1. Is NOTHING SACRED?

CHAPTER ONE

Tell Me Why

We used to sing a lot when I was a child, around the campfire at summer camp, at school and Sunday school, or gathered around the piano at home. One of my favorite songs was "Tell Me Why." (For those whose personal memories don't already embrace this little treasure, the music is provided in the appendix. The simple melody and easy harmony line are surprisingly beautiful.)

Tell me why the stars do shine,
Tell me why the ivy twines,
Tell me why die sky's so blue.
Then I will tell you just why I love you.

Because God made the stars to shine, Because
God made the ivy twine, Because God made
the sky so blue. Because God made you, that's
why I love you.

This straightforward, sentimental declaration still brings a lump to my throat—so sweet, so innocent, so reassuring a vision of life!

And then along comes Darwin and spoils the picnic. Or does he? That is the topic of this book. From the moment of the publication of *Origin of Species* in 1859, Charles Darwin's fundamental idea has inspired intense reactions ranging from ferocious condemnation to ecstatic allegiance, sometimes tantamount to religious zeal. Darwin's theory has been abused and misrepresented by friend and foe alike. It has been misappropriated to lend scientific respectability to appalling political and social doctrines. It has been pilloried in caricature by opponents, some of whom would have it

compete in our children's schools with "creation science," a pathetic hodge-podge of pious pseudo-science.[1]

Almost no one is indifferent to Darwin, and no one should be. The Darwinian theory is a scientific theory, and a great one, but that is not all it is. The creationists who oppose it so bitterly are right about one thing: Darwin's dangerous idea cuts much deeper into the fabric of our most fundamental beliefs than many of its sophisticated apologists have yet admitted, even to themselves.

The sweet, simple vision of the song, taken literally, is one that most of us have outgrown, however fondly we may recall it. The kindly God who lovingly fashioned each and every one of us (all creatures great and small) and sprinkled the sky with shining stars for our delight—*that* God is, like Santa Claus, a myth of childhood, not anything a sane, undeluded adult could literally believe in. *That* God must either be turned into a symbol for something less concrete or abandoned altogether.

Not all scientists and philosophers are atheists, and many who are believers declare that their idea of God can live in peaceful coexistence with, or even find support from, the Darwinian framework of ideas. Theirs is not an anthropomorphic Handicrafter God, but still a God worthy of worship in their eyes, capable of giving consolation and meaning to their lives. Others ground their highest concerns in entirely secular philosophies, views of the meaning of life that stave off despair without the aid of any concept of a Supreme Being—other than the Universe itself. Something *is* sacred to these thinkers, but they do not call it God; they call it, perhaps, Life, or Love, or Goodness, or Intelligence, or Beauty, or Humanity. What both groups share, in spite of the differences in their deepest creeds, is a conviction that life does have meaning, that goodness matters.

But can *any* version of this attitude of wonder and purpose be sustained in the face of Darwinism? From the outset, there have been those who thought they saw Darwin letting the worst possible cat out of the bag: nihilism. They thought that if Darwin was right, the implication would be that nothing could be sacred. To put it bluntly, nothing could have any point. Is this just an overreaction? What exactly are the implications of Darwin's idea—and, in any case, has it been scientifically proven or is it still "just a theory"?

Perhaps, you may think, we could make a useful division: there are the parts of Darwin's idea that really are established beyond any reasonable doubt, and then there are the speculative extensions of the scientifically

1. I will not devote any space in this book to cataloguing the deep flaws in creationism, or supporting my peremptory condemnation of it. I take that job to have been admirably done by Kitcher 1982, Futuyma 1983, Gilkey 1985, and others.

irresistible parts. Then—if we were lucky—perhaps the rock-solid scientific facts would have no stunning implications about religion, or human nature, or the meaning of life, while the parts of Darwin's idea that get people all upset could be put into quarantine as highly controversial extensions of, or mere interpretations of, the scientifically irresistible parts. That would be reassuring.

But alas, that is just about backwards. There are vigorous controversies swirling around in evolutionary theory, but those who feel threatened by Darwinism should not take heart from this fact. Most—if not quite all—of the controversies concern issues that are "just science"; no matter which side wins, the outcome will not undo the basic Darwinian idea. That idea, which is about as secure as any in science, really does have far-reaching implications for our vision of what the meaning of life is or could be.

In 1543, Copernicus proposed that the Earth was not the center of the universe but in fact revolved around the Sun. It took over a century for the idea to sink in, a gradual and actually rather painless transformation. (The religious reformer Philipp Melanchthon, a collaborator of Martin Luther, opined that "some Christian prince" should suppress this madman, but aside from a few such salvos, the world was not particularly shaken by Copernicus himself.) The Copernican Revolution did eventually have its own "shot heard round the world": Galileo's *Dialogue Concerning the Two Chief World Systems,* but it was not published until 1632, when the issue was no longer controversial among scientists. Galileo's projectile provoked an infamous response by the Roman Catholic Church, setting up a shock wave whose reverberations are only now dying out. But in spite of the drama of that epic confrontation, the idea that our planet is not the center of creation has sat rather lightly in people's minds. Every schoolchild today accepts this as the matter of fact it is, without tears or terror.

In due course, the Darwinian Revolution will come to occupy a similarly secure and untroubled place in the minds—and hearts—of every educated person on the globe, but today, more than a century after Darwin's death, we still have not come to terms with its mind-boggling implications. Unlike the Copernican Revolution, which did not engage widespread public attention until the scientific details had been largely sorted out, the Darwinian Revolution has had anxious lay spectators and cheerleaders taking sides from the outset, tugging at the sleeves of the participants and encouraging grandstanding. The scientists themselves have been moved by the same hopes and fears, so it is not surprising that die relatively narrow conflicts among theorists have often been not just blown up out of proportion by their adherents, but seriously distorted in the process. Everybody has seen, dimly, that a lot is at stake.

