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Excerpt
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Introduction

This book focuses on the search for a universal theory of life. It is concerned with the history of attempts to develop such a theory, diagnosing why these efforts have thus far been unsuccessful, and determining what is required to forge ahead and successfully pursue such a theory. It is of course possible that the diverse phenomena of life lack an objective natural unity, and hence that no such theory will ever be forthcoming. Indeed, this view has become popular among some biologists and many philosophers of biology. One of the central themes of the book is that skepticism about the prospects of universal biology is not only very premature but also potentially self-fulfilling: One does not want to short-circuit the potentially successful pursuit of universal biology by rejecting it out of hand.

This book is designed for both scientists and philosophers. Its goal is to integrate pertinent philosophical material that is unfamiliar to most scientists with scientific material (from microbiology, biogeochemistry, and planetary science) that is not well known to many philosophers. It should thus be accessible to the well-educated reader who is a specialist in neither area. Nevertheless, scientifically inclined readers may find some of the philosophical discussions tedious and difficult; Chapters 2 and 3 are challenging for anyone without a background in logic and technical philosophy. Similarly, philosophically inclined readers may struggle a bit with some of the scientific material. While it may be tempting to skip over areas with which one is least familiar, I urge the reader to refrain from doing so. To fully understand the challenges posed by the pursuit of a truly general theory of life, readers need to gain the broader interdisciplinary perspective provided by this book. In this context, a brief thematic roadmap, providing an overview of the philosophical and scientific issues covered in this book and how they relate to each other, may be helpful.

Chapter 1 traces the pursuit of universal biology back more than two thousand years to its roots in the work of the Greek philosopher Aristotle, who is also credited with being the first biologist. Aristotle's lasting influence on biology, which is not widely appreciated, is readily seen in the following characteristics, which are held up by modern biologists as fundamental to life: (1) the capacity to self-organize and maintain self-organization for an extended period of time against both external and internal perturbations (metabolism) and (2) the capacity to reproduce and (in light of Darwin's theory of evolution) transmit to progeny adaptive characteristics. I will henceforth refer to the former as "O" and the latter as "R." As Chapter 1 discusses, the conceptual parallels between characteristics O and R and Aristotle's ideas about life are remarkably close. Aristotle identified "nutrition" (metabolism) and "reproduction" as the basic functions of life, and debated (as do so many contemporary researchers) which is more fundamental. Aristotle also bequeathed to biology the thorny problem of teleology, that is, the notion that the basic functions of life involve a strange form of causation that is intrinsically directed at achieving a future goal. On Aristotle's account, organisms are not just fed, they feed *themselves*, and they are not just copied, they copy *themselves*. Chapter 1 traces the history of efforts to exorcise the problematic notion of goal-directed self-causation from biology. Darwin is often credited with having done so but, as will become apparent, it still lurks at the foundations of biology in popular definitions of life and models of the origin(s) of life, both of which are closely patterned on characteristic O or R.

Despite strenuous efforts over the past couple of hundred years, biologists have yet to come up with an empirically fruitful, truly general theory of familiar Earth life, let alone one that applies to all life, wherever and whenever it may be found in the universe. Some philosophers and scientists have responded by giving up on the program of universal biology. The great eighteenth century philosopher and astronomer, Immanuel Kant, despairingly concluded that there would never be a Newton of biology. Many contemporary biologists delight in showcasing exceptions to any allegedly universal principle of life. As a result, most philosophers of biology now embrace a pluralist view of biology, contending that, unlike other natural categories (e.g., water) studied by modern science, life does not have a unified nature. There is another, rarely entertained, possibility, however: The failure of biologists to come up with a universal theory of life is at least in part the result of tacit commitment to an anachronistic Aristotelian framework for reasoning about life. The latter is a central theme of this book.

This issue is taken up again in Chapter 4, which explores, in the context of examples from the history of science, factors that can thwart the development of successful scientific theories. One of the most serious of these factors is commitment to a defective theoretical framework of core concepts for reasoning about a domain of natural phenomena. Pick the wrong theoretical concepts and empirically fruitful general principles will not be forthcoming. Notions of impetus (active internal principles of motion) and rest (the natural state of an inanimate terrestrial body), inspired by Aristotle's writings on motion, held a grip on the scientific mind until around the sixteenth century. Newton's universal theory of motion – consisting of three laws of terrestrial motion and a law of universal gravitation – critically depended upon replacing these ideas with the very different concept of inertia (passive resistance to a change in motion). Similarly, the development of a universal (chemical) theory of material substance occurred rapidly after Lavoisier's discovery that Aristotle was wrong in thinking that water (along with air, earth, and fire) was a basic element. Viewed from this perspective, it seems somewhat scandalous that biology is the only natural science still dominated (albeit often tacitly) by Aristotelian ideas.

