Bringing together the latest scientific advances and some of the most enduring subtle philosophical puzzles and problems, this book collects original historical and contemporary sources to explore the wide range of issues surrounding the nature of life.

Selections ranging from Aristotle and Descartes to Sagan and Dawkins are organized around four broad themes covering classical discussions of life, the origins and extent of natural life, contemporary artificial life creations, and the definition and meaning of “life” in its most general form. Each section is preceded by an extensive introduction connecting the various ideas discussed in individual chapters and providing helpful background material for understanding them. With its interdisciplinary perspective, this fascinating collection is essential reading for scientists and philosophers interested in astrobiology, the origin of life, synthetic biology, and the philosophy of life.

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The Nature of Life: Classical and Contemporary Perspectives from Philosophy and Science

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This book is a collection of readings about the nature of life. The idea for it was born when we first met and discovered our mutual interest in the nature of life, a shared background in philosophy of science and philosophy of biology, and a complementary scientific expertise in the origin of life and astrobiology (Cleland) and artificial life and synthetic biology (Bedau). We both wanted to have a book like this, so we decided to compile it together. Our interests and orientation led us to include material in four general areas: (i) classical philosophical and scientific discussions about the nature of life, (ii) contemporary scientific and philosophical discussions of the origins of life, and of chemical possibilities for unfamiliar forms of natural life, (iii) discussions of contemporary artificial life creations, including not just computer simulations but also self-reproducing robots, protocells, and other synthetic biology constructions created in the wet lab, and (iv) attempts by contemporary scientists and philosophers to describe and explain the nature of life in its most general, non-Earthcentric, form. Producing this book confirmed for us the value of combining multiple perspectives on life.

We hope that this book will inform philosophers about the latest scientific advances and introduce scientists to subtle philosophical puzzles and problems, and thereby foster new, well-informed and thoughtful philosophical and scientific reflection about the nature of life. In our opinion, genuine progress in understanding life crucially depends upon combining both scientific and philosophical perspectives on life.

Our book is aimed at a broad audience. Some of the chapters are quite accessible and others are fairly technical. Each section is preceded by an introduction connecting the various ideas discussed in individual chapters and providing helpful background material for understanding them. We hope that philosophers interested in life (including those working in philosophy of biology, philosophy of science, and philosophy of mind) will pay especially close attention to the scientific chapters, and that scientists interested in the nature of life (including biologists, chemists, physicists, astronomers, geologists, and astrobiologists) will pay especially close attention to the philosophical chapters. Graduate and undergraduate students in any of these areas will also find the book useful as a text in interdisciplinary courses on life. Anyone from the general public who is curious about up-to-date scientific and philosophical perspectives on life should enjoy the book as well.

Mark Bedau, Portland, Oregon
Carol Cleland, Boulder, Colorado
Acknowledgments

The editors would like to thank the authors and publishers who gave us permission to collect their work in this anthology. We owe a special thanks to Chris Shields, for permitting us to publish part of his new translation of De Anima, forthcoming from Oxford University Press.

We would also like to thank many friends and colleagues who have shared and fostered our growing fascination with life and our attempts to understand it, and who helped us while developing this book. Thanks to Bob Hanna for help with the Kant selections, and to Meg Scharle for help on Aristotle. Thanks to Kellyn Bardeen for collecting permissions, copy-editing, and producing the final manuscript, and to Emily Parke for myriad crucial assistance. Thanks to Ben Paglar and Michael Zerella at the Boulder campus of the University of Colorado for help with assembling the bibliography. We owe an important debt to the up and coming philosophers and scientists in Carol Cleland’s 2006 graduate seminar on life for enthusiastically and industriously working through the articles in the original Table of Contents, helping us to decide which should be included as chapters in the final version. Thanks to the NASA Astrobiology Institute for providing partial funding for this project through a grant to the University of Colorado’s Astrobiology Center, and to Reed College for a Stillman Drake grant that supported this project. Thanks also to the Center for Advanced Computation at Reed College, for hospitality during a crucial final stage in the preparation of the book.
Grateful acknowledgment is made to the following publishers and authors:


Aristotle (384 BC–322 BC), a student of Plato and teacher of Alexander the Great, was a prominent Greek philosopher and one of the most important founding figures in Western philosophy. With the scope of his work encompassing morality, science, logic, aesthetics, metaphysics and politics, he was the first to create a comprehensive system of Western philosophy. In addition, Aristotle is sometimes regarded as the originator of the scientific study of life, as he was among the first to articulate a systematic and comprehensive method for biological investigation. His own studies of animals were extensive, and several of his biological observations waited more than two millennia to be confirmed by modern science.

