



Life and life only: a radical alternative to life definitionism

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Received: 21 June 2017 / Accepted: 9 June 2018
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Abstract

To date, no definition of life has been unequivocally accepted by the scientific community. In frustration, some authors advocate alternatives to standard definitions. These include using a list of characteristic features, focusing on life's effects, or categorizing biospheres rather than life itself; treating life as a fuzzy category, a process or a cluster of contingent properties; or advocating a 'wait-and-see' approach until other examples of life are created or discovered. But these skeptical, operational, and pluralistic approaches have intensified the debate, rather than settled it. Given the failure of even these approaches, we advocate a new strategy. In this paper, we reverse the usual line of reasoning and argue that the "life problem" arises from thinking incorrectly about the nature of life. Scientists most often conceptualize life as a class or kind, with earthly life as a single instance of it. Instead, we advocate thinking about Earth's Life (with a capital 'L') as an individual, in the way that species are now thought to be. In this view, Life is a monophyletic clade that originated with a last universal common ancestor, and includes all its descendants. We can continue to use the category 'life' (lower case 'l') pragmatically to refer to similarities between various phenomena and Life. But the relevant similarities are a matter of interest and preference, not a matter of fact. The search for other life in the Universe, then, is merely a search for entities that resemble parts of Life in whatever sense astrobiologists find most appealing (e.g. metabolism, evolution, information, etc.). This does not mean that the search for evolved complexity elsewhere in the universe or its creation in the lab are futile endeavors, but that debates over whether they count as 'life' are. Ironically, finally abandoning the concept 'life' may make our searches for evolved complexity more fruitful. We explain why.

Keywords Life · Definitions of life · LUCA · Philosophy of astrobiology · Origin of life · Theory of life

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1 Introduction: The Viking mission and defining life

In the 1970s, humans sent several missions to Mars, including Viking I and II. These missions were the first successful soft landings on Mars' surface and were notable for including cameras and life-detection equipment. One life-detection experiment, designed by Gilbert Levin, used organic molecules radiolabeled with ^{14}C . The goal was to see if they were 'metabolized' by putative microbes and converted to $^{14}\text{CO}_2$ or other gases. In fact, in the experimental condition, such gases were observed over the next few days, while a control soil sample heated to $160\text{ }^\circ\text{C}$ eliminated the effect. The interpretation was that the heated soil 'killed' the putative Martians, preventing any metabolism. According to Levin (2010), this met the then agreed-upon standard for discovering life on Mars. He points out that subsequent similar experiments on Earth never revealed false positives. On the other hand, similar experiments on Earth (in the presence of microbes) also revealed a different pattern than what was seen on Mars. On Earth, further introductions of organic molecules to Earth soils continued to produce more labeled gases, which did not happen with Martian soils (Plaxco and Gross 2006, p. 223).

Three other experiments are relevant. One introduced CO and CO_2 to Martian soil to measure anaerobic metabolism. It detected some fixed carbon compounds, significantly more than a control experiment that heated soil to $175\text{ }^\circ\text{C}$ for several hours prior to the introduction of the gases. Other soils, heated to merely $50\text{ }^\circ\text{C}$ also produced more limited results, conditions quite different than those of the Levin experiment. Another experiment revealed the production of oxygen from an introduction of water vapor, but not from an introduction of aqueous nutrient broth. Control samples heated to $145\text{ }^\circ\text{C}$ produced as much oxygen as their experimental counterparts. The final experiment failed to uncover any organic molecules whatsoever.

What did these experiments detect? NASA scientists, confused by the results, found them inconclusive. If we had discovered microbes on Mars, such microbes did not use the same materials as Life on Earth, and behaved in ways that could hardly be given a consistent biological interpretation. Levin maintains to this day that the experiments evidenced life on Mars, but Mars, it seems, is a planet that has bewildered our attempts to provide operational criteria for identifying life.

In the intervening 40 years, many researchers have puzzled over these results. The current consensus is that these experiments are suggestive of a curious abiotic chemistry. Such a consensus presumes that there is a meaningful distinction between life and non-life, definable independently of human interests. In other words, researchers presume there is a broader natural kind, 'life', of which Life on Earth, a historical entity descended from a common ancestor LUCA, is an instance. We argue that this consensus is wrong.

