Without Miracles

2 The Fit of Biological Structures

Providence

Every organised natural body, in the provisions which it contains for its sustenation and propagation, testifies a care, on the part of the Creator, expressly directed to these purposes.

--William Paley[1]

Instruction

All that nature has caused individuals to gain or lose by the influence of the circumstances to which their race has been exposed for a long time, and, consequently, by the influence of a predominant use or disuse of an organ or part, is conserved through generations in the new individuals descending from them, provided that these acquired changes are common to the two sexes or to those which have produced these new individuals.

--Jean-Baptiste Lamarck[2]

Selection

Slow though the process of selection may be, if feeble man can do much by his powers of artificial selection, I can see no limit to the amount of change, to the beauty and infinite complexity of the coadaptations between all organic beings, one with another and with their physical conditions of life, which may be effected in the long course of time by nature's power of selection.

--Charles Darwin[3]

Most of the puzzles of fit mentioned in the preceding chapter have to do with either the structure or behavior of living organisms. The striking diversity and adapted complexity of our planet's life forms have led philosophers and scientists to expend considerable time and energy attempting to account for their existence. This chapter presents three types of explanations for the fit of organisms to their environments.

Fit by Providence

The oldest, most intuitively appealing, and still most widely held explanation for the adapted complexity shown by living organisms is that of a knowledgeable designer who expressly created the remarkably fit forms and behaviors we observe for the very purposes they serve. Thus we find Aristotle (384-322 b.c.) asking how it is that "the front teeth [of humans] come up with an edge, suited to dividing the food, and the back ones flat and

good for grinding it," and that "the swallow makes her nest and the spider his web, and that plants make leaves for the sake of the fruit and strike down (and not up) with their roots in order to get their nourishment."[4] Aristotle's answer is that nature created all these things for a purpose, and so they consequently reflect nature's goals and knowledge. This philosophy, which attributes the adapted complexity of living entities to some higher source of purpose and knowledge, became a major component of Judeo-Christian thought that eventually replaced the notion of a purposeful Mother Nature with that of an all-knowing, all-powerful, and personal God.

It is within this tradition of Christian thinking that we find William Paley, an English archdeacon, theologian, and philosopher who lived from 1743 to 1805. In his *Natural Theology,* first published in 1802, Paley used the adapted complexity found in the design of plants and animals as powerful arguments for the existence of God. His thesis is quite simple and, on first hearing, quite appealing. Paley asks us to consider our reaction to finding a watch lying on the ground and being asked to explain its origin. On opening the watch's case, we find an elaborate and complex mechanism consisting of finely interlocking wheels, cogs, and springs. We also notice that when wound, the watch's mechanism functions for a particular purpose, that is, to mark the passage of time accurately. Clearly, it would not occur to us that the watch had always lain at that spot on the ground, or that it had somehow been constructed and deposited there by the blind and random forces of nature in the way that we might explain the presence of a nearby stone. It is absolutely clear to Paley that "the watch must have had a maker: that there must have existed, at some time, and at some place or another, an artificer or artificers who formed it for the purpose which we find it actually to answer: who comprehended its construction, and designed its use."[5]

Paley then goes on to provide numerous examples from plants, insects, and animals that show even more impressive achievements of adapted complexity than that of the watch. These include bones and their joints, muscles, circulatory systems, internal organs, sense organs, and instinctive behaviors. To see that Paley's idea of adapted complexity is consistent with the concept of fit introduced in the previous chapter, we need only to look at the headings listed under chapter 17 in the table of contents of a later edition of his book. There we find "wings of birds--fins of fish--air and water; ear to the air; organs of speech--voice and respiration to air; eye to light; size of animals to external things; of the inhabitants of the earth and sea to their elements; sleep to night." For all of these puzzles of fit there can be, for Paley, only one possible explanation--a grand designer in the form of an all-knowing and benevolent God who fashioned every remarkable contrivance of the living world for the very purpose for which it is seen to be fit.