Moreover, although Darwin's own articulation of his theory was monumental, and its powers were immediately recognized by many of the scien-

tists and other thinkers of his day, there really were large gaps in his theory that have only recently begun to be properly filled in. The biggest gap looks almost comical in retrospect. In all his brilliant musings, Darwin never hit upon the central concept, without which the theory of evolution is hopeless: the concept of a *gene*. Darwin had no proper *unit* of heredity, and so his account of the process of natural selection was plagued with entirely reasonable doubts about whether it would work. Darwin supposed that offspring would always exhibit a sort of blend or average of their parents' features. Wouldn't such "blending inheritance" always simply average out all differences, turning everything into uniform gray? How could diversity survive such relentless averaging? Darwin recognized the seriousness of this challenge, and neither he nor his many ardent supporters succeeded in responding with a description of a convincing and well-documented mechanism of heredity that could combine traits of parents while maintaining an underlying and unchanged identity. The idea they needed was right at hand, uncovered ("formulated" would be too strong) by the monk Gregor Mendel and published in a relatively obscure Austrian journal in 1865, but, in the best-savored irony in the history of science, it lay there unnoticed until its importance was appreciated (at first dimly) around 1900. Its triumphant establishment at the heart of the "Modern Synthesis" (in effect, the synthesis of Mendel and Darwin) was eventually made secure in the 1940s, thanks to the work of Theodosius Dobzhansky, Julian Huxley, Ernst Mayr, and others. It has taken another half-century to iron out most of the wrinkles of that new fabric.

The fundamental core of contemporary Darwinism, the theory of DNA-based reproduction and evolution, is now beyond dispute among scientists. It demonstrates its power every day, contributing crucially to the explanation of planet-sized facts of geology and meteorology, through middle-sized facts of ecology and agronomy, down to the latest microscopic facts of genetic engineering. It unifies all of biology and the history of our planet into a single grand story. Like Gulliver tied down in Lilliput, it is unbudge-able, not because of some one or two huge chains of argument that might— hope against hope—have weak links in them, but because it is securely tied by hundreds of thousands of threads of evidence anchoring it to virtually every other area of human knowledge. New discoveries may conceivably lead to dramatic, even "revolutionary" *shifts* in the Darwinian theory, but the hope that it will be "refuted" by some shattering breakthrough is about as reasonable as the hope that we will return to a geocentric vision and discard Copernicus.

Still, the theory is embroiled in remarkably hot-tempered controversy, and one of the reasons for this incandescence is that these debates about scientific matters are usually distorted by fears that the "wrong" answer would have intolerable moral implications. So great are these fears that they

are carefully left unarticulated, displaced from attention by several layers of distracting rebuttal and counter-rebuttal. The disputants are forever changing the subject slightly, conveniently keeping the bogeys in the shadows. It is this misdirection that is mainly responsible for postponing the day when we can all live as comfortably with our new biological perspective as we do with the astronomical perspective Copernicus gave us.

Whenever Darwinism is the topic, the temperature rises, because more is at stake than just the empirical facts about how life on Earth evolved, or the correct logic of the theory that accounts for those facts. One of the precious things that is at stake is a vision of what it means to ask, and answer, the question "Why?" Darwin's new perspective turns several traditional assumptions upside down, undermining our standard ideas about what ought to count as satisfying answers to this ancient and inescapable question. Here science and philosophy get completely intertwined. Scientists sometimes deceive themselves into thinking that philosophical ideas are only, at best, decorations or parasitic commentaries on the hard, objective triumphs of science, and that they themselves are immune to the confusions that philosophers devote their lives to dissolving. But there is no such thing as philosophy-free science; there is only science whose philosophical baggage is taken on board without examination.

The Darwinian Revolution is both a scientific and a philosophical revolution, and neither revolution could have occurred without the other. As we shall see, it was the philosophical prejudices of the scientists, more than their lack of scientific evidence, that prevented them from seeing how the theory could actually work, but those philosophical prejudices that had to be overthrown were too deeply entrenched to be dislodged by mere philosophical brilliance. It took an irresistible parade of hard-won scientific facts to force thinkers to take seriously the weird new outlook that Darwin proposed. Those who are still ill-acquainted with that beautiful procession can be forgiven their continued allegiance to the pre-Darwinian ideas. And the battle is not yet over; even among the scientists, there are pockets of resistance.

Let me lay my cards on the table. If I were to give an award for the single best idea anyone has ever had, I'd give it to Darwin, ahead of Newton and Einstein and everyone else. In a single stroke, the idea of evolution by natural selection unifies the realm of life, meaning, and purpose with the realm of space and time, cause and effect, mechanism and physical law. But it is not just a wonderful scientific idea. It is a dangerous idea. My admiration for Darwin's magnificent idea is unbounded, but I, too, cherish many of the ideas and ideals that it *seems* to challenge, and want to protect them. For instance, I want to protect the campfire song, and what is beautiful and true in it, for my little grandson and his friends, and for their children when they grow up. There are many more magnificent ideas that are also jeopardized,

it seems, by Darwin's idea, and they, too, may need protection. The only good way to do this—the only way that has a chance in the long run—is to cut through the smokescreens and look at the idea as unflinchingly, as dispassionately, as possible.

On this occasion, we are not going to settle for "There, there, it will all come out all right." Our examination will take a certain amount of nerve. Feelings may get hurt. Writers on evolution usually steer clear of this apparent clash between science and religion. Fools rush in, Alexander Pope said, where angels fear to tread. Do you want to follow me? Don't you really want to know what survives this confrontation? What if it turns out that the sweet vision—or a better one—survives intact, strengthened and deepened by the encounter? Wouldn't it be a shame to forgo the opportunity for a strengthened, renewed creed, settling instead for a fragile, sickbed faith that you mistakenly supposed must not be disturbed?

There is no future in a sacred myth. Why not? Because of our curiosity. Because, as the song reminds us, *we want to know why*. We may have outgrown the song's answer, but we will never outgrow the question. Whatever we hold precious, we cannot protect it from our curiosity, because being who we are, one of the things we deem precious is the truth. Our love of truth is surely a central element in the meaning we find in our lives. In any case, the idea that we might preserve meaning by kidding ourselves is a more pessimistic, more nihilistic idea than I for one can stomach. If that were the best that could be done, I would conclude that nothing mattered after all.

