CONTENTS

INTRODUCTION..... vii

PART I **ORIGIN AND EVOLUTION OF LIFE**

Christian de Duve — Lessons of Life 5

Paul C.W. Davies — Biological Determinism, Information Theory, and the origin of Life 15

Bernd-Olaf Kuppers — The World of Biological Complexity:The Origin and Evolution of Life 31

Christopher P. McKay — Astrobiology: The Search for Life Beyond the Earth 45

PART II **HUMANITY'S PLACE IN COSMIC EVOLUTION**

Martin J. Rees — Life in Our Universe and Others: A Cosmological Perspective 61

Lee Smolin — Our Relationship to the Universe 79

Arthur Peacocke — The Challenge and Stimulus of the Epic of Evolution to Theology 89

John Leslie — Intelligent Life in Our Universe 119

PART III **EXTRATERRESTRIAL LIFE AND OUR WORLD VIEW**

Freeman J. Dyson — The Many Worlds of Neurology 135

Jill Cornell Tarter — SETI and the Religions of the Universe1 143

Ernan McMullin — Life and Intelligence Far from Earth: Formulating Theological Issues 151

George V. Coyne, S.J. — The Evolution of Intelligent Life on Earth and possibly Elsewhere: Reflections from a Religious Tradition 177

Steven J. Dick — Cosmotheology: Theological Implications Of the New Universe 191

SELECT BIBLIOGRAPHY 211

INDEX .... .213

INTRODUCTION

At the dawn of a new millennium it is striking to consider how much our world view has changed in the past 1000 years. In AD 1000 the geocentric cosmology of Aristotle and Ptolemy dominated intellectual thinking, then centered in Islamic civilization. The ancient Greek view was soon to be passed via the Arabs to the Latin West, where it met head on with Christianity, following which Thomas Aquinas and others made heroic efforts to reconcile the religious and the scientific understanding of the world. Human destiny, as immortalized in Dante's Divine Comedy, was defined by the unchangeable heavens above, the corruptible Earth below, and the threatening inferno within. Less than three centuries later, all that changed within the Sun-centered universe of Copernicus, which made the Earth a planet and the planets Earth, plunging European thought into a crisis from which it arguably has not yet emerged.

But that dethroning of the Earth pales in significance to the startling upheavals in world view unveiled in the past century. One hundred years ago, the entire universe was believed to be a few thousand light years across; now that extent in measured in billions of light years. Then the universe was believed to be static; now it is seen as expanding and evolving, and cosmic evolution is the watchword from the Big Bang to the present. Although the Earth had long been dethroned from the center of the solar system, our Sun and its retinue of planets was believed to be near the center of our galaxy , which many thought constituted the entire universe. Now, billions of galaxies are known to float in Einsteinan space-time, which has not center. And the greatest question of all remains: are we, in all the universe, alone as sentient beings? An increasing number of scientists from many fields believe the answer is no, and that the last vestige of anthropocentrism is rapidly fading, any day to be overthrown by the discovery of extraterrestrial life.

Given these upheavals in our world view, we might have thought that the dialogue between science, philosophy, and religion would be

crackling with synergistic ideals. Instead, some still question whether such a dialogue should even take place. Despite sporadic communication among these disciplines, there have been very few attempts at a "Cosmotheology" that takes the astounding facts of the new universe into account. Nor does this volume, based on a small meeting sponsored by the John Templeton Foundation in November 1998, have any such grandiose ambitions. Rather, it is a preliminary reconnaissance of the issues surrounding theology and the new world view, addressed by scholars from a wide array of disciplines. Here, the reader will find a variety of approaches and a variety of answers that can hardly be characterized as systematic. So it must be for any reconnaissance, and the result, while stimulating in itself, demonstrates how much remains to be done.

