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Defining Life: Synthesis and Conclusions

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Abstract The first part of the paper offers philosophical landmarks on the general issue of defining life. §1 defends that the recognition of "life" has always been and remains primarily an intuitive process, for the scientist as for the layperson. However we should not expect, then, to be able to draw a *definition* from this original experience, because our cognitive apparatus has not been primarily designed for this. §2 is about definitions in general. Two kinds of definition should be carefully distinguished: lexical definitions (based upon current uses of a word), and stipulative or legislative definitions, which deliberately assign a meaning to a word, for the purpose of clarifying scientific or philosophical arguments. The present volume provides examples of these two kinds of definitions. §3 examines three traditional philosophical definitions of life, all of which have been elaborated prior to the emergence of biology as a specific scientific discipline: life as animation (Aristotle), life as mechanism, and life as organization (Kant). All three concepts constitute a common heritage that structures in depth a good deal of our cultural intuitions and vocabulary any time we try to think about "life". The present volume offers examples of these three concepts in contemporary scientific discourse. The second part of the paper proposes a synthesis of the major debates developed in this volume. Three major questions have been discussed. A first issue (§4) is whether we should define life or not, and why. Most authors are skeptical about the possibility of defining life in a strong way, although all admit that criteria are useful in contexts such as exobiology, artificial life and the origins of life. §5 examines the possible kinds of definitions of life presented in the volume. Those authors who have explicitly defended that a definition of life is needed, can be classified into two categories. The first category (or standard view) refers to two conditions: individual self-maintenance and the open-ended evolution of a collection of similar entities. The other category refuse to include reproduction and evolution, and take a sort of psychic view of the living. §6 examines the relationship between the question of the definition of life and that of the origins of life. There is a close parallel between the general conceptions of the origins of life and the definitions of life.

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"Life": A Primarily Intuitive Notion

Before any attempt to define life for scientific or philosophical purposes, it is worth recalling that we are all able to instantly recognize life, discriminating the animate from the inanimate seems to be a remarkable cognitive capacity of all human beings. We recognize animals by movement and shape, and plants by the repeating patterns of leaves and stalks. James Lovelock, in his intellectual testament *The Vanishing Face of Gaia* (Lovelock 2009), insists on this primarily intuitive aspect of the question of how we recognize that something is alive: "our survival and that of our species depends upon a fast and accurate answer to the question: is it alive? (…) The power of our life-detector proves itself when we look into a fast flowing river from a bridge: the constant motion of the water flashes in our eyes as eddies and waves reflect sunlight from the river, yet if the water is clear we can see a fish, especially if it is swimming upstream against the flow, and we know that it is alive. Should you think this easy and obvious and boring, try to design a life-detection device that would detect the presence of that fish. It is far from easy, yet life detection is a free part of our mental equipment…" (Lovelock 2009 p. 125). This "mental equipment" shows itself extremely early in the development of the child, especially when it comes to detecting animals. On the one hand, it is deeply rooted in organic evolution: almost all animals are able to recognize prey and predators in some way. On the other hand, the cognitive capacity of humans to recognize living beings is tremendously refined and improved by learning, and by all sorts of technical devices and scientific knowledge. But, on the whole, this intuitive capacity makes us able to recognize as "living beings" a huge diversity of beings, with different patterns of shape and of movement, from bacteria or the cells that compose our body to macroscopic creatures such as elephants, maples and ourselves. Of course, this intuition is not infallible. The 17th and 18th century's microscopists doubted whether they were observing real microscopic creatures or non-organic bodies submitted to Brownian motion. Similarly, in the 18th century, there were a lot of discussions about whether spores were "alive" or not: did they represent a form of "latent life", or were they able to "resuscitate" (Tirard 2003, 2010)? Today, we have similar doubts if we ask: is a virus a living being? Is an ecosystem—or even the biosphere as a whole—"alive" and (perhaps not exactly the same question) a "living being"?.

In spite of such doubts about borderline cases, the recognition of "life" has always been and remains primarily an intuitive process, for the scientist as for the layperson. In that respect, "life" should be carefully distinguished from other highly abstract terms commonly encountered in science, such as "matter" or "energy". It is often stated that many, if not all fundamental terms in science are difficult to define. Thus it should come as no surprise, the argument goes, that "life", perhaps the most abstract term in biology, is hardly definable. However, likening it to terms such as "matter" or "energy" is ill-founded. Firstly, although we have a number of intuitive representations of matter and energy—mostly rooted in particular cultures—we do not have as immediate and cosmopolitan an intuition of them as we have of what it means to be "alive". Secondly, in contrast with physical terms such as "force" and "energy" in physics", or "gene" in biology, "life" does not function as a theoretical concept in modern biology. That is to say, it is not a term designating a non observable entity that intervenes in fundamental hypotheses able to explain classes of phenomena. As shown in this volume, the concept of life raises important theoretical questions in contemporary science, but these questions do not seem to reduce to questions of explanation. Thirdly, an important aspect of the intuitive notion of life is its antagonistic aspect: what counts is the opposition between "living" and "non-living", more than a special content attached to the abstract notion of "life". The reason for this is that for an infinity of practical situations, biological and social, we *need* to be able to discriminate between living and non living beings. We should not expect, then, to be able to draw a *definition* from this original experience, because our cognitive apparatus has not been primarily designed for this. At best, psychology and the cognitive sciences could provide a list of the discriminating criteria that humans use for recognizing life in varied situations.