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Richard Dawkins is a British ethologist, evolutionary biologist, and popular science author well known for his criticism of religion, creationism, and intelligent design. He currently holds the position of Charles Simonyi Professor of the Public Understanding of Science at Oxford University. His influential first book, The Selfish Gene (1976), popularized the gene-centered view of evolution and introduced the term meme to the discourse on cultural evolution. He is a fellow of the Royal Society and has received the Faraday Award and the Kistler Prize. His most recent book is The God Delusion (2006).

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René Descartes (1596–1650) was a highly influential French philosopher who is generally regarded as the father of modern philosophy. In his pivotal work, Meditations on First Philosophy, he famously put forth the cogito argument as a step in his investigation into the rational foundations of philosophical inquiry and natural science. Descartes made significant contributions to mathematics and science during his lifetime, inventing the Cartesian coordinate system, founding analytic geometry, and discovering the law of refraction. As a strong proponent of the theory of mechanism, he was also a major player in the Scientific Revolution.

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IMMANUEL KANT (1724–1804) was a German philosopher who is widely regarded as one of the most influential thinkers of modern Europe and the late Enlightenment. Grappling with problems in philosophy of mind, Kant developed the doctrine of Transcendental Idealism, which he regarded as a compromise between the conflicting traditions of Rationalism and Empiricism. This doctrine was first set out in his epochal work, The Critique of Pure Reason (1781), which is now uniformly regarded as one of the greatest works in the history of philosophy. Kant also exerted a profound influence on moral philosophy with his contention that morality is required by reason itself.

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ALEKSANDR IVANOVICH OPARIN (1894–1980) pioneered the idea that life arose from inorganic matter through the spontaneous generation of simple organic compounds from inorganic molecules in the prebiotic environment. In his work, he formulated a number of pathways through which biologically important compounds such as amino acids, volatile fatty acids and carbohydrates could have formed in the chemically reductive atmosphere he hypothesized for early Earth. In 1979, he received the Lomonosov Gold Medal from the USSR Academy of Sciences for his work in biochemistry.

LESLIE E. ORGEL (1937–2007) was a distinguished biologist and one of the fathers of the RNA-world theory and the concept of panspermia. Born in London, he received his undergraduate degree and doctorate from Oxford University before pursuing research at Cambridge, the University of Chicago, and the California Institute of Technology. He assisted NASA in analyzing the findings of the Viking missions to Mars and was one of five principal investigators in the NASA-sponsored NSCORT program in exobiology. He was a fellow of the Royal Society and a member of both the National Academy of Sciences and the American Academy of Arts and Sciences.
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CARL SAGAN (1934–1996) was an astronomer, astrochemist, and author who pioneered exobiology, promoted the search for extraterrestrial intelligence, and successfully popularized astronomy, astrophysics and other natural sciences. He played a leading role in the American space program from its inception, acting as an advisor to NASA and being directly involved in the Apollo, Mariner, Viking, and Galileo missions. A best-selling author and Pulitzer Prize winner, Sagan received twenty-two honorary degrees from American colleges and universities for his contributions to science, literature, education, and the preservation of the environment. As one of the first scientists to suggest the possibility of a nuclear winter, he also received multiple awards for his work on the long-term consequences of nuclear war and for his attempts to reverse the nuclear arms race.

DORION SAGAN is an American science writer and General Partner of Sciencewriters, an organization whose goal is to advance science through “enchantment in the form of the finest possible books, videos, and other media”. He has written or co-authored many essays and more than fourteen books on evolution and other topics in biology, and is a recipient of an Ed-Press Award from the Educational Press Association of America for excellence in Educational Journalism. A recent book, Death and Sex, won first place at the 2010 New York Book Show in the general trade nonfiction category.

