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Intelligent Design: The Original Version

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Abstract *William Paley (*Natural Theology, *1802) developed the argument-from-design. The complex structure of the human eye evinces that it was designed by an intelligent Creator. The argument is based on the irreducible complexity ("relation") of multiple interacting parts, all necessary for function. Paley adduces a wealth of biological examples leading to the same conclusion; his knowledge of the biology of his time was profound and extensive. Charles Darwin's* Origin of Species *is an extended argument demonstrating that the "design" of organisms can be explained by natural selection. Moreover, the dysfunctions, defects, waste, and cruelty that prevail in the living world are incompatible with a benevolent and omnipotent Creator. They come about by a process that incorporates chance and necessity, mutation and natural selection. In addition to science, there are other ways of knowing, such as art, literature, philosophy, and religion. Matters of value, meaning, and purpose transcend science.*

Key words: Evolution; Natural selection; Intelligent design; Paley; Darwin

In his *Natural Theology* of 1802, the English theologian William Paley advanced the "argument from design". The living world, he argues, provides compelling evidence of being designed by an omniscient and omnipotent Creator. Paley's first example is the human eye that he compares with a telescope: they are both made upon the same principles and bear a complete resemblance to one another, in their configuration, position of the lenses, and effectiveness in bringing each pencil of light to a point at the right distance from the lens. Could, he asks, these attributes be in the eye without purpose? "There cannot be design without designer; contrivance, without a contriver."

The argument-from-design is elaborated by Paley with greater cogency and more extensive knowledge of biological detail than by any other author before or since. Paley brings in all sorts of biological knowledge, from the geographic distribution of species to the interactions between predators and their prey, the interactions between the sexes, the camel's stomach and the woodpecker's tong, the compound eyes of insects and the spider's web. He explores the possibility of a sort of "natural selection": organisms may have come about by chance in an endless multiplicity of forms; those now in existence are those that happened to be functionally organized because they are the only ones able to survive and reproduce. Paley's evidence against chance derives from a notion akin to what some contemporary authors have named "irreducible complexity," that he calls "relation": the presence of a great variety of parts interacting with each other to produce an effect, which cannot be accomplished if any of the parts is missing.

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Charles Darwin read and enjoyed *Natural Theology* while a student at Cambridge University and found the argument compelling, but this would change later. I propose that the motivating objective of Darwin's *Origin of Species* was to provide a solution to Paley's problem; namely, to demonstrate how his discovery of natural selection would account for the design of organisms, without the need to recourse to supernatural agencies. As Darwin saw it, if his explanation were correct, biological evolution would follow; organisms would have changed over time and diversified, in response to a diversity of conditions in different places and at different times. Darwin, therefore, assembled evidence for evolution, because the occurrence of evolution corroborates his explanation of design as a result of natural selection.

The interaction between chance processes, such as genetic mutation and recombination, with natural selection yields a creative process which generates novelty (new sorts of organisms) and adaptation. The organisms appear to be designed to live in their environments, and their parts appear to be designed to fulfill certain functions, as a consequence of the incremental, step-by-step dialogue and barter between chance and natural selection, exercised over eons of time. But the process is haphazard, imperfections are pervasive, and the immense majority of species become extinct. The defective and dysfunctional design of organisms amounts to an argument-from-imperfection for the origin of organisms by natural processes.

I conclude with a brief statement pointing out that science is not the only way to acquire knowledge about the natural world. A scientific view of the world is by itself hopelessly incomplete, because there remain questions of value, purpose, and meaning that are outside science's realm, while they may be approached by other ways of knowing such as art and literature, philosophical reflection, and religious inspiration.

William Paley's intelligent design

The English clergyman and author William Paley (1743–1805) was intensely committed to the abolition of the slave trade and had become by the 1780s a much sought after public lecturer against slavery. He was also an influential writer of works on Christian philosophy, ethics, and theocracy. *The Principles of Moral and Political Philosophy* (1785) and *A View of the Evidence of Christianity* (1794) earned him prestige and well-endowed ecclesiastical benefices, which allowed him a comfortable life. Illness forced him in 1800 to give up his public speaking career, which provided ample time to study science, particularly biology, and write *Natural Theology; or, Evidences of the Existence and Attributes of the Deity* (1802), the book by which he has become best known to posterity and which would greatly influence Darwin. With *Natural Theology,* Paley sought to update John Ray's *Wisdom of God Manifested in the Works of the Creation* (1691), taking advantage of one century of additional scientific knowledge.

Paley's keystone claim is that: "There cannot be design without a designer; contrivance, without a contriver; order, without choice; . . . means suitable to an end, and executing their office in accomplishing that end, without the end ever having been contemplated."[1] *Natural Theology* is a sustained argument manifesting the obvious design of humans and their parts, as well as the design of all sorts of organisms, in themselves, and in their relations to one another and to their environment. There are chapters dedicated to the complex design of the human eye; to the human frame, which displays a precise mechanical arrangement of bones, cartilage, and joints; to the circulation of the blood and the disposition of blood vessels; to the comparative anatomy of humans and animals; to the digestive system, kidneys, urethras, and bladder; to the wings of birds and the fins of fish; and much more. For 352 pages, *Natural Theology* conveys Paley's expertise: extensive and accurate biological knowledge, as detailed and precise as it was available in the year 1800. After detailing the precise organization and exquisite functionality of each biological object or process, Paley draws again and again the same conclusion, that only an omniscient and omnipotent Deity could account for these marvels of mechanical perfection, purpose, and functionality, and for the enormous diversity of inventions that they entail.

Paley's first model example is the human eye, in chapter three, "Application of the Argument." I will quote him at some length, for there is no better way to display his knowledge of the anatomy of the eye or his skill of argumentation.

> I know no better method of introducing so large a subject, than that of comparing a single thing with a single thing: an eye, for example, with a telescope. As far as the examination of the instrument goes, there is precisely the same proof that the eye was made for vision as there is that the telescope was made for assisting it. They are made upon the same principles; both being adjusted to the laws by which the transmission and refraction of rays of light are regulated. . . . For instance, these laws require, in order to produce the same effect, that the rays of light, in passing from water into the eye, should be refracted by a more convex surface than when it passes out of air into the eye. Accordingly we find that the eye of a fish, in that part of it called the crystalline lens, is much rounder than the eye of terrestrial animals. What plainer manifestation of design can there be than this difference? What could a mathematical instrument maker have done more to show his knowledge of [t]his principle, his application of that knowledge, his suiting of his means to his end . . . to testify counsel, choice, consideration, purpose?[2]

It is worthwhile to follow Paley's argument further:

> The lenses of the telescopes and the humors of the eye bear a complete resemblance to one another, in their figure, their position, and in their power over the rays of light, namely, in bringing each pencil to a point at the right distance from the lens; namely, in the eye, at the exact place where the membrane is spread to receive it. How is it possible, under circumstances of such close affinity, and under the operation of equal evidence, to exclude contrivance from the one, yet to acknowledge the proof of contrivance having been employed, as the plainest and clearest of all propositions, in the other?[3]

He brings in, to his argument's advantage, the issue of dioptric distortion:

> In dioptric telescopes there is an imperfection of this nature. Pencils of light, in passing through glass lenses, are separated into different colors, thereby tinging the object, especially the edges of it, as if it were viewed through a prism. To correct this