2 Background: Millennia of failure

There are hundreds of published definitions of life (see Box 1). In fact, as Box 1 shows, there is a wide range of proposed *taxonomies* of definitions, let alone definitions themselves. This debate is ancient. Some of the broad distinctions

Box 1

- Sagan (1970) proposed that most definitions of life fell into five broad categories: *thermodynamic*, focused on equilibrium, order, and the openness of systems; *genetic*, focused on evolution, origins, and the cumulative change of small mutations; *biochemical*, viewing biological polymers such as DNA or RNA as central; *metabolic*, focused on boundaries, material exchange, and self-maintenance; and *physiological*, focused on biological functions, like eating, excreting, moving, or growing.
- Pályi et al. (2002) suggest the categories of *mechanistic-reductionist*, which equates life with physico-chemical processes without addressing broader issues; *'dialectic-materialist'*, which holds life originated via qualitative jumps (e.g. Woese's Darwinian Threshold) driven by quantitative changes (e.g. gradual evolution); *holism*, which view life as a collective property; and *vitalism*, which attribute some hidden force to life.
- Popa (2004) adds on several contrast classes of life: *holistic* contrasts with *mechanistic*, which roughly maps onto an *emergence/reductionist* distinction; *cybernetic* definitions take artificial life simulations to help guide our definitions of life; *generalist* definitions, which tend to be detailed and technical, contrast with *minimalist* definitions, which abstract away from broad categories; *cellularist* definitions take cells to be the key paradigm case of life and generalize from there, while *genetic* definitions take variation and replication to be key; *parametric* definitions take particular criteria and use them as diagnostic of life; and *material-related* definitions, which take the materials of life on Earth to be essential to defining life.
- Trifonov (2011) studies 123 proposed definitions and clusters them based on reference to similar words. His proposed nine conceptual clusters are *System*, *Matter*, *Chemical*, *Complexity*, *Reproduction*, *Evolution*, *Environment*, *Energy*, and *Ability*.
- Mix (2015) suggests *Woeseian* life, which is life that possesses SSU RNA, *Darwin* life, which exhibits evolution by natural selection; and *Haldane* life, which exhibits metabolism and maintenance. Mix (2016) generalizes from that categorization and finds *Existence* Life, which is merely physical existence, *Organismal* Life, which is the focus of most modern attempts to define life, *Conscious* Life, which is life that has experience and conscious intentionality, *Mental* Life, which is intelligent and reasons, and *Transcendent* Life, which is beyond all of those and global or divine in nature.

(such as physiological categories, reproduction, and metabolism) were recognized almost 2400 years ago by Aristotle (Arist. DA 412a13-416b trans. Shields). It may be disheartening to see an issue this central to biology still unresolved. Relatively recent attempts to define life date back to work by Müller (1926), Schrödinger (1944), Lederberg (1960), and Oparin (1936/Oparin 2010 trans. Syngé et al.). Advances in several biological fields, including molecular biology, have done little to affect the views covered by such authors. Many biologists now accept a laundry list of features characteristic of life rather than a unified account. Textbooks commonly acknowledge the importance of a capacity for evolution, self-replication, growth, differentiation, metabolism, homeostasis, response to the environment, thermodynamic disequilibrium, orderedness, information, boundaries, and mutations. These lists have been presented as necessary and sufficient conditions, accidental similarities between all living entities, and everything in between. Authors differ about which properties to treat as essential and which to view as mere consequences or accidents. Most freely admit that their definitions are exception-riddled or tentative.

The problems of defining life are well known. For any set of defining traits, one can either show obviously living cases that are left out of the definition or unexpected non-living cases included in the definition. Life is organized. So are geological formations. Life processes energy, so does fire. Life evolves, so do star systems. Life is at ther-

modynamic disequilibrium, so is a car. Life is made of complex biochemistry, so are prions. Life exhibits functional complexity, so does a clock. Living creatures embody contained, functionally integrated programs, but so do robots. Life reproduces. Mules don't, bubbles do. Life is self-sustaining. Parasites are not, the carbon cycle is.