A number of authors in this volume mention this intuitive character of the category of life. But, as indicated in the title, the problem addressed in this special issue is that of *defining* life. The issues, then, are: why do modern scientists (biologists, but also other scientific disciplines) feel it necessary to define this concept? And, if this task is justified, how can we move from our powerful intuition of life to a genuine concept of life, which may or may not confirm our intuition, but should be based on other grounds? These are the major questions behind all the contributions of this fascinating collection of essays. As easily seen by the reader, the disagreements between the authors are deep, and this is what makes the whole volume so exciting. Furthermore, as an outsider, I would like to say that have highly appreciated the format of the papers: all seem to have adopted the implicit rule of "making a statement" and of defending it in a restricted number of pages. This shared attitude confers on the volume the interesting aspect of map of the relevant questions and answers within the present state of knowledge. In the rest of these concluding remarks, I will explore the terrain charted by this map, taking short trips along three routes: (1) should one define "life" and why? (stakes); (2) how is life defined? (intellectual resources); (3) what is the relation between defining life and the problem of the origins of life? (a particular scientific question). However, before carrying out this analysis, I will propose a few reflections on "defining" in science in general, and on the problem of "defining life".

Science and Definition

Christophe Malaterre (this volume) offers an interesting reflection on the general question of the methods commonly used for reaching the definition of any term. This subject has been extensively treated by logicians and linguists (e.g. Clark and Welsh 1962; Robinson 1950). First, one should distinguish between lexical definitions and stipulative definitions. Lexical definitions explain the meaning of a word by referring to its effective usage in explicit contexts. This is what dictionaries commonly do, but so do historians, and anyone who has doubts about what a given word means. Stipulative definitions, also called "legislative" definitions" (Robinson 1950), deliberately assign a meaning to a word, for the purpose of clarifying arguments. A stipulative definition may agree with the common use(s) of a word, but it may also contradict it (or them). A stipulative definition often consists in adopting one of the many current meanings of a word, but it can also settle a totally new convention for the utilization of this word. Anyway, adopting a stipulative definition is adopting a rule: "by the word *x*, we mean…". Scientific definitions are most often stipulative. If you apply this distinction to the present volume, you will easily see that both lexical and stipulative definitions are used. For instance, André Brack (this volume) relates that on the occasion of a recent meeting of the International Society for the Study of the Origins of Life, each member was asked to give a definition of life. 78 different answers were given, that occupy 40 pages of the proceedings of the meeting (see Palyi et al.). If we make use of such a document, we are discussing lexical definitions, because we are saying that this or that biologist, or chemist, or roboticist, in this or that precise context, has used the word "life" in this or that sense. But when the same André Brack adheres to the working definition adopted in 1992 by the NASA Exobiology program ("Life is a self-sustained chemical system capable of undergoing Darwinian evolution"), he posits a stipulative definition. I will let the reader determine whether the various definitions of life given in this special issue are lexical or stipulative. (S)he will probably observe that there is an unusual amount of "lexical" attitude. This may come as a surprise in a scientific context, but this is also a clear sign that there is no scientific consensus on the definition of life, and that scientists feel the need of adopting a critical attitude toward this subject.

But it is not enough to define the notion of definition. From the viewpoint of epistemological analysis, perhaps a more important issue is why defining is important in science, and what its limits are. In his reflection on essentialism, the philosopher Karl Popper has provided a powerful critical tool (Popper 1945). For Popper, essentialism (a word coined by himself) is a conception of scientific knowledge that privileges questions of the sort "What is a certain sort of thing?", or "What is its true nature?". Privileging such questions leads to a practice based upon the idea that the essential task of science is to define, in the sense of expressing the essence of something. Popper considers that this attitude has been the major source of sterility in the history of science as well as in philosophy since Antiquity. Genuine knowledge, for Popper, does not consist in defining terms and then deducing something from these fundamental statements (as in Aristotle's demonstrative method), but in formulating empirically testable *hypotheses*. Science does not aim at revealing essences through definitions, but at describing and explaining the behavior of things in given circumstances, through conjectural universal laws. This does not mean that definitions are unimportant. They are necessary, of course, but only from a pragmatic point of view : we need definitions for the purpose of clear communication. What we need is not to tell "what something is" but "what we mean by something" in a given scientific context. Definitions should always be understood in a nominalist, non essentialist, manner; they are no more than "useful abbreviations". With an admirable pedagogical sense, Popper says that definitions "should be read, not from left to right, but from right to left". By this he meant (for instance), that what counts is not "What is life?" but "What do we call life?". What counts are the hypotheses that we make about observable phenomena; definitions should be subordinated to this primary goal of science (Popper 1945, II: 1–24).