ERWIN SCHRODINGER (1887–1961) was an Austrian physicist best known for his contributions to the understanding of quantum mechanics, particularly the Schrödinger Equation, for which he received the Nobel Prize in 1933. He also devised the famous “Schrödinger's cat” thought experiment to illustrate what he saw as a problem with the Copenhagen interpretation of quantum physics. In 1944, he wrote What is Life? in which he derived the concept of a complex molecule as a carrier for genetic information. This book directly influenced James Watson and Francis Crick whose work eventually led to the discovery of DNA in 1953.

ROBERT SHAPIRO is Professor Emeritus and Senior Research Scientist in the Department of Chemistry at New York University. He is author or co-author of over 125 publications, primarily in the areas of DNA chemistry and the origin of life. In his research, he and his co-workers have studied the ways in which environmental interactions, genetic evolution, and the development of early life systems cut across disciplines, centering on the definition of life, protocell models (in vitro and in silico), and major transitions in the origin of living systems.
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Introduction

This book is a collection of classic and contemporary readings by philosophers and scientists on the nature of life. Philosophers have pondered the question “what is life?” since at least the time of the ancient Greek philosopher Aristotle. In recent years the question has taken on increasing scientific importance. Molecular biologists and biochemists investigating the origin of life or trying to synthesize chemical life in the laboratory from basic molecular building blocks want to know at what stage an ensemble of nonliving molecules turns into a primitive living thing. Astrobiologists charged with designing instrument packages for spacecraft to detect extraterrestrial life struggle with the question of which characteristics of familiar Earth life (metabolism? reproduction? Darwinian evolution? carbon-based chemistry?) are universal indicators of life. Even computer scientists find themselves mired in questions about the nature of life when they speculate whether lifelike systems constructed of software (purely informational or digital structures) or hardware (metal, plastic, and silicon) could ever literally be alive. Many of these pressing questions are notable for their lack of obvious scientific solutions; one cannot answer them merely by performing more experiments or constructing additional lifelike systems. Although they arise out of science, these questions are deeply philosophical.

The twentieth-century American philosopher W. V. O. Quine proposed that epistemology could be viewed as an “enterprise within natural science” (Quine, 1975, p. 68). In a similar spirit, the editors of this volume believe that collaboration between scientists and philosophers provides the best hope for achieving a compelling answer to the question of the nature of life. Contemporary science has greatly expanded our understanding of the complexities of natural life, and it has provided many intriguing new examples of lifelike artificial systems. But an intellectually satisfying answer to the question “what is life?” requires more than this. It requires analyzing, evaluating, and systematizing disparate information emerging from a multiplicity of scientific disciplines. It is natural for philosophy to play a central role in this process. Philosophers are trained in logical and conceptual analysis. They have expertise in sorting out foundational issues, rooting out subtle inconsistencies, transforming vague generalizations into logically precise principles, tracing logical relations among concepts, principles, hypotheses, and empirical evidence, and evaluating the strength of arguments and theories. Philosophy brings conceptual clarity and logical rigor to scientific theorizing. At the same time, science grounds philosophical reflection on empirical evidence gleaned from careful observation and experiment. Together, contemporary philosophy and science hold forth the promise of finding a satisfactory answer to the age-old question of the nature of life.

The contents of this anthology are the outcome of many lively discussions among the editors and their scientific and philosophical colleagues concerning which issues about life matter most. The chapters selected represent only a small portion of a vast philosophical and scientific literature on life; readers are urged to consult the extensive Supplementary Bibliography at the end for many excellent and important additional writings on life. We tried to be representative, that is, to include classical writings that covered the historically most influential scientific and philosophical ideas, and the leading contemporary scientific and philosophical positions. Chapters were selected also on the basis of their promise for shedding light on central contemporary issues and controversies about life, such as how recent discoveries in microbiology have challenged traditional conceptions of the nature of life. We also made a point to include different approaches to methodology, such as whether the best answer to the question “what is life?” is a definition or a theory, or something else entirely.
We divided the anthology into four sections, corresponding to four central areas of contemporary philosophical and scientific research: Classical Discussions of Life (Section I), The Origin and Extent of Natural Life (Section II), Artificial Life and Synthetic Biology (Section III), and Defining and Explaining Life (Section IV). Each section is preceded by an introduction that conveys the current scientific and philosophical debate about the nature of life, under-scoring lines of agreements and disagreements, and raising questions that, in our view, need greater attention. We hope that, taken together, the readings in this book will help inform and guide further scientific and philosophical investigations into the nature of life.