The argument from design, as Paley's reasoning is now known, has probably been used in some form or another in every human society that ever developed to the point of being able to marvel at the living world of nature and ponder its origin. All human societies, even those without advanced technology, are able to build shelters and fashion clothing for protection against the elements, and produce hunting and farming tools to obtain food. No society, however, not even the most technologically advanced, has developed the technology and tools for creating even the simplest living organism out of nonliving matter. It therefore seems only reasonable to conclude that the existence of life, in all its diversity, must be the creation of an intelligence and power that far surpasses that of humankind. This type of explanation is attractive in that it can reduce many mysteries (the existence of millions of different living plants and animals) to just one (their creation by a supernatural power). If a major purpose of religion is to make sense out of the world, it is hardly surprising that most if not all religions explain the existence of the earth's flora and fauna as being provided by a supernatural being. This can be referred to as a *providential* explanation for the fit of living things to their environments.[6]

The argument from design to divine providence, however, loses its appeal when examined more closely. If God

is responsible for the origin of the adapted complexity of all living organisms, what (or who), may we ask, is responsible for the origin of God? A typical answer is that God has no origin, that He always existed and will continue to exist for all eternity. This, however, is tantamount to an admission that *an explanation for the existence of a complex being is not necessary*. If this is indeed the case, the argument from design effectively contradicts itself, for all it does is pass the buck of the origin of adapted complexity back to a being who must be even more complex than any of his creations but for whom no explanation is needed![7] If a being as knowledgeable as God (who, by all accounts far surpasses the complexity of a watch) requires no explanation, then why does the watch? And why do the earth's living creatures, including our own species? We can only conclude, therefore, that this oldest, most intuitively appealing, and probably still most widely held explanation is seriously flawed. That is not to say, however, that we can confidently discount the idea that living organisms are the result of special creation by a supernatural being. Indeed, it could be argued that an explanation *does* exist for a creative deity, but that we are simply unable to grasp it. Nonetheless, when examined critically, the argument from design should fail to convince us of the existence of God in the way that it so compellingly convinced Paley and other natural theologians of his and our time.

Fit by Instruction

Jean-Baptiste Lamarck lived in France from 1744 to 1829, a period of intense interest in natural history in Europe. Lamarck, who first gained fame as a botanist for his practical guide to French plant life, went on to develop a new science to account for the origin, structure, and interrelationships of all living organisms. He called his new science *biologie*.[8]

Lamarck's biological theory had two central tenets. First, although early in his career Lamarck believed that all species had originally come into existence in much the same form as he saw them during his lifetime, he eventually came to accept the mutability of species, that is, that over the course of long periods of time, organisms could change enough to evolve into new species. Second, he saw the complexity of organisms not as the direct work of God, but rather as a natural outcome of the "power of life" and the interaction of organisms with their environment. We can therefore appreciate that Lamarck's theory of evolution was primarily a *constructive* or *creative* one, in contrast with the purely providential perspectives of Aristotle and Paley.[9]

How did Lamarck propose to explain the increasing complexity of organisms and the correlation of their form and behavior to their environments without recourse to God?[10] He invoked two processes. First, he observed that organisms seemed to change in response to their environment. For example, the giraffe, finding little edible ground vegetation, would, on straining upward to find its sustenance from the trees, stretch and thereby permanently elongate its neck and legs:

> In regard to habits, it is interesting to observe a product of them in the peculiar form and the height of the giraffe. . . . This animal, the largest of the mammals, is known to live in the interior of Africa in places where the earth is nearly always arid and without pasturage, obliging it to browse on the leaves of trees and to continually strive to reach up to them. This habit, maintained for a long time by all the members of the race, has resulted in the forelegs becoming longer than the hind legs and the neck being so lengthened that the giraffe, without standing on its hindlegs, with its head raised reaches a height of six meters.[11]

Conversely, a lizard finding it advantageous to remain in a cave completely devoid of light, would eventually lose the use of its eyes. In other words, organs that were used a great deal would be stimulated to continue to

develop, whereas those used seldom or not at all would slowly atrophy and perhaps ultimately disappear. This was Lamarck's principle of "use and disuse" by which "the development of the organs and their power of action are always related to the use of these organs."[12]

Second, Lamarck believed that the "characters" acquired by an organism through use and disuse were inherited by its offspring:

> Everything which has been acquired, outlined or changed in the organization of the individuals in the course of their life, is preserved through the reproduction, and is transmitted to the new individuals which spring from those who have undergone these changes.[13]

This principle came to be known as the inheritance of acquired characters, and it is for this theory that Lamarck is still remembered today.