This book, then, is for those who agree that the only meaning of life worth caring about is one that can withstand our best efforts to examine it. Others are advised to close the book now and tiptoe away.

For those who stay, here is die plan. Part I of the book locates the Darwinian Revolution in the larger scheme of things, showing how it can transform the world-view of those who know its details. This first chapter sets out die background of philosophical ideas that dominated our thought before Darwin. Chapter 2 introduces Darwin's central idea in a somewhat new guise, as the idea of evolution as an *algorithmic process,* and clears up some common misunderstandings of it. Chapter 3 shows how this idea overturns the tradition encountered in chapter 1. Chapters 4 and 5 explore some of the striking—and unsettling—perspectives that the Darwinian way of thinking opens up.

Part II examines the challenges to Darwin's idea—to neo-Darwinism or the Modern Synthesis—that have arisen within biology itself, showing that contrary to what some of its opponents have declared, Darwin's idea survives these controversies not just intact but strengthened. Part HI then shows what happens when the same thinking is extended to the species we care about most: *Homo sapiens*. Darwin himself fully recognized that this

was going to be the sticking point for many people, and he did what he could to break the news gently. More than a century later, there are still those who want to dig a moat separating us from most if not all of the dreadful implications they think they see in Darwinism. Part III shows that this is an error of both fact and strategy; not only does Darwin's dangerous idea apply to us directly and at many levels, but the proper application of Darwinian thinking to human issues—of mind, language, knowledge, and ethics, for instance—illuminates them in ways that have always eluded the traditional approaches, recasting ancient problems and pointing to dieir solution. Finally, we can assess the bargain we get when we trade in pre-Darwinian for Darwinian thinking, identifying both its uses and abuses, and showing how what really matters to us—and ought to matter to us—shines through, transformed but enhanced by its passage through the Darwinian Revolution.

2. WHAT, WHERE, WHEN, WHY—AND HOW?

Our curiosity about things takes different forms, as Aristotle noted at the dawn of human science. His pioneering effort to classify them still makes a lot of sense. He identified four basic questions we might want answered about anything, and called their answers the four *aitia,* a truly untranslatable Greek term traditionally but awkwardly translated the four "causes."

(1) We may be curious about what something is made of, its matter or *material cause*.
(2) We may be curious about the form (or structure or shape) that that matter takes, its *formal cause*.
(3) We may be curious about its beginning, how it got started, or its *efficient cause*.
(4) We may be curious about its *purpose or goal* or *end* (as in "Do the ends justify the means?"), which Aristotle called its *telos,* sometimes translated in English, awkwardly, as "final cause."

It takes some pinching and shoving to make these four Aristotelian *aitia* line up as the answers to the standard English questions "what, where, when, and why." The fit is only fitfully good. Questions beginning with "why," however, do standardly ask for Aristotle's fourth "cause," the *telos* of a thing. Why this? we ask. What is it/or? As the French say, what is its *raison d'etre,* or reason for being? For hundreds of years, these "why" questions have been recognized as problematic by philosophers and scientists, so distinct that the topic they raise deserves a name: teleology.

A *teleological* explanation is one that explains the existence or occurrence of something by citing a goal or purpose that is served by the thing. Artifacts are the most obvious cases; the goal or purpose of an artifact is the function it was designed to serve by its creator. There is no controversy about the *telos* of a hammer: it is for hammering in and pulling out nails. The *telos* of more complicated artifacts, such as camcorders or tow trucks or CT scanners, is if anything more obvious. But even in simple cases, a problem can be seen to loom in the background:

"Why are you sawing that board?"
"To make a door."
"And what is the door for?"
"To secure my house."
"And why do you want a secure house?"
"So I can sleep nights."
"And why do you want to sleep nights?" "Go run along and stop asking such silly questions."

This exchange reveals one of the troubles with teleology: where does it all stop? What *final* final cause can be cited to bring this hierarchy of reasons to a close? Aristotle had an answer: God, the Prime Mover, the *for-which* to end all *for-whiches*. The idea, which is taken up by the Christian, Jewish, and Islamic traditions, is that all *our* purposes are ultimately God's purposes. The idea is certainly natural and attractive. If we look at a pocket watch and wonder *why* it has a clear glass crystal on its face, the answer obviously harks back to the needs and desires of the users of watches, who want to tell time, by looking at the hands through the transparent, protective glass, and so forth. If it weren't for these facts about *us,* for whom the watch was created, there would be no explanation of the "why" of its crystal. If the universe was created by God, for God's purposes, then all the purposes we can find in it must ultimately be due to God's purposes. But what are God's purposes? That is something of a mystery.

One way of deflecting discomfort about that mystery is to switch the topic slightly. Instead of responding to the "why" question with a "because"-type answer (the sort of answer it seems to demand), people often substitute a "how" question for the "why" question, and attempt to answer it by telling a story about *how it came to be* that God created us and the rest of the universe, without dwelling overmuch on just why God might want to have done that. The "how" question does not get separate billing on Aristotle's list, but it was a popular question and answer long before Aristotle undertook his analysis. The answers to the biggest "how" questions are *cosmogonies,* stories about how the *cosmos,* the whole universe and all its denizens, came into existence. The book of Genesis is

a cosmogony, but there are many others. Cosmologists exploring the hypothesis of the Big Bang, and speculating about black holes and superstrings, are present-day creators of cosmogonies. Not all ancient cosmogonies follow the pattern of an artifact-maker. Some involve a "world egg" laid in "the Deep" by one mythic bird or another, and some involve seeds' being sown and tended. Human imagination has only a few resources to draw upon when faced with such a mind-boggling question. One early creation myth speaks of a "self-existent Lord" who, "with a thought, created the waters, and deposited in them a seed which became a golden egg, in which egg he himself is born as Brahma, the progenitor of the worlds" (Muir 1972, vol. IV, p. 26).