I feel uncomfortable about what can be made of such provocative thought by the specialists on the origins of life, exobiology and robotics who have written for the present volume. If I try to apply Popper's recommendation, it seems that one should not try to define "life" in a realistic way. Popper might add that life is not a scientific concept any more than "matter" is, because this term is not part of hypotheses that genuinely attempt to account for given classes of observable phenomena. But he might also admit that it is justified to propose a stipulative definition able to orient our research on the origins of life, or on objects similar to terrestrial living beings on other planets.

Philosophical vs Scientific Definitions of Life

Bruylants, Bartik and Reisse (this volume) rightly observe that "in the majority of general treatises devoted to biology, the words 'life' and 'living' are never defined". This relates to the very history of biology as a discipline. The circumstances within which the word "biology" was created and applied to a new scientific discipline are now well known (for a historiographical summary, see Gayon 2008). To sum up in a few words, the word itself has been known in a Latin form (*biologia*) since at least the 17th century in German speaking universities, where it was conventionally used for obituaries. "Biology", then, was the name for a narrative of the entire life of someone. In 1766, Christian Hanov, a disciple of the philosopher Christian Wolff, used it (in Latin again) in the title of a big treatise in which he advocated the idea of a science devoted to the study of the most general laws common to plants and animals (for this important historical discovery, see McLaughlin 2002). This fits well with a common claim among historians of science, according to which the idea of a science entirely and exclusively devoted to the phenomena of life and to living beings, emerged in the second half of the 18th century. It also puts back the origin of the word more than three decades earlier than the traditional account does. In fact, when Treviranus, Lamarck and Bichat solemnly introduced the word "Biologie" in German and in French, their proposal did not come from nowhere. Both the word "biologie" and the idea of a science encompassing the phenomena of life in all its dimensions (general laws, classification, and history) already existed. But it was only in the years following 1840, after the philosopher Auguste Comte had popularized the word, that it really began to be widely used. I have proposed elsewhere (Gayon 1988) an explanation for the reasons why ever since Comte, the term "biology" has been used more and more in the very sense that Hanov, Treviranus, Lamarck and Bichat had proposed: a science that studies all and only the different forms and manifestations of life. The tremendous success of this word has nothing to do with the more or less awkward attempts of these authors do define life; it has resulted from the fact that 19th and 20th centuries indeed developed several theories that were general enough to encompass the entire spectrum of phenomena and beings that we commonly (and intuitively) name "life". The cellular theory was the first step. Then came the evolutionary theory, and, finally biochemistry and molecular biology, which showed that all known living beings are made of the same stuff (nucleic acids, proteins, etc.), and exhibit a remarkable metabolic unity (universal existence of quasi-universal mechanisms and metabolic pathways). Note that none of these sub-disciplines of biology ever tried to define life. But all of them have definitively shown that there are very strong reasons to believe that living beings share a number of properties that distinguish them from any other natural beings, and that justify the existence of a methodologically autonomous science. Of course, from this knowledge that we all share today, it would be tempting to infer some general definition of life. Such a definition would consist in extracting the most general doctrines from cellular biology, evolutionary theory, biochemistry, and molecular biology. Almost all current definitions of life are more or less convincing attempts to do this. Some insist on membranes and metabolism, others on reproduction and evolvability, others on the basic "building blocks" of life (organic molecules). Still others attempt to provide a formula as abbreviated as possible. Among these are the NASA definition quoted above, or the phenomenological definition proposed by Damiano & Luisi in this volume.

All these attempts amount to saying (I apologize for the crudeness of my formulation): "Hey, colleagues! Haven't we created a great science over the last two centuries? There is no doubt that 'biology' has succeeded beyond all expectation to develop a number of general theories that tell us what the living beings that we know have in common. Let us summarize them in the most compact formula, and we will feel more comfortable with the margins of life: the origins of terrestrial life, other possible forms life elsewhere, viruses, ecological entities, and, why not, artificial life". I cannot avoid thinking here of Popper's reflections evoked earlier: what counts are empirically testable hypotheses and theories. Thus, if we want to speak of vital phenomena, the best thing to do is to begin with the available theories. But, if we want to go further and provide a general definition of life, we must be aware that it cannot be more than a stipulative definition, in relation with particular scientific theories. Such a definition will always be conventional, and for this reason, the wisest attitude that we may have is to accept that it is open to change, in response to new knowledge. If we do not accept this, Popper would probably go on, we must be aware that we enter into the realm of metaphysics.

At that point, I would like to observe that, if on the whole biologists have avoided defining life for approximately two centuries, they nevertheless inherited a very long philosophical tradition that offered them genuine definitions of life. Since a number of scientists today claim that they need, as scientists, to elaborate a definition of life, it may be worth recalling what the major philosophical models of life have been.

Philosophers did not wait for the advent of biology for constructing general conceptions of life (in the trivial sense of animals and plants). In reality, the major theoretical possibilities seem to have been exhausted before the 19th century. Georges Canguilhem, in a legendary article (Canguilhem 1968), identifies three major concepts of life, each associated with an outstanding philosopher: life as animation, life as mechanism, and life as organization.