Such counterexamples cause consternation for anybody wrestling with the definition of life. The pre-theoretic notions of the concept of 'life' do not match up with the diversity of beings we see in nature. A common response has been to continue this debate in hope of coming to a consensus with respect to these counterexamples (see lists collated by Lahav 1999, Popa 2004, or Trifonov 2011). Others, discussed in the next section, are pessimistic about current approaches and seek new evidence. Their "wait-and-see" approach is gaining in popularity. We maintain, however, that hope for a consensus is vain and that new evidence will not solve the problem. We favor *eliminativism*. This would take as the null hypothesis that our folk-belief in a category life—separable in any definable and meaningful way from the rest of materiality—is illusory. Definitions of life may still find use, but it should be recognized that these definitions are interest-specific and collectively negotiated, not discovered.

3 Contemporary pessimism

A prominent series of recent articles advocate what has been called 'definitional pessimism' (Machery 2012; Smith 2016). A key early (and in a sense provisional) pessimist view was that of Sagan 1974, who argued that until we find other examples of life, we will never be able to understand which aspects of life are contingent and which are essential. This sentiment has been echoed by many authors (for example Feinberg and Shapiro 1980), and more recently by Carol Cleland and Christopher Chyba (Chyba and McDonald 1995; Cleland and Chyba 2002; Cleland 2004, 2006; Cleland and Chyba 2007; Cleland 2012).

Other authors find different reasons to be permanently pessimistic about definition: Some argue the distinction between abiotic and biotic objects is vague (Küppers 1990; Turner 2004; Malaterre 2010; Bedau 2012). Tsokolov is more general, suggesting many of the methodological approaches to defining life are epistemologically suspect (2009). Machery argues there has been a conflation in what we take to be the project of defining life. If we wish to meet a folk intuition, we will never succeed, as the folk intuition is varied and inconsistent (2012). On the other hand, if we wish to define a scientific concept, it is pointless as each science or scientist would stipulate different phenomena to be considered life. Szostak agrees, arguing no definition of life is needed for any work in the study of the origin and evolution of Life on Earth (2012). One could, theoretically, give a detailed description of every step that led to the current diversity of Life on Earth without ever defining "life" itself. Jabr argues there is no distinction between life and non-life (2013). On the other hand, definitional optimists still insist these discussions are worth pursuing as they may shed light into our understanding of biology (Koonin 2012; Smith 2016).

Just as definitions of life recapitulate debates going back centuries, definitional pessimism retreads ground covered over 300 years ago. In Descartes' *Treatise on Man*, he compared non-human animals to automata and argued there was a sharper distinction

between humans and all other organisms than between animals and immaterial objects (Descartes 1664/2010 trans. Cottingham et al.).

Cartesian or ‘mechanistic’ views have existed roughly ever since, typically contrasted with those of vitalists, who stressed the importance of the as-yet unexplained nature of vital properties and the holistic and teleological nature of living creatures (Mayr 1998). Vitalism as a view lasted—in various guises—from the 1600s to as late as 1930 (Mayr 1998). Indeed, it has even been contended that continued insistence that life is real but undefineable as a category is a sort of residual vitalism (Wolfe 2011; Ellington 2012).

The literature on life definitionism remains vast, repetitive, and inconclusive. To the extent that there is any consensus, it is that most authors believe there is something to be described (but see Jabr 2013), that life is a kind of thing (but see Hermida 2016), and that life exists independently of our interests (but see Machery 2012). This is precisely the position we seek to disrupt in the next two sections. What most differentiates our approach from earlier formulations is the recognition that viewing Life as an individual makes it easier to question the reality of life as a class. If life is a kind at all, it is an interest-specific artificial, not a natural, one.

4 Natural kinds, classes and individuals

Many researchers, astrobiologists among them, hold to the so-called $N = 1$ problem: the presumption that life on Earth represents a single instance of life in the Universe. This is why certain authors are keen to investigate artificial life (Langton 1989), synthesize life (Gibson et al. 2010), discover a shadow biosphere here on Earth (Davies and Lineweaver 2005), or discover life elsewhere (Levin and Straat 1977). With more instances, we would better understand the phenomenon of life, which many scientists and philosophers see as more akin to a natural kind than an arbitrary collection of properties. Only then, they argue, might we be able to define life: the “wait-and-see” approach.