Lamarck was so convinced that changes acquired during an organism's lifetime were passed on to its offspring that he wrote that the "law of nature by which new individuals receive all that has been acquired in organization during the lifetime of their parents is so true, so striking, so much attested by facts, that there is no observer who has been unable to convince himself of its reality."[14] Indeed, the theory was well accepted in Britain and Europe throughout most of the nineteenth century. Yet few such apparent "facts" have caused more grief in biology.

Although Darwin convincingly argued in *The Origin of Species,* published in 1859, that there was more to evolution than the inheritance of acquired characteristics, it was not until the 1880s that the transmission of acquired characteristics from parents to offspring was seriously challenged. German embryologist August Weismann (1834-1914) made an important distinction between cells of an organism that pass genetic information to the offspring (germ cells) and all the other cells that have no direct role in reproduction (somatic cells). According to Weismann, it was simply not possible for changes to the somatic cells (for example, those in the giraffe's neck) to be transmitted to the germ cells so that offspring could inherit the acquired characteristics of its parents. He set out to demonstrate his point by amputating the tails of several generations of mice and showing that successive generations failed to grow shorter tails.

In contrast, Austrian biologist Paul Kammerer appeared to have obtained considerable success in producing what was thought to be clear evidence of the inheritance of acquired characteristics. However, in 1926 it was announced that Kammerer's last remaining specimen of Lamarckian inheritance, the so-called nuptial pads of the midwife toad, showed no evidence of the claimed evolutionary change and had instead been doctored using injections of India ink. Six weeks later on an Austrian mountain path Kammerer put a bullet through his head. Unfortunately, this personal tragedy did nothing to dissuade Russian biologist Trofim Denisovich Lysenko from his doomed attempt to increase the productivity of Soviet agriculture based on Lamarckian principles. Stalin's receptivity to and imposition of Lysenko's Lamarckian ideas were to cripple the development of Soviet biology and genetics until the 1960s.[15]

Weismann's separation of germ from somatic cells remains today in biology an almost universally accepted barrier to Lamarckian inheritance of acquired characteristics.[16] Lamarck's principle of use and disuse also encounters serious difficulties. Let us take the blacksmith's arm as an example.[17] We know that the blacksmith is required to do much of his work with a heavy hammer, and we therefore expect this activity to make him strong and muscular, at least in the arm he uses to swing his hammer. The same expectation leads countless fitness-conscious individuals to subject themselves to various forms of discomfort in gyms and health clubs in an

attempt to firm up muscles that would otherwise be flab. This would seem to be a clear example of the acquisition of a characteristic from interacting with the environment. But we must stop and ask ourselves why it is that the increased use of muscles makes them bigger and stronger. Indeed, from our observations of nonliving objects we should expect just the opposite. Our shoes do not grow thicker soles the more we walk in them, nor do they become thin by the disuse of being left unworn in the closet for long periods of time. On the contrary, their soles wear thin from extended use and maintain their original condition only if not used. Automobile engines do not develop more horsepower with increased use, or atrophy and shrink away when left to sit in a garage or museum for extended periods of time. Why then should the blacksmith's arm not also be worn away by its heavy work load? How can the environment instruct the arm's muscles to grow in size, strength, and endurance in response to the work they do? And what is it that tells the retired blacksmith's arm to give up its hard-earned strength? In an attempt to provide an explanation for such adaptive changes, Lamarck made reference to a providential-sounding "plan of nature" and the "power of life" by which organisms could somehow bring about necessary adaptive changes by their own efforts.[18]

Lamarck's theory fails not once but twice for its reliance on environmental instruction. First, according to the principle of use and disuse, the environment must in some way transmit to the organism instructions to make the required adaptive changes. The cold must somehow instruct the beaver to grow thicker fur. The stretching of the giraffe's neck must instruct it to grow longer (and also stronger to support its increased size). And the heavy workload of the blacksmith's arm must instruct its muscles to gain in strength and endurance. Second, since only a single living cell is passed from parent to offspring, the changed body of the parent must somehow transmit instructions to the germ cell (sperm or egg) for these changes to be passed on. Yet biological science has been unable to discover any mechanism that would make either mode of instructive transmission possible.[19]

So today Lamarck's theory of the inheritance of acquired characteristics is rejected by virtually all biologists. It did, however, enjoy wide popularity throughout most of the nineteenth century, and this despite the total lack of any clear experimental support. It even seems likely that it would have retained its popularity much longer if a competing, noninstructionist explanation for the adapted complexity of life forms had not been proposed in the second half of the nineteenth century.

