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Definitely Life but not Definitively

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Abstract Although there have been attempts at a definition of life from many disciplines, none is accepted by all as definitive. Some people believe that it is impossible to define 'life' adequately at the moment. We agree with this point of view on linguistic grounds, examining the different types of definition, the contexts in which they are used and their relative usefulness as aids to arriving at a scientific definition of life. We look at some of the more recent definitions and analyse them in the light of our criteria for a good definition. We argue that since there are so many linguistic and philosophical difficulties with such a definition of life, what is needed is a series of working descriptions, which are suited to the audience and context in which they are used and useful for the intended purpose. We provide some ideas and examples of the forms these may take.

Keywords definition of life · definitions · living systems · living entities · working descriptions · what is life · origin of life · life · lexicology · astrobiology · science definitions

There has recently been much research activity in the field of origins of life; lipid vesicles in prebiotic hydrothermal environments (Furuuchi et al. 2005); prebiotic purine synthesis (Borquez et al. 2005); primordial polysaccharides (Tolstoguzov 2004); synthesis of life in vitro (Szostak et al. 2001); chirality on crystalline surfaces (Hazen and Sholl 2003); phosphates and DNA (Benner and Hutter 2002); nucleic acid enzymes (Joyce 2004);

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alternative nucleic acids in RNA (Kolb et al. 2003; Perry and Kolb 2004a). Some researchers believe it may not even be possible to determine the point at which non-life became life if it evolved from chemicals to biology in a series of emergences in a transition zone (Perry and Kolb 2004b, c). In order for all these fields of research to come to some agreement which might pave the way for future collaboration, it would seem vital that we should know what we are looking for when we search for the first examples of life. An agreed definition of 'life' would prove invaluable to this end. It is also needed in astrobiology, to provide a basis for the search for life on other planets and should help us decide whether we should denote Artificial Intelligence, viruses and prions as having life. There have been many attempts at a definition of life from Aristotle onwards and there are several books which include collections of definitions (Luisi 1998; Palyi et al. 2002; Popa 2004; Rizzotti 1996). With so many definitions available from many different fields it would seem that we have no problem recognising life but defining it precisely is much more difficult, a conundrum expressed interestingly as "Life is like music; you can describe it but not define it" (Lazcano 1994). Paraphrasing Theodosius Dobzhansky Friedman as quoted in (Palyi et al. 2002) gave it a different slant; "Life is what the scientific establishment (probably after some healthy disagreement) will accept as life."

We might expect that the formulation of an agreed definition would become easier as knowledge about life increases but in fact this has only given us more information about what life does and how it is manifested. We do not seem to be any closer to knowing what 'life' is and many philosophers and scientists believe that therefore, any attempt at a definition is bound to fail (Cleland and Chyba 2002). In some ways we would support the conclusion that a single definition of life seems impossible. However, we would hypothesise that this is because we are asking the wrong question and looking for the answer in the wrong places. The problem lies not only in the science but also in the language difficulties inherent in all definitions, particularly those of an abstract property or concept. It is those language problems, which are at the centre of this paper.

Let us look at the phrase 'definition of life.' In the words of the Oxford English Dictionary (OED), a definition is "a statement of the meaning of a word or the nature of a thing." In other words it provides limits and boundaries to set something apart from all other things that do not share its nature and it provides a way of identifying those which do. A definition is a series of superimposed language filters and only the definiendum (the term to be defined) can penetrate it.

Take the definition of a simple object, a chair for example. Every dictionary will have a slight variation and sometimes several contextual definitions, a point we will come back to later. But for consistency we will take the definition provided by the OED. "Chair – a separate seat for one person, of various forms, usually having a back and four legs."

There is probably general agreement with that definition but it is not irrefutable. How do we know whether a chair with three or five legs or, in the case of many arm chairs, no legs, falls into this category? How often is 'usually?' And if we then try to make a distinction between a chair and a stool we come across further problems. The OED again "Stool – a seat without back or arms, usually for one person and consisting of a wooden slab on three or four legs or a single pedestal."

Many bar stools have backs or arms and are made from a variety of non-wooden materials. Does this make them chairs? Or something else altogether? We have problems with definitions of simple objects yet we use the words every day with very little confusion because the words are understood in their context. But if we cannot come to a definition of 'chair' which applies to and enables us to classify all its members, the fact that no-one has yet arrived at a universally accepted definitive definition of ‘life,’ a concept vastly more various and complex than ‘chair,’ is not at all surprising.

In some ways, definitions are like scientific theory; they talk about the correlation between language and reality. Just as there are disagreements amongst scientists, there are also disagreements amongst lexicographers. There is no single accepted definition of a definition. In fact there are many different types of definition; the six most common are listed here.

1. LEXICAL DEFINITIONS These are dictionary type definitions, attempts to give the meaning of a word as it is used contemporaneously.
2. COMPLEMENTARY DEFINITIONS These give all the complements in a set, an activity which is impractical for a set as large as ‘life.’
3. PERSUASIVE DEFINITIONS maintain the emotional connotations of a word and its positive or negative associations.
4. THEORETICAL DEFINITIONS are often used in science and philosophy. They are definitions constructed in the light of theories.
5. STIPULATIVE DEFINITIONS are used to define wholly new terms or to restrict meaning to a particular context.
6. OPERATIONAL DEFINITIONS are a form of stipulative definition used to set out parameters so one can verify whether or not the term can be applied.