And what's the point of all this egg-laying or seed-sowing or world-building? Or, for that matter, what's the point of the Big Bang? Today's cosmologists, like many of their predecessors throughout history, tell a diverting story, but prefer to sidestep the "why" question of teleology. Does the universe exist for any reason? Do reasons play any intelligible role in explanations of the cosmos? Could something exist for a reason without its being *somebody's* reason? Or are reasons—Aristotle's type (4) causes— only appropriate in explanations of the works and deeds of people or other rational agents? If God is not a person, a rational agent, an Intelligent Artificer, what possible sense could the biggest "why" question make? And if the biggest "why" question doesn't make any sense, how could any smaller, more parochial, "why" questions make sense?

One of Darwin's most fundamental contributions is showing us a new way to make sense of "why" questions. Like it or not, Darwin's idea offers one way—a clear, cogent, astonishingly versatile way—of dissolving these old conundrums. It takes some getting used to, and is often misapplied, even by its staunchest friends. Gradually exposing and clarifying this way of thinking is a central project of the present book. Darwinian thinking must be carefully distinguished from some oversimplified and all-too-popular impostors, and this will take us into some technicalities, but it is worth it. The prize is, for the first time, a stable system of explanation that does not go round and round in circles or spiral off in an infinite regress of mysteries. Some people would much prefer the infinite regress of mysteries, apparently, but in this day and age the cost is prohibitive: you have to get yourself deceived. You can either deceive yourself or let others do the dirty work, but there is no intellectually defensible way of rebuilding the mighty barriers to comprehension that Darwin smashed.

The first step to appreciating this aspect of Darwin's contribution is to see how the world looked before he inverted it. By looking through the eyes of two of his countrymen, John Locke and David Hume, we can get a clear vision of an alternative world-view—still very much with us in many quarters—that Darwin rendered obsolete.

3. LOCKE'S "PROOF" OF THE PRIMACY OF MIND

John Locke invented common sense, and only Englishmen have had it ever since!

—BERTRAND RL'SSEU.[2]

John Locke, a contemporary of "the incomparable Mr. Newton," was one of the founding fathers of British Empiricism, and, as befits an Empiricist, he was not much given to deductive arguments of the rationalist sort, but one of his uncharacteristic forays into "proof deserves to be quoted in full, since it perfectly illustrates the blockade to imagination that was in place before the Darwinian Revolution. The argument may seem strange and stilted to modern minds, but bear with it—consider it a sign of how far we have come since then. Locke himself thought that he was just reminding people of something obvious! In this passage from his *Essay Concerning Human Understanding* (1690, IV, x, 10), Locke wanted to *prove* something that he thought all people knew in their hearts in any case: that "in the beginning" there was Mind. He began by asking himself what, if anything, was eternal:

> If, then, there must be something eternal, let us see what sort of Being it must be. And to that it is very obvious to Reason, that it must necessarily be a cogitative Being. For it is as impossible to conceive that ever bare incogitative Matter should produce a thinking intelligent Being, as that nothing should of itself produce Matter....

Locke begins his proof by alluding to one of philosophy's most ancient and oft-used maxims, *Ex nihilo nihil fit*. nothing can come from nothing. Since this is to be a deductive argument, he must set his sights high: it is not just unlikely or implausible or hard to fathom but *impossible to conceive* that "bare incogitative Matter should produce a thinking intelligent Being." The argument proceeds by a series of mounting steps-.

2. Gilbert Ryle recounted this typical bit of Russellian hyperbole to me. In spite of Ryle's own distinguished career as Waynflete Professor of Philosophy at Oxford, he and Russell had seldom met, he told me, in large measure because Russell steered clear of academic philosophy after the Second World War. Once, however, Ryle found himself sharing a compartment with Russell on a tedious train journey, and, trying desperately to make conversation with his world-famous fellow traveler, Ryle asked him why he thought Locke, who was neither as original nor as good a writer as Berkeley, Hume, or Reid, had been so much more influential than they in the English-speaking philosophical world. This had been his reply, and the beginning of the only good conversation, Ryle said, that he ever had with Russell.

> Let us suppose any parcel of Matter eternal, great or small, we shall find it, in itself, able to produce nothing___ Matter then, by its own strength, cannot produce in itself so much as Motion: the Motion it has, must also be from Eternity, or else be produced, and added to Matter by some other Being more powerful than Matter __ But let us suppose Motion eternal too: yet Matter, incogitative Matter and Motion, whatever changes it might produce of Figure and Bulk, could never produce Thought: Knowledge will still be as far beyond the power of Motion and Matter to produce, as Matter is beyond the power of nothing or nonentity to produce. And I appeal to everyone's own thoughts, whether he cannot as easily conceive Matter produced by nothing, as Thought produced by pure Matter, when before there was no such thing as Thought, or an intelligent Being existing. ...

It is interesting to note that Locke decides he may safely "appeal to everyone's own thoughts" to secure this "conclusion." He was sure that *his* "common sense" was truly *common* sense. Don't we see how obvious it is that whereas matter and motion could produce changes of "Figure and Bulk," they could *never* produce "Thought"? Wouldn't this rule out the prospect of robots—or at least robots that would claim to have genuine Thoughts among the motions in their material heads? Certainly in Locke's day—which was also Descartes's day—the very idea of Artificial Intelligence was so close to unthinkable that Locke could confidently expect unanimous endorsement of this appeal to his audience, an appeal that would risk hoots of derision today.[3] And as we shall see, the field of Artificial Intelligence is a quite direct descendant of Darwin's idea. Its birth, which was all but prophesied by Darwin himself, was attended by one of the first truly impressive demonstrations of the formal power of natural selection (Art Samuel's legendary checkers-playing program, which will be described in some detail later). And both evolution and AI inspire the same loathing in many people who should know better, as we shall see in later chapters. But back to Locke's conclusion:

> So if we will suppose nothing first, or eternal: Matter can never begin to be: If we suppose bare Matter, without Motion, eternal: Motion can never begin to be: If we suppose only Matter and Motion first, or eternal: Thought can never begin to be. For it is impossible to conceive that Matter either with or without Motion could have originally in and from itself Sense,

3. Descartes's inability to think of Thought as Matter in Motion is discussed at length in my book *Consciousness Explained* (1991a). John Haugeland's aptly titled book, *Artificial Intelligence: The Very Idea* (1985), is a fine introduction to the philosophical paths that make this idea thinkable after all.