Fit by Selection

Any student preparing for the bachelor of arts degree examination at Cambridge University in 1831 was expected to be thoroughly familiar with the arguments for the existence of God provided by Paley. One such individual who was particularly impressed with the bishop's examples of fit was a divinity student and naturalist named Charles Robert Darwin (1809-1882).

Although Darwin remained impressed until the end of his days by the puzzles of fit shown by nature's living things, he eventually came to reject Paley's providential explanation for their origin. And although he was never able totally to reject Lamarck's theory of the inheritance of acquired characteristics (nor did he understand why such an instructionist theory was genetically problematic), he found it incomplete. Consequently, he developed an alternative theory for the evolution and growth of adapted complexity that did not rely on Lamarckian instruction. Darwin's theory, published in 1859 as *On the Origin of Species by Means of Natural Selection*, was the major scientific achievement of the nineteenth century.

Darwin discovered an explanation for the emergence of adapted complexity in nature that required neither a supernatural provider nor an instructive environment. He proposed a thoroughly natural theory to account for

organic fit, the basic principles of which are so easy to grasp that once they are, the discovery itself seems much less remarkable than the fact that so many great minds before him had failed to come up with it first. As Darwin's close friend and defender Thomas Huxley wrote after learning of the theory of natural selection: "How extremely stupid not to have thought of that!"[20]

The theory of evolution has three primary components. First, Darwin observed that all species showed considerable *natural variation* in the forms and behaviors of individual organisms, due primarily to the fact that offspring usually differed, if only slightly, from their parents. Second, he recognized *superfecundity*, that is, species typically produce many more offspring than can be supported by the environment. These two conditions being the case, Darwin's great insight was to realize that the individuals that by their particular variations are better suited to survival and reproduction must leave more offspring (which eventually come to dominate the population) than those that, for whatever reason, are less fit to survive and reproduce. This process Darwin referred to as *natural selection*.

The theory of natural selection seems strikingly simple when so stated, yet it was Darwin's genius to realize that such a process, operating cumulatively and given enough time, could account for the evolution of the wondrous diversity and adapted complexity of all living things, including our own species, starting with the simplest living organism as a common ancestor. For the same reason that the theory became and remains the cornerstone of biology (it relies on neither instruction nor providence), it has evoked more controversy and condemnation than any scientific theory ever proposed.

We will not discuss here the details of the theory, or give examples of evidence supporting it, since many excellent readable accounts are available.[21] However, since a selectionist account of adapted complexity as first proposed by Darwin is the major theme of this book, a few important points have to be made before proceeding.

First, although considerable controversy concerning Darwin's theory of evolution still exists among nonscientists, the basic principles continue to constitute the core of modern biology. The observation of evolution on a small scale both in nature and the laboratory, the patterns of similarity and diversity revealed by the scientific classification of organisms, and fossil records all provide strong support for natural selection.[22] And although biologists still do not agree on all the details of how evolution occurs, no serious rival theories have been proposed to challenge the process.

Second, since Darwin's theory explains evolution as a natural process that does not entail the existence of a supernatural designer, his emphasis was quite different from Paley's. Paley emphasized what he saw to be the perfect design of the earth's living things; Darwin repeatedly made a point of describing how nature's design, although complex and well adapted to its environment, is not necessarily optimal. This is because "ideal arrangement is a lousy argument for evolution, for it mimics the postulated action of an omnipotent creator. Odd arrangements and funny solutions are the proof of evolution--paths that a sensible God would never tread but that a natural process, constrained by history, follows perforce. No one understood this better than Darwin."[23] It is for this reason that Darwin provided so many examples of useless organs and inelegant, although still functional, solutions to the unending challenges of survival and reproduction.

It is crucial to realize that the variation considered by Darwin to be the fuel for natural selection and evolution was not required to be in any way intelligent or foresighted. Confessing ignorance as to the source of variations in nature, he made clear that it was not the presence of variations alone that resulted in adapted complexity, but

rather the *cumulative selection* of those relatively few variations that by blind chance gave the organism fortunate enough to possess them even the slightest advantage for survival and reproduction. Thus Darwin concluded chapter 5 of *The Origin* ("Laws of Variation") with the statement that "whatever the cause may be of each slight difference in the offspring from their parents . . . it is the steady accumulation, through natural selection, of such differences, when beneficial to the individual, that gives rise to all the more important modifications of structure, by which the innumerable beings on the face of this earth are enabled to struggle with each other, and the best adapted to survive."[24]

