THE BLIND WATCHMAKER

Why the evidence of evolution reveals a universe without design

Richard Dawkins

With a new introduction

W·W·NORTON & COMPANY
New York *London*

Chapter 1

Explaining the very improbable

We animals are the most complicated things in the known universe. The universe that we know, of course, is a tiny fragment of the actual universe. There may be yet more complicated objects than us on other planets, and some of them may already know about us. But this doesn't alter the point that I want to make. Complicated things, everywhere, deserve a very special kind of explanation. We want to know how they came into existence and why they are so complicated. The explanation, as I shall argue, is likely to be broadly the same for complicated things everywhere in the universe; the same for us, for chimpanzees, worms, oak trees and monsters from outer space. On the other hand, it will not be the same for what I shall call 'simple' things, such as rocks, clouds, rivers, galaxies and quarks. These are the stuff of physics. Chimps and dogs and bats and cockroaches and people and worms and dandelions and bacteria and galactic aliens are the stuff of biology.

The difference is one of complexity of design. Biology is the study of complicated things that give the appearance of having been designed for a purpose. Physics is the study of simple things that do not tempt us to invoke design. At first sight, man-made artefacts like computers and cars will seem to provide exceptions. They are complicated and obviously designed for a purpose, yet they are not alive, and they are made of metal and plastic rather than of flesh and blood. In this book they will be firmly treated as biological objects.

The reader's reaction to this may be to ask, 'Yes, but are they *really* biological objects?' Words are our servants, not our masters. For different purposes we find it convenient to use words in different senses. Most cookery books class lobsters as fish. Zoologists can become quite apoplectic about this, pointing out that lobsters could with greater justice call humans fish, since fish are far closer kin to humans than they are to lobsters. And, talking of justice and lobsters, I understand that a court of law recently had to decide whether lobsters were insects or 'animals' (it bore upon whether people should be allowed to boil them alive). Zoologically speaking, lobsters are certainly not insects. They are animals, but then so are insects and so are we. There is little point in getting worked up about the way different people use words (although in my nonprofessional life I am quite prepared to get worked up about people who boil lobsters alive). Cooks and lawyers need to use words in their own special ways, and so do I in this book. Never mind whether cars and computers are 'really' biological objects. The point is that if anything of that degree of complexity were found on a planet, we should have no hesitation in concluding that life existed, or had once existed, on that planet. Machines are the direct products of living objects; they derive their complexity and design from living objects, and they are diagnostic of the existence of life on a planet. The same goes for fossils, skeletons and dead bodies.

I said that physics is the study of simple things, and this, too, may seem strange at first. Physics appears to be a complicated subject, because the ideas of physics are difficult for us to understand. Our brains were designed to understand hunting and gathering, mating and child-rearing: a world of medium-sized objects moving in three dimensions at moderate speeds. We are ill-equipped to comprehend the very small and the very large; things whose duration is measured in picoseconds or gigayears; particles that don't have position; forces and fields that we cannot see or touch, which we know of only because they affect things that we can see or touch. We think that physics is complicated because it is hard for us to understand, and because physics books are full of difficult mathematics. But the objects that physicists study are still basically simple objects. They are clouds of gas or tiny particles, or lumps of uniform matter like crystals, with almost endlessly repeated atomic patterns. They do not, at least by biological standards, have intricate working parts. Even large physical objects like stars consist of a rather limited array of parts, more or less haphazardly arranged. The behaviour of physical, nonbiological objects is so simple that it is feasible to use existing mathematical language to describe it, which is why physics books are full of mathematics.

Physics *books* may be complicated, but physics books, like cars and computers, are the product of biological objects – human brains. The objects and phenomena that a physics book describes are simpler than a single cell in the body of its author. And the author consists of trillions of those cells, many of them different from each other, organized with intricate architecture and precision-engineering into a working machine capable of writing a book (my trillions are American, like all my units: one American trillion is a million millions; an American billion is a thousand millions). Our brains are no better equipped to handle extremes of complexity than extremes of size and the other difficult extremes of physics. Nobody has yet invented the mathematics for describing the total structure and behaviour of such an object as a physicist, or even of one of his cells. What we can do is understand some of the general principles of how living things work, and why they exist at all.

This was where we came in. We wanted to know why we, and all other complicated things, exist. And we can now answer that question in general terms, even without being able to comprehend the details of the complexity itself. To take an analogy, most of us don't understand in detail how an airliner works. Probably its builders don't comprehend it fully either: engine specialists don't in detail understand wings, and wing specialists understand engines only vaguely. Wing specialists don't even understand wings with full mathematical precision: they can predict how a wing will behave in turbulent conditions, only by examining a model in a wind tunnel or a computer simulation – the sort of thing a biologist might do to understand an animal. But however incompletely we understand how an airliner works, we all understand by what general process it came into existence. It was designed by humans on drawing boards. Then other humans made the bits from the drawings, then lots more humans (with the aid of other machines designed by humans) screwed, rivetted, welded or glued the bits together, each in its right place. The process by which an airliner came into existence is not fundamentally mysterious to us, because humans built it. The systematic putting together of parts to a purposeful design is something we know and understand, for we have experienced it at first hand, even if only with our childhood Meccano or Erector set.