> inconvenience has been long a desideratum in the art. At last it came into the mind of a sagacious optician, to inquire how this matter was managed in the eye, in which there was exactly the same difficulty to contend with as in the telescope. His observation taught him that in the eye the evil was cured by combining lenses composed of different substances, that is, of substances which possessed different refracting powers. Our artist borrowed thence his hint, and produced a correction of the defect by imitating, in glasses made from different materials, the effects of the different humors through which the rays of light pass before they reach the bottom of the eye. Could this be in the eye without purpose, which suggested to the optician the only effectual means of attaining that purpose?[4]

The functional anatomy of the eye is, later on, summarized as follows:

> [We marvel] knowing as we do what an eye comprehends, namely, that it should have consisted, first, of a series of transparent lenses—very different, even in their substance, from the opaque materials of which the rest of the body is, in general at least, composed, and with which the whole of its surface, this single portion of it excepted, is covered: secondly, of a black cloth or canvas—the only membrane in the body which is black—spread out behind these lenses, so as to receive the image formed by pencils of light transmitted through them; and placed at the precise geometrical distance at which, and at which alone, a distinct image could be formed, namely, at the concourse of the refracted rays: thirdly, of a large nerve communicating between this membrane and the brain; without which, the action of light upon the membrane, however modified by the organ, would be lost to the purposes of sensation.[5]

Could the eye have come about without design or preconceived purpose, as a result of chance? Paley had set the argument against chance, in the very first paragraph of *Natural Theology*, arguing rhetorically by analogy:

> In crossing a heath, suppose I pitched my foot against a *stone*, and were asked how the stone came to be there, I might possibly answer, that for any thing I knew to the contrary it had lain there for ever; nor would it, perhaps, be very easy to show the absurdity of this answer. But suppose I had found a *watch* upon the ground, and it should be inquired how the watch happened to be in that place, I should hardly think of the answer which I had before given, that for any thing I knew the watch might have always been there. Yet why should not this answer serve for the watch as well as for the stone; why is it not as admissible in the second case as in the first? For this reason, and for no other, namely, that when we come to inspect the watch, we perceive—what we could not discover in the stone—that its several parts are framed and put together for a purpose, *e.g.* that they are so formed and adjusted as to produce motion, and that motion so regulated as to point out the hour of the day; that if the different parts had been differently shaped from what they are, or placed after any other manner or in any other order than that in which they are placed, either no motion at all would have been carried on in the machine, or none which would have answered the use that is now served by it.[6]

The strength of the argument against chance derives, Paley tells us, from what he names "relation," a notion akin to what contemporary anti-evolutionists have named "irreducible complexity" (and that some of them have given themselves credit for its discovery). This is how Paley formulates the argument:

> When several different parts contribute to one effect, or, which is the same thing, when an effect is produced by the joint action of different instruments, the fitness of such parts or instruments to one another for the purpose of producing, by their united action, the effect, is what I call *relation*; and wherever this is observed in the works of nature or of man, it appears to me to carry along with it decisive evidence of understanding, intention, art . . . all depending upon the motions within, all upon the system of intermediate actions.[7]

A remarkable example of complex parts, fit together so that they cannot function one without the other, are the sexes, "manifestly made for each other . . . subsisting, like the clearest relations of art, in different individuals, unequivocal, inexplicable without design."[8]

The outcomes of chance do not exhibit relation among the parts or, as we might say, organized complexity:

> the question is, whether a useful or imitative conformation be the product of chance . . . Universal experience is against it. What does chance ever do for us? In the human body, for instance, chance, that is, the operation of causes without design, may produce a wen, a wart, a mole, a pimple, but never an eye. Among inanimate substances, a clod, a pebble, a liquid drop might be; but never was a watch, a telescope, an organized body of any kind, answering a valuable purpose by a complicated mechanism, the effect of chance. In no assignable instance has such a thing existed without intention somewhere.[9]

Paley considers and rejects an interesting hypothesis that would combine chance and natural selection:

> The hypothesis teaches, that every possible variety of being hath, at one time or other, found its way into existence—by what cause or in what manner is not said—and that those which were badly formed perished . . . The hypothesis, indeed, is hardly deserving of the consideration which we have given to it. What should we think of a man who, because we had never ourselves seen watches, telescopes, stocking-mills, steam-engines, etc., made, knew not how they were made, nor could prove by testimony when they were made, or by whom, would have us believe that these machines . . . derive [their curious structures] from no other origin than this; namely, that a mass of metals and other materials having run, when melted, into all possible figures, and combined themselves in all possible forms and shapes and proportions, these things which we see are what were left from the incident . . . I cannot distinguish the hypothesis, as applied to the works of nature, from this solution, which no one would accept as applied to a collection of machines.[10]

This hypothesis is reminiscent of the philosopher of classic Greece Empedocles' account of the origin of complex entities, such as animals and plants, and it seems similar to the model of chance and selection rejected by some contemporary anti-evolutionists, but it has nothing significant in common with Darwin's theory of natural selection, an incremental process that incorporates adaptive changes, one small step at a time, in response to the environmental circumstances of the organisms. But Darwin's theory had not yet been formulated and one can only credit Paley for a serious exploration of the subject, carrying it as far as the biology of his time made it possible.

Paley's natural theology fails, even in his time, when seeking an account of imperfections, defects, pain and cruelty that would be consistent with his notion of the Creator. Chapter 23 is entitled "Of the Personality of the Deity" and it would surprise many by its well meaning, if naïve, arrogance, as Paley seems convinced that he can determine God's "personality." This is how the chapter starts:

> Contrivance, if established, appears to me to prove . . . the *personality* [Paley's emphasis] of the Deity, as distinguished from what is sometimes called nature, sometimes called a principle . . . Now, that which can contrive, which can design, must be a person. These capacities constitute personality, for they imply consciousness and thought. . . . The acts of a mind prove the existence of a mind; and in whatever a mind resides, is a person. The seat of intellect is a person.[11]

Paley proceeds, in the ensuing chapter to set "the natural attributes of the Deity," namely, omnipotence, omniscience, omnipresence, eternity, self-existence, necessary existence and spirituality—all these Paley infers from the observation of natural processes!

Paley raises the question of organs or parts seemingly unnecessary or superfluous. He considers two possible states of affairs: "in some instances the operation, in others the use, is unknown."[12] Examples of the first kind include the lungs of animals, which we know to be necessary for survival, although we are not "acquainted with the action of the air upon the blood, or in what manner that action is communicated by the lungs."[13] He cites the lymphatic system as a second example of this kind. Instances "may be numerous; for they will be so in proportion to our ignorance. . . . Every improvement of knowledge diminishes their number."[14] Examples of organs with unknown use include the spleen, which seems not to be necessary for "it has been extracted from dogs without any sensible injury to their vital functions." But it may well be the case that the part serves some unknown function, even if not necessary for survival in the short run. In any case, he adds, "superfluous parts do not negative the reasoning which we instituted concerning those parts which are useful."[15]

This last comment seems to me remarkable in that it is so unconvincing and so inconsistent with Paley's conceptual framework. Yet this is his general explanation for nature's imperfections: "Irregularities and imperfections are of little or no weight . . . but they are to be taken in conjunction with the unexceptionable evidences which we possess of skill, power, and benevolence displayed in other instances."[16] But if functional design manifests an intelligent designer, why should not deficiencies indicate that the designer is less than omniscient, or less than omnipotent, or less than omnivolent? Paley cannot have it both ways. Moreover, we know that some deficiencies are not just imperfections, but they are outright dysfunctional, jeopardizing the very function the organ or part is supposed to serve. This is a matter to which I shall return below. We now know, of course, that the explanation for dysfunction and imperfection is natural selection, which can account for design and functionality, but does not achieve any sort of perfection, nor is it omniscient or omnipotent.