Animism is certainly the oldest and the most universal notion of life. It defines and explains life by a specific principle, the soul. Aristotle has provided the most impressive elaboration of this conception. Perhaps his most important statement is that the soul is the cause of life in the sense that it is the coordinated exercise of all the body's capacities to act. Soul, Aristotle says, is for the entire body what sight is for the eye. The soul is thus both the ensemble of functions, and their coordination. Many other versions of animism have been given: sometimes the soul is an entirely immanent power (as in Aristotle), sometimes, it is rather an independent power that governs the body in a more Platonic way (as in Stahl's thinking). The important point is that the conception of life as animation posits that living beings have properties that distinguish them from all other natural beings, and thus require a special type of explanation.

The concept of life as mechanism makes exactly the opposite postulate. According to it, all vital functions are no more than mechanisms, and the living body itself is a machine. While it is much more complicated than any artifact made by humans, it does not require a special type of theoretical principle to explain its functioning. Descartes has given this conception its most elaborate form. The mechanistic concept of life is founded on a representation of nature which does not admit a real distinction between non living bodies and living bodies. Pushed to its limits, the mechanistic concept of life leads to the avoidance of the word "life". This is exactly what happens in Descartes' works.

The last philosophical concept of life consists in emphasizing organization, and consequently, it identifies living beings with "organisms". This conception developed throughout the 18th century, and led to the invention and spread of the word "organism", which became common at the beginning of the 19th century. It came as a sort of *tertium* for both animists and mechanicists, because it relies upon both mechanistic intuitions (the living body as similar to an organ—the musical instrument that is able to play by itself, on the basis of its own mechanisms), and upon animist ideas ("organization" and "organism" come for the Greek word *organon*, which signifies a means with respect of an end—whence the finalistic connotation of these words). Immanuel Kant, in his *Critique of Judgment*, has provided a remarkable philosophical elaboration of this conception. He proposed to equate the notions of "natural purposiveness" and "organized being" (the context making clear that organized beings are living beings). An organized being, Kant explains, is a being in which any part is both a means and productive cause for the others.

Such a being is different from a machine, in which every part is a means relative to the others, but is not “produced” in any sense by them. In the same text, Kant also insisted that “organized beings” are able to “self-organize” (self-maintain, self repair and self-reproduce). In addition to the fact that Kant’s reflection upon organization had a tremendous influence upon a number of biologists in the 19th century and part of the 20th century, modern biologists of the 19th and the 20th centuries have massively adopted the spirit of this conception through the equation that they have made between “living being” and “organism”. We can hardly imagine someone denying that living beings are “organisms”. I do not believe that this is a pure matter of convenience.

Beside these three philosophical concepts of life, I doubt that anything really new has been produced since the advent of biology. Our representation of life remains structured, on the one hand, by the immediate or intuitive notion of life that I have evoked at the beginning of this paper, and, on the other hand, by the three philosophical concepts of animation, mechanism, and organization. Of course the scientists who today want a *definition* of life want more than this; they want a *scientific* concept of life. But I would be very much surprised if their search for such a scientific definition were not influenced by these old philosophical schemas. Most probably, most of them would say that, of course, they adhere to the organizational concept of life, but that they also want this concept to be more precise in terms of the formal and/or empirical properties able to make it operational for scientific purposes. Nevertheless, I am not sure that all scientists would definitely refuse either the mechanistic or the animist concept of life. For instance, when I see that several authors in this volume deny that any realistic definition of life is possible, and say that any definition is a matter of convention, or of degree (e.g. Forterre or Bruylants/Bartik/Reisse), I tend to think that, ultimately, they feel more comfortable with the Cartesian or mechanistic view of life rather than anything else. Similarly, Damiano/Luisi’s emphasis upon the presence of a “cognitive” element in their definition of life makes me irresistibly think of Aristotle’s bio-psychic concept of the soul. But I may be wrong. The important point, anyway, is that modern scientists (as well as philosophers) should be aware of the strength of the three philosophical models of life that I have briefly examined. All three are a common heritage that structures in depth a good deal of our cultural intuitions and vocabulary any time we try to think about “life”.

Should One Define Life? What is at Stake?

So far, I have formulated a few personal views on the subject of this volume. I have insisted upon the strength of our immediate intuition of life, on the pitfalls of definitions in general in science, and upon traditional philosophical concepts of life that are part of the common heritage of present science. In some cases, I have ventured to indicate cross-relations with some contributions of the present collection of essays. I will now come closer to the content of the volume, and provide, as far as I can, a categorization of the recurrent problems and solutions that have been proposed. As said earlier, it seems to me that three major questions have been discussed: Should we define life, and why? If so, what kind of definition should we adopt? And, finally, how does the question of definition relate to that of the origins of life? These three questions are in fact closely interrelated. Not every question has been discussed by all participants in the volume. But, taken jointly, they confer a high degree of interaction between the various papers.

Let us begin with the question of whether and why one should define life or not. No doubt, this question has been the most hotly debated among the authors.