‘Natural kind’ is an enigmatic concept. ‘Natural kinds’ are special classes or categories of objects.¹ Classes can be arbitrary collections (e.g. animals born on Tuesdays, things Trump tweets). Typically, classes are identified by shared properties, which may be as simple as pairwise similarity in a single respect. Natural kinds, however, are meant to be more than this—non-arbitrary classes that reflect some deep underlying reality of the Universe, all members sharing some common feature. In a slogan, ‘natural kinds carve nature at its joints.’ Atomic elements are paradigmatic natural kinds. It is not an accident, one thinks, that gold atoms have more interesting features in common with each other than any individual gold atom has with, say, an atom of uranium-238.

Philosophers distinguish between classes, including natural kinds, and individuals, which are entities that exist in space and time. Individuals are, as David Hull says, “chunks of the genealogical nexus, they cannot be viewed as classes” (1976). You may not share many properties with yourself as a child, but you are still the same *individual*

¹ The distinction between classes and categories is inconsistent across philosophical subdisciplines. We use them interchangeably throughout.

Table 1 A review of the differences between the metaphysical features of classes and individuals. Several authors have argued that many biological entities, such as species and populations, are better understood as metaphysical individuals than classes. Along with Hermida (2016), we advocate thinking about Life on Earth as an individual

	Classes	Individuals
Identifiable by	Shared properties (e.g. H ₂ O)	Continuous history (space and time)
Existence criteria	Exist even without instances	Exist in the world or do not exist at all
Extreme consequences	Members of a class can share no common history and still remain members of the class	Do not have defining properties—can change any or all properties and still remain the same individual
Divisibility	Existing elements are ‘instances’ ‘members’ or ‘subclasses’	Existing elements are ‘parts’
Proper labeling	Names designated by lower-case letters (e.g. ‘water,’ ‘gold’)	Have proper names, deserving of capital letters (e.g. George Washington, <i>Homo sapiens</i>)

in virtue of your body’s (or mind’s) continuity through time. Table 1 summarizes the distinctions between the ontology of individuals and that of classes. In another slogan, individuals are identified by their history, classes by their properties.

5 Species as individuals: paving the way to eliminative pluralism

...[Species] have been treated as classes (universals). In fact they may be considered individuals (particular things)... If species are individuals, then: 1) their names are proper, 2) there cannot be instances of them, 3) they do not have defining properties (intensions), 4) their constituent organisms are parts, not members.

– Michael T. Ghiselin 1974 – “A Radical Solution to the Species Problem”

One of the important contributions of philosophy of biology in the last century is widely acknowledged to be the observation that particular species (for example *Drosophila melanogaster* or *Homo sapiens*), as they are understood in contemporary biology, are better thought of as individuals than classes (Ghiselin 1974, Hull 1976). Particular species are identified by a continuous history rather than shared properties, which can and do change over time. History is how we can distinguish mimic species such as the Scarlet King Snake from their otherwise very similar venomous cousins, Coral Snakes. Coral Snakes took a different evolutionary path than King Snakes. It is not shared properties (though there may be many) that determine whether a snake is a part of a species, it is having the ‘right kind’ of history. No matter how similar evolution may in future make King Snakes appear to Coral Snakes, they will never *be* Coral Snakes, even were they to acquire venom.

The alternative view, that species membership should be determined by shared genetic or phenotypic properties, is not often at odds with the historical picture, but does differ in limit cases: as when evolution yields massively improbable similarity (homoplasy) or when researchers or natural mechanisms take DNA from one species and insert it into another. Although this is a consistent philosophical position, it was debated thoroughly in the 1980s and 1990s, with most philosophers concluding that any plausible notion of similarity was parasitic on the history of the species at issue (e.g. Mishler and Brandon 1987; Ereshefsky 1992a). Human look-alikes independently arising elsewhere in the universe would not be considered members of *H. sapiens* by most biologists or philosophers.

Although members of individual species share many properties with each other (Boyd 1999; Slater 2015), the amount and nature of these shared properties varies widely among and between domains of Life (Doolittle and Zhaxybayeva 2009). For example, while individual *E. coli* cells may share less than half of their genetic information with each other, members of *H. sapiens* share closer to 99.5 percent. There is no property that is shared by all species other than that they comprise lineages of organisms that we choose to call ‘species’ (Mishler and Brandon 1987; de Queiroz 2005). Most philosophers still debating the “species problem” admit that there is no “one-size fits all” solution: they are species pluralists.