> Perception, and Knowledge, as is evident from hence, that then Sense, Perception, and Knowledge must be a property eternally inseparable from Matter and every particle of it.

So, if Locke is right, Mind must come first—or at least tied for first. It could not come into existence at some later date, as an effect of some confluence of more modest, mindless phenomena. This purports to be an entirely secular, logical—one might almost say mathematical—vindication of a central aspect of Judeo-Christian (and also Islamic) cosmogony: in the beginning was something with Mind—"a cogitative Being," as Locke says. The traditional idea that God is a rational, thinking agent, a Designer and Builder of the world, is here given the highest stamp of scientific approval: like a mathematical theorem, its denial is supposedly impossible to conceive.

And so it seemed to many brilliant and skeptical thinkers before Darwin. Almost a hundred years after Locke, another great British Empiricist, David Hume, confronted the issue again, in one of the masterpieces of Western philosophy, his *Dialogues Concerning Natural Religion* (1779).

4. HUME'S CLOSE ENCOUNTER

Natural religion, in Hume's day, meant a religion that was supported by the natural sciences, as opposed to a "revealed" religion, which would depend on revelation—on mystical experience or some other uncheckable source of conviction. If your only grounds for your religious belief is "God told me so in a dream," your religion is not natural religion. The distinction would not have made much sense before the dawn of modern science in the seventeenth century, when science created a new, and competitive, standard of evidence for all belief. It opened up the question:

> Can you give us any *scientific* grounds for your religious beliefs?

Many religious thinkers, appreciating that the prestige of scientific thought was—other things being equal—a worthy aspiration, took up the challenge. It is hard to see why anybody would want to shun scientific confirmation of one's creed, if it were there to be had. The overwhelming favorite among purportedly scientific arguments for religious conclusions, then and now, was one version or another of the Argument from Design: among the effects we can objectively observe in the world, there are many that are not (cannot be, for various reasons) mere accidents; they must have been designed to be as they are, and there cannot be design without a Designer; therefore, a Designer, God, must exist (or have existed), as the source of all these wonderful effects.

Such an argument can be seen as an attempt at an alternate route to Locke's conclusion, a route that will take us through somewhat more empirical detail instead of relying so bluntly and directly on what is deemed inconceivable. The actual features of the observed designs may be analyzed, for instance, to secure the grounds for our appreciation of the wisdom of the Designer, and our conviction that mere chance could not be responsible for these marvels.

In Hume's *Dialogues,* three fictional characters pursue the debate with consummate wit and vigor. Cleanthes defends the Argument from Design, and gives it one of its most eloquent expressions.[4] Here is his opening statement of it:

> Look round the world. Contemplate the whole and every part of it: You will find it to be nothing but one great machine, subdivided into an infinite number of lesser machines, which again admit of subdivisions to a degree beyond what human senses and faculties can trace and explain. All these various machines, and even their most minute parts, are adjusted to each other with an accuracy which ravishes into admiration all men who have ever contemplated them. The curious adapting of means to ends, throughout all nature, resembles, exactly, though it much exceeds, the productions of human contrivance—of human design, thought, wisdom, and intelligence. Since therefore the effects resemble each other, we are led to infer, by all the rules of analogy, that the causes also resemble, and that the Author of Nature is somewhat similar to the mind of man, though possessed of much larger faculties, proportioned to the grandeur of the work which he has executed. By this argument *a posteriori,* and by this argument alone, do we prove at once the existence of a Deity and his similarity to human mind and intelligence. [Pt. II]

Philo, a skeptical challenger to Cleanthes, elaborates the argument, setting it up for demolition. Anticipating Paley's famous example, Philo notes: "Throw several pieces of steel together, without shape or form; they will never arrange themselves so as to compose a watch."[5] He goes on: "Stone, and mortar, and wood, without an architect, never erect a house. But the

4. William Paley carried the Argument from Design into much greater biological detail in his 1803 book, *Natural Theology,* adding many ingenious flourishes. Paley's influential version was the actual inspiration and target of Darwin's rebuttal, but Hume's Cleanthes catches all of the argument's logical and rhetorical force.

5. Gjertsen points out that two millennia earlier, Cicero used the same example for the same purpose: "When you see a sundial or a water-clock, you see that it tells the time by design and not by chance. How then can you imagine that the universe as a whole is devoid of purpose and intelligence, when it embraces everything, including these artifacts themselves and their artificers?" (Gjertsen 1989, p. 199).

ideas in a human mind, we see, by an unknown, inexplicable economy, arrange themselves so as to form the plan of a watch or house. Experience, therefore, proves, that there is an original principle of order in mind, not in matter" (Pt. II).

Note that the Argument from Design depends on an inductive inference: where there's smoke, there's fire; and where there's design, there's mind. But this is a dubious inference, Philo observes: human intelligence is

> no more than one of the springs and principles of the universe, as well as heat or cold, attraction or repulsion, and a hundred others, which fall under daily observation__ But can a conclusion, with any propriety, be transferred from parts to the whole?... From observing the growth of a hair, can we learn any thing concerning the generation of a man?... What peculiar privilege has this little agitation of the brain which we call thought, that we must thus make it the model of the whole universe?... Admirable conclusion! Stone, wood, brick, iron, brass have not, at this time, in this minute globe of earth, an order or arrangement without human art and contrivance: Therefore the universe could not originally attain its order and arrangement, without something similar to human art. [Pt. II.]