I am filled with amazement and respect for Paley's extensive and profound biological knowledge. He discusses the air-bladder of fish, the fang of vipers, the claw of herons, the camel's stomach, the woodpecker's tongue, the elephant's proboscis, the hook in the bat's wing, the spider's web, the compound eyes of insects, and their metamorphosis, the glowworm, univalve and bivalve mollusks, seed dispersal, and on and on, with accuracy and as much detail as known to the best biologists of his time.

Paley's textbooks were part of the canon at the University of Cambridge for nearly half a century after his death and thus were read by Charles Darwin, who was an undergraduate student there between 1827 and 1831, with profit and "much delight." Darwin writes in his *Autobiography*:

> In order to pass the B.A. examination, it was also necessary to get up Paley's *Evidences of Christianity*, and his *Moral Philosophy*. This was done in a thorough manner, and I am convinced that I could have written out the whole of the *Evidences* with perfect correctness, but not of course in the clear language of Paley. The logic of this book and, as I may add, of his *Natural Theology*, gave me as much delight as did Euclid. The careful study of these works, without attempting to learn any part by rote, was the only part of the academic course which, as I then felt and as I still believe, was of the least use to me in the education of my mind. I did not at that time trouble myself about Paley's premises; and taking these on trust, I was charmed and convinced by the long line of argumentation.[17]

William Paley was not alone in Britain in the first half of the nineteenth century. The *Bridgewater Treatises*, published between 1833 and 1840, were written by eminent scientists and philosophers to set forth "the Power, Wisdom, and Goodness of God as manifested in the Creation." The complex functional organization of the human hand was one example elaborated as incontrovertible evidence that the hand had been designed by the same omniscient Power that had created the world. The treatises are marvels of biological knowledge and insight, even though the line of argumentation seems derivative by comparison to Paley's *Natural Theology*.

The emergence of modern science: Copernicus and Darwin

There is a priggish version of the history of the ideas that sees a parallel between Copernicus' and Darwin's monumental intellectual contributions, which are said to have eventuated two revolutions. According to this version, the Copernican Revolution consisted in displacing the Earth from its previously accepted locus as the center of the universe, moving it to a subordinate place as one more planet revolving around the sun. In congruous manner, this version affirms, the Darwinian Revolution consisted in displacing humans from their position as the center of life on Earth, with all other species created for the purpose of humankind, and placing humans instead as one species among many in the living world, so that humans are related to chimpanzees, gorillas, and other species by shared common ancestry. Copernicus had accomplished his revolution with the heliocentric theory of the solar system; Darwin's achievement emerged from his theory of organic evolution.

I will proffer that this version of the two revolutions is inadequate. What it says is true, but it misses what is most important about these two intellectual revolutions, namely, that they ushered in the beginning of science in the modern sense of the word. These two revolutions may jointly be seen as the one Scientific Revolution, with two stages, the Copernican and the Darwinian.

Darwin is deservedly given credit for the theory of biological evolution, because he accumulated evidence demonstrating that organisms evolve; and he discovered the process, natural selection, by which they evolve their functional organization. But the import of *The Origin of Species* is that it completed the Copernican Revolution, initiated three centuries earlier, and thereby radically changed our conception of the universe and the place of humankind in it.

The Copernican Revolution was launched with the publication in 1543, the year of Nicolaus Copernicus' death, of his *De revolutionibus orbium celestium* (*On the Revolutions of the Celestial Spheres*), and bloomed with the publication in 1687 of Isaac Newton's *Philosophiae naturalis principia mathematica* (*The Mathematical Principles of Natural Philosophy*). The discoveries of Copernicus, Kepler, Galileo, Newton, and others, in the sixteenth and seventeenth centuries, had gradually ushered in a conception of the universe as matter in motion governed by natural laws. It was shown that the earth is not the center of the universe, but a small planet rotating around an average star; that the universe is immense in space and in time; and that the motions of the planets around the sun can be explained by the same simple laws that account for the motion of physical objects on our planet. (Laws such as $f = m \times a$, *force = mass × acceleration*, or the inverse-square law of attraction, $f = g(m_1 m_2)/r^2$.) These and other discoveries greatly expanded human knowledge, but the conceptual revolution they brought about was more fundamental yet: a commitment to the postulate that the universe obeys immanent laws that account for natural phenomena. The workings of the universe were brought into the realm of science: explanation through natural laws. Physical phenomena could be accounted for whenever the causes were adequately known.

Darwin completed the Copernican Revolution by drawing out for biology the ultimate conclusion of the notion of nature as a lawful system of matter in motion. The adaptations and diversity of organisms, the origin of novel and highly organized forms, the origin of mankind itself, could now be explained by an orderly process of change governed by natural laws.

The origin of organisms and their marvelous adaptations were attributed, before Darwin, to the design of an omniscient Creator. God had created the birds and bees, the fish and corals, the trees in the forest, and best of all, humans. God had given human beings eyes so that they might see; and God had provided fish with gills to breathe in water. Paley, like the authors of the *Bridgewater Treatises* and many other philosophers and theologians, argued that the functional design of organisms manifests the existence of an all-wise Creator. Wherever there is design, there is a designer; the existence of a watch evinces the existence of a watchmaker.

The advances of physical science had driven humankind's conception of the universe to a split-personality state of affairs, which persisted well into the mid-nineteenth century. Scientific explanations, derived from natural laws, dominated the world of nonliving matter, on the earth as well as in the heavens. Supernatural explanations, depending on the unfathomable deeds of the Creator, accounted for the origin and configuration of living creatures—the most diversified, complex, and interesting realities of the world.

It was Darwin's genius to resolve this conceptual schizophrenia. Darwin completed the Copernican Revolution by drawing out for biology the notion of nature as a lawful system of matter in motion that human reason can explain without recourse to extra-natural agencies.

The conundrum faced by Darwin can hardly be overestimated. The strength of the argument-from-design to demonstrate the role of the Creator was easily set forth. Wherever there is function or design, we look for its author. Paley had belabored this argument with great skill and profusion of detail. It was Darwin's greatest accomplishment to show that the complex organization and functionality of living beings can be explained as the result of a natural process, natural selection, without any need to resort to a Creator or other external agent. The origin and adaptation of organisms in their profusion and wondrous variations were thus brought into the realm of science.

Darwin accepted that organisms are "designed" for certain purposes, i.e. they are functionally organized. Organisms are adapted to certain ways of life and their parts are adapted to perform certain functions. Fish are adapted to live in water, kidneys are designed to regulate the composition of blood, and the human hand is made for grasping. But Darwin went on to provide a natural explanation of the design. The seemingly purposeful aspects of living beings could now be explained, like the phenomena of the inanimate world, by the methods of science, as the result of natural laws manifested in natural processes.