What about our own bodies? Each one of us is a machine, like an airliner only much more complicated. Were we designed on a drawing board too, and were our parts assembled by a skilled engineer? The answer is no. It is a surprising answer, and we have known and understood it for only a century or so. When Charles Darwin first explained the matter, many people either wouldn't or couldn't grasp it. I myself flatly refused to believe Darwin's theory when I first heard about it as a child. Almost everybody throughout history, up to the second half of the nineteenth century, has firmly believed in the opposite – the

Conscious Designer theory. Many people still do, perhaps because the true, Darwinian explanation of our own existence is still, remarkably, not a routine part of the curriculum of a general education. It is certainly very widely misunderstood.

The watchmaker of my title is borrowed from a famous treatise by the eighteenth-century theologian William Paley. His *Natural Theology – or Evidences of the Existence and Attributes of the Deity Collected from the Appearances of Nature*, published in 1802, is the best-known exposition of the 'Argument from Design', always the most influential of the arguments for the existence of a God. It is a book that I greatly admire, for in his own time its author succeeded in doing what I am struggling to do now. He had a point to make, he passionately believed in it, and he spared no effort to ram it home clearly. He had a proper reverence for the complexity of the living world, and he saw that it demands a very special kind of explanation. The only thing he got wrong – admittedly quite a big thing! – was the explanation itself. He gave the traditional religious answer to the riddle, but he articulated it more clearly and convincingly than anybody had before. The true explanation is utterly different, and it had to wait for one of the most revolutionary thinkers of all time, Charles Darwin.

Paley begins *Natural Theology* with a famous passage:

> 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 anything 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 anything I knew, the watch might have always been there.

Paley here appreciates the difference between natural physical objects like stones, and designed and manufactured objects like watches. He goes on to expound the precision with which the cogs and springs of a watch are fashioned, and the intricacy with which they are put together. If we found an object such as a watch upon a heath, even if we didn't know how it had come into existence, its own precision and intricacy of design would force us to conclude

> that the watch must have had a maker: that there must have existed, at some time, and at some place or other, 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.

Nobody could reasonably dissent from this conclusion, Paley insists, yet that is just what the atheist, in effect, does when he contemplates the works of nature, for:

> every indication of contrivance, every manifestation of design, which existed in the watch, exists in the works of nature; with the difference, on the side of nature, of being greater or more, and that in a degree which exceeds all computation.

Paley drives his point home with beautiful and reverent descriptions of the dissected machinery of life, beginning with the human eye, a favourite example which Darwin was later to use and which will reappear throughout this book. Paley compares the eye with a designed instrument such as a telescope, and concludes that 'there is precisely the same proof that the eye was made for vision, as there is that the telescope was made for assisting it'. The eye must have had a designer, just as the telescope had.

Paley's argument is made with passionate sincerity and is informed by the best biological scholarship of his day, but it is wrong, gloriously and utterly wrong. The analogy between telescope and eye, between watch and living organism, is false. All appearances to the contrary, the only watchmaker in nature is the blind forces of physics, albeit deployed in a very special way. A true watchmaker has foresight: he designs his cogs and springs, and plans their interconnections, with a future purpose in his mind's eye. Natural selection, the blind, unconscious, automatic process which Darwin discovered, and which we now know is the explanation for the existence and apparently purposeful form of all life, has no purpose in mind. It has no mind and no mind's eye. It does not plan for the future. It has no vision, no foresight, no sight at all. If it can be said to play the role of watchmaker in nature, it is the *blind* watchmaker.

I shall explain all this, and much else besides. But one thing I shall not do is belittle the wonder of the living 'watches' that so inspired Paley. On the contrary, I shall try to illustrate my feeling that here Paley could have gone even further. When it comes to feeling awe over living 'watches' I yield to nobody. I feel more in common with the Reverend William Paley than I do with the distinguished modern philosopher, a well-known atheist, with whom I once discussed the matter at dinner. I said that I could not imagine being an atheist at any time before 1859, when Darwin's *Origin of Species* was published. 'What about Hume?', replied the philosopher. 'How did Hume explain the organized complexity of the living world?', I asked. 'He didn't', said the philosopher. 'Why does it need any special explanation?'

