A New Definition of Artificial Life

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> *Vitalism amounted to the assertion that living things do not behave as though they were nothing but mechanisms constructed of mere material components; but this presupposes that one knows what mere material components are and what kind of mechanisms they can be built into.*
>
> C.H. Waddington, The Nature of Life

Abstract

In previous publications, I have defined Artificial Life as "Life made by Man rather than by Nature." However, the more I have explored what it means to be "made by man rather than by nature," the more I have become unhappy with the fundamental distinction we make between "The Natural" and "The Artificial." In this paper, I retrace my thinking about this distinction, which now seems quite odd to me, and consider the implications for our understanding of life if we were to drop this distinction altogether.

Introduction

I will start out with a quick reminder of what the field of Artificial Life is all about, taken from my Introduction to the Proceedings of the first Artificial Life Workshop, held in Los Alamos in 1987:

Review

Artificial Life is the study of man-made systems that exhibit behaviors characteristic of natural living systems. It complements the traditional biological sciences concerned with the analysis of living organisms by attempting to synthesize life-like behaviors within computers and other artificial media. By extending the empirical foundation upon which biology is based beyond the carbon-chain life that has evolved on Earth, Artificial Life can contribute to theoretical biology by locating life-as-we-know-it within the larger picture of life-as-it-could-be.

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Biology is the scientific study of life - in principle anyway. In practice, biology is the scientific study of life based on carbon-chain chemistry. There is nothing in its charter that restricts biology to the study of carbon-based life; it is simply that this is the only kind of life that has been available for study. Thus, theoretical biology has long faced the fundamental obstacle that it is difficult, if not impossible, to derive general theories from single examples.

Certainly life, as a dynamic physical process, could "haunt" other physical material: the material just needs to be organized in the right way. Just as certainly, the dynamic processes that constitute life - in whatever material bases they might occur - must share certain universal features - features that will allow us to recognize life by its dynamic form alone, without reference to its matter. This general phenomenon of life - life writ-large across all possible material substrates - is the true subject matter of biology.

Without other examples, however, it is extremely difficult to distinguish essential properties of life - properties that must be shared by any living system in principle - from properties that are incidental to life, but which happen to be universal to life on Earth due solely to a combination of local historical accident and common genetic descent. Since it is quite unlikely that organisms based on different physical chemistries will present themselves to us for study in the foreseeable future, our only alternative is to try to synthesize alternative life-forms ourselves - Artificial Life: life made by man rather than by nature.

Whereas biology has largely concerned itself with the material basis of life, Artificial Life is concerned with the formal basis of life. Biology has traditionally started at the top, viewing a living organism as a complex biochemical machine, and worked analytically downwards from there - through organs, tissues, cells, organelles, membranes, and finally molecules - in its pursuit of the mechanisms of life. Artificial Life starts at the bottom, viewing an organism as a large population of simple machines, and works upwards synthetically from there - constructing large aggregates of simple, rule-governed objects which interact with one-another nonlinearly in the support of complex, global dynamics.

The ``key'' concept in AL is emergent behavior. Natural life emerges from out of the organized interactions of a great number of non-living molecules, with no global controller responsible for the behavior of every part. Rather, every part is a behav**or** itself, and life is the behavior that emerges from out of all of the local interactions among individual behav**ors**. It is this bottom-up, distributed, local-determination of behavior that AL employs in its primary

individual behav**ors**. It is this bottom-up, distributed, local-determination of behavior that AL employs in its primary methodological approach to the generation of life-like behaviors.

(End of review)

This manifesto, as it has been called, has stood up rather well over the decade since I first wrote it down. However, we have learned a lot more as the field of Artificial Life has matured, and there remains a fundamental problem concerning the Strong Claim of Artificial Life, which holds that we will eventually be able to go beyond creating mere "simulations" or "models" of life, to actually create the real thing - Life Itself - incarnated in machines of our own fabrication.

Why is there a problem with this "claim"?

There seems to be a fundamental, impenetrable barrier between anything that we create - any artifact - no matter how complex its behavior, and the incredibly rich, flexible, and robust dynamics of naturally occurring living organisms. Is this gap really fundamental? Is life *essentially* beyond the reach of mechanical technology, as the vitalists suppose? Or could it be the case, as Waddington suggests in the quote above, that we simply have not yet discovered how to push mechanical technology into the domain of indisputably living things?

Every shred of scientific evidence we have suggests that living organisms are nothing more than extremely complex biochemical machines, and it seems reasonable to suppose that our mechanical capabilities will eventually reach a similar level of complexity. Is complexity enough? Is it simply a matter of the "quantity" of complexity that we are able to realize mechanically? Or is it more a function of the "quality" of the complexity that we construct? Not more complex, but complexity organized in a different way than we have traditionally employed in our mechanical endeavors?

