Complexity and the Physical Aspect of Life

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Life on earth is diverse, from simple, unicellular microorganisms, to complex lifeforms where trillions of cells work together in harmony. In the study of life, despite prodigious progress in science, we still have a few fundamental questions left unanswered: Are all life phenomena explainable by physical laws? How shall we approach the nature of life? An essential way to explore them would be through looking at the complexity of life.

We ought to begin by looking at how the processes of life are generated, beginning from the simplest building blocks—atoms. Atoms are undoubtably inanimate, and with only 118 discovered elements, many of which not participating in normal physiology or even existing naturally (Holden *et al.*), it does not seem that much would be possible with atoms alone. However, atoms can be arranged into molecules, and while the molecules of life are vast in number, we would not say they are alive, either. Once they are assembled into a cell, we may then begin to start calling it alive. For simpler organisms, such as bacteria, the structure of life stops here, but for multicellular organisms, like most animals or plants, the complexity continues to rise. Each cell in these organisms has its distinctive role, and they could form into tissues and organs, which in turn comprise the entire organism ("Organization of Life").

Over the entire process, what is most important is how, beginning from the atomic level, increasingly more complex structures are formed. Along each step, new properties that its constituents do not originally have are gained; already in the level of molecules, there is far more diverse organization than that of atoms. It is through this phenomenon, known as emergence, that living organisms are able to gain complexity ("Emergence").

The concept of hylomorphism, or the duality of matter and property (Ainsworth) may help us understand this phenomenon better. In Aristotle's worldview, he had drawn a distinction between properties and their "subject", that is the object to which the properties are attributed (Lindberg 19). While Aristotle's thought as a whole may not be compatible with modern-day science, him having rejected the idea of atoms (Berryman), we may nevertheless apply only the essence of this concept, that properties are distinctive from matter. When viewed from this perspective, a whole living being would thus not only consist of matter, but also its various properties—most obviously, that of being alive. While life may have originated from matter and is as such inseparable from it (Lindberg 20), emergence allows new properties to be attributed to life, rendering it more than simply matter alone.

It is safe to say that a living being is more than the sum of its parts, but then where does the excess come from? The modern scientific thought is that they are a result of physical laws (Watson 139). It does make sense that complex structures can arise from humble beginnings; in cellular automata, such as Conway's Game of Life, simple rules[1] already allow for the creation

1 Conway's Game of Life is played on a grid, with each cell being considered as either "living" or "dead". Each turn, if a "living" cell has fewer than two or more than three "living" cells around it, it becomes "dead", while a "dead" cell with exactly three "living" cells becomes "living" ("Where Does Complexity").

of complex structures. With a more expansive ruleset, such as that of natural scientific principles, the effect would be even more apparent ("Where Does Complexity"). Indeed, through the discovery of DNA's structure and how it replicated, scientists including James Watson were able to demonstrate from a fundamental level that life did not emerge from some mysterious "vital force"[2] or undiscovered laws of nature, but existing ones of physics and chemistry, and it was only a matter of how these laws are organized (Watson 139).

In addition, it is possible for complexity to have arisen naturally in living beings. Darwinian evolution has conventionally been considered to be one of the primary driving forces towards complexity; Darwin himself had conjectured that natural selection could lead to a divergence in character (Darwin 94), a process that given sufficient time could accumulate to great amounts of complexity, and this has since been proven by evidence from diverse fields of science ("II. Evolution of Complexity"). Recent research has however shown that even without the involvement of natural selection, complexity can still be spontaneously generated through the process of random mutation, showing that there is a natural tendency towards complexity in life (Zimmer).

Given the above, it makes perfect sense that the complexity of life could have arisen from physical phenomena, and indeed advancements in biological and medical science have led to numerous discoveries allowing us to explain the workings of life from a deep, molecular level, with one jarring exception—consciousness.

2 Incidentally, if such a force did exist and was tangible enough to be readily measurable, then the act of defining life would be much simpler, at least if only considering life on Earth—whether or not this "vital force" also exists in alien life would however likely be a point of serious debate.