Paley knew that it needed a special explanation; Darwin knew it, and I suspect that in his heart of hearts my philosopher companion knew it too. In any case it will be my business to show it here. As for David Hume himself, it is sometimes said that that great Scottish philosopher disposed of the Argument from Design a century before Darwin. But what Hume did was criticize the logic of using apparent design in nature as *positive* evidence for the existence of a God. He did not offer any *alternative* explanation for apparent design, but left the question open. An atheist before Darwin could have said, following Hume: 'I have no explanation for complex biological design. All I know is that God isn't a good explanation, so we must wait and hope that somebody comes up with a better one.' I can't help feeling that such a position, though logically sound, would have left one feeling pretty unsatisfied, and that although atheism might have been *logically* tenable before Darwin, Darwin made it possible to be an intellectually fulfilled atheist. I like to think that Hume would agree, but some of his writings suggest that he underestimated the complexity and beauty of biological design. The boy naturalist Charles Darwin could have shown him a thing or two about that, but Hume had been dead 40 years when Darwin enrolled in Hume's university of Edinburgh.

I have talked glibly of complexity, and of apparent design, as though it were obvious what these words mean. In a sense it is obvious – most people have an intuitive idea of what complexity means. But these notions, complexity and design, are so pivotal to this book that I must try to capture a little more precisely, in words, our feeling that there is something special about complex, and apparently designed things.

So, what is a complex thing? How should we recognize it? In what sense is it true to say that a watch or an airliner or an earwig or a person is complex, but the moon is simple? The first point that might occur to us, as a necessary attribute of a complex thing, is that it has a heterogeneous structure. A pink milk pudding or blancmange is simple in the sense that, if we slice it in two, the two portions will have the same internal constitution: a blancmange is homogeneous. A car is heterogeneous: unlike a blancmange, almost any portion of the car is different from other portions. Two times half a car does not make a car. This will often amount to saying that a complex object, as opposed to a simple one, has many parts, these parts being of more than one kind.

Such heterogeneity, or 'many-partedness', may be a necessary condition, but it is not sufficient. Plenty of objects are many-parted and heterogeneous in internal structure, without being complex in the sense in which I want to use the term. Mont Blanc, for instance, consists of many different kinds of rock, all jumbled together in such a way that, if you sliced the mountain anywhere, the two portions would differ from each other in their internal constitution. Mont Blanc has a heterogeneity of structure not possessed by a blancmange, but it is still not complex in the sense in which a biologist uses the term.

Let us try another tack in our quest for a definition of complexity, and make use of the mathematical idea of probability. Suppose we try out the following definition: a complex thing is something whose constituent parts are arranged in a way that is unlikely to have arisen by chance alone. To borrow an analogy from an eminent astronomer, if you take the parts of an airliner and jumble them up at random, the likelihood that you would happen to assemble a working Boeing is vanishingly small. There are billions of possible ways of putting together the bits of an airliner, and only one, or very few, of them would actually be an airliner. There are even more ways of putting together the scrambled parts of a human.

This approach to a definition of complexity is promising, but something more is still needed. There are billions of ways of throwing together the bits of Mont Blanc, it might be said, and only one of them is Mont Blanc. So what is it that makes the airliner and the human complicated, if Mont Blanc is simple? Any old jumbled collection of parts is unique and, *with hindsight*, is as improbable as any other. The scrap-heap at an aircraft breaker's yard is unique. No two scrap-heaps are the same. If you start throwing fragments of aeroplanes into heaps, the odds of your happening to hit upon exactly the same arrangement of junk twice are just about as low as the odds of your throwing together a working airliner. So, why don't we say that a rubbish dump, or Mont Blanc, or the moon, is just as complex as an aeroplane or a dog, because in all these cases the arrangement of atoms is 'improbable'?

The combination lock on my bicycle has 4,096 different positions. Every one of these is equally 'improbable' in the sense that, if you spin the wheels at random, every one of the 4,096 positions is equally unlikely to turn up. I can spin the wheels at random, look at whatever number is displayed and exclaim with hindsight: 'How amazing. The odds against that number appearing are 4,096:1. A minor miracle!' That is equivalent to regarding the particular arrangement of rocks in a mountain, or of bits of metal in a scrap-heap, as 'complex'. But one of those 4,096 wheel positions really is interestingly unique: the combination 1207 is the only one that opens the lock. The uniqueness of 1207 has nothing to do with hindsight: it is specified in advance by the manufacturer. If you spun the wheels at random and happened to hit 1207 first time, you would be able to steal the bike, and it would seem a minor miracle. If you struck lucky on one of those multi-dialled combination locks on bank safes, it would seem a very major miracle, for the odds against it are many millions to one, and you would be able to steal a fortune.