This "steady accumulation" of beneficial differences is an essential part of the theory. Since variations are blindly and ignorantly produced, it is overwhelmingly likely that any given variation will be detrimental to the survival and reproduction of the organism, particularly since the current standards of form and behavior for that species have obviously so far proved successful, or the species would no longer exist. But organic evolution does not abide by the maxim, "if it ain't broke, don't fix it." Through genetic mutation and the sexual reshuffling of genes, new variations are constantly being tried out. And whereas it is a rather rare event that any one of them will prove to be advantageous, given enough variations and enough time, an adaptive change will eventually occur, and to this improvement (as measured by reproductive success) more can be added later. These adaptive changes will tend to be gradual in their evolution since more drastic changes will be even less likely to result in better adaptations. This does not mean that a sudden and dramatic mutation cannot be beneficial to a species, but simply that a very large adaptive change (such as the appearance in one generation of a complex, functioning eye in a species that had been completely blind) is astronomically improbable, and therefore does not provide a reasonable explanation for the puzzles of fit achieved by evolution. The process of adaptive evolution can therefore be summarized as "cumulative blind variation and selection."[25]

Neither is natural selection guided by purpose or planning. Many of Darwin's readers misconstrued just such a purposeful, foresighted, and providential view, imagining nature to be guided by a supernatural intelligence in the production and selection of variations most useful to the organism. It was for this reason that Darwin later adopted Herbert Spencer's term "survival of the fittest," since as Alfred Russel Wallace noted in a letter written to Darwin in 1866, survival of the fittest "is a plain expression of fact; Natural Selection is a metaphorical expression of it, and to a certain degree indirect and incorrect, since, even personifying Nature, she does not so much select special variations as exterminate the most unfavorable ones."[26] It may in some ways be more appealing and certainly kinder to think of nature as selecting out and preserving the most useful variants. However, selection is in fact achieved by a process of elimination, a process that may be kept in mind more easily by thinking of it as Darwin's hammer.[27]

It should not be overlooked, however, that despite the immediate and continuing success of Darwin's theory, his view of evolution suffered from a number of serious defects. Ignorant (as was the rest of the world) of the genetic basis of inheritance as revealed by the work of Austrian monk and pea gardener Gregor Mendel (1822-1884), Darwin had no explanation for how heredity operated or how heritable variation was produced. In addition, he wrote, "I think that there can be little doubt that use in our domestic animals strengthens and enlarges certain parts, and disuse diminishes them; and that such modifications are inherited."[28] Thus like Lamarck, he believed in the inheritance of acquired characteristics. The realization that natural selection alone was the mechanism underlying all biological evolution had to wait until Weismann's work in the 1880s, and it was not until after the tragic Kammerer affair in 1926 that the theory of the inheritance of acquired characteristics became almost universally rejected in biological circles.

Nonetheless, Darwin did make a convincing argument that increases in adapted complexity can arise naturally

without instruction, without prior design, and without the miraculous intervention of a supernatural creator or guide. Where Paley's ultimate watchmaker was an all-knowing and benevolent God, Darwin's watchmaker was totally blind. Where Lamarck had seen heritable adaptations as the direct instructive effects of environment on organism, Darwin saw them as the results of the selection of purposeless and accidentally advantageous variations. Darwin dared to see design without a designer and fit without instruction, and the world has yet to appreciate fully the implications of his vision.

Much has happened in biology since Darwin's time. Many more species have been discovered and catalogued, and many others have disappeared forever. Much more is known of the lifestyles of organisms ranging from protozoa to gorillas. Great strides have been made in unlocking the secrets of the molecular foundations of life responsible for the processes of metabolism, reproduction, and heredity. The language of the genetic code has been deciphered. Yet despite these developments, Darwin's theory of natural selection remains as the central pillar of modern biology.

This is not to say that the theory has remained unchanged since 1859. Indeed, many biologists today are more likely to refer to "neo-Darwinism" or the "synthetic theory of evolution" than to "Darwinism" or "Darwinian theory." But despite these newer terms, which reflect updatings based on recent advances in evolutionary theory, population genetics, and molecular biology, the fundamental features of Darwinian theory remain essentially unchanged. An exception is the almost universal rejection today of the inheritance of acquired characteristics, a belief that Darwin himself was never able to reject completely. Darwin's theory has been challenged, but as yet it has no serious rivals. Not "neutralism,"[29] "mutationism,"[30] or "molecular drive"[31] can account for the adaptive evolution of organisms.[32] (Other challenges to natural selection will be considered in chapter 16.) Furthermore, since current evolutionary theory rejects all forms of Lamarckian instruction and considers natural selection to be the sole mechanism for adaptive evolutionary change, neo-Darwinian theory can be considered in this respect to be more Darwinian than Darwin was himself.