Besides, Philo observes, if we put mind as the first cause, with its "unknown, inexplicable economy," this only postpones the problem:

> We are still obliged to mount higher, in order to find the cause of this cause, which you had assigned as satisfactory and conclusive ___ How therefore shall we satisfy ourselves concerning the cause of that Being, whom you suppose the Author of nature, or, according to your system of anthropomorphism, the ideal world, into which you trace the material? Have we not the same reason to trace that ideal world into another ideal world, or new intelligent principle? But if we stop, and go no farther; why go so far? Why not stop at the material world? How can we satisfy ourselves without going on *in infinitum?* And after all, what satisfaction is there in that infinite progression? [Pt. IV.)

Cleanthes has no satisfactory responses to these rhetorical questions, and there is worse to come. Cleanthes insists that God's mind is *like the human*— and agrees when Philo adds "the liker the better." But, then, Philo presses on, is God's mind perfect, "free from every error, mistake, or incoherence in his undertakings" (Pt. V)? There is a rival hypothesis to rule out:

> And what surprise must we entertain, when we find him a stupid mechanic, who imitated others, and copied an art, which, through a long succession of ages, after multiplied trials, mistakes, corrections, deliberations, and controversies, had been gradually improving? Many worlds might have been botched and bungled, throughout an eternity, ere this system was struck out: Much labour lost: Many fruitless trials made: And a slow, but continued improvement carried on during infinite ages of world-making. (Pt. V.]

When Philo presents this fanciful alternative, with its breathtaking anticipations of Darwin's insight, he doesn't take it seriously except as a debating foil to Cleanthes' vision of an all-wise Artificer. Hume uses it only to make a point about what he saw as the limitations on our knowledge: "In such subjects, who can determine, where the truth; nay, who can conjecture where the probability, lies; amidst a great number of hypotheses which may be proposed, and a still greater number which may be imagined" (Pt. V). Imagination runs riot, and, exploiting that fecundity, Philo ties Cleanthes up in knots, devising weird and comical variations on Cleanthes' own hypotheses, defying Cleanthes to show why his own version should be preferred. "Why may not several Deities combine in contriving and framing a world?... And why not become a perfect anthropomorphite? Why not assert the Deity or Deities to be corporeal, and to have eyes, a nose, mouth, ears, etc.?" (Pt. V). At one point, Philo anticipates the Gaia hypothesis: the universe

> bears a great resemblance to an animal or organized body, and seems actuated with a like principle of life and motion. A continual circulation of
> matter in it produces no disorder ___The world, therefore, I infer, is an animal, and the Deity is the SOUL of the world, actuating it and actuated by it. [Pt. VI.]

Or perhaps isn't the world really more like a vegetable than an animal?

> In like manner as a tree sheds its seed into the neighboring fields, and produces other trees; so the great vegetable, the world, or this planetary system, produces within itself certain seeds, which, being scattered into the surrounding chaos, vegetate into new worlds. A comet, for instance, is the seed of a world.... [Pt. VII.]

One more wild possibility for good measure:

> The Brahmins assert, that the world arose from an infinite spider, who spun this whole complicated mass from his bowels, and annihilates afterwards the whole or any part of it, by absorbing it again, and resolving it into his own essence. Here is a species of cosmogony, which appears to us ridiculous; because a spider is a little contemptible animal, whose operation we are never likely to take for a model of the whole universe. But still here is

a new species of analogy, even in our globe. And were there a planet wholly inhabited by spiders (which is very possible), this inference would there appear as natural and irrefragable as that which in our planet ascribes the origin of all things to design and intelligence, as explained by Cleanthes. Why an orderly system may not be spun from the belly as well as from the brain, it will be difficult for him to give a satisfactory reason. [Pt. VII.]

Cleanthes resists these onslaughts gamely, but Philo shows fatal flaws in every version of the argument that Cleanthes can devise. At the very end of the *Dialogues,* however, Philo surprises us by agreeing with Cleanthes:

... die legitimate conclusion is that... if we are not contented with calling the first and supreme cause a *God* or *Deity,* but desire to vary the expression, what can we call him but *Mind* or *Thought* to which he is jusly supposed to bear a considerable resemblance? [Pt. XII.]

Philo is surely Hume's mouthpiece in the *Dialogues*. Why did Hume cave in? Out of fear of reprisal from the establishment? No. Hume knew he had shown that the Argument from Design was an irreparably flawed bridge between science and religion, and he arranged to have *his Dialogues* published after his death in 1776 precisely in order to save himself from persecution. He caved in because *he just couldn't imagine* any other explanation of the origin of the manifest design in nature. Hume could not see how the "curious adapting of means to ends, throughout all nature" could be due to chance—and if not chance, what?

What could possibly account for this high-quality design if not an intelligent God? Philo is one of the most ingenious and resourceful competitors in any philosophical debate, real or imaginary, and he makes some wonderful stabs in the dark, hunting for an alternative. In Part VIII, he dreams up some speculations that come tantalizingly close to scooping Darwin (and some more recent Darwinian elaborations) by nearly a century.

Instead of supposing matter infinite, as Epicurus did, let us suppose it finite. A finite number of particles is only susceptible of finite transpositions: And it must happen, in an eternal duration, that every possible order or position must be tried an infinite number of times __ Is there a system, an order, an economy of things, by which matter can preserve that perpetual agitation, which seems essential to it, and yet maintain a constancy in the forms, which it produces? There certainly is such an economy: For this is actually the case with the present world. The continual motion of matter, therefore, in less than infinite transpositions, must produce this economy or order; and by its very nature, that order, when once established, supports itself, for many ages, if not to eternity. But wherever matter is so poised, arranged, and adjusted as to continue in perpetual motion, and yet preserve a constancy in the forms, its situation must, of necessity, have all the same appearance of art and contrivance which we observe at present __ A defect in any of these particulars destroys the form; and the matter, of which it is composed, is again set loose, and is thrown into irregular motions and fermentations, till it unite itself to some other regular form __

Suppose ... that matter were thrown into any position, by a blind, unguided force; it is evident that this first position must in all probability be the most confused and most disorderly imaginable, without any resemblance to those works of human contrivance, which, along with a symmetry of parts, discover an adjustment of means to ends and a tendency to self-preservation __ Suppose, that the actuating force, whatever it be, still continues in matter __ Thus the universe goes on for many ages in a continued succession of chaos and disorder. But is it not possible that it may settle at last... ? May we not hope for such a position, or rather be assured of it, from the eternal revolutions of unguided matter, and may not this account for all the appearing wisdom and contrivance which is in the universe?