Returning to Chapter 2, another central theme of this book is that the popular scientific project of defining life is profoundly mistaken. Definitions of life, which are invariably founded upon characteristics O and/or R, dominate scientific discussions about the nature of life. The most informative definitions supply necessary and sufficient conditions for membership in the class of living things, which has the advantage of exhaustively subdividing the world into things that are living and things that are not. An astrobiologist could (at least in principle) determine whether an extraterrestrial system on Mars or Titan is a living thing simply by applying whatever definition of life they have agreed upon. Similarly, ALife (artificial life) researchers could invent new forms of life simply by tailoring their inventions to such a definition. As discussed in Chapter 2, however, a definition of life is more likely to hinder than facilitate the discovery of truly novel life.

The problem is that definitions are concerned with language and human concepts – with the analysis of the meanings (*qua* concepts in our heads) of terms (words and expressions). Defining bachelor as an unmarried human male provides a good illustration. It tells us what the word 'bachelor' means by dissecting our concept of bachelor into other concepts (being unmarried, human, and male); anything that is unmarried, human, and male is *by definition* a bachelor and vice versa. As Chapter 2 discusses, however, things are not quite this simple. Natural languages are vague. On our definition of 'bachelor', a male infant would qualify as a bachelor, and attempts to fix this problem by adding 'adult' will not fully resolve it. Still, ignoring the problem of vagueness, our definition of bachelor provides a pretty good answer to the question 'what is a bachelor?'

The question is, could a definition of 'life' provide an equally satisfactory answer to the question 'what is life?' Unfortunately, the answer is 'no'. When a scientist asks 'what is life?' she is not interested in the meaning of the word 'life'. She wants to know what life *truly* is: What distinguish bacteria, slime molds, fungi, fish, trees, elephants, and all other living things, wherever and whenever they may be found, from nonliving physicochemical systems. Analysis of the twenty-first century concept of life is unlikely to provide her with a scientifically satisfying answer to this question.

So why does a definition of 'bachelor' provide a good answer to the question 'what is a bachelor?' but a definition of 'life' does not provide a good answer to the question 'what is life?' The answer is complex, having to do with the logical character of definition and an important distinction in philosophy of language between terms designating categories (e.g., water and star) that would exist had there been no human beings and categories (e.g., bachelor and garbage) that are carved out by human interests and concerns; philosophers dub the former 'natural kinds' and the latter 'non-natural [human] kinds'. To make a long story short, if life (like water) is a natural kind, attempts to "define" it will be futile; the extensions of natural kind terms are too open ended to be decided by means of necessary and sufficient conditions. On the other hand, if life is not a natural kind, the scientific program of universal biology is doomed; for (as pluralists contend) the diverse phenomena of life have no natural unity. Either way, as Chapter 2 explains, life cannot be "defined."

Some scientists and philosophers who advance "definitions" of life do not have in mind the traditional logical notion of definition. This is the topic of Chapter 3. Nonstandard definitions resemble traditional definitions structurally in supplying necessary and sufficient conditions for membership in a natural kind. Their authority derives from empirical investigations, however, as opposed to analyses of human concepts. In this way philosophers advocating nonstandard definitions of life hope to evade the serious logical problems discussed in Chapter 2; most scientists are not familiar with those difficulties.