Two authors provide historical information that profitably contextualize the enthusiasm for defining life in today's science. Stéphane Tirard observes that a number of major authors who have explored the problem of the origin of life from the 18th to the 20th century, either with the aim of offering hypotheses, or with that of denying its relevance, have done so without having any well-circumscribed definition of life. Although he is cautious, as any historian should be indeed on such subjects, Tirard tends to believe that this has been a rather general rule until recently. Thus, over approximately two centuries, just as the biologists in general, the specialists of the origin of life seem to have been able to think about and work on the problem of the origin of life without being haunted by defining life. Florence Raulin-Cerceau complements nicely these negative results of Tirard' enquiry. She insists upon the highly speculative character of research on the origin of life until the last decades of the 20th century. Especially, she observes (as does François Raulin) that after 1980, the research programs in astrobiology, especially those of NASA, became much more pragmatic than they were before. Therefore, instead of imagining exotic forms of life elsewhere, they "mainly focused on the search for life based on liquid water, with chemical or biological parameters closely linked to terrestrial ones".

More generally, almost all authors seem to admit Bersini's and Reisse's (2007) assertion that the necessity of defining life has resulted from the converging needs of three domains of research that have developed spectacularly over approximately the past two or three decades: exobiology (formerly "astrobiology"), artificial life, and origins of life. Thus it is not in the traditional areas of biology that the quest for a definition of life has developed. All authors also agree that these three domains have generated the need for an operational criterion, as unequivocal as possible, for pragmatic reasons: exobiologists need it because without it they would hardly know what they are looking for on other planets; and all three disciplines need it for the mutual benefit they derive from their many interactions with each other, as well as with chemists, biologists, geologists and paleontologists. I would like to make several observations about this consensus. First, there is something very plausible about this pragmatic demand. It makes sense to try to build an operational criterion if three different disciplines claim that they want to identify life outside the scope of our common intuitions about living beings (inquiries into the origins of life deal with objects outside the temporal scope of these intuitions, exobiology deals with ones that lie outside of their spatial scope, and robotics and artificial life deal with ones that lie outside of their material scope).

Secondly, it is worth recalling that giving a definition and giving an operational criterion are not necessarily the same task. A definition is a theoretical construction, ideally founded on some or several characters that we believe to be essential to the thing defined, even if we do not adopt a realistic or platonic stance relative to definitions. A good definition is one that captures something important in terms of the conceptual content of the term defined. Of course, we may call the set of distinctive elements that such a definition identifies a "criterion". But this should not be confounded with offering a reliable criterion for the purpose of diagnosis. For instance, having "hair" is a good criterion for distinguishing mammals from all other vertebrates. But we would hardly accept this criterion as sufficient for a definition of Mammals (if such a definition can be provided—this is another matter). It is exactly the same for life. A number of scientists seem to be satisfied with the NASA definition of life, already mentioned: "Life is a self-sustained chemical system capable of undergoing Darwinian evolution". But, as Radu Popa observes, the capacity to evolve (with the implicit ideas of reproduction, imperfect replication of some information, and competition in populations) is probably more a consequence than a definitional element of living systems. Therefore, Popa adds, this element should not be retained in a genuine definition of life; it is a "diagnostic feature", not a definitional element. This being said, I do not deny that diagnostic criteria may be tremendously important in practice. But one should never forget that a good definition requires more, even for a methodological nominalist, such as Popper.

Among those authors who have expressed their skepticism about the possibility of any clear-cut and unequivocal definition of life, several have endorsed what Christophe Malaterre calls “definitional pluralism”. I identify two different sorts of this pluralism in the papers in this volume. They are not exclusive, and sometimes coexist in the same authors. The first sort of pluralism is what I would call methodological, because the various definitions are necessarily anchored to particular scientific contexts. This attitude is illustrated by Malaterre himself, but also by Michel Troublé, a roboticist who has a fascinating dialogue with the chemist André Brack. In contrast with many specialists of artificial life, Troublé doubts that robotics deals with objects similar to chemical systems. Consequently, he concludes that the discourses of chemists and biologists, on the one hand, and roboticists on the other, are “heterogeneous”. Another kind of pluralism can be found in Bruylants/Bartik/Reisse and in Malaterre. These authors propose to think of the distinction between living and non-living, not in terms of a sharp boundary (whence the air of skepticism towards any harsh operational criterion), but in terms of “degrees and modes of lifeness” (Malaterre). They mean by this that if we look at the borderline cases of prebiotic evolution, exobiology and robotics, the problem is not whether this thing is alive or not, but whether it is “more or less” alive, and what makes it so. Bruylants/Bartik/Reisse go in the same direction. They propose a scale on which “0” means that a given entity is definitely not alive, and “1” means that we have not the slightest doubt of it being alive. For instance, all past or present bacteria and eukarya would be attributed a value of lifeness of 1 on this scale. This version of pluralism could be labeled as “gradualism”. Note that this gradualism needs not to be thought of in terms of a linear scale, a sort of resurrected *scala naturae*. Modern science does not need that. Rather it is a methodological pluralism, admitting that degrees of lifeness may have developed (or may develop today in the world of artifacts) along many lines, and require some sort of fuzzy logic (Bruylants/Bartik/Reisse).