Now, hitting upon the lucky number that opens the bank's safe is the equivalent, in our analogy, of hurling scrap metal around at random and happening to assemble a Boeing 747. Of all the millions of unique and, with hindsight equally improbable, positions of the combination lock, only one opens the lock. Similarly, of all the millions of unique and, with hindsight equally improbable, arrangements of a heap of junk, only one (or very few) will fly. The uniqueness of the arrangement that flies, or that opens the safe, is nothing to do with hindsight. It is specified in advance. The lock-manufacturer fixed the combination, and he has told the bank manager. The ability to fly is a property of an airliner that we specify in advance. If we see a plane in the air we can be sure that it was not assembled by randomly throwing scrap metal together, because we know that the odds against a random conglomeration's being able to fly are too great.

Now, if you consider all possible ways in which the rocks of Mont Blanc could have been thrown together, it is true that only one of them would make Mont Blanc as we know it. But Mont Blanc as we know it is defined with hindsight. Any one of a very large number of ways of throwing rocks together would be labelled a mountain, and might have been named Mont Blanc. There is nothing special about the particular Mont Blanc that we know, nothing specified in advance, nothing equivalent to the plane taking off, or equivalent to the safe door swinging open and the money tumbling out.

What is the equivalent of the safe door swinging open, or the plane flying, in the case of a living body? Well, sometimes it is almost literally the same. Swallows fly. As we have seen, it isn't easy to throw together a flying machine. If you took all the cells of a swallow and put them together at random, the chance that the resulting object would fly is not, for everyday purposes, different from zero. Not all living things fly, but they do other things that are just as improbable, and just as specifiable in advance. Whales don't fly, but they do swim, and swim about as efficiently as swallows fly. The chance that a random conglomeration of whale cells would swim, let alone swim as fast and efficiently as a whale actually does swim, is negligible.

At this point, some hawk-eyed philosopher (hawks have very acute eyes – you couldn't make a hawk's eye by throwing lenses and light-sensitive cells together at random) will start mumbling something about a circular argument. Swallows fly but they don't swim; and whales swim but they don't fly. It is with hindsight that we decide whether to judge the success of our random conglomeration as a swimmer or as a flyer. Suppose we agree to judge its success as an Xer, and leave open exactly what X is until we have tried throwing cells together. The random lump of cells might turn out to be an efficient burrower like a mole or an efficient climber like a monkey. It might be very good at wind-surfing, or at clutching oily rags, or at walking in ever decreasing circles until it vanished. The list could go on and on. Or could it?

If the list really *could* go on and on, my hypothetical philosopher might have a point. If, no matter how randomly you threw matter around, the resulting conglomeration could often be said, with hindsight, to be good for *something*, then it would be true to say that I cheated over the swallow and the whale. But biologists can be much more specific than that about what would constitute being 'good for something'. The minimum requirement for us to recognize an object as an animal or plant is that it should succeed in making a living *of some sort* (more precisely that it, or at least some members of its kind, should live long enough to reproduce). It is true that there are quite a number of ways of making a living – flying, swimming, swinging through the trees, and so on. But, *however many ways there may be of being alive, it is certain that there are vastly more ways of being dead*, or rather not alive. You may throw cells together at random, over and over again for a billion years, and not once will you get a conglomeration that flies or swims or burrows or runs, or does *anything*, even badly, that could remotely be construed as working to keep itself alive.

This has been quite a long, drawn-out argument, and it is time to remind ourselves of how we got into it in the first place. We were looking for a precise way to express what we mean when we refer to something as complicated. We were trying to put a finger on what it is that humans and moles and earthworms and airliners and watches have in common with each other, but not with blancmange, or Mont Blanc, or the moon. The answer we have arrived at is that complicated things have some quality, specifiable in advance, that is highly unlikely to have been acquired by random chance alone. In the case of living things, the quality that is specified in advance is, in some sense, 'proficiency'; either proficiency in a particular ability such as flying, as an aero-engineer might admire it; or proficiency in something more general, such as the ability to stave off death, or the ability to propagate genes in reproduction.

Staving off death is a thing that you have to work at. Left to itself – and that is what it is when it dies – the body tends to revert to a state of equilibrium with its environment. If you measure some quantity such as the temperature, the acidity, the water content or the electrical potential in a living body, you will typically find that it is markedly different from the corresponding measure in the surroundings. Our bodies, for instance, are usually hotter than our surroundings, and in cold climates they have to work hard to maintain the differential. When we die the work stops, the temperature differential starts to disappear, and we end up the same temperature as our surroundings. Not all animals work so hard to avoid coming into equilibrium with their surrounding temperature, but all animals do *some* comparable work. For instance, in a dry country, animals and plants work to maintain the fluid content of their cells, work against a natural tendency for water to flow from them into the dry outside world. If they fail they die. More generally, if living things didn't work actively to prevent it, they would eventually merge into their surroundings, and cease to exist as autonomous beings. That is what happens when they die.