One may immediately ask, Why bother with the theme of Theology and the New Universe? Arthur Peacocke, both a biochemist and an Anglican priest, express one point of view in this volume when he says "any theology —any attempt to relate God to all-that-is—will be moribund and doomed if it does not incorporate this perspective [of cosmic evolution] into its very bloodstream." Although some may argue with this sentiment, it is a guiding principle of many, though not all, the authors in this volume. In Sir Martin Ree's essay, England's Astronomer Royal writes that cosmologists may not have much that is new to cosmology may say much about the role of terrestrial life. At the other end of the spectrum, Nobel biochemist Christian de Duve argues in his essay that science especially biology, "urgently calls for an informed and unbiased dialogue" among science, philosophy, and religion. Physicist and author Paul Davies observes that "if it turns out to be the case that the universe is inherently biofriendly...then...the scientific, theological, and philosophical implications will be extremely significant.

The reader will also find in this volume a difference of opinion as to how much our concepts of God need to be modified in the light of what we know about the universe. Freeman Dyson writes that the modern universe "has not changed the age-old mystery of God's relation to the physical universe," that God is beyond the limits of our understanding and unlikely to be impressed with our efforts to read his mind. On the other hand, Lee Smolin boldly claim that "the old idea of and outside creator and knower has served its purpose and may now be relegated to history." Rather than a creator who stands eternally outside his creation, the "creative being, the knowledge of all its mani-

fold variety, and that world itself, are one and the same thing." Similarly, I argue that, just as Aristotle's celestial- terrestrial dichotomy of the universe was abandoned after two millennia, so cosmotheology may have to abandon the 4,000-years-old supernatural God of the ancient Near East in favor of a "natural God" inside the universe. Even if we retain our traditional concepts of God, doctrines of particular religious traditions may be affected in ways that are also discussed in these pages.

Any volume such as this, which proposes to treat the relation of science and religion, must be well grounded in science. The authors of Parts I and II provide a foundation for Part III in this respect, as well as drawing philosophical and theological lessons themselves. Part I focuses on what lessons might be learned withhe latest knowledge of the origin and evolution of life. After discussing some of the lessons of life, Christian de Duve immediately draws a sharp distinction between two possibilities: that of the French biochemist Jacques Monod, who in his book Chance and Necessity (1971) argued that "the universe was not pregnant with life, nor the biosphere with man," and the point of view (which de Duve prefers) that the pregnancy erroneously negated by Monod is in fact "the outcome of very special features built into the natural structure of the universe." De Duve views life as a "cosmic imperative," with all that implies for philosophy and theology. Physicist Paul Davies and biophysicist Bernd-Olaf Kuppers both stress the informational aspects of the origin of life, and both return in the end to the question of chance and necessity. Davies concludes that if life and intelligence are freak accidents as some believe, then bleak atheism may be justified; however, if life arises as an "automatic and natural parts of an ingeniously biofriendly universe" (as he believes), then "atheism would seem less compelling and something like design more plausible." Kuppers, while not accepting Monod's claim that life is a lottery, also believes de Duve's cosmic imperative for life goes too far in the direction of determinism; consideration must be given to the historical circumstances under which generation and transformational of the boundaries that encode the blueprint of the living organism. Christopher McKay, a NASA scientist and expert on Mars, argues that these questions may only be answered when extraterrestrial life is discovered. He explores strategies for a successful search based on the principles of astrobiology in an essay that also extends the discussion from theology to environmental ethics.

Part II broadens the scope of the conversation to cosmic evolution. Indeed, what Arthur Peacocke calls the "genesis for the third millennium" is the theme that underlies the entire book. Sir Martin Rees lays out the panoply and grandeur of cosmic evolution, extending even to the evolution of other universes that may compose what he terms an infinite and eternal "multiverse." Theoretical physicist Lee Smolin discusses how natural selection of universes may play a role in cosmic evolution and posits a cosmological theory in which all scientific questions are explicable in terms of the history of the universe, who laws may "result from natural and comprehensible processes of self-organization." Peacocke examines in considerable detail the stages and mechanisms of evolution for what they reveal about nature, humanity, and God. For Peacocke, the dynamic nature of living world impels us to reintroduce the notion of a "semper Creator," who "creates in and through the process of natural order." Philosopher John Leslie tackles the significance of the fact that the universe seems to be fine tuned in life-permitting ways. This has suggested to some people that many universes exist with widely varying characteristics; among these, only appropriately tuned universes could be observed by anyone, as Brandon Carter's "anthropic principle" reminds us. Leslie comments than any observed fine tuning might, however, have resulted from "divine selection of our universe's properties." He defends a neoplatonic theory of God, implying, among other reasons, that the universe exists because it is ethically better that it exist.