One aspect of this proposal which I like very much is the parallel made between the living/non living distinction and the failure of evolutionary biologists to define the category of species. Although species are immensely important for evolutionary biology as well as in practice, there is no “golden rule”, as Darwin said, for unequivocally defining the concept of “species”. There are various ways of “being a species” in nature, because there are various modes of discontinuity between the past and present collections of organisms (e.g. common descent, intersterility, ecological disruptions, etc.). It is probably wise to adopt a similar attitude towards “living” and “non-living”. I do not see why the collection of living beings should be totally distinct from the collection of the non-living ones, whereas at all levels, taxonomic categories fail to define clear-cut boundaries.

Nevertheless, there is a possible strong objection to such a perspective. A number of authors, perhaps including some in this volume, are convinced that a clear-cut boundary does exist between the living and the non-living, because the difference is not a matter of historical science, but a matter of physics, or something close to it—it is described by a nomological science, not an “idiopathic” science.[1] These authors think that some highly abstract property is the signature of life, and is the result of some kind of jump or bifurcation in the behavior of a certain sort of dynamic system. Of course, if living systems rely on *sui generis* properties that universally belong to them in virtue of laws of nature, the problem of defining life amounts to identifying these laws, and (not the same question), to

[1] Nomological science: a science based on universal statements of unrestricted scope (laws). Idiopathic sciences: sciences dealing with events that happen only once.

delineating the conditions under which such systems can be generated. There is no need to insist that this remains an open question in the context of present science—theoretical as well as experimental. But it is obviously an important open question.

How is Life Defined?

As already mentioned, a number of definitions of life have been proposed, catalogued and discussed in recent years. Palyi et al. (2002) have listed around forty definitions; Popa (2004) has listed and discussed ninety. Such an inflation of definitions makes me think of the incredible number of definitions of species that have been found in past and present literature. In his authoritative review, Mayden discusses eighteen different concepts of the biological species used by biologists, all of which are considered as operational (Mayden 1997). A number of authors, however, admit between twenty and thirty acceptable concepts, whereas Lherminier and Solignac (2000) have listed ninety two "definitions of authors" in past and (principally) contemporary literature. These numbers are in good agreement with Bruylants', Bartik's, and Reisse's parallel made between the unending attempts to define both the category of species and the boundary between a non-living state of matter and a living system. Bruylants/Bartik/Reisse also observe that most authors who try to define this boundary content themselves with giving a list of properties shared by all (or at least many) well-known terrestrial living systems. Such lists are variable. Some authors insist on components and on their coupling (macromolecules such as nucleic acids, proteins interacting in an aqueous solvent, etc.), others on thermodynamic properties, others on the necessity for a living system to exhibit some sort of metabolism within the limits of a partially permeable membrane, others on reproduction and replication (or either metabolic cycles or precise material structures), and the majority propose a combination of any of such criteria.

But some authors adopt a more theoretical attitude, and claim that a genuine universal definition of life is possible, one that is of course able to include all terrestrial beings, past or present, that we recognize as "living beings", but also anything that would deserve the name of "living system", be it manufactured in our test-tubes, on our screens, or possibly existing anywhere else in the universe. In the present volume, at least four papers represent that camp, the camp of the "definers": Ruiz-Mirazo/Peretó/Moreno, Popa, Bersini (with reservations, see below), and Damiano/Luisa. Brack could also be added, but he makes clear that his adoption of the NASA definition results from a purely pragmatic, rather than theoretical, motivation -detecting life outside the Earth. It is thus interesting to look at these definitions, and classify them.

All these definitions proceed *genus et differentia*; they enunciate an essential property that delineates a larger class, and then one or several other properties which define life as a subclass of this larger class (on this method, see Malaterre's interesting comments on the various methods of definition). Each definition can also be equivalently interpreted as a conjunction of properties such that the conjunction is a necessary and sufficient condition for a given entity to be called a "living system". All these definitions are brief and they closely resemble each other. It is worth it then to reproduce all of them.

Here is Ruiz-Mirazo/Peretó/Moreno's definition (reproducing the definition given by Ruiz-Mirazo and Moreno 2009):

> "[Life is] a complex network of self-reproducing autonomous agents whose basic organization is instructed by material records generated through the open-ended, historical process in which that collective network evolves."

In this definition, the authors insist on the importance of both the individual dimension and the evolutionary dimension. Functional autonomy and self-reproduction are each essential to individual living systems. But they are not enough; the open-ended history of living systems in collective networks is also part of the definition. This is typically an “holistic” or “synthetic” definition.

Here is now Brack’s definition (reproducing the definition given by NASA program of exobiology):

> “Life is a self-sustained chemical system capable of undergoing Darwinian evolution.”

This definition basically expresses the same requirements as the previous one. But, since it explicitly aims at providing a practical touchstone for recognizing living systems, it sounds less theoretical in comparison with Ruiz-Mirazo/Peretó/Moreno, who try to explicate the two parts of this operational definition. The only difference is the reference to a particular theory of evolution (“Darwinian evolution”), an element that Ruiz-Mirazo et al. probably find too restrictive. Nevertheless, Ruiz-Mirazo *et al*. clearly refer to the evolution of “collective networks”. It is hard to imagine such an evolution without processes such as random sampling and selection.