With the exception of artificial machines, which we have already agreed to count as honorary living things, nonliving things don't work in this sense. They accept the forces that tend to bring them into equilibrium with their surroundings. Mont Blanc, to be sure, has existed for a long time, and probably will exist for a while yet, but it does not work to stay in existence. When rock comes to rest under the influence of gravity it just stays there. No work has to be done to keep it there. Mont Blanc exists, and it will go on existing until it wears away or an earthquake knocks it over. It doesn't take steps to repair wear and tear, or to right itself when it is knocked over, the way a living body does. It just obeys the ordinary laws of physics.

Is this to deny that living things obey the laws of physics? Certainly not. There is no reason to think that the laws of physics are violated in living matter. There is nothing supernatural, no 'life force' to rival the fundamental forces of physics. It is just that if you try to use the laws of physics, in a naïve way, to understand the behaviour of a *whole* living body, you will find that you don't get very far. The body is a complex thing with many constituent parts, and to understand its behaviour you must apply the laws of physics to its parts, not to the whole. The behaviour of the body as a whole will then emerge as a consequence of interactions of the parts.

Take the laws of motion, for instance. If you throw a dead bird into the air it will describe a graceful parabola, exactly as physics books say it should, then come to rest on the ground and stay there. It behaves as a solid body of a particular mass and wind resistance ought to behave.

But if you throw a live bird in the air it will not describe a parabola and come to rest on the ground. It will fly away, and may not touch land this side of the county boundary. The reason is that it has muscles which work to resist gravity and other physical forces bearing upon the whole body. The laws of physics are being obeyed within every cell of the muscles. The result is that the muscles move the wings in such a way that the bird stays aloft. The bird is not violating the law of gravity. It is constantly being pulled downwards by gravity, but its wings are performing active work – obeying laws of physics within its muscles – to keep it aloft in spite of the force of gravity. We shall think that it defies a physical law if we are naïve enough to treat it simply as a structureless lump of matter with a certain mass and wind resistance. It is only when we remember that it has many internal parts, all obeying laws of physics at their own level, that we understand the behaviour of the whole body. This is not, of course, a peculiarity of living things. It applies to all man-made machines, and potentially applies to any complex, many-parted object.

This brings me to the final topic that I want to discuss in this rather philosophical chapter, the problem of what we mean by explanation. We have seen what we are going to mean by a complex thing. But what kind of explanation will satisfy us if we wonder how a complicated machine, or living body, works? The answer is the one that we arrived at in the previous paragraph. If we wish to understand how a machine or living body works, we look to its component parts and ask how they interact with each other. If there is a complex thing that we do not yet understand, we can come to understand it in terms of simpler parts that we do already understand.

If I ask an engineer how a steam engine works, I have a pretty fair idea of the general kind of answer that would satisfy me. Like Julian Huxley I should definitely not be impressed if the engineer said it was propelled by *'force locomotif'*. And if he started boring on about the whole being greater than the sum of its parts, I would interrupt him: 'Never mind about that, tell me how it *works*.' What I would want to hear is something about how the parts of an engine interact with each other to produce the behaviour of the whole engine. I would initially be prepared to accept an explanation in terms of quite large subcomponents, whose own internal structure and behaviour might be quite complicated and, as yet, unexplained. The units of an initially satisfying explanation could have names like fire-box, boiler, cylinder, piston, steam governor. The engineer would assert, without explanation initially, what each of these units does. I would accept this for the moment, without asking how each unit does its own particular thing. *Given* that the units each do their particular thing, I can then understand how they interact to make the whole engine move.

Of course, I am then at liberty to ask how each part works. Having previously accepted the *fact* that the steam governor regulates the flow of steam, and having used this fact in my understanding of the behaviour of the whole engine, I now turn my curiosity on the steam governor itself. I now want to understand how it achieves its own behaviour, in terms of its own internal parts. There is a hierarchy of subcomponents within components. We explain the behaviour of a component at any given level, in terms of interactions between subcomponents whose own internal organization, for the moment, is taken for granted. We peel our way down the hierarchy, until we reach units so simple that, for everyday purposes, we no longer feel the need to ask questions about them. Rightly or wrongly for instance, most of us are happy about the properties of rigid rods of iron, and we are prepared to use them as units of explanation of more complex machines that contain them.