Darwin's discovery

The central argument of the theory of natural selection is summarized by Darwin in *The Origin of Species* as follows:

> As more individuals are produced than can possibly survive, there must in every case be a struggle for existence, either one individual with another of the same species, or with the individuals of distinct species, or with the physical conditions of life. . . . Can it, then, be thought improbable, seeing that variations useful to man have undoubtedly occurred, that other variations useful in some way to each being in the great and complex battle of life, should sometimes occur in the course of thousands of generations? If such do occur, can we doubt (remembering that more individuals are born than can possibly survive) that individuals having any advantage, however slight, over others, would have the best chance of surviving and of procreating their kind? On the other hand, we may feel sure that any variation in the least degree injurious would be rigidly destroyed. This preservation of favorable variations and the rejection of injurious variations, I call Natural Selection.[18]

Darwin's argument addresses the same issues as Paley's: how to account for the adaptive configuration of organisms, the obvious "design" of their parts to fulfill certain functions. Darwin argues that hereditary adaptive variations ("variations useful in some way to each being") occasionally appear, and that these are likely to increase the reproductive chances of their carriers. The success of pigeon fanciers and animal breeders clearly evinces the occasional occurrence of useful hereditary variations. Over the generations, favorable variations will be preserved, multiplied, and conjoined; injurious ones will be eliminated. In one place, Darwin adds: "I can see no limit to this power [natural selection] in slowly and beautifully *adapting* each form to the most complex relations of life."[19] Natural selection was proposed by Darwin primarily to account for the adaptive organization, or "design," of living beings; it is a process that preserves and promotes adaptation. Evolutionary change through time and evolutionary diversification (multiplication of species) are not directly promoted by natural selection (hence, the so-called evolutionary stasis emphasized by the theory of punctuated equilibrium), but they often ensue as by-products of natural selection fostering adaptation.

There is a possible reading of Darwin's *Origin of Species* that sees it, first and foremost, as a sustained effort to solve Paley's problem within a scientific explanatory framework. It is, indeed, how I interpret Darwin's masterpiece. The Introduction and Chapters I to VIII explain how natural selection accounts for the adaptations and behaviors of organisms, their "design." The extended argument starts in Chapter I, where Darwin describes the successful selection of domestic plants and animals and, with considerable detail, the success of pigeon fanciers seeking exotic sports. This evidence manifests what selection can accomplish using spontaneous variations beneficial to man. The ensuing chapters extend the argument to variations propagated by natural selection (i.e. reproductive success) for the benefit of the organisms, rather than by artificial selection for traits desirable to humans. Organisms exhibit design, but it is not "intelligent design," imposed by God as a supreme engineer, but the result of natural selection promoting the adaptation of organisms to their environments. Organisms exhibit complexity, but it is not irreducible complexity emerged all of a sudden in its current elaboration, but has arisen gradually and cumulatively, step by step, promoted by the adaptive success of individuals with incrementally more complex elaborations.

If Darwin's explanation of the adaptive organization of living beings is correct, evolution necessarily follows, as organisms become adapted to different environments and to the changing conditions of all environments, and as hereditary variations become available at a particular time that improve the organisms' chances of survival and reproduction. The *Origin*'s evidence for biological evolution is central to Darwin's explanation of "design," because his explanation postulates the occurrence of biological evolution, which he, therefore, seeks to demonstrate in most of the remainder of the book (Chapters IX–XIII), returning to the original theme in the concluding Chapter XIV. In the last paragraph of the *Origin*, Darwin eloquently returns, indeed, to the dominant theme of adaptation or design:

> It is interesting to contemplate an entangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these

> *elaborately constructed* forms, *so different* from each other, and dependent on each other *in so complex a manner*, have all been produced by laws acting around us. . . . Thus, from the war of nature, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows. There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning *endless forms most beautiful and most wonderful* have been, and are being, evolved.[20] (Emphasis added.)

Natural selection as a "design" process

The modern understanding of the principle of natural selection is formulated in genetic and statistical terms as differential reproduction. Natural selection implies that some genes and genetic combinations are transmitted to the following generations with a higher probability than their alternates. Such genetic units will become more common in subsequent generations and their alternates less common. Natural selection is a statistical bias in the relative rate of reproduction of alternative genetic units.

Natural selection does not operate in the manner of Paley's unaccepted hypothesis, acting on randomly formed organisms, allowing the functional ones to survive while the great majority dies. Natural selection does not operate, either, as a sieve that retains the rarely arising useful genes and lets go the more frequently arising harmful mutants; at least, not only. Natural selection acts in the filtering way of a sieve, but it is much more than a purely negative process, for it is able to generate novelty by increasing the probability of otherwise extremely improbable genetic combinations. Natural selection is thus a creative process. It does not create the entities upon which it operates, but it produces adaptive (functional) genetic combinations that could not have existed otherwise.

The creative role of natural selection must not be understood in the sense of the absolute creation that traditional Christian theology predicates of the divine act by which the universe was brought into being *ex nihilo,* or in the manner of creation in which Paley assumes God, the supreme engineer, had created the adaptations of organisms. Natural selection may rather be compared to a painter who creates a picture by mixing and distributing pigments in various ways over the canvas. The canvas and the pigments are not created by the artist but the painting is. It is inconceivable that a random combination of the pigments might result in the orderly whole that is the final work of art, say Leonardo's *Mona Lisa*. In the same way, the combination of genetic units which carries the hereditary information responsible for the formation of the vertebrate eye could have never been produced by a random process such as mutation. Not even if we allow for the three billion years plus during which life has existed on earth. The complicated anatomy of the eye like the exact functioning of the kidney are the result of a nonrandom process—natural selection.

How natural selection, a purely material process, can generate novelty in the form of accumulated hereditary information may be illustrated by the following example. Some strains of the colon bacterium, *Escherichia coli*, in order to be able to reproduce in a culture medium, require that a certain substance, the amino acid histidine, be provided in the medium. When a few such bacteria are added to ten cubic centimeters of liquid culture medium, they multiply rapidly and produce between 20 and 30 billion bacteria in a few hours. Spontaneous mutations to streptomycin resistance occur in normal (i.e. sensitive) bacteria at rates of the order of one in one hundred million (1×10^{-8}) cells. In the bacterial culture we expect between 200 and 300 bacteria to be resistant to streptomycin due to spontaneous mutation. If a proper concentration of the antibiotic is added to the culture, only the resistant cells survive. The two or three hundred surviving bacteria will start reproducing, however, and allowing one or two days for the necessary number of cell divisions, 20 billion or so bacteria are produced, all resistant to streptomycin. Among cells requiring histidine as a growth factor, spontaneous mutants able to reproduce in the absence of histidine arise at rates of about four in one hundred million (4×10^{-8}) bacteria. The streptomycin resistant cells may now be transferred to a culture with streptomycin but with no histidine. Most of them will not be able to reproduce, but about 1000 will and will start reproducing until the available medium is saturated.

Natural selection has produced in two steps bacterial cells resistant to streptomycin and not requiring histidine for growth. The probability of the two mutational events happening in the same bacterium is of about four in ten million billion ($1 \times 10^{-8} \times 4 \times 10^{-8} = 4 \times 10^{-16}$) cells. An event of such low probability is unlikely to occur even in a large laboratory culture of bacterial cells. With natural selection, cells having both properties are the common result.

Critics have sometimes alleged as evidence against Darwin's theory of evolution examples showing that random processes cannot yield meaningful, organized outcomes. It is thus pointed out that a series of monkeys randomly striking letters on a typewriter would never write *The Origin of Species*, even if we allow for millions of years and many generations of monkeys pounding at typewriters.

This criticism would be valid if evolution would depend only on random processes. But natural selection is a non-random process that promotes adaptation by selecting combinations that "make sense," i.e., that are useful to the organisms. The analogy of the monkeys would be more appropriate if a process existed by which, first, meaningful words would be chosen every time they appeared on the typewriter; and then we would also have typewriters with previously selected words rather than just letters in the keys, and again there would be a process to select meaningful sentences every time they appeared in this second typewriter. If every time words such as "the," "origin," "species," and so on, appeared in the first kind of typewriter, they each became a key in the second kind of typewriter, meaningful sentences would occasionally be produced in this second typewriter. If such sentences became incorporated into keys of a third type of typewriter, in which meaningful paragraphs were selected whenever they appeared, it is clear that pages and even chapters "making sense" would eventually be produced. The end product would be an irreducibly complex text.