This denial of a unitary species category is termed “eliminative pluralism” by Marc Ereshefsky and we use it as a basis for our view. For species, Ereshefsky writes ...

Eliminative pluralism assumes that there is one genealogical tree of life, but that tree is segmented by different evolutionary forces into different lineages (often with the same organisms belonging to more than one type of lineage). As a result, the tree of life is segmented into different taxonomies: one taxonomy consisting of interbreeding units, another consisting of ecological units, and a third comprising monophyletic taxa. The resultant taxonomies are taxonomies of different aspects of the tree of life....

In particular, the lack of consilience among various species concepts does not show that the taxa they pick out are not real. The taxa are real; they just do not fall under a single category (the species category). (Ereshefsky 1992b, pp. 681–685)

6 Life is an individual

Darwin imagined life as “having been originally breathed into a few forms or into one” (Darwin 1859, p. 490), and current thinking is similar. Molecular phylogenetic trees are most often interpreted as having a single root—the last common universal ancestor, or LUCA—though there is disagreement over what sort of entity LUCA was, mostly because lateral gene transfer (LGT) is so frequent that many individual gene trees disagree. The most plausible view is that LUCA was a single cell or species, but that LGT has replaced most or all its original genes in surviving descendant lineages (Booth et al. 2016). Sometimes transfers have been from other descendants of LUCA, but other times the donors were cellular lineages diverging before LUCA, and now extinct.

The other prominent view is that “LUCA was a population”, from which modern life might have emerged several times, to produce bacteria, archaea and, possibly eukaryotes, as discrete cellular lineages. Even those who hold this view do not doubt that such commonalities as the universal genetic code, glycolysis or ribosome structure and function reflect common ancestry back to some very early stage in the evolution of the genetic and metabolic machinery.

By either view, whether or not life has a single origin depends on when in the imagined progression from a primitive RNA world to the extant three domains one decides that life began, which requires that ‘life’ be defined. If RNA origins or cellularizations, for instance, are accepted as an origin of life, then there were likely many such origins, though only one (LUCA and its descendants) is still with us. On the other hand, if only organisms descended from LUCA count as living, then life arose once on Earth.

In any case, as Szostak (2012) and we would argue, the word ‘life’ does no work in any such origin scenarios. One may in principle describe the progression to LUCA and beyond, to Mozart, say, without ever attempting to define life. Disagreement over the nature of LUCA notwithstanding (see the long debate following Theobald 2010; Koonin and Wolf 2010), few would doubt that all living things on this planet are related at some importantly deep level. Thus, researchers often refer to an $N = 1$ problem. If life on earth were an instance of some natural kind, it would be the only known instance, but possibly others ($N > 1$) might someday be found on other planets. But that life on Earth is an instance of some natural kind, a token of a type, a class that exists independently of our aims and interests, is what we question.

In many of the ways that species are accepted as individuals, Life (now properly denoted by a capital letter) is one. Consider Ghiselin’s four criteria for species individuality quoted in the previous section. First, since we regard the names of higher taxa such as Mammalia or Bacteria as proper, and capitalize them, and since the clade of descendants of LUCA is the highest taxon, we should call this clade ‘Life’ and use a capital first letter (as we will henceforth do). Second, as an individual, Life has parts identifiable by historical relatedness, not instances. If we were to discover creatures very like mammals or bacteria on Mars (and could be reasonably sure that they had arisen there), we would not call them parts of Mammalia or Bacteria, nor should we include them in Life. (As to whether they are instances of a broader category called ‘life,’ see further.) Third, millennia of searching for defining properties or intensions of life, have not succeeded in finding any such uncontroversial properties that uniquely identify living matter. Fourth, in discussions of biodiversity, we generally conceive of taxa as parts of a whole, not instances of a class.