Physicists, of course, do not take iron rods for granted. They ask why they are rigid, and they continue the hierarchical peeling for several more layers yet, down to fundamental particles and quarks. But life is too short for most of us to follow them. For any given level of complex organization, satisfying explanations may normally be attained if we peel the hierarchy down one or two layers from our starting layer, but not more. The behaviour of a motor car is explained in terms of cylinders, carburettors and sparking plugs. It is true that each one of these components rests atop a pyramid of explanations at lower levels. But if you asked me how a motor car worked you would think me somewhat pompous if I answered in terms of Newton's laws and the laws of thermodynamics, and downright obscurantist if I answered in terms of fundamental particles. It is doubtless true that at bottom the behaviour of a motor car is to be explained in terms of interactions between fundamental particles. But it is much more useful to explain it in terms of interactions between pistons, cylinders and sparking plugs.

The behaviour of a computer can be explained in terms of interactions between semiconductor electronic gates, and the behaviour of these, in turn, is explained by physicists at yet lower levels. But, for most purposes, you would in practice be wasting your time if you tried to understand the behaviour of the whole computer at either of those levels. There are too many electronic gates and too many interconnections between them. A satisfying explanation has to be in terms of a manageably small number of interactions. This is why, if we want to understand the workings of computers, we prefer a preliminary explanation in terms of about half a dozen major subcomponents – memory, processing mill, backing store, control unit, input–output handler, etc. Having grasped the interactions between the half-dozen major components, we then may wish to ask questions about the internal organization of these major components. Only specialist engineers are likely to go down to the level of AND gates and NOR gates, and only physicists will go down further, to the level of how electrons behave in a semiconducting medium.

For those that like '-ism' sorts of names, the aptest name for my approach to understanding how things work is probably 'hierarchical reductionism'. If you read trendy intellectual magazines, you may have noticed that 'reductionism' is one of those things, like sin, that is only mentioned by people who are against it. To call oneself a reductionist will sound, in some circles, a bit like admitting to eating babies. But, just as nobody actually eats babies, so nobody is really a reductionist in any sense worth being against. The nonexistent reductionist – the sort that everybody is against, but who exists only in their imaginations – tries to explain complicated things *directly* in terms of the *smallest* parts, even, in some extreme versions of the myth, as the *sum* of the parts! The hierarchical reductionist, on the other hand, explains a complex entity at any particular level in the hierarchy of organization, in terms of entities only one level down the hierarchy; entities which, themselves, are likely to be complex enough to need further reducing to their own component parts; and so on. It goes without saying – though the mythical, baby-eating reductionist is reputed to deny this – that the kinds of explanations which are suitable at high levels in the hierarchy are quite different from the kinds of explanations which are suitable at lower levels. This was the point of explaining cars in terms of carburettors rather than quarks. But the hierarchical reductionist believes that carburettors are explained in terms of smaller units . . ., which are explained in terms of smaller units . . . , which are ultimately explained in terms of the smallest of fundamental particles. Reductionism, in this sense, is just another name for an honest desire to understand how things work.

We began this section by asking what kind of explanation for complicated things would satisfy us. We have just considered the question from the point of view of mechanism: how does it work? We concluded that the behaviour of a complicated thing should be explained in terms of interactions between its component parts, considered as successive layers of an orderly hierarchy. But another kind of question is how the complicated thing came into existence in the first place. This is the question that this whole book is particularly concerned with, so I won't say much more about it here. I shall just mention that the same general principle applies as for understanding mechanism. A complicated thing is one whose existence we do not feel inclined to take for granted, because it is too 'improbable'. It could not have come into existence in a single act of chance. We shall explain its coming into existence as a consequence of gradual, cumulative, step-by-step transformations from simpler things, from primordial objects sufficiently simple to have come into being by chance. Just as 'big-step reductionism' cannot work as an explanation of mechanism, and must be replaced by a series of small step-by-step peelings down through the hierarchy, so we can't explain a complex thing as *originating* in a single step. We must again resort to a series of small steps, this time arranged sequentially in time.

In his beautifully written book, *The Creation*, the Oxford physical chemist Peter Atkins begins:

> I shall take your mind on a journey. It is a journey of comprehension, taking us to the edge of space, time, and understanding. On it I shall argue that there is nothing that cannot be understood, that there is nothing that cannot be explained, and that everything is extraordinarily simple . . . A great deal of the universe does not need any explanation. Elephants, for instance. Once molecules have learnt to compete and to create other molecules in their own image, elephants, and things resembling elephants, will in due course be found roaming through the countryside.

Atkins assumes the evolution of complex things – the subject matter of this book – to be inevitable once the appropriate physical conditions have been set up. He asks what the minimum necessary physical conditions are, what is the minimum amount of design work that a very lazy Creator would have to do, in order to see to it that the universe and, later, elephants and other complex things, would one day come into existence. The answer, from his point of view as a physical scientist, is that the Creator could be infinitely lazy. The fundamental original units that we need to postulate, in order to understand the coming into existence of everything, either consist of literally nothing (according to some physicists), or (according to other physicists) they are units of the utmost simplicity, far too simple to need anything so grand as deliberate Creation.