Defenders of nonstandard definitions of life are keen to establish a close logical relationship between the structures of definitions and scientific theories, contending either that (i) a scientific theory of life can be somehow compressed into a statement supplying necessary and sufficient conditions for life or that (ii) a statement supplying necessary and sufficient conditions for life can be logically inferred from a scientific theory of life; on the latter view, a nonstandard definition of life could be viewed as a crucial building block for a theory of life. In this context, Chapter 3 begins with an extended discussion of scientific theories, paying close attention to the highly influential formal (syntactic and semantic) conceptions, which reconstruct scientific theories along the lines of those of mathematics. As will become clear, while both the syntactic and semantic conceptions of scientific theory support the claim that a theory of life can be compressed into a definition-like statement, neither supports the narrower claim that supplying necessary and sufficient conditions *for life* (*qua* natural kind) can encapsulate a scientific theory of life. Moreover, neither conception of scientific theory supports the claim that one can logically infer necessary and sufficient conditions for life from a scientific theory of life. The arguments in this chapter are somewhat technical and difficult but well worth slogging through. What they establish is that scientific theories are far more open ended and fluid than mathematical theories; otherwise they could not accommodate novel and sometimes startling empirical discoveries, which are ultimately a major source of the empirical fruitfulness of a scientific theory. Viewed in this light it is not surprising that formal conceptions of scientific theory have fallen out of favor among philosophers of science. They have been replaced by informal, model-based approaches, which provide no support for the claim that nonstandard definitions can provide a scientifically compelling answer to the question 'what is life?' It is high time that scientists and philosophers abandon the project of defining life in all its nefarious guises.

As alluded to earlier, Chapter 4 focuses on conditions that facilitate and hinder the development of successful scientific theories. This focus is important for the program of universal biology because we currently lack a truly general theory of life. At best, given our limited experience with life (viz., familiar Earth life), we are in the early stage of formulating such a theory. As Chapter 4 explains, the development of an empirically fruitful scientific theory critically depends upon the selection of a promising ontology (set of basic theoretical concepts) for generalizing about a domain of natural phenomena. There are many different, seemingly natural, ways of carving up a domain of natural phenomena into basic categories, most of which are incapable of supporting scientifically fruitful generalizations.[1] Newton's predecessors failed to come up with a truly general theory of motion because they were working with unpropitious theoretical concepts such as impetus, bulk (occupied volume), impenetrability, and weight. Newton succeeded because he opted for (what turned out to be) a more promising concept (inertia). Unfortunately, as Chapter 4 discusses, when faced with predictive or explanatory failure, scientists have a tendency to retain ontologies and revise the generalizations based upon them.[2] This flawed approach can significantly delay the development of a successful, truly unifying, scientific theory. It is thus important to resist becoming prematurely wedded to a theoretical framework for generalizing about a domain of natural phenomena.

[1] As this chapter discusses, scientific pluralists are thus right in maintaining that there are equally legitimate ways of carving up a domain of natural phenomena into categories *depending upon one's interests and concerns*. But as Chapter 4 explains, most ontologies will not yield empirically and theoretically powerful generalizations *of the sort sought by scientists*; indeed, the history of science suggests that those that will are few and far between. Instead of taking a stand on the contentious issue of whether monism or pluralism is true of the natural world – an issue that is difficult to defend scientifically or philosophically – I defend (what I dub) a "monist stance" towards natural phenomena, most notably life, over Kellert and colleagues' (2006, xiii–xvi) pluralist stance.

[2] As Chapters 4 and 6 discuss, examples from biology are not hard to find. The bacterial species problem provides an especially salient illustration. In the face of unsuccessful efforts to extend a eukaryote-centric concept of species to unicellular microorganisms, some scientists and many philosophers of biology propose a pluralist conception of species, in effect retaining it (come what may) instead of seeking newer, more unifying concepts for understanding the evolutionary relatedness of known life on Earth.

The tendency to retain ontologies in the face of predictive and explanatory failure is a serious concern for the program of universal biology. As Chapter 5 discusses, compelling theoretical and empirical reasons exist for suspecting that familiar Earth life may not be representative of life considered generally. Molecular biologists have established that all known life on Earth today descends from a last universal common ancestor (LUCA), which means that our experience with life is limited to a single example; this is known as the $N = 1$ problem of biology. Moreover, biochemists have established that life could be at least modestly different at the molecular and biochemical level, and they concede that it is not at all clear how different it could be. Last but certainly not least, since the time of Aristotle, most theorizing about life has been based upon complex multicellular eukaryotes (primarily plants and animals), which are highly specialized, fragile latecomers to our planet. We now know that archaea and bacteria are far older and more diverse, both genetically and metabolically, than multicellular eukaryotes. They are also the most common form of life on Earth today. The human body, for instance, contains many more archaea and bacteria than somatic cells, and the number of viruses in the human body far outnumbers those of archaea and bacteria. The upshot is that much of contemporary biology – especially areas dealing with fundamental questions about the nature and origin(s) of life – is founded upon an unrepresentative subsample of a single example of life. In this light, Chapter 6 explores possibilities for reframing biological theory from a microbial standpoint. While a more microbial centered biology will not solve the infamous $N = 1$ problem, basing a theoretical framework for life on the most representative form of Earth life holds forth the promise of achieving a better understanding of familiar life. And it just might pave the way to a better foundation for exploring the possibilities of life elsewhere. Astrobiologists concur that most life in the universe is microbial and moreover probably bacteria-like.[3]