The theory of evolution by natural selection remains central to the field of modern biology, but it has not met with similar success among the general population, at least not in the United States. In a poll conducted by the Gallup Organization in 1991, 47% of Americans expressed a belief that "God created man pretty much in his present form at one time within the last 10,000 years," and only 9% agreed that "man has developed over millions of years from less advanced forms of life. God had no part in this process."[33] Perhaps even more troubling, a survey of 387 United States high school biology teachers conducted in 1987 found that about one-third of them held beliefs incompatible with Darwinian evolution, such as that "Adam and Eve were the first human beings and were created by God" and that "the Bible's account of creation should be taught in public schools as an explanation of origins."[34]

It is hard not to come to the conclusion that, for the majority of Americans, the argument from design, whether explicitly considered or not, plays a major role in the widespread rejection of Darwinian evolution. We see a world full of fit plants and animals, but very little of the blind and therefore overwhelmingly unfit variation that the theory says must be generated for natural selection to work. It therefore seems reasonable that the design we see was planned in advance. But the folly of such a view is made clear in a simple thought experiment described by philosopher Daniel Dennett:

> You obtain a mailing list of serious gamblers, divide it in half, and send one half the prediction that team A will win the championship next week, and the other half the prediction that team A will lose. A week later, half your mailing list has received a true prediction from you--free of charge. Discard

> the other half of the mailing list; divide the remainder in half again, and send them a second brace of complementary predictions; this cuts down your pool of suckers, but now they have two "proofs" of your clairvoyance. After a few more "successes," you announce that the free trial period is over; for your next prediction they will have to pay.[35]

The same sort of phenomenon occurs in biological evolution: since we only see those organisms which survive, we are like one of Dennett's "suckers." Because a sucker does not know about all the wrong predictions which are sent out, he thinks the con man knows in advance which team will win. Similarly, we think that evolution is purposeful, but it is not--nature is only guessing. Only when he looks at the larger picture can a sucker see that he is being conned; only when we look at the larger picture can we see how random variation is producing organisms which fit.[36]

Of course, it must be admitted that no argument can ever be produced that will offer definite proof against a supernatural designer who is responsible for planning and implementing biological adapted complexity. If such an entity were indeed able to create all the earth's living organisms, it could also no doubt be successful in hiding its presence from us, if that were also part of its plans. Indeed, such an omnipotent being could have fabricated the fossil evidence for evolution as a test of spiritual faith, making the believers of natural selection the real (and damned) suckers. But admitting these possibilities does nothing to weaken the argument that Darwin's theory is immeasurably more plausible than Paley's conclusion, for the simple fact that "Darwin's theory does not require positing things for which we have no evidence. The argument from design involves a being of unimaginable powers, while the theory of natural selection involves forces and mechanisms that we observe today and that are easily explained."[37] In short, natural selection provides a nonmiraculous explanation of puzzles of fit.

We should now be better able to appreciate the power and appeal of Darwin's account of adaptive biological evolution. It alone provides a nonprovidential and noninstructionist account of the emergence of adapted complexity. Indeed, its power and appeal are such that Oxford evolutionary zoologist Richard Dawkins proposed "universal Darwinism." He believes that if life were ever discovered elsewhere in the universe, it too would almost certainly be the product of a long series of gradual increases in adapted complexity brought about by cumulative variation and natural selection.[38] This, he argues, is because natural selection turns out to be the only known theory that, *in principle,* is able to offer a natural explanation for the many puzzles of fit we observe in living things. It might be difficult to find a better test of the intelligence of any advanced extraterrestrial beings we might someday encounter than to inquire as to whether they have yet discovered the cumulative process of blind variation and selection that is responsible for their own existence.

[1]Paley (1813, p. 539).

[2]Lamarck (1809; translated by Burkhardt, 1977, p. 166).

[3]Darwin (1859, p. 109).

[4]Aristotle (1929, pp. 173, 175).