Part III addresses most directly many of the questions commonly associated with theological implications of extraterrestrial life. With his usual knack for innovative thinking, physicist Freeman Dyson demonstrates that we need not leave Earth to assess the effects of different world views; alien worlds exist, in a deeply physiological sense, all around us. They are inhabited by people with neurological impairments such as autism—and the lesson to be learned from trying to imagine them is humility. From the extraterrestrial perspective, astronomer Jill Cornell Tarter, who heads the Project Phoenix Search fro Extraterrestrial Intelligence, believes that an extraterrestrial message, unambiguously decoded, might be "a missionary campaign without precedent in terrestrial history," leading to the replacement of our diverse collection of terrestrial religions by a "universal religion." Alternatively, a message that indicates long-lived extraterrestrials with no need for God or religion might undermine our religious would view completely. Ernan McMullin, a priest and philosopher at the

University of Notre Dame, and George Coyne, the Jesuit director of the Vatican Observatory, provide reflections from within the Christian tradition, in particular addressing how the astronomical world view might affect particular dogmas such as Incarnation and Redemption. "Coping with the reality of the Stranger," McMullin reminds us, "has always been a challenge for the theologians of the Book." Coyne points out that the God of Scripture and tradition is not an explainer but a lover —and that anthropocentrism need not imply exclusivity. In the closing essay, as an astronomer and historian of Science I argue that it is time to take cosmotheology seriously, for religion to take into account what we know about the universe, no matter where it may lead us in our conceptions of God and in the revision of religious doctrines. Following that line of reasoning, we can only wonder where theology will be at the dawn of the next millennium.

A recognized limitation of this volume is that it is Western-centric. The majority of Earth's population is non-Western, non-Christian, and not necessarily imbued with the values we take for granted, and we must not ignore the multiplicity of our world in the new millennium. The new universe has implications for all areas of human thought and for all the world's cultures. A logical next step is a discussion of these implications for non-Western thought.

The meeting that served as the basis for this volume took place on November 22-24, 1998, in Lyford Cay, Nassau, The Bahamas. I thank Paul Davies, the meeting chair and co-organizer; Mary Ann Meyers, senior fellow of the Templeton Foundation, who also did much of the essential work of organization; and Sir John Templeton, the Foundation's creator, who attended the sessions and without whom the meeting would not have taken place. It goes without saying that the stimulating ideas and cooperation of the authors were essential for this volume. It was the consensus of the group that these discussions should reach beyond the confines of a small island; if this volume stimulates further discussions, it will have served its purpose.

I close with the stirring words of Christian de Duve: "The advances of biology have revolutionized the view we have for ourselves and our significance in the world. Many myths have had to be abandoned. But mystery remains, more profound and beautiful than ever before, a reality almost inaccessible to our feeble human means."

Steven J. Dick
Washington, D.C.

Part I
Origin and Evolution of Life

CHRISTIAN DE DUVE

Christian de Duve, who shared the 1974 Nobel Prize in Physiology or Medicine for pioneering work on cell structure and function, has devoted his career to studying the biochemistry of life. A native of Belgium, he studied at the Catholic University of Louvain where he earned an M.D., Ph.D., and advanced master's degree in chemical sciences. After postdoctoral fellowships at the Medical Nobel Institute in Stockholm and Washington University in St. Louis, he was appointed a lecturer in physiological chemistry on the Faculty of Medicine of the Catholic University of Louvain in 1947, becoming emeritus professor in 1985. Since 1962, he has shared his time between his Belgian alma mater and the Rockefeller University in New York, where he was named Andrew W. Mellon professor in 1974, reaching emeritus status in 1988. Dr. de Duve is the founder of the International Institute of Cellular and Molecular Pathology in Brussels, served as its president director from 1974 to 1991, and now is a member of the Institute's board of directors. Dr. de Duve has served on many advisory boards and committees. He is a member of numerous academies and learned societies, including the U.S. National Academy of Sciences, the American Philosophical Society, and the Royal Society. He holds sixteen honorary degrees from universities in Europe, South America, Canada, and the United States. He is the author of some 375 scientific papers and three books; the most recent is *Vital Dust: Life as a Cosmic Imperative.*