Hull (1976), who shared Ghiselin’s opinion that species are individuals, would nevertheless not have agreed that Life is an individual. He wrote: “... integration by descent is only a necessary condition for individuality; it is not sufficient. If it were, all genes, all organisms and all species would form but a single individual. A certain cohesiveness is also required which is also problematic at the level of species and populations.” For him, cohesiveness could be provided by within-population sexual reproduction: asexual species or higher taxa (and thus, obviously, Life) would be beyond this pale. Later publications (e.g. Hull 1978, 1980) make it clear that one of Hull’s principle concerns was whether individuality is necessary or sufficient to be a unit of selection.

In a recent paper entitled “Life on Earth is an individual”, Hermida 2016 very nicely deals with several concerns about Life’s individuality. She writes (p. 1)...

“Assuming that all life on Earth has a common origin, all living organisms, cells, and tissues descending from this origin exhibit continuity of the life processes at the cellular level, as well as many of the features that define the individual character of species: spatio-temporal localization and restriction, continuity, historicity, and cohesiveness.” She accepts Hull’s complaint that lack of cohesiveness limits higher taxa less inclusive than all life on Earth to the status of “historical group” but asserts that “there is one higher taxon that can be considered an individual in the same sense as species are individuals: namely, the taxon that contains all life on earth that shares a single origin” (2016, p. 38) And horizontal gene transfer is one force for cohesion, facilitated by the shared genetic code (see also Doolittle 2017). Hermida nevertheless retains the notion that Life, as an individual, is but one instance of a larger class of individuals, life, writing that: “Therefore, life on Earth is an ontological individual. Independent origins of life will have produced other such individuals” (p. 37). We instead argue that accepting Hermida’s first conclusion (as we do) paves the way to the second conclusion that we make here: the status of natural kind is as problematic for “life” as it was for “species” (Ghiselin 1974; Hull 1976, 1978; Ereshefsky 1992b).

Hermida emphasizes spatio-temporal localization and continuity. Not only does Life represent all and only LUCA’s descendants, there is physical continuity: organisms are “produced out of matter and structures already present in a previously existing organism” (p. 39). And although even manifestly un-cohesive entities like the Universe might be taken as historical individuals, Hermida asserts, *contra* Hull, Life does have mechanisms of cohesion. Just as sexual reproduction unites members of a species, events of LGT interconnect all Life, and “the fact that they are possible at all depends on life on Earth sharing a mostly similar genetic code and compatible biochemical processes and cellular machinery” (p. 40).

Admittedly LGT is much less frequent than sex in sexual species, but it might be viewed as a clade-level trait (and thus a trait of Life, the largest clade), selected for both at that level and the level of the selfish agents that promote it (Doolittle 2014, 2017). Clade-level cooperativeness, species number, geographic dispersal and ecological disparity between species are properties that can only be properly attributed to clades and should confer differential persistence upon them. Similarly, the shared genetic code and what Janković and Čirković call “the coding concept” are Life-wide properties (2016). Arguably, these and other features such as that Life’s species are all connected ecologically justify considering Life itself as a biological unit with its own properties.

6.1 Eliminative pluralism about life: while Life is an individual, the class life is only a parasitic property cluster

In parallel to Ereshefsky’s “eliminative pluralism”, we claim that looking for a fundamental relationship of Life to any “other such individuals” is equivalent to comparing