I will argue (or course!) for the latter. In this paper, I want to explore some issues centered around the "qualitative" differences between naturally and artificially constructed machines.

The Natural and the Artificial

First, some standard dictionary definitions (all definitions from *The American Heritage Dictionary of the English Language*)

The term "**artificial**" means "made by humans rather than by nature."

So, Artificial Life is:

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Life made by humans rather than by nature.

So far so good, but, what is "life?"

According to the dictionary,

life (n.):

1. Biology.

a. *The property or quality that distinguishes living organisms from dead organisms and inanimate matter,* ***manifested in functions*** *such as metabolism, growth, reproduction, and response to stimuli or adaptation to the environment originating from within the organism.*

Thus, plugging in the definition for "life,"

Artificial Life is:

> *[The property or quality that distinguishes living organisms from dead organisms and inanimate matter, manifested in functions such as metabolism, growth, reproduction, and response to stimuli or adaptation to the environment originating from within the organism] made by humans rather than by nature.*

But, we don't "make" properties or qualities directly. Rather, we make "things" that have properties or qualities. So, we retrench a bit and say that an instance of Artificial Life is:

> *An "artifact" (something made by humans rather than by nature) that has the property or quality....manifested in functions.....originating from within the organism.*

Now we have to face up to a fundamental problem faced by most definitions of life.

Just because living things typically exhibit these "manifest functions" (MF), are we justified in claiming that anything that exhibits the MF is alive? Unfortunately, we are not. This is not a valid deductive argument. It is like saying that all ravens are black, **A** is black, therefore **A** is a raven. Just because an object exhibits the MF, it does not necessarily follow that the object has "that property or

therefore **A** is a raven. Just because an object exhibits the MF, it does not necessarily follow that the object has "that property or quality....etc."

So, we are really not justified, in claiming that an artifact that we build is "alive", even if it exhibits the manifest functions.

So, we must retreat again and say that Artificial Life is the study of:

Man made things that exhibit the manifest functions.

We may pause here for a brief digression to claim an achievement of sorts.

At this point, we could stop and simply admit right up front that, in studying artifacts that exhibit life-like behaviors, our first and foremost concern need not be whether or not they are "alive." There is plenty to study and learn about the manifest functions of life themselves, without concerning ourselves, for the time being, with the nature of life itself. In order to underscore this point, we will employ the adjective "animate" (pronounced with the second "a" sounding like a short "e", as in "met") rather than "life-like" to characterize artifacts that exhibit the manifest functions.

"Animate" literally means "having the qualities associated with living organisms." It is a convenient term, because we can use it even if we can't be precise about just what those qualities are. Furthermore, the term "animate" clearly supports a continuum, whereas the term "life" seems much more binary (something is alive or not). An object can be more or less animate as it exhibits more or less of the MF.

So, whereas Biology is the study of *naturally occurring* animate objects,

Artificial Life is the study of man-made animate objects.

Thus, we take the stand for the time being that Artificial Life is the study of man-made objects that exhibit the MF, and agree that it includes the study of objects all along the animate scale. Thus, machines that reproduce themselves, but do not metabolize or grow, are included, even though they do not exhibit all of the MF associated with life: they represent a valid point on the "animate continuum."

Returning to our primary concern, however, while accepting that the study of the MF and their implementation is interesting on its own rights, it will prove to be useful to employ man-made animate objects as probes of our understanding of "life" itself.

Why is it that we are reluctant to attribute "life" to a man-made thing that exhibits many of the functions exhibited by "real" living things?

What is it that is lacking in our man made things that causes us to

What is it that is lacking in our man made things that causes us to deny them the status of being alive, even though we would classify a naturally occurring thing exhibiting the same MF as alive? Whatever that "lack" is, it must be a part of our implicit understanding of life, even if we can't express it. By building animate machines, and using them to confront that "lack" directly, we can give more form to the "lack" and characterize it more explicitly.

We don't have to actually build animate machines to employ them toward this end.

We can perform thought experiments in which we build machines that exhibit many of the MF, and compare them with living organisms and ask: Is life something more than just the exhibition of the MFs?

I think that it is obvious that it is. By performing the above thought experiments in our heads, we can even give some shape to the "lack" that seems to remain.

Here, "Purpose" raises its ugly (or pretty!) head: Living organisms don't just exhibit the MF - they employ them towards some end. In a living organism, the MF's are coordinated in complex ways according to some inscrutable internal "purpose" on the part of the living organism - something for which all the MF are employed "in the aid of," so to speak. So, it is not the MF's*, qua* MF's, that constitute life, rather it is the temporal pattern with which the MF's are employed, and the ends toward which they are employed, that is crucial to life.