LESSONS OF LIFE*

CHRISTIAN DE DUVE

The twentieth century will be remembered for some of the most decisive breakthroughs in the history of human knowledge. Physics and cosmology captured the limelight in the first half of the century with the discovery of atomic structure, elementary particles, relativity, quantum mechanics, galaxies, the expanding universe, and the Big Bang. The awesome exploitation of nuclear power stands as the most epoch-making application of this new knowledge. The second half of the century belongs to biology, with elucidation of the key features of cell structure and function, the double-helical conformation of DNA, and the genetic code, leading to unprecedented mastery over life.

These revolutionary advances in science, especially those in biology, have affected in a profound manner our understanding of the nature, origin, and destiny of humankind—concerns traditionally addressed largely by philosophy and religion. The current situation urgently calls for an informed and unbiased dialogue between the two groups of disciplines. In this essay, I review briefly some of the most important notions that have been disclosed by recent biological discoveries, examine critically the evidence put forward in their support, and attempt to derive what lessons, if any, they hold for philosophy and religion. I do so from the vantage point of my own limited expertise in the life sciences. A more complete coverage of many of the topics discussed may be found in a recent book.[1]

I am greatly indebted to my friend Neil Patterson for many useful suggestions in the writing of this chapter and to Larry Martin, who had severely, but constructively, criticized an earlier version. Neither, of course, bears any responsibility in the ideas expressed.

The Nature of Life

A major lesson to be derived from our newly acquired understanding is that life is explainable in terms of the laws of physics and chemistry. This, of course, is the central postulate on which the scientific study of life rests. As such, it is a working hypothesis that guides and justifies our investigations, not a dogmatic a priori statement. While this is true historically, the present state of our knowledge makes the hypothesis into something as close to established fact as can be affirmed within the self-imposed boundaries of science.

We truly understand the basic processes that support life, and we successfully explain them in physical and chemical terms. The best proof that our explanations are both correct and sufficient is provided by the powerful achievements of biotechnology. The old concept of living organisms made of matter "animated" and goal-directed by some special force or "vital spirit" must be abandoned. Vitalism and finalism no longer are accepted by the vast majority of scientists.

The Unity of Life

Another affirmation that may now be made with considerable confidence is that all known living organisms, be they bacteria, protists, plants, fungi, or animals, including humans, descend from a single ancestral form of life, from which they have inherited a number of shared key properties. All known organisms are made of one or more cells. All cells are constructed out of the same building blocks assembled into the same kinds of polysaccharides, lipids, proteins, nucleic acids, and other general biological substances. All cells manufacture their constituents by the same processes. They all use similar mechanisms to derive energy from their environments and convert it into useful work. There are differences, of course. But the mechanisms, whether tied to sunlight, respiration, or anaerobic fermentation, boil down to similar electron exchanges, proton potentials, and phosphate-linked group transfers. Most important, all living organisms use the same language; they obey the same genetic code.

Already strongly supported by those common properties, the unity of life is incontrovertibly proven by the close similarities among the amino-acid sequences of proteins that perform the same functions in different organisms and among the nucleotide sequences of the nucleic acids that code for these proteins. Such similarities are found univer-

sally and enforce the conclusion that the molecules—and therefore the organisms to which they belong—are derived from a common ancestor. Comparative sequencing can even serve for reconstructing filiations among organisms. The underlying assumption—subject to many refinements—is that the degree of sequence dissimilarity between two homologous molecules, which corresponds roughly to the number of genetic modifications they have undergone independently, is a measure of the evolutionary distance separating their owners from their last common ancestor. This technique is now used on a large scale. In the resulting reconstructions, the human species clearly appears as one among millions of terminal twigs on the tree of life—the outcome, like every other living species, of a very long evolutionary history. The evidence supporting this view is overwhelming.