Hmm, it seems that something like this might work... but Hume couldn't quite take Philo's daring foray seriously. His final verdict: "A total suspense of judgment is here our only reasonable resource" (Pt. VIII). A few years before him, Denis Diderot had also written some speculations that tantalizingly foreshadowed Darwin: "I can maintain to you ... that monsters annihilated one another in succession; that all the defective combinations of matter have disappeared, and that there have only survived those in which the organization did not involve any important contradiction, and which could subsist by themselves and perpetuate themselves" (Diderot 1749). Cute ideas about evolution had been floating around for millennia, but, like most philosophical ideas, although they did seem to offer a solution of sorts to the problem at hand, they didn't promise to go any farther, to open up new investigations or generate surprising predictions that could be tested, or explain any facts they weren't expressly designed to explain. The evolution revolution had to wait until Charles Darwin saw how to weave an evolutionary hypothesis into an explanatory fabric composed of literally thousands of hard-won and often surprising facts about nature. Darwin neither invented the wonderful idea out of whole cloth all by himself, nor understood it in its entirety even when he had formulated it. But he did such a monumental job of clarifying the idea, and tying it down so it would never again float away, that he deserves the credit if anyone does. The next chapter reviews his basic accomplishment.

CHAPTER 1: *Before Darwin,* a *"Mind-first" view of the universe reigned unchallenged; an intelligent God was seen as the ultimate source of all Design, the ultimate answer to any chain of "Why?" questions. Even David*

Hume, who deftly exposed the insoluble problems with this vision, and had glimpses of the Darwinian alternative, could not see how to take it seriously.

CHAPTER 2: *Darwin, setting out to answer a relatively modest question about die origin of species, described a process he called natural selection, a mindless, purposeless, mechanical process. This turns out to be the seed of an answer to a much grander question: how does Design come into existence?*

CHAPTER TWO

An Idea Is Born

1. WHAT IS SO SPECIAL ABOUT SPECIES?

Charles Darwin did not set out to concoct an antidote to John Locke's conceptual paralysis, or to pin down the grand cosmological alternative that had barely eluded Hume. Once his great idea occurred to him, he saw that it would indeed have these truly revolutionary consequences, but at the outset he was not trying to explain the meaning of life, or even its origin. His aim was slightly more modest: he wanted to explain the origin of *species*.

In his day, naturalists had amassed mountains of tantalizing facts about living things and had succeeded in systematizing these facts along several dimensions. Two great sources of wonder emerged from this work (Mayr 1982). First, there were all the discoveries about the *adaptations* of organisms that had enthralled Hume's Cleanthes: "All these various machines, and even their most minute parts, are adjusted to each other with an accuracy which ravishes into admiration all men who have ever contemplated them" (Pt. II). Second, there was the prolific *diversity* of living things—literally millions of different kinds of plants and animals. Why were there so many?

This diversity of design of organisms was as striking, in some regards, as their excellence of design, and even more striking were the patterns discernible within that diversity. Thousands of gradations and variations between organisms could be observed, but there were also huge gaps between them. There were birds and mammals that swam like fish, but none with gills; there were dogs of many sizes and shapes, but no dogcats or dogcows or feathered dogs. The patterns called out for classification, and by Darwin's time the work of the great taxonomists (who began by adopting and correcting Aristotle's ancient classifications) had created a detailed hierarchy of two kingdoms (plants and animals), divided into phyla, which divided into classes, which divided into orders, which divided into families, which divided into genera (the plural of "genus"), which divided into species.

Species could also be subdivided, of course, into subspecies or varieties—cocker spaniels and basset hounds are different varieties of a single species-, dogs, or *Canis familiaris*.

How many different kinds of organisms were there? Since no two organisms are exactly alike—not even identical twins—there were as many different kinds of organisms as there were organisms, but it seemed obvious that the differences could be graded, sorted into minor and major, or *accidental* and *essential*. Thus Aristotle had taught, and this was one bit of philosophy that had permeated the thinking of just about everybody, from cardinals to chemists to costermongers. All things—not just living things— had two kinds of properties: essential properties, without which they wouldn't be the particular *kind* of thing they were, and accidental properties, which were free to vary within the kind. A lump of gold could change shape *ad lib* and still be gold; what made it gold were its essential properties, not its accidents. With each kind went an essence. Essences were definitive, and as such they were timeless, unchanging, and all-or-nothing. A thing couldn't be *rather* silver or *quasi-gold* or a semi'-mammal.

Aristotle had developed his theory of essences as an improvement on Plato's theory of Ideas, according to which every earthly thing is a sort of imperfect copy or reflection of an ideal exemplar or Form that existed timelessly in the Platonic realm of Ideas, reigned over by God. This Platonic heaven of abstractions was not visible, of course, but was accessible to Mind through deductive thought. What geometers thought about, and proved theorems about, for instance, were the Forms of the circle and the triangle. Since there were also Forms for the eagle and the elephant, a deductive science of nature was also worth a try. But just as no earthly circle, no matter how carefully drawn with a compass, or thrown on a potter's wheel, could actually be one of the perfect circles of Euclidean geometry, so no actual eagle could perfectly manifest the essence of eaglehood, though every eagle strove to do so. Everything that existed had a divine specification, which captured its essence. The taxonomy of living things Darwin inherited was thus itself a direct descendant, via Aristotle, of Plato's essen-tialism. In fact, the word "species" was at one point a standard translation of Plato's Greek word for Form or Idea, *eidos*.

