functional organization at various levels of organization (such as sub-cellular, cells, tissues, organs, organisms, groups etc.). In other words, a program itself may have a nested structure in the sense that it can be made up of many sub-programs. The notion of a program, implying an end and many sub-programs nested within it, may also help us to explain the unity of a functional organization typical of organisms. This conception of organization, allows for a hierarchical structure of nested constituents, in such a way that each nested individual has its own sub-program and internal principle of organization. In turn, each constituent consists of further sub-programs. All these sub-programs, however, belong nonetheless to one dominant program in the sense that each sub-program contributes to the realization of the dominant program. Here, however, we must not forget a sharp difference: while, for Leibniz, the nested structure of an individual continues to infinity, in contemporary biology, the different levels of organization are finite.

In contemporary biology then, the notion of a program is used in explaining internal regulation and the possibility of self-correction characteristic of living beings. Furthermore, a program allows for an integration of mechanical and teleological, chemical and biological explanations, along the lines suggested by Jacob³⁹. In addition, such a program is consistent with the nested structure that, according to Leibniz, is characteristic of living beings, as it functionally organizes the constituents of a natural machine. In other words, for both Leibniz and Jacob, the notion of a program can be seen as a mark of living beings.

5. Combinatorial Possibility and Biological Individuality

One of the most important features of Leibniz's view of individuality is the thesis that each individual has a unique concept that specifies its unique nature in complete detail. On this remarkable view, each detail and minute characteristic becomes essential for a thing's individuation. Since this is not the place

38 Nonetheless, I would not like to leave an impression that the relation between genotype and phenotype is a simple affair. On the contrary, as we now know, this relation is far more complex than conveyed by the optimistic tone of Jacob's writings. However important the complete mapping of the genes in the Genome project may be, in the end, it also illustrates how little can be inferred from the level of genes to the (phenotypic level of the) whole organism. See also note 34.

39 Jacob: *The Logic of Life* (see note 14).

to explore this fascinating and original view in any detail, I will only note four points, which are most pertinent for my purposes: (1) The concept of an individual defines a unique possibility or, in other words, an entity that can exist; (2) Each such concept is specified through a unique structure of predicates, whose order and arrangement play an essential role in its individuation. For example, two individuals might have the same predicates (the same matter, in Leibniz's jargon) and differ in their order (i. e., their form); (3) The basic constituents of such a concept are simple and universal, that is, all individuals share the same basic constituents and the variety among them is obtained through the different combinations of these similar elements; (4) Taken together, these individual concepts may be seen as presenting an exhaustive inventory of possibilities. In other words, by defining all individual concepts, the logical space they occupy encompasses all possible forms of beings. Thus, in Leibniz's view, the individuality and variety among concepts is accounted for by virtue of unique combinations and orderings of simple and universal forms⁴⁰.

However abstract, there is an interesting corollary here between this Leibnizian principle and the way in which the genetic material of different biological individuals is specified, viz., through the arrangement of base pairs in the DNA molecule. Both theories employ a combinatorial account of variety, namely, the idea that different sequences of several elements produce information accounting for a variety of unique individuals. In other words, the general outline of Leibniz's theory of the complete concept is exemplified in our current theory of the structure of the genetic material. Jacob has articulated this point, as follows:

"[...] the variety of the living world, the wonderful diversity of forms, structures and properties at the macroscopic level are based on the combinative system of a few molecular species, that is, on very simple devices at the microscopic level"⁴¹.

"These four sub-units [A, G, C, T] are repeated by millions in infinitely varied combinations and permutations along the chain. By analogy, this linear sequence is often compared to the arrangement of the letters of the alphabet in a text. Whether in a book or a chromosome, the specificity comes from the order in which the sub-units, letters or organic bases, are arranged"⁴².

Jacob is drawing here on the sequence hypothesis, whose classical formulation is due to Francis Crick. In 1957, Crick formulated the hypothesis as follows: "In its simplest form, it [the hypothesis] assumes that the specificity of a piece of nucleic acid is expressed solely by the sequence of its bases, and that this sequence is a (simple) code for the amino acid sequence of a particular protein"⁴³. Jacob observes that, since the basic material of all living beings (i. e., the four organic radicals) is identical, it follows that "originality comes from

40 For details, see Stefano Di Bella: *The Science of the Individual: Leibniz's Ontology of Individual Substance* (= *Topoi Library* 6), Dordrecht 2005, part I, and Nachtomy: *Possibility, Agency, and Individuality* (see note 23), chapter 2.

41 Jacob: *The Logic of Life* (see note 14), p. 299.

42 Ibid., p. 274. In other words, "The plan of the organism is mapped out by a combinative system of chemical symbols" (ibid., p. 254).