A pressing problem remains: How can scientists conduct a search for unfamiliar life without a definition or theory of life to guide it? Chapters 7, 8 and 9 explore three strategies for overcoming this problem: (1) artificially creating novel forms of life right here on Earth (Chapter 7), (2) searching for extraterrestrial microbial life by identifying potentially biological anomalies using tentative (versus defining) criteria for life (Chapter 8), and (3) searching for a "shadow biosphere" (microbial life on Earth descended from an alternative biogenesis) (Chapter 9). As will become apparent, the first (artificial life) strategy is too closely based on current Earth-centric concepts of life to tell us much about the possibilities for truly

[3] Even Dirk Schulze-Makuch and William Bains (2017), who provocatively argue that complex multicellular life is far more common in the universe than most scientists believe, would concede this point since they do not disagree that the first living things to arise from nonliving chemicals are unicellular and moreover that their unicellular descendants continue to flourish as life becomes increasingly more complex.

different forms of life. What is needed to make progress on the $N = 1$ problem are samples of *natural* life descended from an alternative biogenesis. This strategy is the topic of Chapters 8 and 9. Chapter 8 advocates searching for extraterrestrial life using tentative (versus defining) criteria based on familiar life. The function of tentative criteria is not (like a definition) to decide the question of life, but instead to identify promising candidates for further, more focused, scientific investigations. Such candidates will manifest as anomalous, that is, as resembling familiar life in provocative ways and yet also differing from it in unanticipated ways. In this context, Chapter 9 explores the intriguing possibility that we may not need to look beyond Earth to discover novel life; our home planet may be host to as yet unrecognized forms of life descended from an alternative biogenesis.

1

The Enduring Legacy of Aristotle: The Battle over Life as Self-Organization or (Genetic-Based) Reproduction

1.1 Overview

There are universal theories in physics and chemistry but no universal theories in biology. The failure of biologists to come up with such a theory is not due to a lack of effort. Philosophers and scientists have struggled to formulate universal principles of life since at least the time of Newton. This chapter traces the history of these efforts back to their roots in the work of the ancient Greek philosopher Aristotle. Aristotle's influence can be seen today in the view, which dominates contemporary biological thought about the nature and origin(s) of life, that the following abstract functional characteristics are basic to life: (1) the capacity to self-organize and maintain self-organization for an extended period of time against both external and internal perturbations and (2) the capacity to reproduce and (in light of Darwin's theory of evolution) transmit to progeny adaptive characteristics. For the sake of simplicity, I refer to the former as "O" and to the latter as "R" throughout this chapter. As Section 1.2 discusses, the conceptual parallels between O and R and Aristotle's ideas about life are remarkably close. He identified "nutrition" and "reproduction" as the basic functions of life and debated (as do so many contemporary researchers) which is more basic. Aristotle also bequeathed to biology the thorny problem of teleology – the notion that the allegedly basic functions of life (in their contemporary guise, metabolism and genetic-based reproduction) require a strange (to the modern scientific mind) form of causation that is intrinsically directed at achieving a future goal. As Aristotle argued, living things are not just fed, they feed *themselves*, and they are not just copied, they reproduce *themselves*. Characteristic O reflects this view in explicitly referring to the idea of self-organization. Similarly, characteristic R implicitly assumes that organisms contain an internal principle for generating organisms resembling themselves; external processes do not (like a 3D printer) duplicate them.