We must address the fact that there exists within the organism some self-originated purpose, directing all the MF's; some higher-order "functions" that elude our words or observational criteria. It is these higher-order functions (HF) that we are really referring to when we say that some entity is "alive". In our observations of the natural world so far, entities with these higher-order functions all exhibit the MF's, to some degree. However, it is obvious that merely exhibiting the MF's does not guarantee the existence of those higher-order functions - which are closer to "that property or quality..." referred to in the dictionary definition of "life" above.

When we study life, we study the MF's and come to understand how they work. However, even if we understand all the MF's, we still don't understand how they are all directed and organized in their behavior by those higher-order functions or organizing principles - we don't have access to them directly, they only reveal themselves in the patterns of behavior of the MF's that we can observe. Something about the collective dynamics of the whole is essential to life, but how can we make that "something" explicit?

how can we make that "something" explicit?

It is these organizing principles, or higher-order functions, that the vitalists claimed were not physically realizable, but must be due to some "higher" level of existence, quintessence, vital fluid, or whatever. We will not toss up our hands like the vitalists, but we have to admit that they have put their finger on the fundamental problem: how are such organizing principles realized physically? We don't know ..... yet, but we do have some clues.

Perhaps we can gain more insight into the problem if we continue our attempt at definition.

Having delved into our problems in defining "life", and having run into the problem of understanding and defining "purpose", we return now to the term "artificial", because there are deeper truths to be learned from analyzing what we really mean by that term....

We have taken, as a first cut at the meaning of the term:

artificial: *made by man rather than by nature.*

A bit of thought shows another problem here.

This was fine when we believed that man himself was "made by God rather than by nature," and that we were, essentially, an artifact of God's handiwork. However, since Darwin, we know that man himself was made by nature, so now we have the puzzle that an artifact is "something made by something made by nature rather than by nature."

With our current belief in the natural origin of man, it seems that it is no longer tenable to maintain a fundamental distinction between things made by man and things made by other natural organisms or processes. Why not say that a termite mound is "made by termites rather than by nature"....?

The source of the problem becomes clearer when we state the definition of "artificial" a little more carefully:

Artificial: *something **made** by man rather than **made** by nature...*

All we have done is to unpack the double-duty played by the original single instance of the term "made".

With just a single mention of the term "made", we were constrained to the same sense of the term in both uses. However, with two mentions of the term, it becomes possible to ask whether the term means different things in the two cases. It is immediately obvious that it does, and that it is possible to consider that the basis of our distinction between "natural" and "artificial" does not rest so much on the "man Vs nature" distinction, but, rather, on the fact that the term

distinction between "natural" and "artificial" does not rest so much on the "man Vs nature" distinction, but, rather, on the fact that the term "made" is being used in two different senses....the sense in which man "makes(1)" things, is fundamentally different from the sense in which nature "makes(2)" things.

To see this, we need to look more carefully at the definitions of the terms "artifact" and "nature."

The term "artifact" contains the root term "art", which means:

art (art) n.

1. *Human effort to imitate, supplement, alter, or counteract the work of nature.*

It derives from an older Indo-European stem **ar-** which means "To fit together." The term "nature" is rich with multiple meanings. However, the Indo-European root again provides an underlying meaning that shows the relations between all the senses in which we use the term "nature" today.

na-ture (n.)

1. The material world and its phenomena.

2. The forces and processes that produce and control all the phenomena of

the material world: the laws of nature.

3. The world of living things and the outdoors: the beauties of nature.

4. A primitive state of existence, untouched and uninfluenced by civilization

or artificiality: couldn't tolerate city life anymore and went back to nature.

5. Theology. Humankind's natural state as distinguished from the state of

grace.

6. A kind or sort: confidences of a personal nature.

7. The essential characteristics and qualities of a person or thing..

8. The fundamental character or disposition of a person; temperament..

9. The natural or real aspect of a person, place, or thing..

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10. The processes and functions of the body.

The Indo-European root of "nature" is **genœ -**, which means:

genœ -

To give birth, beget; with derivatives referring to aspects and results of

procreation and to familial and tribal groups.

Here, then, we see a fundamental difference between things that are created by "art" and those created by "nature".

Artifacts are things that are put together by someone or something else - which may be of a very different "kind" - whereas objects produced "by nature" are produced by themselves, or something of the same kind. Furthermore, the "act" of creating or generating the object involves assembling already extant pieces in the case of "art", whereas it involves something more like "birth" and "growth" in the case of nature, in which the new parts are derived from the existing parts of the creating entity.

To summarize:

make(1) = take separate things and put them together to make another kind of thing.