43 Quoted in Fox Keller: *The Century of the Gene* (see note 3), p. 52.

the cooking and seasoning”⁴⁴. Thus, it is by virtue of the variations in the order of the four elements that the genetic information of all biological individuals is stored⁴⁵. Furthermore, through variations in this sequence, instructions for the production of three-dimensional proteins are encoded in the genetic code. The input of this production process are triplets of DNA sequences and the output are 64 different proteins. Such variations in the DNA sequence constitute the genetic information necessary (but of course not sufficient) for the development of the set of unique properties of all biological individuals as well as the genetic material they transmit to future generations.

This view bears an interesting similarity to Leibniz’s insight that, while all matter remains the same (referring to the simple elements), individuality derives from variations in form – i. e., from combinations and permutations of the same elements⁴⁶. In this respect, the variation of inherited DNA sequences, encoded in the genetic material, can be taken to illustrate the Leibnizian notion of the complex relation between identity and diversity. In considering the method required for variations in the genome, we see that a similar notion of individuality underlies both Leibniz’s theory of possible individuals and the contemporary concept of genomic individuality⁴⁷. An important point of dissimilarity should be noted however: while DNA sequences are very long, they are finite. In contrast, the series of predicates in Leibniz’s complete concepts is infinite and expresses an infinite universe.

Although our discussion might seem quite abstract at the moment, it is important to note that a theory of biological possibility is crucial for contemporary

- 44 Jacob: *The Logic of Life* (see note 14), “Introduction”. It is now rather clear that Jacob overstated the significance of the genetic material in the development of an organism. It is currently not controversial that the environment plays an essential role in the transition from the genotype to the phenotype. As Sterelny and Griffiths note, “If there is one thing all biologists agree on, it is that the phenotype is the product of the interaction of genetic and environmental factors” (Kim Sterelny and Paul Griffiths: *Sex and Death. An Introduction to Philosophy of Biology*, Chicago 1999, p. 15).
- 45 From a formal point of view, the four elements actually reduce to the two couples AG, and CT, which are always bonded together.
- 46 “Item tot posse esse substantias singulares quot sunt diversae combinationes omnium attributorum compatibilium. Et hinc patet principium individuationis, de quo irritae habentur multorum Scholasticorum concertationes” (“There can be as many singular substances as there are diverse combinations of all compatible attributes. And this is the source of the principle of individuation, about which so many disputes took place among the Scholastics”; A VI, 4 A, 306). Since Leibniz states that, ‘there can be as many singular substances’, it seems fair to suppose that he thinks of possible individuals or complete concepts rather than of actual individual substances.
- 47 The extent of this contribution is controversial. While gene centric positions and gene determinism is highly popular among biologists and philosophers alike (such as Dawkins, and Watson), it is also vigorously contested by some very able critics (such as Lewontin and Fox Keller). In the 1970s, Jacob has adapted a position that might seem somewhat naïve about the decisive role genes play in individuation and development. The paradigmatic example to think about this issue remains the case of identical twins, whose genetic material is exactly the same and whose phenotypic differences are due to environmental factors occurring in their development.

biology. This is particularly clear in the context of the theory of evolution. While natural selection occurs only in living beings, the combinatorial structure of the DNA allows for genetic variability (i. e., the possibility of change), which is required for variation among actual individuals⁴⁸. Let us consider then some ways in which current biology uses possibilities. Empirical biologists might be suspicious of discussing such possibilities. Empirical scientists are trained to examine actual phenomena or, in short, facts. Possibilities, however, are not the kind of thing that can be observed. At the same time, the central role possibilities play in biology has been recognized by some prominent contributors to the discipline. One such early contributor is R. A. Fisher who adapted this approach in his *The Genetical Theory of Natural Selection* (1930). Francois Jacob, whose analysis makes an explicit use of the distinction between the biologically possible and the biologically actual, stands out. More recently, Elliott Sober (who cites Fisher's work) argues that taking possibilities into account is part of the usual scientific practice not only in evolution but more generally as well:

“Evolutionary theory aims not only to describe the *patterns* that may be found in the history of life on earth but also to characterize the *processes* that produced them. Its strategy for identifying the *actual* causes that have shaped the tree of life is the usual scientific one: scientists try to characterize a range of *possible* causes of evolution, and then to determine which of these possibilities actually obtained. The actual is understood by first embedding it in the possible”⁴⁹.

In his influential book, *The Origins of Order*⁵⁰, Kauffman employs the notion of possible patterns in biological research. Analogously to a *phase space* in physics, Kaufman introduces the notion of “adaptation in *sequence space*, such as among possible DNA or proteins”, and argues that it also “leads to the abstract concept of catalytic task space”⁵¹. He points out that “this possibility is not merely abstract. [...] It is now possible to use genetic engineering techniques to generate extremely large numbers of random or quasi-random DNA sequences, hence very large numbers of random or quasi-random RNA sequences and quasi-random proteins. Thus it is possible to explore sequence space for the first time”⁵².