Some of these are not relevant for the purpose of defining life, persuasive definitions for instance, which are concerned with emotive language. They are often used in advertising e.g., ‘Coke – it’s the real thing’ and have no place in science which is concerned with objectivity. The three most useful to science, particularly in the context of origins of life on Earth or the search for life on other planets are theoretical, stipulative and operational definitions.

Theoretical definitions are useful but their shelf life is limited. They are subject to constant change as information becomes available, which is the essence of science. (Cleland and Chyba 2002; Kripke 1999) point out that ‘water’ was not precisely defined until it became possible to analyse it atomically as H_2O.

Stipulative definitions can be extremely useful in a given context, e.g. ‘When searching for life on Mars, we take ‘life’ to be X; ‘Let us call a particle with properties A and B a Y.’ It is very difficult to keep to those precise meanings in any extended communication – our every day use of terms exerts a strong attraction – but the definition also has no relevance outside the particular context in which it is being used.

Operational definitions are even more limited and define things in terms of their use, or more usually measurement, in individual contexts. In 1927 Bridgman proposed a series of operational definitions to minimise the problems faced by physicists with quantum theory, e.g., ‘length as measured by sonar,’ ‘intelligence as numerical IQ score’ (Bridgeman 1927), DNA as base-pair sequences. Since these can only be used in each individual circumstance they become unwieldy and can hinder progress, as they are not transferable. However “‘life’ as defined by its chemistry” or “‘life’ defined thermodynamically” may have use in a limited context.

So these types of definitions may help in the search for a single useful definition of life. However, we are also concerned with the quality of that definition. We assume that a good definition should:

(a) Be a necessary and sufficient explanation of the term to be defined.
(b) Be universal. It should apply to all past, present and future members of a set. Our objective is well expressed as a definition which would “apply not only to life

presently existing on our planet but also to the first living organisms on Earth as well as to life-like phenomena existing presumably on other planets in the Universe" (Korzniewski 2001).

(c) Capture the essence of the term. This often means including what it does or was meant to do or its uses, e.g., you cannot define a microscope without mentioning its function.

(d) Be able to settle ambiguous cases, e.g., does the definition of life help us decide whether we can include as living entities a virus, a growing crystal, fire or cells from a dead person.

Most people would agree that very few definitions fulfil all these criteria.

But in the end the type of definition chosen depends on its effectiveness in the context and on the precision with which we understand and apply the meanings of the words. And this is the central problem. Definitions are communicated in language and language is not transparent. Language is, on the whole, negotiable, dependant on its context, fuzzy, and science needs it to be precise, empirical and denotative. That is why many of the definitions of life falter. Having provided the words to, as far as we are able, encompass all the myriad examples of the manifestation of life, we are then trapped by language into searching for ways to make the examples fit the definition. We can illustrate the problem by applying our criteria for a good definition to some examples. We have chosen these to illustrate the problems with language, not because they are the most well known nor because we think they are the best or worst examples.

Many people take as the defining characteristics of life, the fact that living systems have a boundary and are able to reproduce, metabolise and interact with their environment. Our first example was chosen because it includes all these attributes;

> We propose to define living systems as those that are (1) composed of bounded micro-environments in thermodynamic equilibrium with their surroundings (2) capable of transforming energy to maintain their low-entropy states and (3) able to replicate structurally distinct copies of themselves from an instructional code perpetuated indefinitely through time, despite the demise of the individual carrier through which it is transmitted (Schulze-Makuch et al. 2002).

This is a stipulative definition – it specifies the use of its terms – "living systems are those that are...." Note that it does not say it is defining 'life.' This serves to illustrate one of the major language problems with definitions of 'life.' 'Evolved life,' 'living systems,' 'living organisms' etc. are often used interchangeably with 'life' and of course in terms of language and even science this is not accurate. 'Life' is an abstract classifying noun and making it gerundive as in 'living system' gives the noun the property of being alive, it is not 'life' itself. Mahner and Bunge (1997) address the language problem inherent in definitions of life. They take life to be a concept, an extension of the predicate 'to be alive.' Life is the collection of all living beings past, present and future. 'Being alive' is an intrinsic property of a biosystem (which is not synonymous with an organism) so its origin and history are irrelevant (Mahner and Bunge 1997). This is pertinent to another difficulty, which we come across at the end of this definition, the question of reproduction. This has proved particularly difficult for biologists.

> Whenever biologists try to formulate definitions of life, they are troubled by the following: a virus; a growing crystal; Penrose's tiles; a mule; a dead body of

> something that was indisputably alive; an extraterrestrial creature whose biochemistry is not based on carbon; an intelligent computer or robot (Poundstone 1984).