Popa provides one definition for “living entities”, one for “being alive”, and one for “life”:

> “Living entities are self-maintained systems, capable of adaptive evolution, individually, collectively or as a line of descent.”
> “Being alive is the state of expressing these capabilities.”
> “Life is a concept indicating that the capacity to express these attributes is either virtually or actually present.”

The two last definitions are in fact closely dependent on the definition of living entities. They do not bring anything new in terms of necessary and sufficient conditions. They make one think of Aristotle’s distinction between the two senses of *entelecheia* (first and second entelechy) when he proposes a definition of both the soul and life in his *De Anima* (II, 2). Being alive means expressing effectively, at a definite time, the capacities of living entities. Life is a name for these capacities as such, whether expressed or not. This being said, Popa’s definition resembles very much the two previous ones. Individual self-maintenance and evolutionary history are equally important.

Bersini does not propose an explicit definition of life. But he claims that the current theoretical definitions by chemists and biologists depend too much upon the particular “hardware” (molecules, membranes, metabolic pathways, etc.) that support them in living systems. Therefore he proposes a purely formal and functional approach to the properties commonly invoked by chemists and biologists, *i.e.*: *“self-maintenance”, “self-organization”, “metabolism”, “autonomy”, “self-replication”, “open-ended evolution”*. Thus, although Bersini claims that “artificial life does not attempt to provide an extra thousandth attempt of definition of life, any more than do most biologists”; his paper suggests that he accepts the previous definitions as a provisional working tool. But we clearly understand that he would be just as pleased to set up experimental software platforms able to implement other requirements.

Finally, Damiano and Luisi propose the following definition:

> “A system is living when [it] is self-maintaining due to a regenerative network of processes taking place within the boundary of its own making, and which has a cognitive adaptive interaction with the medium.”

This definition is clearly quite different from the previous ones. First, we see that it does not refer at all to reproduction and evolution. This is clearly an individually-centered definition. Secondly, it explicitly introduces an element that is absent from or (only implicit) in the other definitions: the interaction of a living being with its "medium" or (if I interpret it correctly) its environment. Nevertheless this difference may be negligible, since the previous definitions implicitly postulate something like a "milieu" of some sort. Thirdly, and most importantly, Damiano and Luisi insist on a "cognitive element". According to them, this cognitive element is a necessary complement to Maturana's and Varela's definition of autopoietic systems, which they summarize: "*A living system is a system which is capable of self-production and self-maintenance through a network of regenerative process from within a boundary of its own making.*" Another significant difference with the previous definitions is the method that produces it, according to Damiano and Luisi. They claim to rely upon "phenomenological observation" rather than "speculation". In fact, they take for granted that the biological cell is "the minimal form of life". Such a method means that they try to identify the essence (in any sense you wish, scholastic or phenomenological) of present terrestrial life as everyone understands it today. Although I do think that this reflection is very much in the metaphysical mood of what Popper condemned so energetically, I must confess that it is philosophically very interesting. Such a definition might well be listed as a fourth (and fascinating) philosophical definition of life, beyond the three that we have listed above. This definition looks like a mixture of the animist (or Aristotelian) definition and the organizational (or Kantian) definition. Beyond its reflective interest, I doubt that such a definition can either provide a diagnostic criterion for life, or found a theoretical program, whereas Maturana's and Varela's definition would probably do these two things.

Therefore, to summarize, we can fairly say that those authors who have explicitly defended that a definition of life is needed, and have coherently offered one, can be classified into two categories. The first category includes Ruiz-Mirazo/Peretó/Moreno, Brack, Popa, and, to a lesser degree, Bersini. More or less crudely, all refer to two conditions: individual self-maintenance and the open-ended evolution of a collection of similar entities. This category could be labeled as the standard view among theoretical biologists. The other category is represented by Damiano and Luisi, who refuse to include reproduction and evolution, and take a sort of psychic view of the living, which also emphasizes the environment. This definition makes me think of previous thinkers such as Uexküll. In my subjective opinion, it is a philosophical interpretation as much as an operational definition.

Definition of Life and Origins of Life

Although the subject of the present collection of essays is not the origins of life as such, it is obvious that this subject is the main theoretical motivation behind the entire volume. Furthermore, a majority of authors are known as specialists of the origins of life, either as practicing scientists, or as philosophers and historians of that subject. We should not be surprised then, to find echoes of the major theoretical debates that characterize present research on the origins of life. These debates pervade the entire volume. They are most explicitly treated in Bruylants/Bartik/Reisse, Lazcano, and Weber. But, as already noted, they can be identified in all papers.

I will be brief on this topic, and just point out its relationship to the problem of the definition of life. Lazcano provides a very illuminating description of the central debate that has structured the field of the origins of life for more than half-a-century. This debate is familiar to all readers of OLEB. With the risk of oversimplifying, there are two camps. One emphasizes the importance of metabolic cycles and the emergence of vesicles whose membranes partially isolate these metabolic cycles. Oparin and Haldane are the founding fathers of this school of thinking. The other camp focuses primarily on macromolecules able to store genetic information, and perhaps to have both auto-catalytic and hetero-catalytic capacities. Lazcano seemingly favors the second school, but he clearly says that no firm conclusion can be drawn from available data in favor of either the "metabolic" camp or the "genetic polymers" camp.