In this way, the combinatorial structure of the genetic material gives rise to the specific notion of *sequence space*. Since the structure of genetic information encoded in the DNA molecule strongly depends on the sequencing of simple elements, the notion of combinatorial possibilities suggests itself in this context. In fact, I would argue that the notion of DNA sequence space (with its implication on RNA sequence space) provides an elegant and concrete example of Leibniz's

48 The transition from an infinite range of possibilities to a small number of feasible routes of actual development is itself a remarkable phenomenon that has been termed by Elliott Sober canalization.

49 Elliott Sober: *The Nature of Selection. Evolutionary Theory in Philosophical Focus*, Cambridge, Mass. 1984, p. 13.

50 Stuart A. Kauffman: *The Origins of Order. Self-Organization and Selection in Evolution*, New York – Oxford 1993.

51 Ibid., p. xv.

52 Ibid.

rather abstract and general notion of combinatorial possibility. Furthermore, the combinatorial notion of possibility underlying the structure of the DNA molecule is very significant for appreciating the explanatory power of the genetic material not only in genetics but in evolution and medicine as well. If there were no variations in the genetic sequence, it would be impossible to account for either mutations, which are crucial in accounting for change in the theory of evolution, as well as for some genetic flaws, which are crucial in understanding and treating genetics diseases and some malfunctions in development. Genetic flaws are often characterized as subtle distortions in the order of bases in the DNA sequence⁵³. Such distortions might bring about abnormal functioning of cells and organs. This shows that the notions of normality and abnormality at the genetic level may be understood in terms of the order of the basic constituents in the DNA molecule. Both notions – of normality and abnormality of the DNA – presuppose a range of possibilities in what Kauffman calls *sequence space*.

In this sense, our current understanding of both genetic malfunctions and genetic disease and the theory of evolution presuppose not only the actual structure of the genetic material but also some of its possible permutations – in the past as well as in the future. This point suffices for demonstrating that possible structures (not just actual ones) play a crucial role in contemporary biology, biotechnology, and medicine⁵⁴. As I pointed out earlier, Leibniz, in the 17th century, articulates a notion of combinatorial possibility that gives rise to all possible individuals in logical space. The current notion of sequence space thus illustrates a particular version of the Leibnizian universal notion of logical space in a biological context.

6. Conclusion

I have suggested above that both a DNA sequence and a Leibnizian complete concept may be seen as a program or as a set of instructions. In both cases, the individual's development is understood as informed from within by its internal program. In addition, in both cases, the program itself is a mere possibility – an unrealized course of action, which requires force and suitable conditions for its realization. While the program defines an invariable essence or possibility, its execution takes place in the variable realm of time and space. More importantly, the notion of a program implies directed action towards an end and entails numerous sub-programs. For this reason, it emerges as a promising candidate to account

53 As is well known, various genetic 'flaws' can cause malfunctions in the production of proteins and, consequently, in the development and function of organisms. Some of the clear and recognized cases of single gene disorder are Tay-Sachs, Huntington's disease, and cystic fibrosis. However, such diseases caused by mutations in a single gene are rare and exceptional.

54 As briefly noted above, the notion of possibility clearly plays a role in the theoretical problem of defining biological individuality that also pertains to the identification of units of selection.

for the notion of functional organization in the nested structure characteristic of both Leibnizian and biological individuals (bearing in mind the finite versus infinite difference between them). Thus, it appears that the notion of internal regulation according to a program, with the unifying effect of a nested structure, plays an essential role in characterizing living beings, as distinct from artificial machines and non-living bodies.

In closing, let us recall some significant points of dissimilarity between Leibniz's and the contemporary views of life. Leibnizian individuals are self-sufficient units endowed with internal force that remains constant and fixed throughout their life. These are closed systems that do not physically interact with others or with the environment. Leibnizian individuals are supernaturally created by God and can only be annihilated by him. They have a fixed essence that does not evolve. All this is flatly rejected in the current view that individuals are historical entities, subject to contingent evolutionary forces as a result of their complex interaction with the environment. In this sense, the contemporary model of life is much more epigenetic than Leibniz's. In addition, Leibniz's notion of individuality is infinite in various dimensions whereas the notion of individuality in contemporary biology is finite in all these dimensions (the finite number of levels of organization, the nested levels, the number of bases on the DNA and the length of the DNA sequences are clearly finite). Given these differences, the significant similarities between Leibniz's model of living beings and the contemporary one noted above are all the more remarkable.

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