Consciousness remains a major scientific mystery as to how exactly it is generated (Kandel 181). We cannot deny the fact that the physical body has some involvement in the generation of consciousness; as an example, physical factors such as illness, trauma or drugs can interfere with the brain and in turn consciousness. The question that remains would then be how consciousness originates and interplays with the physical body, given that all current purely physical explanations have fallen short in explaining it, especially regarding the "hard problem" of consciousness: how subjective experience is generated (184).

Though the consensus is that the physical basis of consciousness lies in the brain, there are divergent views on whether or not it can ever be studied in a rigorous, scientific manner. On one extreme, some scientists contend that fundamental limits to human cognition render the study of consciousness impossible, while on the other, some deny that there is a problem, stating that there is a readily available answer to the nature of consciousness under our current knowledge (182). But between the both is the arguably more realistic and constructive view that consciousness is understandable, but not with existing methods and information; before it is to be completely explainable at all, there may need to be a paradigm shift in how we approach it (184–185). Such a shift could come in various ways.

To start with, we could devise new methodologies that can help us to tackle the issue of subjective experience (184–185). With this view, we can suppose that consciousness, like life, originated from some form of emergence as well, being also a highly complex process that is more than the sum of its parts. This makes it much harder to understand than other properties of the brain (182), but through the formulation of basic rules on how consciousness arises, starting from the most elementary components of brain function and consciousness (184–185), we may eventually be able to create a complete picture of consciousness, a process mirroring that of physics and chemistry explaining other life functions.

A different pathway entails pushing the boundaries of science with radical new discoveries. The quantum mind is one such theory, which attempts to link consciousness with the physical world through the understanding of quantum phenomena (Atmanspacher). Though difficult to prove and not necessarily true, it does demonstrate how new insight in physical sciences can potentially help us to find a solution.

Specific life processes aside, we still have a generally good grasp of how life works—or do we? Currently, we still do not have a consensus on the definition of life. A proper answer to this question has tantalized scientists for millennia, even though we may be able to intuitively distinguish between the living and the non-living (Gabbatiss).

The modern scientific way to define life would be to draft a list of properties using various life processes, which if an entity were to meet all of them, would reasonably be considered as a living being. A more specific and most commonly used definition involves the universal characteristics of life, including a complex organization, metabolism, excretion, homeostasis, response to stimuli, reproduction, and physical growth (Cleland and Chyba). A broader definition, in contrast, strips down to only select core characteristics, an example being a "material system that undergoes reproduction, mutation, and natural selection" (McCay).

For the most part, these definitions appear to make sense. If we subject them to intense scrutiny, however, we may see cases where they begin to fall apart. Specific definitions may not be able to reliably classify entities missing some properties; as an example, a man in a vegetative state[3] is no longer able to respond to external stimuli, at least not in a meaningful way, but we would not usually conclude that the man is dead[4], and thus terminate life support. Broad definitions, being more inclusive, are less like to encounter this problem, but this same property also causes them to include more controversial or even non-cases. Viruses are also capable of reproduction, albeit not independently, as well as mutation and natural selection. However, since they have no metabolism to speak of, whether or not they are actually living is still under debate ("Are Viruses Alive?"). Similar borderline cases have given life a rather fuzzy quality, unlike the clear-cut one that we are more intuitively familiar with (Cleland and Chyba).

In the end, the act of semantically defining life itself has its limitations. First, our definitions only reflect our understanding of language, and not necessarily the true nature of the world (Cleland and Chyba). Second, using these definitions inevitably leads to us evaluating each part of life individually, blinding us to the whole picture of life (Brown). Finally, we currently have only one known example of life, that is life on Earth, and our definitions are naturally based on it; thus, we may not have a fundamental understanding on what life actually is (McKay). Given the above, would attempting to define life become an essentially futile exercise? The answer would be no; though flawed, such an act would remain situationally useful, nonetheless. A well-structured definition could be the first step for us to

3 No human beings were physically harmed in the making of this article.

4 Some may consider this fate as being *worse* than death; the analysis of this proposition is beyond the scope of this article.

understand life from a narrow, microscopic scale. For this purpose, the specific definitions, most notably the universal characteristics of life, would prevail as they allow individual potential lifeforms to be roughly and practically evaluated, without needing to delve deeply into detail[5]. This is especially important in the search for extraterrestrial life, in which a concrete definition plays an influential role (Cleland and Chyba); despite its restrictions, a sufficiently accurate definition, based on readily observable characteristics, could nevertheless bring us closer to the discovery of alien life[6].