We need not carry the analogy too far, since the analogy is not fully satisfactory, but the point is clear. Evolution is not the outcome of purely random processes, but rather there is a "selecting" process, which picks up adaptive combinations because these reproduce more effectively and thus become established in populations. These adaptive combinations constitute, in turn, new levels of organization upon which the mutation (random) plus selection (non-random or directional) process again operates. The complexity of organization of animals and plants is "irreducible" to simpler components in one or very few steps, but not thorough the millions and millions of generations and the multiplicity of steps and levels made possible by eons of time.

The critical point is that evolution by natural selection is an incremental process, operating over eons of time and yielding organisms better able to survive and reproduce than others, which typically differ from one another at any one time only in small ways; for example, the difference between having or lacking an enzyme able to catalyze the synthesis of the amino acid histidine. Notice also that increased complexity is not a necessary outcome of natural selection, although such increases occur from time to time, so that, although rare, they are very conspicuous over eons of time. Increased complexity is not a necessary consequence of evolution by natural selection, but rather emerges occasionally as a matter of statistical bias. The longest living organisms on earth are the microscopic bacteria, which have continuously existed on our planet for 3.5 billion years and yet those now living exhibit no greater complexity than their old time ancestors. More complex organisms came about much later, without the elimination of their simpler relatives. For example, the primates appeared on earth some 50 million years ago and our species, *Homo sapiens*, came about two hundred thousand years ago.

As illustrated by the bacterial example, natural selection produces combinations of genes that would otherwise be highly improbable because natural selection proceeds stepwise. The vertebrate eye did not appear suddenly in all its present perfection. Its formation required the appropriate integration of many genetic units, and thus the eye could not have resulted from random processes alone, nor did it come about suddenly or in a few steps. The ancestors of today's vertebrates had for more than half a billion years some kind of organs sensitive to light. Perception of light, and later vision, were important for these organisms' survival and reproductive success. Accordingly, natural selection favored genes and gene combinations increasing the functional efficiency of the eye. Such genetic units gradually accumulated, eventually leading to the highly complex and efficient vertebrate eye. Natural selection can account for the rise and spread of genetic constitutions and, therefore, of types of organisms, that would never have existed under the uncontrolled action of random mutation. In this sense, natural selection is a creative process, although it does not create the raw materials—the genes—upon which it acts.[21]

Design and chance

There is an important respect in which an artist makes a poor analogy of natural selection. A painter has a preconception of what he wants to paint and will consciously modify the painting so that it represents what he wants. Natural selection has no foresight, nor does it operate according to some preconceived plan. Rather it is a purely natural process resulting from the interacting properties of physicochemical and biological entities. Natural selection is simply a consequence of the differential multiplication of living beings, as pointed out. It has some appearance of purposefulness because it is conditioned by the environment: which organisms reproduce more effectively depends on what variations they possess that are useful in the place and at the time where the organisms live. But natural selection does not anticipate the environments of the future; drastic environmental changes may be insuperable to organisms that were previously thriving. Species extinction is the common outcome of the evolutionary process. The species existing today represent the balance between the origin of new species and their eventual extinction. More than 99% of all species that ever lived on earth have become extinct without issue. These may have been more than one billion species; the available inventory of living species has identified and described less than two million out of some ten million estimated to be now in existence.

The team of typing monkeys is also a bad analogy of evolution by natural selection, because it assumes that there is "somebody" who selects letter combinations and word combinations that make sense. In evolution there is no one selecting adaptive combinations. These select themselves because they multiply more effectively than less adaptive ones.

There is a sense in which the analogy of the typing monkeys is better than the analogy of the artist, at least if we assume that no particular statement was to be obtained from the monkeys' typing endeavors, but just any statements making sense. Natural selection does not strive to produce predetermined kinds of organisms, but only organisms that are adapted to their present environments. Which characteristics will be selected depends on which variations happen to be present at a given time in a given place. This in turn depends on the random process of mutation, as well as on the previous history of the organisms (i.e., on the genetic make-up they have as a consequence of their previous evolution). Natural selection is an opportunistic process. The variables determining in what direction it will go are the environment, the preexisting constitution of the organisms, and the randomly arising mutations.

Thus, adaptation to a given environment may occur in a variety of different ways. An example may be taken from the adaptations of plant life to the desert climate. The fundamental adaptation is to the condition of dryness, which involves the danger of desiccation. During a major part of the year, sometimes for several years in succession, there is no rain. Plants have accomplished the urgent necessity of saving water in different ways. Cacti have transformed their leaves into spines, having made their stems into barrels storing a reserve of water; photosynthesis is performed on the surface of the stem instead of in the leaves. Other plants have no leaves during the dry season, but after it rains they burst into leaves and flowers and produce seeds. Ephemeral plants germinate from seeds, grow, flower, and produce seeds—all within the space of the few weeks while rainwater is available; the rest of the year the seeds lie quiescent in the soil.

The opportunistic character of natural selection is also well evidenced by the phenomenon of adaptive radiation. The evolution of drosophila flies in Hawaii is a relatively recent adaptive radiation. There are about 1500 drosophila species in the world. Approximately 500 of them have evolved in the Hawaiian archipelago, which has a small land area, about one twenty-fifth the size of California. Moreover, the morphological, ecological, and behavioral diversity of Hawaiian drosophila exceeds that of drosophila in the rest of the world. There are more than 1000 species of land snails in Hawaii, all of which have evolved in the archipelago. There are 72 bird species, all of which but one exist nowhere else.

Why should have such explosive evolution have occurred in Hawaii? The overabundance of drosophila flies there contrasts with the absence of many other insects. The ancestors of Hawaiian drosophila reached the archipelago before other groups of insects did, and thus they found a multitude of unexploited opportunities for living. They responded by a rapid adaptive radiation; although they are all derived from a single colonizing species, they adapted to the diversity of opportunities available in diverse places or at different times by developing appropriate adaptations, which range broadly from one to another species. The geographic remoteness of the Hawaiian archipelago seems, in any case, a more reasonable explanation for these explosions of diversity of a few kinds of organisms than assuming an inordinate preference on the part of the Creator for providing the archipelago with numerous drosophila, but not with other insects, or a peculiar distaste for creating land mammals in Hawaii, since none existed there until introduced by humans.

The process of natural selection can explain the adaptive organization of organisms, as well as their diversity and evolution, as a consequence of their adaptation to the multifarious and ever changing conditions of life. The fossil record shows that life has evolved in a haphazard fashion. The radiations, expansions, relays of one form by another, occasional but irregular trends, and the ever-present extinctions, are best explained by natural selection of organisms subject to the vagaries of genetic mutation and environmental challenge. The scientific account of these events does not necessitate recourse to a pre-ordained plan, whether imprinted from without by an omniscient and all-powerful designer, or resulting from some immanent force driving the process towards definite outcomes. Biological evolution differs from a painting or an artifact in that it is not the outcome of preconceived design.

Natural selection accounts for the "design" of organisms, because adaptive variations tend to increase the probability of survival and reproduction of their carriers at the expense of maladaptive, or less adaptive, variations. The arguments of Paley against the incredible improbability of chance accounts of the adaptations of organisms are well taken as far as they go. But not Paley and not any other author before Darwin, was able to discern that there is a natural process (namely, natural selection) that is not random, but rather is oriented and able to generate order or "create." The traits that organisms acquire in their evolutionary histories are not fortuitous but determined by their functional utility to the organisms, designed as it were to serve their life needs.