The Origin of Life

According to most experts, life arose naturally by way of processes entirely explainable by the laws of physics and chemistry. However, there is no definitive proof of this statement, since the origin of life is not known. The alternative theory, that life was launched on its course by a special act of creation, cannot be excluded; but this theory, in the light of compelling evidence, now appears gratuitous and heuristically sterile. The naturalist explanation is consistent with the explainability of life itself and is supported by all available data.

Organic radicals and molecules, some identical with the building blocks of life, are found in meteorites, comets, and even interstellar dust. Some of the steps whereby such substances can arise spontaneously and interact to form more complex compounds under plausible "prebiotic" conditions have been reproduced in the laboratory. Key stages in the development of life—the so-called "RNA world" is one—have been recognized. Reconstructing life in the test tube is still a distant goal but not, in the view of many scientists, an unattainable one.

An apparent corollary of the naturalistic explanation of life's origin is that life was bound to arise, in a form basically similar to its form on Earth, under the physical-chemical conditions that prevailed where and when it was born—presumably on Earth, a little less than four billion years ago. This opinion, which is shared by most biochemists, runs counter to the view, popularly accepted in many other circles, that life is the product of a highly improbable combination of chance events, so improbable as to be almost certainly unique in the entire universe.

With only a single instance of life known, discrimination between the two contrasting views can be based only on theoretical assessments. The deterministic explanation is supported by the fact that life must have arisen by way of chemical reactions. Chemistry deals with strictly reproducible processes that depend on the statistical behavior of trillions of molecules of different kinds and that leave little, if anything, to chance. Under specified conditions, chemical reactions always follow the same course. Such must have been the case of the reactions responsible for the emergence of life. Furthermore, a very large number of steps must have been involved in this process. The spontaneous appearance in a single shot, or even in a small number of steps, of something as complex as even the most primitive living cell is utterly impossible. Given the laws of probability, a process involving a large number of steps could have come to fruition only if, on average, the probability of each individual step had been reasonably high. Had this not been the case, the succession of steps leading to life most likely would have aborted before reaching a stage where self-support and self-perpetuation were ensured.

A deterministic view of the origin of life does not necessarily imply that life is widespread in the universe. It only means that life is as frequent—or as rare—as the physical-chemical conditions under which it must obligatorily arise. Should such conditions be so improbable as to be unique in the whole universe, then life, although the product of highly deterministic processes, would also be unique, and the consequence, albeit indirectly, of a highly improbable combination of circumstances. This is not a question for the biologist to answer. All that can be said is that the majority of cosmologists believe that there must be, in our galaxy alone, as well as in others, many celestial bodies with a history similar to that of planet Earth. If they are right, then the deterministic view leads to the conclusion that life is indeed widespread, a normal manifestation of matter in many sites of the universe, a cosmic imperative. Perhaps space exploration techniques will some day be sufficiently refined to settle this point.

THE HISTORY OF LIFE

Modern biology has confirmed and fleshed out in clear molecular terms Darwin's fundamental intuition that the evolution of life is driven by natural selection, acting after the fact in merely passive fashion, to sift accidentally arising genetic variants according to their ability to

survive and produce progeny under prevailing environmental conditions. A basic tenet of this concept is that the variations offered to natural selection are induced by causes that are unrelated, except in a strictly fortuitous manner, to the evolutionary advantages their effects may entail. It rules out any form of directionality imposed on the evolutionary process by some hidden guiding principle and is consistent with the rejection of vitalism and finalism already mentioned. It is supported by all we know of evolution as it takes place today and by all the findings of molecular biology.

This concept seems to imply that the course of evolution was ruled entirely by chance, a point often invoked in support of the view that humankind, like every other living species, owes its emergence to a very unlikely succession of accidental events, devoid of any sort of significance. Even if there should be many other foci of life in the universe, it is argued, the probability that any one would evolve into conscious, intelligent beings is extremely low. Hence the view that humankind is most likely unique in this respect and that even its appearance on Earth is a highly improbable event that could very well never have happened, were it not for an extraordinary combination of circumstances.