Still, for us to truly comprehend the complete scale and nature of life, we need more than just semantic definitions; we would also benefit from introducing alternative perspectives, just as we might in the study of consciousness. One such approach is by applying general systems theory, understanding how life functions from a macroscopic view as a complete system; a system in this case can mean any pattern of relationship, from the microscopic world of atoms, to the macroscopic realm of ecology. Through this perspective, instead of breaking down life and studying the resultant parts, we may study life phenomena in terms of dynamic relationships and define life through these relationships. We would discover common patterns present across all living systems, and inevitably some of them, such as complex organization, response to stimuli and adaptability, which echo the previous attempts at defining

5 In here we would need to give special consideration to cases which fail to meet all the criteria but would still be considered alive under our common-sense understanding, such as the aforementioned case of the vegetative man. Relaxing these definitions to count entities meeting *most* criteria would help with these cases, but doing so would also run the risk of including controversial or non-cases, similarly to the broad definitions.

6 Inevitably, an Earth-centric definition means that the life we find under the definition would display characteristics similar to life on Earth.

life (Brown); a broad systemic perspective treats them as emergent properties of a whole system, as opposed to individual defining points of life.

Obviously, viewing life as a complex system makes the act of analyzing it much complex in turn. However, it is also essential in our continued exploration of life in several ways. By making the relationships of life the subject of study, we will be more able to account for the emergent complexity of life, which previous approaches that analyze life independently by each component are weak in (Brown). It also highlights the interrelatedness of life, a view especially important in ecology; given that there is a dense web of life on Earth with intimate and often essential relationships between different organisms, any effects on only one part will certainly reverberate across the entire ecosystem (Carson 141–142), an example being that the destruction of sagebrush has led to cascading effects with detrimental effects beyond the original target area of the upland plains (142–145). Through this approach, we can overcome the shortcomings of our existing definitions, and in turn construct a more detailed picture of life.

In conclusion, knowledge on the complexity of life is essential in answering some of the fundamental questions of life. Life is an emergent system, and it is possible through the laws of physics and chemistry that the complex processes of life emerge, although the issue of consciousness will certainly prove a tricky matter to solve, at least without any major breakthroughs. In addition, in the exploration of the nature of life, the act of semantically defining it is innately deficient; though practical, it yields a microscopic picture of life only. In any case, new perspectives or directions will certainly be helpful towards obtaining an answer. For consciousness, new methodologies or knowledge can help us unravel the complexity of consciousness; as for the nature of life, we may complement our existing definitions with a macroscopic, systematic perspective that takes into account the fundamental complexity of life, ultimately leading to a complete picture of life.

Works Cited

Ainsworth, Thomas. "Form vs. Matter". *Stanford Encyclopedia of Philosophy*, 25 Mar. 2020. Accessed 22 Apr. 2020.

"Are Viruses Alive?" *Microbiology Society*, microbiologysociety.org/publication/past-issues/what-is-life/article/are-viruses-alive-what-is-life.html. Accessed 29 Apr. 2020.

Atmanspacher, Harald. "Quantum Approaches to Consciousness." *Stanford Encyclopedia of Philosophy*, 16 Apr. 2020. Accessed 24 Apr. 2020.

Berryman, Sylvia. "Ancient Atomism." *Stanford Encyclopedia of Philosophy*, Stanford U, 15 Dec. 2016. Accessed 20 Apr. 2020.

Brown, Molly Young. "Patterns, Flows, and Interrelationship." *Wayback Machine*, 2002, web.archive.org/web/20111003154955/www.mollyyoungbrown.com/systems_article.htm. Accessed 2 May 2020.

Carson, Rachel. *Silent Spring*, 1990. Rpt. in *In Dialogue with Nature: Textbook for General Education Foundation Programme*. Edited by Chi-wang Chan, Wai-man Szeto, and Wing-hung Wong. Rev. 2nd ed., Office of University General Education, The Chinese U of Hong Kong, 2016, pp. 141–156.