Chance is, nevertheless, an integral part of the evolutionary process. The mutations that yield the hereditary variations available to natural selection arise at random, independently of whether they are beneficial or harmful to their carriers. But this random process (as well as others that come to play in the great theatre of life) is counteracted by natural selection, which preserves what is useful and eliminates the harmful. Without hereditary mutation, evolution could not happen because there would be no variations that could be differentially conveyed from one to another generation. But without natural selection, the mutation process would yield disorganization and extinction because most mutations are disadvantageous. Mutation and selection have jointly driven the marvelous process that starting from microscopic organisms has yielded orchids, birds, and humans.

The theory of evolution conveys chance and necessity jointly intricated in the stuff of life; randomness and determinism interlocked in a natural process that has spurted the most complex, diverse, and beautiful entities in the universe: the organisms that populate the earth, including humans who think and love, endowed with free will and creative powers, and able to analyze the process of evolution itself that brought them into existence. This is Darwin's fundamental discovery, that there is a process that is creative though not conscious. And this is the conceptual revolution that Darwin completed: that everything in nature, including the 'design' of living organisms, can be accounted for as the result of natural processes governed by natural laws. This is nothing if not a fundamental vision that has forever changed how mankind perceives itself and its place in the universe.

The 'fact' of evolution

The biological disciplines provide overwhelming evidence that organisms are related by common descent with modification: paleontology, comparative anatomy, biogeography, embryology, biochemistry, molecular genetics, and others. The idea first emerged from observations of graded changes in the succession of fossil remains found in a sequence of layered rocks, as well as numerous remains of kinds of organisms no longer in existence. The layers have a cumulative thickness of tens of kilometers that represent up to 3.5 billion years of geological time. The general sequence of fossils from bottom upward in layered rocks had been recognized before Darwin proposed that the succession of biological forms strongly implied evolution. The farther back into the past one looked, the less the fossils resembled recent forms, the more the various lineages merged, and the broader the implications of a common ancestry for organisms presently quite diverse, such as fish, reptiles, and mammals.

Although gaps in the paleontological record remain now, many have been filled by the research of paleontologists since Darwin's time. Millions of fossil organisms found in well-dated rock sequences represent a succession of forms through time and manifest many evolutionary transitions. Microbial life of the simplest type (i.e. procaryotes, which are cells whose genetic matter is not bound by a nuclear membrane) was already in existence more than three billion years ago. The oldest evidence of more complex organisms (i.e. eukaryotic cells with their genetic matter enclosed in a chamber known as the nucleus) has been discovered in flinty rocks approximately 1.4 billion years old. More advanced forms, like algae, fungi, higher plants, and a great variety of animals have been found only in younger geological strata.

The sequence of observed forms and the fact that all (except the procaryotes) are constructed from the same basic cellular type; strongly imply that all these major categories of life (including animals, plants, algae, and fungi) have a common ancestry in the first eukaryotic cells. Moreover, there have been so many discoveries of intermediate forms between fish and amphibians, between amphibians and reptiles, between reptiles and mammals, and so on, that it is often difficult to identify categorically along the line when the transition occurs from one to another particular genus or, more generally, from one to another kind of organism. Nearly all fossils can be regarded as intermediates in some sense; they are life forms that come between ancestral forms that preceded them and those that followed.

Inferences about common descent derived from paleontology have been reinforced by comparative anatomy. The skeletons of humans, dogs, whales, and bats are strikingly similar, despite the different ways of life led by these animals and the diversity of environments in which they have flourished. The correspondence, bone by bone, can be observed in every part of the body, including the limbs: a person writes, a dog runs, a whale swims, and a bat flies with structures built of the same bones organized in the same pattern. Structures that manifest great similarity in their composition and configuration are called "homologous," and are best explained by common descent from a kind of organism that already exhibited the same composition and configuration, but so that modifications followed that made the structures suitable to the way of life of the descendants. Comparative anatomists investigate such homologies, not only in bone structure, but in other parts of the body as well, working out degrees of relationships from degrees of similarity.

The mammalian ear and jaw offer an example in which paleontology and comparative anatomy combine to show common ancestry through transitional stages. The lower jaws of mammals contain only one bone, whereas those of reptiles have several. The additional bones in the reptile jaw are homologous with bones now found in the mammalian ear. What function could these bones have had, either in the mandible or in the ear, during intermediate stages? Paleontologists have discovered two transitional forms of mammal-like reptiles (Therapsida) with a double jaw-joint—one joint composed of the bones that persist in the mammalian jaw, the other consisting of the quadrate and articular bones that eventually became the hammer and anvil of the mammalian ear. The complex structure of the jaw of the Therapsida made possible the gradual evolution of some of its bones into a different function, while the remainder retained the jaw function. Similar examples are numerous.

Other biological disciplines that manifest biological evolution include embryology and biogeography, already known in Darwin's time, as well as more recently developed disciplines, such as biochemistry, genetics, and comparative ethology. It is not my intention here to review the evidence forthcoming from these biological disciplines, because it is readily available in numerous textbooks and treatises. However, I do want to point out that the most encompassing as well as detailed evidence comes from molecular biology, a recent discipline that emerged in the second half of the twentieth century. It is the most encompassing evidence because the most diverse kinds of organisms can all be compared in many different respects at once, from the lowly bacteria and the microscopic protozoa to the multicellular plants, fungi, and animals visible to the human eye. Molecular biology is remarkable in that organisms encompass thousands of genes and proteins, each one of which can be evaluated as an independent test of the evolutionary relationships among any particular organisms. Moreover, the evidence can readily be quantified. The possibility exists today of determining the evolutionary history of any group of organisms with as much detail as wanted. Only the limitations of human or other resources stand in the way of reconstructing the grand panorama of the evolution of all life, from the microscopic creatures of 3.5 thousand million years ago to the microorganisms, animals, and plants of today.

The proteins and nucleic acids that are essential to the makeup of all organisms are informational macromolecules that retain a record of their evolutionary history. The evolutionary information is contained in the linear sequence of their component elements in much the same way as semantic information is contained in the sequence of letters of an English sentence. This evolutionary information is so detailed that it not only makes it possible to reconstruct the phylogenetic topology, or evolutionary relationships of parentage among organisms, but also opens up the possibility of timing the events in that history, even those that occurred in the remote past of life's history. The information is quantifiable because the number of units that differ between organisms is readily established when the sequences of the component units are obtained for a given protein or gene. There is very little that comparative anatomy can say about the relative similarity of organisms as diverse as yeasts, pine trees, and human beings, but there are homologous macromolecules that can be compared among all three.

Nucleic acids (such as DNA, or deoxyribonucleic acid, which embodies the hereditary information) and proteins are linear molecules made up of units, called nucleotides in the case of nucleic acids, amino acids in the case of proteins. Evolution typically occurs by the substitution of some of these units gradually, one at a time, so that the number of differences between two organisms is an indication of the recency of their common ancestry, in a similar way as the distance between two cars reflects how long they have been traveling in opposite directions.

The theory of evolution encompasses three issues: (i) the fact of evolution; that is, that organisms are related by common descent with modification; (ii) evolutionary history; that is, the time when lineages split from one another and the changes that occur in each lineage; and (iii) the mechanisms or processes by which evolutionary change occurs.

The fact of evolution is the most fundamental issue, and one established with utmost certainty. Most biologists agree that the evolutionary origin of organisms is today a scientific conclusion established with the kind of certainty attributable to such scientific concepts as the roundness of the earth, the motions of the planets, and the molecular composition of matter. This degree of certainty beyond reasonable doubt is what is implied when biologists say that evolution is a "fact"; the evolutionary origin of organisms is accepted by the immense majority of biologists.

