LIFE IMITATES LIFE

Part 2 in a series on Life
by Michael Harwood

In this article I want to examine questions such as "What exactly is life?" "Why is it so hard to make something that is alive?" and "Why does life only come from living things?" When trying to come up with a title for this article, I tried to find quotes that relate to life. There are *Ars longa vita brevis* and *Vita non est vivere sed valere vita est*. Then there is "art imitates life" and "life imitates art", which led me to my actual title which encapsulates what I'm discussing.

From the beginning of human thought up until around 1900 AD, people thought that there was some magical property that makes living things alive. It could be called "vitalism" or the "vital spark" or the "qi". This concept of a life force or "qi" makes sense because we simply can't make living things from non-living ingredients.

Consider a dog or a mouse that is dead. Can we reanimate it somehow? Hook it up to the mysterious power of lightning à la Frankenstein? No. This is still impossible, with the possible exception of cryogenically freezing an organism while it is still alive (which is cheating because it was already initially alive). If we have a complete organism with all of its parts, organs, blood, etc., why can we not bring it back to life if it's dead?

The idea of a life force is consonant not just with Frankenstein's monster, but also with Louis Pasteur's famous biogenesis experiment that disproved spontaneous generation and showed that life only comes from life. Even though nowadays we have a fairly good scientific understanding of what life is and have made huge advances in biochemistry, these concepts linger in our culture with Feng Shui and "the Force" in Star Wars.

What is Life?

In grade 9 we learn that it is actually surprisingly hard to define life (similar to the problem we have defining time). As humans interacting with our environment, we instinctively understand what is alive and what is not, notwithstanding the incredible variety of life that exists on earth. Generally what one does is list criteria that an object must have in order to be considered alive: grow, heal, reproduce, use energy, produce waste, and respond to its environment. On earth, all life is based on DNA and all life is based on cells, but as far as we know, these are not necessarily universal requirements, but are rather simply observations of our carbon-based life. Note that there are things that have some of these properties but are not alive since they don't have all of them. Crystals can grow, cars take in energy and produce waste, and rocks "reproduce" by breaking.

A number of websites point out that fire is alive by these definitions, yet we know it is not. So we need one more criterion: Life involves some form of metabolism, building up complex structures, reversing local entropy.

NASA's Exobiology Program uses the working definition of life as "a self-sustaining chemical system capable of Darwinian evolution." I know that NASA has indeed put much thought and discussion into this definition since its origin in 1994, but I am still surprised that it is the best they can do. In my opinion, this is a terrible definition and doesn't actually describe anything about life at all, other than it is self sustaining. If we're imagining life on other planets, many sci-fi authors such as L. Niven, R. Forward, F. Herbert, and S. Baxter have gone further and imagined non-carbon based life forms: life based on gas clouds, life based on electromagnetic fields in nebulas, life on neutron stars. We don't require that all life be based on DNA or have cells, so why on earth would we require all life to be capable of Darwinian evolution? If you look at the Bandersnatchi in Larry Niven's books, they're specifically designed to NOT be able to evolve, ever! So NASA's definition is found wanting and was probably written this way for philosophical or religious rather than scientific reasons (not to imply that science is better than philosophy or religion). Simply calling a reaction self-sustaining is not enough. The sun has self-sustaining reactions and it evolves (from proto-star to main sequence to red giant, etc.). However, these reactions are nuclear rather than chemical. The earth has self-sustaining geological reactions with is subduction zones and volcanic arcs. Is the earth alive? We can argue that is has evolved and changed appearance from the Pre-Cambrian era to modern eras. I would say that the evolution part of the definition should at least specify that it must be able to reproduce to make another organism. Perhaps saying "Darwinian evolution" is sufficient to clarify this point; however, neo-Darwinism has replaced old-school Darwinism, so NASA's definition is already decades out of date (and neo-Darwinism may be updated to something else soon).

It seems strange to define life by adding a requirement that you must know about the past history of that life over millions of years. What if we found some silicon-based life form on a planet? If it doesn't use good old DNA for its molecular data storage, then we would have no way of knowing if it is capable of neo-Darwinian evolution. By this definition we couldn't tell if it was alive no matter what our observations were! We would have to determine its biochemistry and hazard a guess as to whether the silicon chains could evolve or not. Based on this decision about its evolution we would then classify the entity as alive or dead. But we could be wrong in our understanding of silicon biochemistry, so then after a few years, we have to change our minds and call it dead (or vice versa). The alternative is to observe it and its progeny for millions of years to see if it evolves. This strikes me as a very silly criterion to tack onto the definition of life, one that causes more problems than it solves.

Does something have to be able to die to be alive? I would tend to say yes, since I can't imagine something that is alive that cannot die, but maybe it depends on which murky definition of life you're using. One can die, but also be immortal. Consider the future where medicine has advanced to allow people to live for ever. A scan is made of your cells when you mature, and from this template, repairs are made to the cells so that nothing wears out. You will live forever, but you could still be killed by an accident or homicide. (Asimov in his "I Robot" stories explores this question, but he focuses more on what it means to be human.)

Another criterion for life that some people add is that living things contain reproducible hereditary information. However, there are problems with this: it rules out any sort of artificial intelligence and requires that things must be able to reproduce. This causes problems with mules and worker bees which are sterile but definitely alive.