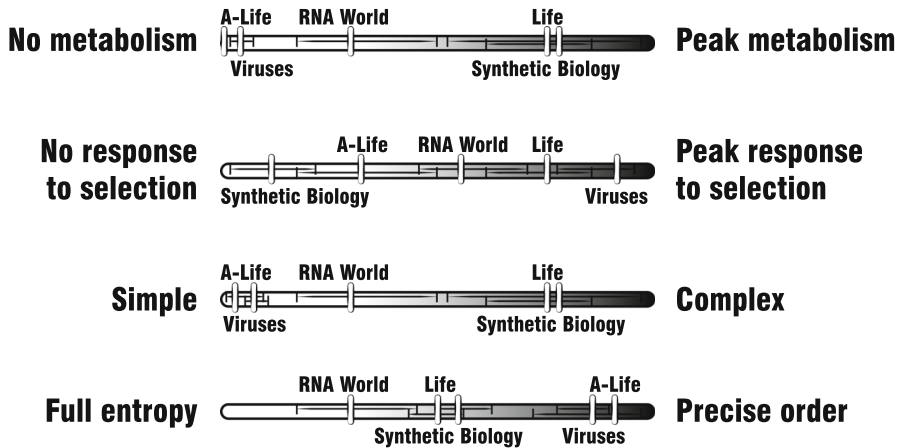


Fig. 1 We label certain objects as located along various continua with Life, the individual, for illustration purposes. By synthetic biology, we have in mind bottom-up protocells, by A-Life we have in mind computer-based software, but we include error bars to signify there is a wide range of consistent locations on this bar for each item. Other entities share some degree of similarity with Life, the individual. Some of these axes of similarity are particularly interesting with respect to our interests, but there is no natural cut off that makes some objects count as ‘similar enough’ to Life to be considered part of the category ‘life.’ Because life is not a natural kind, membership within the nominal category ‘life’ is a decision, not a discovery

Loxodonta africana (an elephant) and *Escherichia coli* (a bacterium) to each other as members of the category ‘species’. Obligately sexual reproducers such as *L. africana* share no essential species-defining or delimiting process with a predominantly clonal bacterial lineage like *E. coli*, (for all the latter may exhibit unidirectional recombination; Doolittle and Zhaxybayeva 2009). Similarly, the category ‘life’ lacks any character shared by all proposed members that would distinguish them from non-members. Indeed it lacks even an analog of the unifying feature of being segments of a metapopulation lineage that is shared by species (De Queiroz 2005). Instead, membership is determined solely by resemblance to one or more of the properties of Life the individual, or one of its parts.

We can now see why the problem cases described above are so persistent. Life as an individual is real and it has many properties that interest scientists. There are various other entities that are similar to Life the individual in some way: ‘shadow’ life (Davies and Lineweaver 2005; Cleland and Copley 2005), Martians yet to be discovered, synthesized life, perhaps viruses or prions. But similarity relations come in degrees and various people have pointed out that only some (and different) distinctive aspects of Life are shared by diverse entities such as computer viruses (e.g. evolution), fire (e.g. metabolism), cultural institutions (e.g. complexity). These do not fall under a single category with any definable set of characteristics other than that some researchers may have decided to call them instances of life as a class, by some inferred similarity to Life as an individual. See Fig. 1.

Thus, Life as an individual is ontologically prior to any class ‘life’ we may construct. We may seek life elsewhere, but any resulting discoveries would only highlight analogies or disanalogies to Life with respect to particular shared features. These dis-

coveries would not reveal anything about Life that we cannot learn by studying its known parts.

This is in contrast to Cleland and Chyba (2002), who argue that scientific study, especially discovery or creation, might help us formulate a “theory of life.” They write ...

Prior to the elaboration of such a theory, it is not possible to be certain that it will, in fact, ever be formulated – or that it is even possible. Perhaps life is not a natural kind. If it is not, how we define it will forever remain a matter of no more than linguistic choice. But if life is a natural kind, we need a theoretical framework for biology that will support a deeper understanding of life than can be provided by the features that we currently use to recognize it on Earth.

We argue ‘life’ is not a natural kind, and any theory of life would add little to explanations already developed in the biology of Life. Scientific study can offer no independent truth in debates about what is or is not alive: advocates of evolutionary approaches seek entities that might evolve, but so too would advocates of metabolic, thermodynamic, informational, or other views seek their favored phenomena. There is no privileged threshold, no fact of the matter, no discovery we could make that would force us into one theoretical approach or another. Continued consternation over the status of viruses (biological or computational) on our own planet can attest that even knowing the details of the entities in question cannot decide between different definitions of life, as such debates are not at bottom empirical.

Consider Viking—there was no viable biological interpretation for its life-detection experiments, but there were plausible metabolic or even complex chemical interpretations. In subsequent missions, we did not send life-detection experiments partially because whatever existed on Mars was so different from Life and researchers worried such experiments would be a waste. But, as we argue, life-detection experiments are a philosophical error. If we are interested in the kinds of peculiar chemistry evidenced by Viking, we should send follow-up missions, but there is no absolute threshold of similarity to Life for any chemistry we may find— it will always be a matter of debate.