Many people tie themselves in knots because mules and other sterile living entities are not able to structurally replicate. If their definition includes reproduction as a prerequisite for life, they are led to the illogical conclusion that mules, children, worker ants etc. are not alive, whereas crystals, fire and cells from a dead person are. As Luisi (1998) points out, a more general definition of life should allow for the analysis of the life/non-life issue at the level of a single specimen and in the here and now. The accepted NASA definition of life "Life is a self-sustained chemical system capable of Darwinian Evolution" (Joyce 1994) also runs into this problem. As we have seen, only 'living entities,' or other synonymous concrete noun phrases, can be in a grammatically complementary relationship to 'chemical systems.' Further, how are we to tell whether this "chemical system" is capable of Darwinian Evolution or not? We would need to study it over many generations as it mated and mutated and that is impossible, especially if we have only one specimen. On the logical basis of these definitions, no animal, including the human animal, is alive singly because it cannot reproduce unless it is part of a mating pair.

So we can see how definitionists can be led astray by the logic and language of their definitions. It is also clear that neither of these definitions is 'universal' nor 'necessary and sufficient' nor do they 'settle ambiguous cases.' They do not fulfil three out of four of our conditions for a good definition.

Let us consider another definition;

> Life is the process of existence of open non-equilibrium complete systems which are composed of carbon-based polymers and are able to self-reproduce and evolve on the basis of template synthesis of their polymer components (Altstein as quoted in Palyi et al. (2002)).

This was chosen as an example of an earth-centric definition. It may not be helpful If we are going to look for life on other planets as it is not extensible to all other examples. It may be difficult to imagine a living system that is not composed of carbon-based polymers and we do not have an example on Earth but it is possible that one may exist here or on other planets. We need to be able to look for life that does not conform to what we already know.

Here is our definition which implies the concept of autopoiesis (Maturana and Varela 1998), the ability of systems to create and maintain themselves by assimilation and boundary formation, and in that respect it can be seen as a Theoretical Definition.

> Life is the sum total of events which allows an autonomous system to respond to external and internal changes and to renew itself from within in such a way as to promote its own continuation.

We do not present this as a final definition of life but we believe it satisfies the criteria for a good definition in that it can be applied to all cases, past, present and future, captures the essence of 'life' and can be used to settle difficult cases. It is not earth-centric, can be applied to a single specimen and avoids the reproduction and evolution problems. However, we present it merely for discussion particularly as to whether it is necessary and sufficient.

We have limited ourselves by implication to definitions of life as used by scientists because any effective communication should take into account its audience, purpose and context. There are of course many other contexts in which the word 'life' is used multivocally i.e., with several different meanings; 'We had the time of our life,' 'during the life of this parliament,' 'get a life,' and as we previously stated, each of these will be given a separate sub-entry in a lexical definition in a dictionary. One definition of life could not possibly encompass all these meanings any more than one definition of 'chair' could encompass the meaning of 'head of a University department' or 'stool' the concept of excrement. So should we, as Machery (unpublished manuscript, "Why I stopped worrying about the definition of life...") advises, stop worrying about the definition of life because, at least in our analysis of a good definition, it is impossible and pointless? Maybe so. A 'definition' of life in its strict lexical sense is not even useful to science, as Cleland and Chyba (2002) conclude. But it would still be very useful to have operational descriptions of life which would be appropriate in their context, whether that is deciding whether a human is alive or dead or whether an artificial intelligence has life; whether we are looking for evidence of the origin of life on a micro scale or formulating ways of identifying life on Mars.

What we propose as a way forward then, is not a universal definition but a series of working descriptions, relevant to the context in which 'life' is being used, suitable for the immediate purpose and agreed to by the particular audience. They will be formulated by experts in the various fields of science from microbiology to A Life and possible examples may be something like the following;

> "When documenting past life elsewhere in the solar system, the following signs of life should be investigated:
>
> The presence of all stable amino acids.
>
> Stable C and N isotope compositions of amino acids consistent with available substrates.
>
> Isotope fractionations for protein amino acids similar to that on Earth" (Engel and Perry, personal communication).

Or a more general example:

> "Possible indicators of life on Mars (Perry and Kolb 2004a) are:
>
> Chemicals that are polymeric and have the potential to carry information.
>
> Various heterocyclic bases that can hydrogen bind and thus serve as templates.
>
> Organic chemicals that are complexed metals or mineral"

They may have some of the features of theoretical, stipulative and operational definitions or be a mixture of these as in the first example. They would acknowledge the problems with definitions – the fact that they are necessarily transient or could be limited because based on earth-life examples but they would allow for other possibilities. Our first example is based on amino acids, which are present in all life as we know it and can therefore provide a starting point for investigations but would be only one of many such operational descriptions. They will not mention 'life' unless that is specific to their meaning but will deal instead with 'organisms,' 'life carriers,' 'living entities' etc. They will not try to be necessary and sufficient but may provide various subsections for contextual usage in a lexical definition of 'life.' It may mean that we would rarely come across something which fitted the sum of all the physical, chemical, thermodynamic, mathematical etc. working descriptions, but if it did, we would be sure we had found life definitely if not definitively.

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