The father of classical physics, Issac Newton, famously observed in a letter to fellow English scientist Robert Hooke, “if I have seen further, it is by standing on the shoulders of giants.” Newton’s remark reflects the truism that most cutting-edge intellectual work builds upon earlier work. So, it is no surprise that many contemporary debates about life have deep historical roots. The chapters in Section I provide an historical context for the discussions in the rest of the book. We begin with the birth of philosophy in ancient Greece and the rise of modern philosophy and science in the sixteenth and seventeenth centuries, and continue with subsequent seminal scientific and philosophical developments up through the early twentieth century. These readings put contemporary thought about life into historical context and remind us of some great lessons from this history. They also reveal the extent to which contemporary perspectives and problems reflect their historical origins. Here is one illustration: A central theme running through the writings of the ancient Greek philosopher Aristotle up to the present is the idea that living things have functional characteristics, such as metabolism and development, which distinguish them from non-living things. As the chapters in Section I underscore, one of the great controversies about the nature of life bequeathed to us by Aristotle is whether these prima facie “teleological” (purposive, goal-directed or self-causing) characteristics are primitive or somehow “reducible to” nonteleological (structural or compositional) characteristics. Many different approaches (essentialist, mechanistic, vitalist, organismic, Darwinian, information-theoretic, thermodynamic, and chemical) to understanding the prima facie teleological characteristics of life are explored in the classic works included in Section I. Although sometimes disguised in innocuous-sounding contemporary scientific terminology, this debate reoccurs throughout this whole anthology.

Section II provides an overview of our current scientific understanding of the origin and extent of natural forms of life. Most of the authors are scientists who share the view that an understanding of life lies at the level of molecules and biochemical processes, as opposed to higher-level organizational and functional properties. This is reflected in the ways in which they interpret and articulate traditional questions about the nature of life. For example, what was “nutrition” for Aristotle and “metabolism” for early modern biologists becomes “chemical self-organization,” and what was “reproduction” for Aristotle and “Darwinian evolution by natural selection” for nineteenth-century biologists becomes “replication” by means of “genetic [ informational] structures.” The reader is encouraged to consider whether this is the proper level of analysis for theorizing about life in general.

The authors in Section II discuss a variety of important issues about life within the context of recent scientific developments in molecular biology, biochemistry, microbiology, and astrobiology: Is the transition from a nonliving ensemble of molecules to a primitive living thing gradual or abrupt? Can an account of the nature of life be given independently of an account of the origin of life? Which came first, chemical self-organization or genetic structures? Was the original genetic molecule RNA or something else, e.g., a mineral surface? What are the alternative molecular and biochemical possibilities for life? How can we design methods and instruments for searching for truly weird forms of life elsewhere in the solar system, given that all known life on Earth is so similar at the molecular and biochemical level? Could the contemporary Earth contain undetected alternative forms of microbial life descended from a separate origin? A couple of chapters in this section are authored by philosophers who ferret out philosophical assumptions underlying scientific investigations into the origin and extent of life. They also evaluate the bearing of the results of these scientific investigations on some traditional and contemporary philosophical questions about life. Philosophers will want to know the material in this section, so that their discussions about life are scientifically informed.
Any contemporary attempt to understand the nature of life should be informed by important recent scientific developments. Artificial life and synthetic biology are motivating significant philosophical and scientific reflection about the nature of life. Section II concerns the implications of attempts in artificial life and synthetic biology to recreate life in the laboratory and to make lifelike systems out of hardware or software. The scientific state of the art in artificial life and synthetic biology is presented in some chapters. In other chapters philosophers and historians reflect on the larger implications of those scientific developments. The strong thesis of artificial life and synthetic biology is that we can construct new kinds of systems (using software, hardware, or wetware) that literally are alive—as alive as any other form of life we know. It contrasts with a weaker thesis that construes the lifelike systems constructed by artificial life researchers as useful theoretical tools for exploring properties of living systems, but not literally alive. Because research in artificial life aims to create novel kinds of lifelike systems, scientists must ask what really makes something alive. Is it the material stuff out of which it is composed (cytoplasm, flesh and bones, etc.)? Or is it the kinds of metabolic processes in which those materials are participating, in a transitory and fleeting way? Attempts to create lifelike systems or even life itself from nonliving materials also focus attention on a variety of foundational issues, such as whether there is a sharp distinction between life and non-life, or whether there is an open-ended array of alternative kinds of systems that are more or less alive. Artificial life and synthetic biology also raise a fundamental epistemological issue: What kind of evidence should we use when explaining why a given kind of chemical system is lifelike? For example, what weight should we give to artifacts derived only from all known forms of life on Earth?