This inference is not necessarily correct. Chance does not exclude inevitability. However improbable an event may be, it always can be made to occur almost obligatorily—within acceptable limits of time and space—by giving it a sufficient number of opportunities of taking place. As a simple example, take a seven-digit lottery number. Its likelihood of coming out in a single drawing is one in ten million. But with ten million drawings, the probability becomes two in three. And with one hundred million drawings, the probability of the number coming out is 9,999.5 in 10,000, close to certainty. This fact is of little help to lottery players, but it is highly relevant to the evolutionary lottery, to the extent that given events depend on the occurrence of a given mutation in an individual exposed to a given set of environmental conditions. Considering, on the one hand, the constraints imposed on the number of possible mutations by the sizes and structures of genomes and, on the other, the number of individuals at risk and the durations involved, one concludes that mutations rarely act as limiting factors in evolution.

This view is supported by what we know of evolution in action. Consider, for example, the many instances of drug-resistant pathogens and pests that have appeared in less than fifty years. This perspective

also renders more easily understandable the many cases of evolutionary adaptation—such as mimicry, for example—that are often invoked in favor of the intervention of some guiding factor in evolution.

If the view outlined above is correct, the natural variability of biological populations, although due essentially to fortuitous factors, most often is rich enough to provide for a wide spectrum of contingencies. Thus, the decisive role in evolution would most often be played by the screening effect of the environment on the mutations. This still leaves chance a major influence. It is important, in this connection, to distinguish between horizontal and vertical evolution. Horizontal evolution leads to diversity without significant change in body plan; it is dominated by contingency. Vertical evolution, the kind that leads to complexity, is much more stringently constrained. Given the opportunity and here comes the chance factor, evolution is bound to lead to increasing complexity. In animal evolution, the direction toward increasingly complex polyneural networks appears strongly favored by the fact that a more effective brain is advantageous under any circumstance. Thus, if life exists elsewhere in the universe, the likelihood that it may produce intelligent forms, some perhaps more advanced than the human form, is far from negligible.

That this possibility deserves to be seriously entertained threatens one of our most cherished beliefs, a cornerstone not only of many religions, but also of humanism in general, whether religiously inspired or not: the conviction that humankind occupies a central position in a universe somehow constructed around it, if not for it. I shall come back to this.

The Brain-Mind Problem

Another "ism" that has fallen victim to the advances of biology is dualism. There can be little doubt that mental states emerge naturally from the functioning of complex assemblages of neurons in certain parts of the brain, especially the neocortex. All the findings of neurobiology and of neuropathology converge to support this statement. The Cartesian notion of mind, or "spirit," as an entity distinct from the body and of a different nature, which somehow controls the body by way of the brain and helps it interact with the outside world, must be abandoned. As I have argued elsewhere, this notion is not only incompatible with experimental observations, it is logically flawed. If brain and mind are different in essence, how does the brain generate mind

and how does the mind, in turn, influence the brain? Of what essence is the bridge between the two entities?

In the opinion of many experts, the monistic view implies that human behavior is no more than the reflection of neuronal activities over which individuals have no control. Driven to its extreme conclusion, this view denies the existence of free will and, hence, of moral responsibility. The conviction we have of possessing these traits is depicted as an illusion, fostered by natural selection because it favored the cohesion and survival ability of the groups that entertained it. Oddly enough, even the most ardent advocates of this notion hesitate to drive it to its logical conclusion. Belief in free will, they tell us, although now recognized as an illusion, should nevertheless not be abandoned since we are unable ever to know the hidden processes that determine the decisions we assume we make freely. Ignorance creates uncertainty and thereby the feeling of freedom. Furthermore, belief in freedom somehow acts as a self-fulfilling process, in the sense that this belief, or rather its neuronal basis, becomes part of decision making.