Sections 1.3 and 1.4 trace how Aristotle's seminal ideas about life evolved into characteristics O and R. As will become clear, the idea that the causal processes responsible for the distinctive functions of life are intrinsically goal directed poses special challenges to scientific reasoning. Teleological causation is not easily accommodated within the framework of classical physics, which holds that causes precede their effects without anticipating them. With the advent of Darwin's theory of evolution by natural selection, many biologists became convinced that the *prima facie* teleological properties of life could be explained in terms of undirected cause and effect relations after all. As we shall see, this claim is too sweeping. But even supposing that teleological causation has been exorcised from biology, the conceptual parallels between Aristotle's ideas about life and characteristics O and R remain uncannily close. From a philosophical perspective, the parallels between Aristotle's ideas and characteristics O and R are intriguing because, as the history of science reveals, in other domains of scientific inquiry (e.g., chemistry and physics) the most rapid advances occurred after the abandonment of Aristotelian concepts and principles.

The second half of the chapter (Section 1.5) explores the Aristotelian character of contemporary scientific thought about the nature and origin(s) of life. Theories of life are commonly articulated in the form of definitions. Following in the footsteps of Aristotle, definitions of life invariably privilege one of the characteristics O or R over the other (Section 1.5.1). Those privileging characteristic O (metabolic definitions) struggle with explicating a philosophically coherent and scientifically fruitful concept of self-organization, frequently falling back upon concepts (e.g., autopoiesis) that sound suspiciously teleological.

Theories (often called "models") of the origins of life divide along the same lines as definitions of life with regard to characteristics O and R (Section 1.5.2). Tacit appeals to causal processes that are self-generating and goal directed are routine, for example, the "spontaneous assembly" of chemically improbable, primordial biomolecules, such as small proteins (peptides) or small RNA molecules, from more basic molecular components, and the "emergence" of proto-organisms from complex, autocatalytic, chemical reaction networks. In other words, not only do O and R closely parallel Aristotle's account of life in terms of nutrition and reproduction, they are also difficult to explain in terms of ordinary, undirected causal processes. Some origins of life researchers attempt to circumvent this difficulty by arguing that such events are merely extraordinarily improbable, as opposed to being the products of a weird form of causation. As we shall see, however, this strategy is just as unscientific as one that embraces teleological causation.

The purpose of this chapter is to motivate the thesis that contemporary thought about life may be being held hostage to neo-Aristotelian ideas.[1] For this reason it covers a lot of ground (historical, philosophical, and scientific), much of which will be revisited in greater depth in subsequent chapters. Let me hasten to add that I am not claiming that a neo-Aristotelian framework for theorizing about life is mistaken. Although it has thus far been unsuccessful in providing a general theory of familiar Earth life, let alone life considered generally, and is fraught with conceptual problems, it might still turn out to be the best approach. I am arguing that we should stop *reflexively* viewing life through Aristotelian lenses. Before giving up on the prospects for universal biology, as so many pluralists recommend (see Chapter 6), we need to explore the possibility that the ostensible lack of unity among biological phenomena is the result of tacit commitment to a defective, neo-Aristotelian, theoretical framework for reasoning about life. For as Chapter 4 discusses, an unpropitious set of basic theoretical concepts can frustrate the search for unity among a diverse body of natural phenomena *even when it exists*; not every way of carving up a domain of natural phenomena into fundamental categories is capable of yielding empirically powerful, unifying generalizations.

1.2 Aristotle on the Nature of Life: Nutrition Versus Reproduction

The history of thought about the nature of life is rich and complex. I cannot do it justice here. My purpose is to trace the development of a few, highly influential, core assumptions about life in a selective manner.[2] Chief among them is the idea that the distinctive features of life are the product of a special form of causation not found in inanimate material systems. This supposition is important because, as we shall see, it underlies functional characteristics O and R and, most importantly, has reappeared in contemporary scientific debates over the nature and (especially) the origins of life. Our historical journey begins in ancient Greece with the writings of the philosopher-scientist Aristotle. As will become apparent, in almost every domain of natural science except speculation about the nature and origins of life, Aristotle's views have been rejected.

Aristotle (384–323 BC) is credited with being the first biologist because he emphasized the importance of basing theoretical conjectures about life upon empirical investigations.[3] Although limited to what could be seen with unaided human vision (primarily large, complex organisms, viz., plants and animals),

[1] A recent resurgence of neo-Aristotelian ideas about life among philosophers (e.g., Bedau 2010; Groff and Greco 2013) illustrates the continued influence of Aristotle's ideas.
[2] See Coleman (1977), Grene and Depew (2004), and Sapp (2003) for detailed and authoritative discussions of the historical development of biology.
[3] See Guthrie (1990, Ch. II) for more information on the life of Aristotle.