Section IV illustrates the main philosophical and scientific approaches to answering the general question “what is life?” Achieving a satisfactory understanding of the nature of life involves explaining a range of familiar and striking phenomena. As these chapters illustrate, there is not a consensus about which characteristics of familiar life constitute the “signs,” “hallmarks,” or “puzzles” most in need of explanation. We need to figure out what evidential status to give to our current preconceptions about life. It is not obvious what epistemological authority they should have. Part of the problem is that our experience with natural life is limited to familiar Earth life. As the discussions in Section II reveal, we have compelling scientific reasons for believing that all known life on Earth descends from a common ancestor. We also have good scientific reasons for believing that life could have been at least modestly different, but we have very little idea how different it could have been. This makes it difficult to identify which characteristics of familiar Earth life are found universally in all actual examples of life. For all we know, familiar Earth life could constitute an unrepresentative example of all possible forms of life. However, not everyone views this problem as insurmountable. The development of artificial (“hard” and “soft”) life systems and the creation of novel microorganisms in the laboratory by synthetic biologists give us powerful new tools for exploring and expanding our concept of life, and perhaps even increasing the sample size of kinds of life available to us for empirical investigation. The discussions in Section IV also address foundational theoretical issues about life such as the role of reduction and emergence in explanations of life and the question of whether life is a compositional, structural, or functional kind, or some combination thereof. The chapters in this section explore different perspectives on these and related issues within the context of recent scientific and philosophical advances.

The question of the proper methodology for constructing and evaluating views about the nature of life is a central concern of many of the chapters in Section IV written by philosophers. One issue is the evidential status of signs, hallmarks, and puzzles about life. What role should these play when investigating the nature of life? Are they test cases for evaluating accounts of life? A striking feature of investigations into the nature of life is the ambiguous and uncertain application of various methodologies. Another important question concerns the widespread use of definitions in explaining life. Definitions can be distinguished from criteria for life, and from life’s signs and hallmarks. They can take different forms, including pragmatic and operational, although many scientists and philosophers prefer logically complete definitions providing necessary and sufficient conditions for life. Some authors in Section IV reject the project of defining life. They contend that definitions cannot provide satisfactory answers to “what
is” questions about natural kinds, such as water and life. On their view an empirically well-grounded, scientific theory of life is needed. But how does a theory of life differ from a highly complex definition of life? There is also the question of the status of computer simulations of complex living systems. Some authors argue that simulations can be fruitfully construed as distinctively constructive definitions or theories of life. Many of the chapters in Section IV address these issues. Scientists engaged in theorizing about life might find the material in this section especially useful.

The four sections of this anthology are knit together by three central open philosophical and scientific questions about the nature of life:

1. What are the central characteristic phenomena exhibited by all forms of life?
2. What are the best descriptions and explanations of the nature of life?
3. What is the proper way to construct and evaluate views about the nature of life?

In our view, attempting to answer any of these questions in isolation generates a tangle of thorny philosophical and scientific issues that can be resolved only by addressing the two other questions. In fact, we find it difficult to draw a bright red line separating scientific and philosophical questions about life. Fundamental progress in either discipline requires knowing and appreciating the other discipline. This book aims to foster mutual understanding and appreciation among philosophical and scientific perspectives on life. In the long run, a good measure of its success will be the advances in understanding of the nature of life that are eventually made by its readers.

REFERENCES