This position, besides being intellectually shaky, leaves out the fact that consciousness itself is a subjective experience of which there is as yet only a phenomenological account but no objective explanation. The possibility that it may depend on properties not included in the physical descriptions of matter arrived at so far cannot be excluded. Neither can it be ruled out that mind, as an emanation of polyneuronal activities, has the ability to influence the course of these activities, at least in certain cases, to exercise free will. Is the phrase "mental power" just an image, part of the illusion? Or does it correspond to some unknown process? This question is most often shirked by neurobiologists, a majority of whom consider even raising it a dangerous concession to extrasensory perception, spoon bending, and other claims of "metascience." Such an attitude strikes me as overly cautious. Science is strong enough to entertain hypotheses that do not fit with fashionable trends, provided the hypotheses can be subjected to rigorous testing.

Monism, like materialism, is most often understood in a reductionist fashion that, when properly considered, appears as a residue of Cartesian dualism. The notion of "mere matter" is invoked, matter itself being defined in terms of the properties (solidity, inertia, and brute submission to the laws of physics and chemistry) that distinguish it from spirit. This is wrong. What monism truly means is not that we must somehow squeeze spirit into our traditional concept of matter,

but that we must enlarge the definition of matter to include those properties that used to be attributed to spirit. It must be remembered that the senses whereby the human brain apprehends the surrounding world were refined by natural selection as tools of survival, not of knowledge. Only recently has this become evident, thanks to the development of physical instruments that extend the range of our senses and to conceptual tools that allow theoretical processing of the information gathered by these instruments. The glimpses of the "real" world revealed to us in this way have turned out to be so strange as to be utterly beyond the grasp of those who have not been introduced to them by long and arduous training. Even the experts have difficulties translating from their language—most often mathematical—to a more familiar mode of representation.

The capacity to approach reality in this manner is, at least on Earth, an exclusive property of human beings, acquired in the past few million years of evolution thanks, probably, to a remarkable development of the brain, especially the neocortex. This realization raises the question of what might be the impact of further brain development on the ability to investigate and understand nature. A second question concerns the significance of other forms of interaction—besides rational discourse—between the human brain and reality: artistic expression, moral judgment, intuitive apprehension, meditation, or mystic contemplation. Could there be several means of cognition each adapted to a facet of ultimate reality and perhaps each capable of further improvement through additional development of certain areas of the brain? These and other such questions cannot be answered in the present state of our knowledge and perhaps never will be. But they remind us that the relationship between brain and mind is an unsolved problem.

The Future of Life

One last lesson of biology: evolution is far from over. According to cosmologists, our planet should remain able to bear life for about another five billion years before being engulfed in the fiery expansion of the dying sun. What can happen in such an enormous stretch of time is entirely beyond our imagination. Whatever the future may bring, humankind is most unlikely to remain at a standstill during all that time. It will either disappear or evolve. In either case, we are not the ultimate achievement of evolution, only a transient stage. The old anthropocentric view of a human-focused universe must be abandoned, even in its recent reformulation in the so-called "anthropic principle."

It would be surprising if in the future development of life on Earth, vertical evolution toward greater complexity did not continue to take place, perhaps leading to beings endowed with considerably sharper means of apprehending reality than we possess. Such beings could arise by further extension of the human twig, but they do not have to. There is plenty of time for a humanlike adventure to start all over again from another twig and perhaps go further than did the human adventure.

Lessons of Life for Philosophy and Religion

Creationism, vitalism, finalism, dualism, and anthropocentrism have all been left by the wayside by the progression of modern biology. For scientists, the scenery is deeply gratifying in its austere and coherent beauty. But to others, the message may seem disquietingly bleak, because it questions a number of familiar notions, rooted in the biblical tradition and still entertained and propagated in more or less literal form by the major monotheistic religions. Aware of the potential conflicts, many philosophers and theologians have begun reflecting on how basic beliefs can be reconciled with the findings of science. This necessary reappraisal will not be easy, considering the intricate network of social structures that has been knit around the churches by centuries of shared faith and aspirations. In this exercise, the scientist can only point to what is now established beyond reasonable doubt or at least highly probable. Such has been the purpose of my brief survey. As to extrapolating from science to philosophy, scientists are poorly trained for such a venture and generally shy away from it. Here, for what they are worth, are a few suggestions.