An external agent does the assembling, and the purpose of the made thing is derived from that of the external agent.

make(2) = a single thing divides into several identical things. The agent itself makes more of itself via internal division and growth, and the purpose of the made thing is its own.

Thus, naturally generated objects are what they are by virtue of themselves, they have an "essential" nature by virtue of their ancestry. Whereas artificially generated objects are what they are by virtue of something outside of themselves, and their "essence" is not intrinsic to their history or ancestry; it is a function of something else's "purpose", something that existed prior to, and outside of, the constructed object.

Here, then, we appear to have a truly fundamental distinction between things made by man and things made by nature. Note that it also holds for things made by termites Vs things made by nature.

between things made by man and things made by nature. Note that it also holds for things made by termites Vs things made by nature. Termite's artifacts are in the same class as our artifacts, and the fundamental distinction, again, is not that something is made by termites rather than by nature, but rather that something is "made" in sense (1) rather than in sense (2).

So, we restate the definition of Artificial Life as follows:

Artificial Life: *Life "made" in sense (1) rather than in sense (2).*

Therefore, a fundamental question for Artificial Life is:

Can things made in sense (1) ever be considered to be alive?

Another question is:

Can we make(1) things that will go on to make(2) themselves?

and if so, could these be considered to be alive?

If so, then we would seem to have a path to creating "natural" life.

This constitutes an interesting turnabout from the traditional religious stance, in which organisms were considered to have derived "that property or quality..." from having been made in sense (1) by God! Even so far as to the determination of their purpose: it is derived from God's purpose.

In religion, therefore, it is perfectly OK to have an act of make(1) initiate a chain of make(2)'s. Can we infer from this that if we initiate a chain of make(2)'s with an act of make(1), that the ontological status of the resulting entities will be similar?

In the late 1940's, John von Neumann proved that we could make machines in sense (1) that go on to reproduce themselves, making other machines in sense (2). Since Darwin explained how "purpose" could enter into biology without invoking a pre-existing "purpose" in the explanation, and since we can incorporate the mechanisms of evolution by natural selection into our artificially produced machines, I believe that we are, in fact, justified in stating that we will be able to introduce into the world other forms of "natural" life, although the initial genesis may very well be "artificial."

We can make(1) things that will make(2) themselves, and which will go on to gain their own purposeful mechanisms via an autonomous evolutionary process.

To regroup once again:

Living things *are those that exhibit their own "purpose", part of which is to make(2) more of themselves.*

On the previous religious view, we were made(1) by God, and our purpose was, and still is, derived from His purpose: Nature itself was seen as the "art of God". Darwin, however, showed that we result from a long line of make(2).

In fact, clearly make(2) preceded make(1)! The ability to make(1) is a highly evolved characteristic, involving the ability to rearrange external bits and pieces of our world according to our own purposes, to enhance our own chances of survival, and therefore to enhance our own chances to make(2) our offspring.

Now we come to a final, interesting problem of scope, which, I believe, illuminates a clear path to resolving these two different senses of the term "make", and therefore to resolving the distinction we make between "The Natural" and "The Artificial."

A termite mound is clearly made(1) by termites. However, if we consider the colony as a whole - termites and their mounds together - then we have the interesting observation that the aggregate of termites together with termite-mounds makes more aggregates of termites together with termite-mounds. If we look to the whole as "the organism", then termite mounds make more termite mounds in sense(2).

But then, of course we can say the same thing about humans and our large scale artifacts, such as cities and our socio-cultural institutions. Although we seem to make cities and buildings in sense (1), the aggregate of humans together with our artifacts make more such aggregates in sense (2).

Taking this approach to its limit, we then have to accept that all of our artifacts, our socio-cultural institutions as well as the products or our technology, are really not different from nature. Rather, *they are the current state of nature*.

This is not at all the common or accepted view. However, I believe that it is, nonetheless, a necessary implication of the line of reasoning pursued above. Human physical culture and technology are **not** different from nature, they **are** nature.

Therefore, I propose that the term "Artificial Life" be understood as follows:

Artificial Life: *The study of natural life, where "nature" is*

Artificial Life: *The study of natural life, where "nature" is understood to include, rather than to exclude, human beings* ***and their artifacts***.

This is merely to observe that the production of artifacts has always been, is today, and will continue to be, an essential aspect of life.

Hence, finally, a major goal of Artificial Life should be to work toward removing "Artificial Life" as a phrase that differs in meaning **in any fundamental way** from the term "Biology". Although they are currently viewed, and pursued, as very different scientific endeavors, I believe that the day will come when science will ***finally*** acknowledge that which Darwin gave us the key to understand:

Human beings, and all that they do, are a part of Nature.