The theory of evolution seeks to ascertain the evolutionary relationships between particular organisms and the events of evolutionary history (the second issue above). Many conclusions of evolutionary history are well established; for example, that the chimpanzee and gorilla are more closely related to humans than is any of those three species to the baboon or other monkeys. Other matters are less certain and still others—such as precisely when life originated on earth or when multi-cellular animals, plants, and fungi first appeared—remain largely unresolved. But uncertainty about these issues does not cast doubt on the fact of evolution. Similarly we do not know all the details about the configuration of the Sierra Nevada Mountains, but that is not reason to doubt that the mountains exist.

Some anti-evolutionists argue that the theory of evolution is only that, a theory and not a fact. Science relies on observation, replication, and experimentation but, they say, nobody has seen the origin of life or the evolution of species, nor have these events been replicated in the laboratory or by experiment.

This argument ignores that when scientists talk about the theory of evolution, they use the word "theory" differently from its use in ordinary language. In everyday English, a theory is an imperfect fact, as in "I have a theory as to where Osama bin Laden is hiding." In science, however, a theory is based on and incorporates a body of knowledge. According to the theory of evolution, organisms are related by common descent. There is a multiplicity of species because organisms change from generation to generation, and different lineages change in different ways. Species that share a recent ancestor are, therefore, more similar than those with more remote ancestors. Thus, humans and chimpanzees are, in configuration and genetic make-up, more similar to each other than they are to baboons or to elephants. That evolution has occurred is, in ordinary language, a fact.

How is this factual claim compatible with the accepted view that science relies on observation, replication, and experimentation since nobody has observed the evolution of species, much less replicated it by experiment? What scientists observe are not the concepts or general conclusions of theories, but their consequences. Copernicus heliocentric theory affirms that the earth revolves around the sun. Nobody has observed this phenomenon, but we accept it because of numerous confirmations of its predicted consequences. We accept that matter is made of atoms, even though nobody has seen them, because of corroborating observations and experiments in physics and chemistry. The same applies with the theory of evolution. For example, the claim that humans and chimpanzees are more closely related to each other than they are to baboons leads to the prediction that the DNA is more similar between humans and chimps than between chimps and baboons. To test this prediction, scientists select a particular gene, examine its DNA structure in each species, and thus corroborate the inference. Experiments of this kind are replicated in a variety of ways to gain further confidence in the conclusion. So it is for myriad predictions and inferences between all sorts of organisms.

Defects, deficiencies, and dysfunctions

I pointed out earlier the unsatisfactory answer that Paley advances to account for the imperfections of organisms. With respect to organs with unknown functions, he points out, correctly, that this may be a matter of our limited knowledge; a function may eventually be discovered. His suggestion is that, for example, the function of the lungs or of the spleen might eventually be discovered, as indeed it has been the case for these two organs. With respect to actual irregularities or imperfections, he makes the unsatisfactory and, to me, unexpected claim that "they are of little or no weight . . . when taken in conjunction . . . with the unexceptionable evidences that we possess of skill, power, and benevolence displayed in other instances." He adds: " . . . apparent blemishes . . . ought to be referred to some cause, though we be ignorant of it."[22]

One of the recent authors who have reformulated Paley's argument-from-design responds to the critics who point out the imperfections of organisms in the following way.

> The most basic problem is that the argument [against intelligent design] demands perfection at all. Clearly, designers who have the ability to make better designs do not necessarily do so. . . . I do not give my children the best, fanciest toys because I don't want to spoil them, and because I want them to learn the value of a dollar. The argument from imperfection overlooks the possibility that the designer might have multiple motives, with engineering excellence oftentimes relegated to a secondary role. . . . Another problem with the argument from imperfection is that it critically depends on psychoanalysis of the unidentified designer. Yet the reasons that a designer would or would not do anything are virtually impossible to know unless the designer tells you specifically what those reasons are.[23]

So, God may have had his reasons for not designing organisms as perfect as they could have been.

A problem with this explanation is that it destroys intelligent design as a scientific hypothesis, because it provides it with an empirically impenetrable shield.[24] If we cannot reject intelligent design because the designer may have reasons that we could not possibly ascertain, there would seem to be no way to test intelligent design by drawing out predictions logically derived from the hypothesis that are expected to be observed in the world of experience. Intelligent design as an explanation for the adaptations of organisms could be (natural) theology, as Paley would have it, but, whatever it is, it is not a scientific hypothesis.

I would argue, moreover, that is not good theology either, because it leads to conclusions about the nature of the designer quite different from those of omniscience, omnipotence, and omnibenevolence that Paley had inferred as the attributes of the Creator. It is not only those organisms and their parts that are less than perfect, but also that deficiencies and dysfunctions are pervasive, evidencing defective design. Consider the human jaw. We have too many teeth for the jaw's size, so that wisdom teeth need to be removed and orthodontists make a decent living straightening the others. Would we want to blame God for such defective design? A human engineer could have done better. Evolution gives a good account of this imperfection. Brain size increased over time in our ancestors, and the remodeling of the skull to fit the larger brain entailed a reduction of the jaw. Evolution responds to the organisms' needs through natural selection, not by optimal design but by tinkering, as it were, by slowly modifying existing structures. Consider now the birth canal of women, much too narrow for easy passage of the infant's head, so that thousands upon thousands of babies die during delivery. Surely we do not want to blame God for this defective design or for the children's deaths. Science makes it understandable, a consequence of the evolutionary enlargement of our brain. Females of other animals do not experience this difficulty. Theologians in the past struggled with the issue of dysfunction because they thought it had to be attributed to God's design. Science, much to the relief of many theologians, provides an explanation that convincingly attributes defects, deformities and dysfunctions to natural causes.

One more example: why are our arms and our legs, which are used for such different functions, made of the same materials, the same bones, muscles and nerves, all arranged in the same overall pattern? Evolution makes sense of the anomaly. Our remote ancestors' forelimbs were legs. After our ancestors became bipedal and started using their forelimbs for functions other than walking, these became gradually modified, but retaining their original composition and arrangement. Engineers start with raw materials and a design suited for a particular purpose; evolution can only modify what is already there. An engineer, who would design cars and airplanes, or wings and wheels, using the same materials arranged in a similar pattern, would surely be fired.[25]

The defective design of organisms could be attributed to the gods of the ancient Greeks, Romans, and Egyptians, who fought with one another, made blunders, and were clumsy in their endeavors. But, in my view, it is not compatible with special action by the omniscient and omnipotent God of Judaism, Christianity, and Islam.[26]

Powers and limits of science

I will add a final comment that should not be necessary, but probably is, owing to the hubris of some scientists and the pusillanimity of some believers. Science is a wondrously successful way of knowing. Science seeks explanations of the natural world by formulating explanations based on observation and experimentation that are subject to the possibility of rejection or corroboration, by cycles upon cycles of additional observations and experimentation. A scientific explanation is tested by ascertaining whether or not predictions about the world of experience derived from the explanation agree with what is later observed.

Science as a mode of inquiry into the nature of the universe has been successful and of great consequence. Witness the proliferation of science academic departments in universities and other research institutions, the enormous budgets that the body politic and the private sector willingly commit to scientific research, and its economic impact. The Office of Management and the Budget (OMB) of the US government has estimated that 50% percent of all economic growth in the United States since the Second World War can directly be attributed to scientific knowledge and technical advances. The technology derived from scientific knowledge pervades our lives: the high-rise buildings of our cities, thruways and long span-bridges, rockets that bring men to the moon, telephones that provide instant communication across continents, computers that perform complex calculations in millionths of a second, vaccines and drugs that keep bacterial parasites at bay, gene therapies that replace DNA in defective cells. All these remarkable achievements bear witness to the validity of the scientific knowledge from which they originated.