A first notion to be singled out is that we belong to a universe capable of giving rise to life and mind. This affirmation would seem like a mere statement of the obvious, were it not for the widely publicized view that life and mind are freak products of a highly improbable combination of chance circumstances most unlikely to occur any time, anywhere. This attitude was summed up by Jacques Monod when he wrote, “The Universe was not pregnant with life, nor the biosphere with man.”[2] This statement challenges evidence. The facts are that the Universe has given birth to life and the biosphere has given birth to humans. To affirm that those two births took place without pregnancies amounts to invoking miracles, which is certainly not what the great French biologist had in mind.

Miracles, in the form of special creative acts of God, are what religions traditionally invoke to account for the existence of life and mind

in the universe. The lesson of modern biology is that such interventions were not needed and probably did not occur. Life and mind most likely developed through purely natural events rendered possible by the prevailing physical-chemical conditions or perhaps even imposed by these conditions. As the defenders of the anthropic principle have pointed out in great detail, these occurrences require an extraordinary degree of fine tuning of many key properties of the universe. The "pregnancy" that was erroneously negated by Monod is in fact the outcome of very special features built into the natural structure of the universe.

Some contemporary physicists, including Rees and Smolin, two other contributors to this volume, minimize the significance of this fact by assuming that our universe is not unique. They see it as a part or as an evolutionary product of a large set of universes—a "multiverse" in the suggestive terminology proposed by Rees—that display a wide array of physical properties. Lost in this ocean of "nonpregnant" universes, ours would be no more than the odd one that happened, by chance, to have the right combination of properties for life and mind to arise. Intriguing as they are, these theories do not in any way diminish the overwhelming significance of our universe as it exists. Whichever way they appeared, and whatever the probability of their emergence, life and mind are such extraordinary manifestations that their existence can only be a telling revelation of ultimate reality. Even diluted by trillions of lifeless universes, ours remains supremely meaningful. The anthropic principle is correct in this respect, except for its anthropocentric connotation.

A second major lesson of modern biology concerns the humble status of our species, which, far from being the ultimate goal of creation it has long been thought to be, now appears as a transient link or perhaps even a side branch in a long evolutionary process very likely to give rise some day to beings much more advanced than we are. There also is a real possibility that beings with mental attributes similar or superior to ours exist elsewhere in the universe. Although these possibilities have not been verified in reality, they deserve sufficiently serious consideration to be incorporated into our new world view. The resulting picture is not, however, as negative as is maintained by those who see in the findings of science reasons for denigrating the human species.

Even though we may not be the final product of evolution, our emergence nevertheless represents a watershed. Contrary to what I call the "gospel of contingency," popularized by a number of contemporary thinkers, the human species is not the meaningless outcome of

chance events in a pointless universe. For the first time in the history of life, beings exist that have access, albeit in a very primitive and rudimentary fashion, to the reality behind the appearances, including the nature of matter, the structure of the universe, the basic mechanisms of life, the historical processes through which these entities have arisen and evolved, and especially abstract notions, such as truth, beauty, goodness, and love. Although apprehended only dimly, these abstractions are the closest we can get with our feeble means to the ultimate reality to which many give the name of God. No doubt, the beings with expanded mental powers who are likely to succeed us one day will see this reality more clearly. But the glimpses we are afforded already are immensely rewarding.

Also important and unique to the human condition is the acquisition of moral responsibility. Although disputed by some neurobiologists and philosophers, the feeling we have of being in command of our own actions and of being responsible for them is not likely to be abandoned, even by those who question its authenticity. It is an indispensable foundation of our societies. Far from yielding to the advances of science, our responsibility is made increasingly important by those advances, to the extent that they are giving us increasingly effective means of shaping the future of our planet, of the living world, and of our own species. To wield wisely the immense powers with which science in the twentieth century has endowed humankind will be the main concern of coming generations.

Conclusion

The advances of biology have revolutionized the view we have of ourselves and our significance in the world. Many myths have had to be abandoned. But mystery remains, more profound and more beautiful than ever before, a reality almost inaccessible to our feeble human means.

NOTES

1. C. de Duve, *Vital Dust* (New York: Basic Books, 1995).
2. J. Monod, *Chance and Necessity*, trans. A. Wainhouse (New York: Knopf, 1971), 145–146.