[5]Paley (1813, p. 3).

[6]The Latin verb from which the English *providence* derives can be translated as "to foresee," so that divine providence both provides and foresees, the latter being important to provide what will be useful at some future time.

[7] The French encyclopedist Denis Diderot (1713-1784) presented much the same criticisms against the argument from design in his imaginary death-bed dialogue involving the blind English mathematician Nicholas Sanderson and a Reverend Holmes. Diderot creates these words for Sanderson:

> And even if the physical mechanism of animals is as perfect as you claim . . . what has that to do with a sovereignly intelligent being? If it is a matter of astonishment for you, then that may possibly be because you are in the habit of treating everything that is beyond your comprehension as a miracle.
>
> If nature presents us with a knot that is difficult to untie, then let us leave it as it is; let us not insist on cutting it there and then and on employing for the task the hand of a being who thereupon becomes a knot more difficult to untie than the first. Ask an Indian why the globe remains suspended in the air and he will reply that it is borne on the back of an elephant. And on what does the elephant rest? On a tortoise. And the tortoise, who supports that? (reprinted in Bajema, 1983, pp. 50-51). Dawkins made essentially the same argument (1986, p. 147).

[8]Burkhardt (1977, p. 22).

[9]Although Lamarck did not see God directly involved in the creation of current life forms, he referred to God as "the supreme author of all things" (quoted in Burk-hardt, 1977, p. 185).

[10]It should be mentioned that Lamarck was not primarily interested in accounting for the phenomenon of adaptation. Rather, he attempted to account for what he saw as the increasing complexity of organisms over evolutionary time. Nonetheless, he and many others did use his theory to explain the fit between organisms and their environments, as shown in his account of the giraffe's long neck quoted earlier (see Burkhardt, 1979, pp. 174-175).

[11]Lamarck (1809; translated by Burkhardt, 1977, pp. 173-174).

[12]Lamarck (1835; quoted in Løvtrup, 1987, p. 52).

[13]Lamarck (1835; quoted in Løvtrup, 1987, p. 53).

[14]Lamarck (1815-1822; quoted in Burkhardt, 1977, p. 166).

[15]See Medvedev (1969) and Joravsky (1970) for interesting accounts of the life and times of Lysenko.

[16]Indeed, the separation of germ and somatic cells is referred to as the central dogma in molecular biology. In slightly more technical terms, the central dogma states that although the DNA of genes directs the synthesis of proteins and thus has an important influence on the form of an organism and its constituent parts, the reverse is not true--proteins cannot instruct the DNA coded in the genes. Therefore, no acquired changes in an organism's structure can cause changes in the genes of germ cells that can be passed on to offspring and result in structures like those acquired by the parent.

[17]See Ridley (1985, p. 32).

[18]See Burkhardt (1977, p. 145).

[19]A third problem with Lamarckian inheritance pointed out by Gregory Bateson (1979, pp. 151-153) is that it would ultimately make organisms less adaptable to changes in the environment.

[20]Quoted in L. Huxley (1900, p. 170).

[21]See, for example, Dawkins (1986) and Ridley (1985). To these should be added recent research documenting evolution occurring in the wild, the most extensive of which is the work of Peter and Rosemary Grant on Darwin's finches in the Galá-pagos Islands (see Weiner, 1994, for a delightful account of the Grants' work).

[22]Ridley (1985).

[23]Gould (1980, pp. 20-21).

[24]Darwin (1859, p. 170).

[25]See Dawkins (1986, chapter 3) for an explanation of the cumulative nature of biological evolution and how this differs from the one-step selection processes found in the inanimate world.

[26]Wallace (reprinted in F. Darwin & Seward, 1903, p. 268).

[27]I first heard the phrase "Darwin's hammer" used by William T. Powers in a criticism of certain aspects of Darwinian evolution.

[28]Darwin (1859/1966, p. 134).

[29]Kimura (1982).

[30]Ho & Saunders (1984).

[31]Dover (1982).

[32]See Dawkins (1986, chapter 11) for an excellent discussion of how these challenges to natural selection as explanations of adaptive evolutionary change fall far short of their goal.

[33]Sheler (1991, p. 59).

[34]Eve & Dunn (1989).

[35]Dennett (1984, p. 92, footnote).

[36]Stein & Lipton (1989, p. 36).

[37]Stein & Lipton (1989, p. 36).

[38]Dawkins (1983).