Scientific knowledge is also remarkable in the way it emerges by way of consensus and agreement among scientists and in the way new knowledge builds upon past accomplishments rather than starting anew with each generation or each new practitioner. Surely scientists disagree with each other on many matters; but these are issues not yet settled, and the points of disagreement generally do not bring into question previous knowledge. Modern scientists do not challenge that atoms exist, or that there is a universe with a myriad stars, or that heredity is encased in the DNA.

What I want to add is something that seems rather obvious to me: science is a way of knowing, but it is not the only way. Knowledge also derives from other sources, such as common sense, artistic and religious experience, and philosophical reflection. The validity of the knowledge acquired by non-scientific modes of inquiry can be simply established by pointing out that science (in the modern sense of the word) dawned in the sixteenth century, but mankind had for centuries built cities and roads, brought forth political institutions and sophisticated codes of law, advanced profound philosophies and value systems, and created magnificent plastic art, as well as music and literature. We thus learn about ourselves and about the world in which we live and we also benefit from products of this non-scientific knowledge. We learn about the human predicament reading Shakespeare's *King Lear*, watching a Rembrandt *Self-portrait*, and listening to Tchaikovsky's *Symphonie Pathétique* or Elton John's *Candle in the Wind*. The crops we harvest and the animals we husband emerged millennia before science's dawn from practices set down by farmers in the Middle East, Andean Sierras, and Mayan plateaus.

It is not my intention to belabor the extraordinary fruits of nonscientific modes of inquiry. But I have set forth the view that nothing in the world of nature escapes the scientific mode of knowledge, and that we owe this universality to Darwin's revolution. Here I wish simply to state that successful as it is, and universally encompassing as its subject is, a scientific view of the world is hopelessly incomplete. There are matters of value, meaning, and purpose that are outside science's scope. Even when we have a satisfying scientific understanding of a natural object or process, we are still missing matters that may well be thought by many to be of equal or greater import. Scientific knowledge may enrich esthetic and moral perceptions, and illuminate the significance of life and the world, but these are matters outside science's realm.

Notes

1 William Paley, *Natural Theology* (New York: American Tract Society), 15–16. I will cite pages following this American edition, which is undated, but seems to have been printed in the late nineteenth century.
2 Ibid., 20–21.
3 Ibid., 22.
4 Ibid., 22–23.
5 Ibid., 48.
6 Ibid., 1.
7 Ibid., 175–176.
8 Ibid., 180.
9 Ibid., 49.
10 Ibid., 51.
11 Ibid., 265.
12 Ibid., 46.
13 Ibid.
14 Ibid., 47.
15 Ibid.
16 Ibid., 46.
17 Sir Francis Darwin, ed., *Charles Darwin's Autobiography* (New York, 1961), 34–35.
18 Darwin's quote (as well as the two that follow) is from *On The Origin of Species*, a facsimile of the first edition of 1859 (New York: Atheneum, 1967), 63, 80–81.
19 Darwin, *Origin*, 469.
20 Darwin, *Origin*, 489–490.
21 A common objection posed to the account I have sketched of how natural selection gives rise to otherwise improbable features, is that some postulated transitions, for example, from a leg to a wing, cannot be adaptive. The answer to this kind of objection is well known to evolutionists. For example, there are rodents, primates, and other living animals that exhibit modified legs used for both running and gliding. The fossil record famously includes the reptile *Archaeopteryx* and many other intermediates showing limbs incipiently transformed into wings endowed with feathers. One other example is described later in this article; namely, the transition involving bones that make up the lower jaw of reptiles but later evolved into bones now found in the mammalian ear. What possible function could a bone have, either in the mandible or in the ear, during the intermediate stages?
22 Paley, *Natural Theology*, 46.
23 Michael J. Behe, *Darwin's Black Box. The Biochemical Challenge to Evolution* (New York: Touchstone, Simon & Schuster, 1996), 223.
24 Robert T. Pennock, ed., *Intelligent Design Creationism and Its Critics. Philosophical, Theological, and Scientific Perspectives* (Cambridge, MA and London: MIT, 2001), 249. The implications of this point with respect of the teaching of evolution in the schools have been drawn in the public arena. In *The Washington Times*, 21 March 2002, US Senator Edward Kennedy, who has publicly supported the teaching of alternate scientific theories when there is diversity of opinion among scientists, writes that "intelligent design is not a genuine scientific theory and, therefore, has no place in the curriculum of our nation's public school science classes."

25 Examples of deficiencies and dysfunctions in all sorts of organisms can be endlessly multiplied, reflecting the opportunistic, tinkerer-like character of natural selection, rather than intelligent design. The world of organisms also abounds in characteristics that might be called "oddities," as well as those that have been characterized as "cruelties," an apposite qualifier if the cruel behaviors were designed outcomes of a being holding on to human or higher standards of morality. But the cruelties of biological nature are only metaphoric cruelties when applied to the outcomes of natural selection. Examples of cruelty involve not only the familiar predators (say, a chimpanzee) tearing apart their prey (say, a small monkey held alive by a chimpanzee biting large flesh morsels from the screaming monkey), or parasites destroying the functional organs of their hosts, but also, and very abundantly, between organisms of the same species, even between individuals of different sexes in association with their mating. A well-known example is the female praying mantis that devours the male after coitus is completed. Less familiar is that, if she gets the opportunity, the female will eat the head of the male *before* mating, which thrashes the headless male mantis into spasms of sexual frenzy that allow the female to connect his genitalia with hers (S. E. Lawrence, "Sexual cannibalism in the praying mantis, *Mantis religiosa*: A field study," *Animal Behaviour* 43 (1992): 569–583. See also, M. A. Elgar, "Sexual cannibalism in spiders and other invertebrates," *Cannibalism: Ecology and Evolution among Diverse Taxa*, eds. M. A. Elgar and B. J. Crespi (Oxford: Oxford University, 1992.)) In some midges (tiny flies), the female captures the male as if he were any other prey and with the tip of her proboscis she injects into his head her spittle that starts digesting the male's innards that are then sucked by the female; partly protected from digestion are the relatively intact male organs that break off inside the female and fertilize her (J. A. Downes, "Feeding and mating in the insectivorous Ceratopogoninae (Diptera)," *Memoirs of the Entomological Society of Canada* 104 (1978): 1–62.) Male cannibalism is known in dozens of species, particularly spiders and scorpions. Diverse sorts of oddities associated with mating behavior are described in the delightful, but accurate and documented, book by Olivia Judson, *Dr. Tatiana's Sex Advice to All Creation* (New York: Holt, 2002).

26 With a somewhat more strident tone, the distinguished American philosopher of biology, David Hull, has made the same point: "What kind of God can one infer from the sort of phenomena epitomized by the species on Darwin's Galapagos Islands? The evolutionary process is rife with happenstance, contingency, incredible waste, death, pain and horror . . . Whatever the God implied by evolutionary theory and the data of natural selection may be like, he is not the Protestant God of waste not, want not. He is also not the loving God who cares about his productions. He is not even the awful God pictured in the Book of Job. The God of the Galapagos is careless, wasteful, indifferent, and almost diabolical. He is certainly not the sort of God to whom anyone would be inclined to pray" (David L. Hull, "God of the Galapagos," *Nature* 352 (1992): 485–486).

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