Some things can be put into non-living states and then recovered. For example, frozen bacteria are not alive since they cannot do anything until they have been thawed. So there is suspended animation where something that is alive is put into a non-alive state and then brought back. Perhaps this same situation applies to viruses, and they are only alive while they are in a cell.

I wonder if the problems we have in defining life have anything to do with the problems in creating it.

Life is difficult. Why?

Why is it so difficult, nay impossible, to make something live, to create life? We're not even talking about life arising accidentally: we're talking about deliberately and purposefully creating life. The definitions of life above don't provide any explanation of why it is so hard to create life.

If we had all of the parts of a cell, all of the organelles, could we assemble them into a cell and then make it live? As far as I know, this is still nowhere near being possible. Is it futile to even try? Perhaps.

Many people approached this by trying to solve the protein–DNA paradox. To make protein you need protein and DNA. To make DNA you need protein and DNA. So which came first? Much has been written about this, but there is still no answer.

This brings us to another way at looking at life: **life is a series of chemical reactions where the products of one reaction are the reactants of the next.** Looking at some of the major metabolic pathways, we can guess that there are 10 to 20 reactions in any one of these chains. Each of the reactions has complex enzymes mediating the rate of the reaction and often enabling it to happen in the first place. The best picture of what life really looks like are the two Roche Biochemical Pathways maps at biochemical-pathways.com . You'll notice that the reactions of metabolism, of life, are not simple chains, but an interconnected network of processes.

Perhaps life is an emergent property that is only manifested when there are a certain number of different organic chemical reactions working together. It is likely that this number is more than a thousand, and with less than that, well, you just can't have life.

When life stops, this vast number of reactions and the enzymes that control them begin to break down rapidly. To start life up again, a large number of reactions need to be started at the same time. If you just provided the raw materials to the initial reactions and got them working, their products would just start clogging up the cell because the subsequent chemical processes are not working to continue the metabolic chain. Getting even one metabolic pathway to work would probably require at least 40 molecules (proteins, enzymes, as well as lots of ATP and GTP) to be in the right place at the right time. This seems like an insurmountable problem.

An interesting way of examining this problem is Dr Paul Nelson's idea of looking at the functions of a cell and seeing how simple a cell can be while still existing as a living organism. This is similar to the criteria of life laid out in high school science classes, but here we are assuming that the cell is a basic unit of life and looking at its functions. Aside from this assumption, we don't need to specify certain organelles or DNA, just functions that are general enough for any type of life of alien or terrestrial origin.

Anything that is alive must

1. separate itself from its surroundings with some sort of boundary (this is the cell membrane).
2. transport nutrients into the cell and transport waste out.
3. metabolize nutrients into whatever it needs.
   Subsets of metabolism are
   a. converting energy from food or sunlight into a form that can be used by the cell (ATP, GTP).
   b. manufacturing required molecules (proteins, vitamins, nucleotides, etc) needed to perform needed functions.
4. have some template or library to store the patterns of molecules that need to be manufactured.
   a. This information needs to be stored somewhere safe (and ideally should have continuous error correction).
   b. It needs to be duplicated accurately for daughter organisms.
   c. The templates need to be able to move from the storage site to the production site.
5. reproduce into daughter organisms.

Which of these can be removed without killing the cell?
Removing #1, the cell boundary, means that the organism (cell) would just fall apart.
Removing #2, active transport, means that the cell would run out of raw materials and energy. The cell would also choke to death in its own waste. (Passive transport by diffusion and osmosis is unlikely to ever be sufficient for this.)

Removing #3, metabolism, would kill the cell. Without metabolism no new molecules, proteins, enzymes, etc. can be made. The cell will break down as these molecular machines wear out and no more are created.
Removing #4, information storage and reproduction, would also kill the cell fairly soon. Without this the cell will not be able to actually build the molecules that it needs because it does not know what parts they are made of and how to assemble them.
Removing #5, reproduction, is possible. Reproduction is not really a criterion for being alive, but without this the cell would have to live forever.

Which of these can exist without the others?

- Only #1. A boundary is quite easy to have by itself – it is just a bubble or a phospholipid bilayer, but is it by no means alive.
- Removing #2 means that no new materials come into the cell, so #3, #4, and #5 break down too.
- If metabolism, #3, is removed, then transportation will no longer work because the transport proteins are no longer created, and information translation/transcription/replication can not longer be done. Thus, removing #3 ruins #2, #,4 and #5.
- Removing #4 means that no new molecules can be created, so #2, #3, and #5 also stop working.

In summary, transportation, metabolism, and information storage all depend on each other. Reproduction depends on these three too, but they do not in turn require it.

It looks like there is a large gap between the simplest living thing and the most complex non-living thing. We don't know how to close this gap. Maybe there is a "qi" or "nephesh" after all. The essential functions of a cell are one big complex interconnected mess that all have to be there at once. They cannot be built in parts nor disassembled piece by piece, while allowing the cell to stay alive. As Dr. Stuart Kauffman (1995) observes, "All living things seem to have a minimum complexity below which it is impossible to go."

So how did something originally go from non-life to life? Well, abiogenesis is another topic. However, it's logical that before abiogeneis is plausible, we'd have to be able to create life intentionally in our laboratories. So I'll just leave you with this delicious title by Harold S Bernhardt in the journal *Biology Direct*: "The RNA world hypothesis: the worst theory of the early evolution of life (except for all the others)."