Atkins says that elephants and complex things do not need any explanation. But that is because he is a physical scientist, who takes for granted the biologists' theory of evolution. He doesn't really mean that elephants don't need an explanation; rather that he is satisfied that biologists can explain elephants, provided they are allowed to take certain facts of physics for granted. His task as a physical scientist, therefore, is to justify our taking those facts for granted. This he succeeds in doing. My position is complementary. I am a biologist. I take the facts of physics, the facts of the world of simplicity, for granted. If physicists still don't agree over whether those simple facts are yet understood, that is not my problem. My task is to explain elephants, and the world of complex things, in terms of the simple things that physicists either understand, or are working on. The physicist's problem is the problem of ultimate origins and ultimate natural laws. The biologist's problem is the problem of complexity. The biologist tries to explain the workings, and the coming into existence, of complex things, in terms of simpler things. He can regard his task as done when he has arrived at entities so simple that they can safely be handed over to physicists.

I am aware that my characterization of a complex object – statistically improbable in a direction that is specified not with hindsight – may seem idiosyncratic. So, too, may seem my characterization of physics as the study of simplicity. If you prefer some other way of defining complexity, I don't care and I would be happy to go along with your definition for the sake of discussion. But what I do care about is that, whatever we choose to *call* the quality of being statistically-improbable-in-a-direction-specified-without-hindsight, it is an important quality that needs a special effort of explanation. It is the quality that characterizes biological objects as opposed to the objects of physics. The kind of explanation we come up with must not contradict the laws of physics. Indeed it will make use of the laws of physics, and nothing more than the laws of physics. But it will deploy the laws of physics in a special way that is not ordinarily discussed in physics textbooks. That special way is Darwin's way. I shall introduce its fundamental essence in Chapter 3 under the title of *cumulative selection*.

Meanwhile I want to follow Paley in emphasizing the magnitude of the problem that our explanation faces, the sheer hugeness of biological complexity and the beauty and elegance of biological design. Chapter 2 is an extended discussion of a particular example, 'radar' in bats, discovered long after Paley's time. And here, in this chapter, I have placed an illustration (Figure 1) – how Paley would have loved the electron microscope! – of an eye together with two successive 'zoomings in' on detailed portions. At the top of the figure is a section through an eye itself. This level of magnification shows the eye as an optical instrument. The resemblance to a camera is obvious. The iris diaphragm is responsible for constantly varying the aperture, the *f* stop.

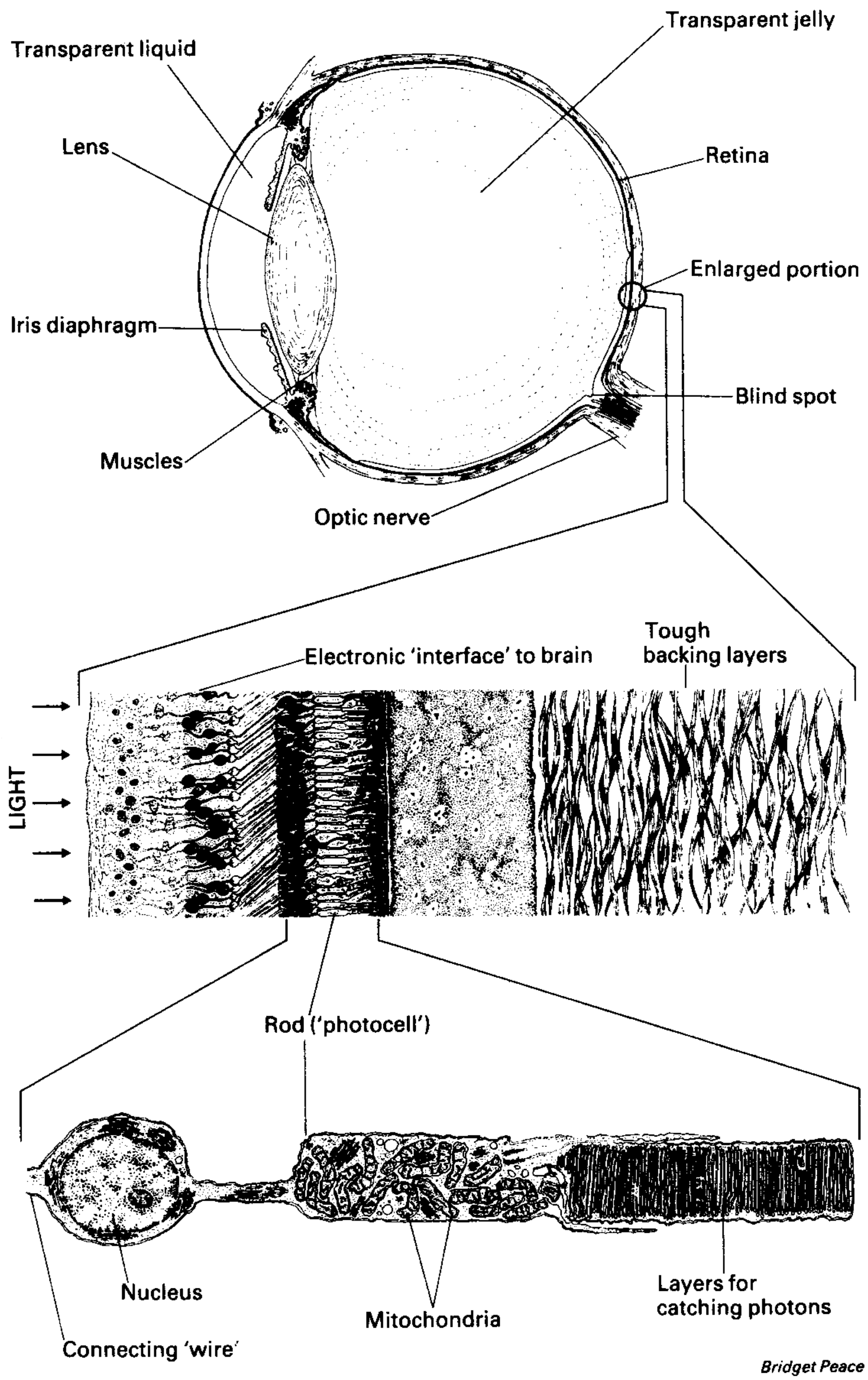
Transparent liquid
Transparent jelly
Lens
Retina
Enlarged portion
Iris diaphragm
Blind spot
Muscles
Optic nerve
Electronic 'interface' to brain
Tough
backing layers
LIGHT
Rod ('photocell')
Nucleus
Mitochondria
Layers for
catching photons
Connecting 'wire'
Bridget Peace