Cleland, Chyba, and Christopher F. Chyba. "Life's Working Definition: Does It Work?" Origins of Life and Evolution of the Biosphere, vol. 32, no. 4, 2002, pp. 386–393. NASA, *NASA's Astrobiology Magazine*, www.nasa.gov/vision/universe/starsgalaxies/life's_working_definition.html. Accessed 28 Apr. 2020.

Darwin, Charles. *On the Origin of Species*, 1859. Rpt. in *In Dialogue with Nature: Textbook for General Education Foundation Programme*. Edited by Chi-wang Chan, Wai-man Szeto, and Wing-hung Wong. Rev. 2nd ed., Office of University General Education, The Chinese U of Hong Kong, 2016, pp. 73–96.

“Emergence.” *Encyclopaedia Britannica Online*, Encyclopædia Britannica, Inc., 16 Jun. 2017, www.britannica.com/science/emergence-science. Accessed 20 Apr. 2020.

“II. The Evolution of Complexity.” *President’s Dream Colloquium*. Simon Fraser U, www.sfu.ca/colloquium/PDC_Top/EoC.html. Accessed 21 Apr. 2020.

Gabbatiss, Josh. “Earth—There Are over 100 Definitions for ‘Life’ and All Are Wrong.” *BBC*, 2 Jan. 2017, www.bbc.com/earth/story/20170101-there-are-over-100-definitions-for-life-and-all-are-wrong. Accessed 28 Apr. 2020.

Holden, Norman E., *et al*. “IUPAC Periodic Table of the Elements and Isotopes (IPTEI) for the Education Community (IUPAC Technical Report).” *Pure and Applied Chemistry*, vol. 90, no. 12, 2018, pp. 1833–2092. doi:10.1515/pac-2015-0703. Accessed 23 Apr. 2020.

Kandel, Eric R. *In Search of Memory*, 2006 Rpt. in *In Dialogue with Nature: Textbook for General Education Foundation Programme*. Edited by Chi-wang Chan, Wai-man Szeto, and Wing-hung Wong. Rev. 2nd ed., Office of University General Education, The Chinese U of Hong Kong, 2016, pp. 177–192.

Lindberg, David C. *The Beginnings of Western Science*, 2007. Rpt. in *In*

Dialogue with Nature: Textbook for General Education Foundation Programme. Edited by Chi-wang Chan, Wai-man Szeto, and Wing-hung Wong. Rev. 2nd ed., Office of University General Education, The Chinese U of Hong Kong, 2016, pp. 11–47.

McKay, Chris P. "What Is Life—and How Do We Search for It in Other Worlds?" *PLoS Biology*, vol. 2, no. 9, 2004. doi: 10.1371/journal.pbio.0020302. Accessed 27 Apr. 2020.

"Organization of Life." *Simply Science*, www.simply.science/index.php/organization-of-life. Accessed 20 Apr. 2020.

Watson, James Dewey. *DNA: The Secret of Life*, 2003. Rpt. in *In Dialogue with Nature: Textbook for General Education Foundation Programme*. Edited by Chi-wang Chan, Wai-man Szeto, and Wing-hung Wong. Rev. 2nd ed., Office of University General Education, The Chinese U of Hong Kong, 2016, pp. 97–140.

"Where Does Complexity Come from?" *President's Dream Colloquium*. Simon Fraser University, www.sfu.ca/colloquium/PDC_Top/EoC/where-does-complexity-come-from-.html. Accessed 23 Apr. 2020.

Zimmer, Carl. "The Surprising Origins of Evolutionary Complexity." *Scientific American*, 1 Aug. 2013, www.scientificamerican.com/article/the-surprising-origins-of-evolutionary-complexity/. Accessed 12 Jul. 2020.

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Teacher's comment:

The nature of life and the nature of consciousness are two prominent questions of modern science, yet little progress has been made in explaining the concepts in scientific terms. As a first step, it seems important to analyze the concepts and the possible methodologies to be employed in the study of the subject. Eldric (TSOI Pui Lam) tackles the problem in a systematic manner. Forming a hierarchy according to complexity, the concept of life is reviewed from the perspectives of a single atom, molecules, unicellular and then multicellular organisms. Instead of using a traditional definition in terms of life characteristics, modern perspectives such as emergent properties are discussed. It certainly is an inspiring essay and it is a delight to read. (LAI Chi Wai Kevin)