Interestingly, one can maintain that the category “life”— though lacking an essence—is a legitimate property cluster kind (Boyd 1991) with a set of properties that do not all need to be present in all members. In this view, the role of Life the individual becomes obvious. Life is the single entity anchoring all candidate conceptions of life as a putative class. For example, some would argue that evolving entities without metabolism (e.g. computer viruses) are alive and some would argue that non-evolving entities with metabolism (e.g. the last surviving member of a species) are alive. Both share an interesting property with Life or its parts, but not the same property. Without Life the individual, there is no relevant connection between computer viruses and the last survivor. So, the dependence of life, the category, on Life, the individual, is parasitic.

7 Conclusion: why this matters and why it should not discourage research

Recognizing Life (LUCA and all its descendants) as an individual (in the sense that individual species are now held to be) motivates a second recognition. There is no category, class, or natural kind ‘life’ that is definable by any set of properties other than resemblance to Life or some of its members. Although useful in motivating much interesting research, the term ‘life’ does no work in the conduct of such research. Problem cases for life criteria are only problematic because we have incorrect assumptions about the nature of the object of inquiry.

In an interesting disquisition on another subject (consciousness), Dennett provides a very succinct description of the position of which we are skeptical, calling it “vitalism.”

Imagine some vitalist who says to the molecular biologists: The easy problems of life include those of explaining the following phenomena: reproduction, development, growth, metabolism, self-repair, immunological self-defense... These are not all that easy, of course, and it may take another century or so to work out the fine points, but they are easy compared to the really hard problem: life itself. We can imagine something that was capable of reproduction, development, growth, metabolism, self-repair and immunological self-defense, but that wasn't, you know, alive. The residual mystery of life would be untouched by solutions to all the easy problems. In fact, when I read your accounts of life, I am left feeling like the victim of a bait-and-switch. (Dennett 1997, 33)

More recently, Dennett (2016) describes such thinking as “illusionism.” In this same way, a good magician can make us believe that he has really cut his assistant in half with a saw, when in fact our normal materialist explanatory toolkit is adequate to describe the apparently magical phenomenon. Dennett’s imaginary vitalist story is not so far off the mark when it comes to much-debated theories of life. The belief that there is such a thing as life, of which Earthly Life may be the only example, could be an illusion—a powerful one of course, with a long philosophical history. As the simplest hypothesis, this should be our null.

We do not think that insistence that life as a category is illusory should in any way compromise research in extraterrestrial complex entities, artificial intelligence, or synthetic biology. Rather it should liberate these fields from futile theorizing or overly-restrictive Life-centric criteria for success or failure, such as may have compromised the first Viking mission.

As to the search for extraterrestrial evolved complexity, our money would be on the possibility that we will indeed find independent examples elsewhere, that these will be carbon based and (maybe) even have nucleic acids and proteins—certainly they will evolve by natural selection. It would be transformatively important to find such entities, which we predict will be much more frequently found than, say, “life” in the form of some disembodied computational algorithms sitting on a planet devoid of complex organic material. But neither kind of discovery will affect debates about whether such disembodied algorithms, or viruses or the products of synthetic biologists are *really* alive nor how such discoveries will give molecular, cellular or systems biologists any new tools that are other than analogical.

Our position is like the eliminative pluralism concerning species advanced by Ereshefsky (1992a, b). Astrobiologists are free to negotiate criteria under which individual instances of extraterrestrial (or undiscovered terrestrial) evolved complexity deserve to be called ‘alive’, just as taxonomists are free to debate how particular ‘species’ are to be circumscribed. Their criteria might or might not embrace artifactually designed complexity, such as creations of “life in the test tube”. And the discovery or creation of entities meeting such criteria will rightfully fascinate, and be supported and celebrated by, astrobiology’s publics who are likely unconcerned about whether these criteria have been negotiated or discovered. All that needs to be abandoned, we claim, is an ontology now often implicit in our $N = 1$ justifications.

Acknowledgements We thank the Natural Sciences and Engineering Research Council of Canada (Grant No. GLDSU/447989) for support, as well as the audiences in POBAM 2016, Duke University, University of Washington, Bryn Mawr College, University of Nevada, Reno, Dalhousie University, SoCIA 2018, Austin Booth, Letitia Meynell, Tyler D.P. Brunet, the editors, and several anonymous reviewers for valuable comments that helped improve this paper.

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