Figure 1

The lens, which is really only part of a compound lens system, is responsible for the variable part of the focusing. Focus is changed by squeezing the lens with muscles (or in chameleons by moving the lens forwards or backwards, as in a man-made camera). The image falls on the retina at the back, where it excites photocells.

The middle part of Figure 1 shows a small section of the retina enlarged. Light comes from the left. The light-sensitive cells ('photocells') are not the first thing the light hits, but they are buried inside and facing away from the light. This odd feature is mentioned again later. The first thing the light hits is, in fact, the layer of ganglion cells which constitute the 'electronic interface' between the photocells and the brain. Actually the ganglion cells are responsible for preprocessing the information in sophisticated ways before relaying it to the brain, and in some ways the word 'interface' doesn't do justice to this. 'Satellite computer' might be a fairer name. Wires from the ganglion cells run along the surface of the retina to the 'blind spot', where they dive through the retina to form the main trunk cable to the brain, the optic nerve. There are about three million ganglion cells in the 'electronic interface', gathering data from about 125 million photocells.

At the bottom of the figure is one enlarged photocell, a rod. As you look at the fine architecture of this cell, keep in mind the fact that all that complexity is repeated 125 million times in each retina. And comparable complexity is repeated trillions of times elsewhere in the body as a whole. The figure of 125 million photocells is about 5,000 times the number of separately resolvable points in a good-quality magazine photograph. The folded membranes on the right of the illustrated photocell are the actual light-gathering structures. Their layered form increases the photocell's efficiency in capturing photons, the fundamental particles of which light is made. If a photon is not caught by the first membrane, it may be caught by the second, and so on. As a result of this, some eyes are capable of detecting a single photon. The fastest and most sensitive film emulsions available to photographers need about 25 times as many photons in order to detect a point of light. The lozenge-shaped objects in the middle section of the cell are mostly mitochondria. Mitochondria are found not just in photocells, but in most other cells. Each one can be thought of as a chemical factory which, in the course of delivering its primary product of usable energy, processes more than 700 different chemical substances, in long, interweaving assembly-lines strung out along the surface of its intricately folded internal membranes. The round globule at the left of Figure 1 is the nucleus. Again, this is characteristic of all animal and plant cells. Each nucleus, as we shall see in Chapter 5, contains a digitally coded database larger, in information content, than all 30 volumes of the *Encyclopaedia Britannica* put together. And this figure is for *each* cell, not all the cells of a body put together.

The rod at the base of the picture is one single cell. The total number of cells in the body (of a human) is about 10 trillion. When you eat a steak, you are shredding the equivalent of more than 100 billion copies of the *Encyclopaedia Britannica*.