One funny thing in the volume is the self-confidence with which other authors in this volume claim that the state of present science has established beyond reasonable doubt that one or the other school is the good one. Please do not take this as an ironic remark. What I mean is that the very content of the volume confirms Lazcano's appreciation of the state of knowledge.

The relation between this fundamental debate and the problem of the origin of life is quite simple (although, again, being a non-specialist, I am aware of oversimplifying). It seems clear that if you emphasize theoretical entities such as metabolic cycles, vesicles and membranes, and some sort of compartmentalization, you privilege a functional approach to the question of what living beings are. Such an approach fits well with the idea that what must be explained is the emergence of individual self-maintained systems. If this is the case, the emergence of life comes down (in a broad philosophical formulation) to the emergence of individuality. On the other hand, if you insist on the replication of polymers, on the reproduction of assemblies of some kind of molecules, and on the evolution of populations of something, you will probably be led to emphasize a notion of life in terms of collectives, descent, and history of related collectives.

This dividing line is echoed in the definitions of life (or living systems) that we find in this volume. Most often, the authors choose a syncretic attitude; they emphasize both individuals and evolution. But this is not always the case. Some require only the first element, and insist that the second one is only a consequence, or, more precisely perhaps, a more or less remote outcome. As I see it, the problem is entirely open.

In conclusion, as a philosopher, I should say that I have been fascinated by the debates developed in this volume. They illustrate a style of interaction between science, philosophy and history that is really exceptional. After reading all the contributions, I am convinced more than ever that contemporary scientists remain exceedingly dependent upon what I called the intuitive or spontaneous intuition of life—an outstanding piece of our cognitive equipment. Perhaps, fifty or one hundred years from now, we will not need to use the word "life" for the kind of problems that we discuss today in terms of "the origins of *life*", or of whether there is *life* of some sort in extraterrestrial habitats or in our refined technological constructs, such as robots and the like. We will then have more operational, and more abstract tools, and we will consider our past discourse on "life" with the same indulgence and condescendence as physicists and chemists speak today of "matter." It will be a useful word in practice, but not a scientific concept, except in very precise contexts where, in fact, you could just avoid the word (as, for instance, when we oppose "matter" and "energy"). When this point will be reached, life will be no longer a concept for the natural sciences, but just a convenient word in practice, in the kind of world that we inhabit. "Life" will be a folk concept. Its specialists will be no longer chemists, biologists, and roboticists; life will be a subject for psychology, cognitive science and anthropology. Is this a sad dream or an exciting one? It is just an idiosyncratic positivist's dream!

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References

Bersini H, Reisse J (2007) Comment définir la vie? Vuibert, Paris
Canghuilhem G (1968) Vie. In: Encyclopaedia Universalis, Paris
Clark R, Welsh P (1962) Introduction to logic. D. Van Nostrand, Princeton
Gayon J (1988) La philosophie et la biologie. In: Mattéi JF (ed) Encyclopédie philosophique universelle, vol IV. Presses Universitaires de France, Paris, pp 2152–2171
Gayon J (2008) De la biologie à la philosophie de la biologie. In: Questions vitales. Vie biologique, vie psychique, ss la dir ; F. Monnoyeur, Paris : Kimé, pp. 83–95
Lherminier P, Solignac M (2000) L'espèce: definitions d'auteurs. Comptes rendus de l'Académie des sciences 323(2):153–165
Lovelock J (2009) The vanishing face of gaia. A final warning. Allen Lane-Penguin Books, Victoria
Mayden RL (1997) A hierarchy of species concepts: the denouement in the saga of the species problem. In: Claridge MF, Dawah HA, Wilson MR (eds) Species: the units of biodiversity. Chapman and Hall, London, pp 381–424
McLaughlin P (2002) Naming biology. Journal of the History of Biology 35:1–4
Palyi G, Zucchi C, Caglioti L (2002) Short definitions of life. In: Palyi G et al (eds) Fundamentals of Life. Elsevier, Paris, pp 15–55
Popa R (2004) Between necessity and probability: searching for the definition and origin of life. Springer-Verlag, Heidelberg
Popper K (1945) The open society and its ennemies, vol 2. Routledge and Kegan Paul, London
Robinson R (1950) Definition. Oxford University Press, Oxford
Ruiz-Mirazo K, Moreno A (2009) New century biology could do with a universal definition of life. In: Terzis G, Arp R (eds) Information and living systems: essays in philosophy of biology. The MIT, Cambridge
Tirard S (2003) La cryptobiose et la reviviscence chez les animaux, le vivant et la structure. In: Études sur la mort Thanatologie (Paris: l'Esprit du Temps), n°124, "Mort biologique, mort cosmique", pp 81–89
Tirard S (2010) La vie latente: des animaux ressuscitants à la cryptobiose, Vuibert-Adapt, Paris (under press)