We post-Darwinians are so used to thinking in historical terms about the development of life forms that it takes a special effort to remind ourselves that in Darwin's day species of organisms were deemed to be as timeless as the perfect triangles and circles of Euclidean geometry. Their individual members came and went, but the species itself remained unchanged and unchangeable. This was part of a philosophical heritage, but it was not an idle or ill-motivated dogma. The triumphs of modern science, from Copernicus and Kepler, Descartes and Newton, had all involved the application of precise mathematics to the material world, and this apparently requires

abstracting away from the grubby accidental properties of things to find their secret mathematical essences. It makes no difference what color or shape a thing is when it comes to the thing's obeying Newton's inverse-square law of gravitational attraction. All that matters is its mass. Similarly, alchemy had been succeeded by chemistry once chemists settled on their fundamental creed: There were a finite number of basic, *immutable* elements, such as carbon, oxygen, hydrogen, and iron. These might be mixed and united in endless combinations over time, but the fundamental building blocks were identifiable by their changeless essential properties.

The doctrine of essences looked like a powerful organizer of the world's phenomena in many areas, but was it true of every classification scheme one could devise? Were there *essential* differences between hills and mountains, snow and sleet, mansions and palaces, violins and violas? John Locke and others had developed elaborate doctrines distinguishing *real* essences from merely *nominal* essences; the latter were simply parasitic on the *names* or words we chose to use. You could set up any classification scheme you wanted; for instance, a kennel club could vote on a defining list of necessary conditions for a dog to be a genuine Ourkind Spaniel, but this would be a mere nominal essence, not a real essence. Real essences were discoverable by scientific investigation into the internal nature of things, where essence and accident could be distinguished according to principles. It was hard to say just what the *principled* principles were, but with chemistry and physics so handsomely falling into line, it seemed to stand to reason that there had to be denning marks of the real essences of living things as well.

From the perspective of this deliciously crisp and systematic vision of the hierarchy of living things, there were a considerable number of awkward and puzzling facts. These apparent exceptions were almost as troubling to naturalists as the discovery of a triangle whose angles didn't quite add up to 180 degrees would have been to a geometer. Although many of the taxonomic boundaries were sharp and apparently exceptionless, there were all manner of hard-to-classify intermediate creatures, who seemed to have portions of more than one essence. There were also the curious higher-order patterns of shared and unshared features: why should it be backbones rather than feathers that birds and fish shared, and why shouldn't *creature with eyes* or *carnivore* be as important a classifier as *warmblooded creature?* Although the broad outlines and most of die specific rulings of taxonomy were undisputed (and remain so today, of course), there were heated controversies about the problem cases. Were all these lizards members of die same species, or of several different species? Which principle of classification should "count"? In Plato's famous image, which system "carved nature at the joints"?

Before Darwin, these controversies were fundamentally ill-formed, and could not yield a stable, well-motivated answer because there was no back-

ground theory of *why* one classification scheme would count as getting the joints right—the way things *really* were. Today bookstores face the same sort of ill-formed problem: how should the following categories be cross-organized: best-sellers, science fiction, horror, garden, biography, novels, collections, sports, illustrated books? If horror is a genus of fiction, then true tales of horror present a problem. Must all novels be fiction? Then the bookseller cannot honor Truman Capote's own description of *In Cold Blood* (1965) as a nonfiction novel, but the book doesn't sit comfortably amid either the biographies or the history books. In what section of the bookstore should the book you are reading be shelved? Obviously there is no one Right Way to categorize books—nominal essences are all we will ever find in this domain. But many naturalists were convinced on general principles that there were real essences to be found among the categories of their Natural System of living things. As Darwin put it, "They believe that it reveals the plan of the Creator; but unless it be specified whether order in time or space, or what else is meant by the plan of the Creator, it seems to me that nothing is thus added to our knowledge" *(Origin,* p. 413).

Problems in science are sometimes made easier by adding complications. The development of the science of geology and the discovery of fossils of manifestly extinct species gave the taxonomists further curiosities to confound them, but these curiosities were also the very pieces of the puzzle that enabled Darwin, working alongside hundreds of other scientists, to discover the key to its solution: species were *not* eternal and immutable; they had evolved over time. Unlike carbon atoms, which, for all one knew, had been around forever in exactly the form they now exhibited, species had births in time, could change over time, and could give birth to new species in turn. This idea itself was not new; many versions of it had been seriously discussed, going back to the ancient Greeks. But there was a powerful Platonic bias against it: essences were unchanging, and a thing couldn't change its essence, and new essences couldn't be born—except of course by God's command in episodes of Special Creation. Reptiles could no more *turn into* birds than copper could turn into gold.

It isn't easy today to sympathize with this conviction, but the effort can be helped along by a fantasy: consider what your attitude would be towards a theory that purported to show how the number 7 had once been an even number, long, long ago, and had gradually acquired its oddness through an arrangement whereby it exchanged some properties with the ancestors of the number 10 (which had once been a prime number). Utter nonsense, of course. Inconceivable. Darwin knew that a parallel attitude was deeply ingrained among his contemporaries, and that he would have to labor mightily to overcome it. Indeed, he more or less conceded that the elder authorities of his day would tend to be as immutable as the species they believed

in, so in the conclusion of his book he went so far as to beseech the support of his younger readers: "Whoever is led to believe that species are mutable will do good service by conscientiously expressing his conviction; for only thus can the load of prejudice by which this subject is overwhelmed be removed" *(Origin,* p. 482).

Even today Darwin's overthrow of essentialism has not been completely assimilated. For instance, there is much discussion in philosophy these days about "natural kinds," an ancient term the philosopher W. V. O. Quine (1969) quite cautiously resurrected for limited use in distinguishing good scientific categories from bad ones. But in the writings of other philosophers, "natural kind" is often sheep's clothing for the wolf of real essence. The essentialist urge is still with us, and not always for bad reasons. Science does aspire to carve nature at its joints, and it often seems that we need essences, or something like essences, to do the job. On this one point, the two great kingdoms of philosophical thought, the Platonic and the Aristotelian, agree. But the Darwinian mutation, which at first seemed to be just a new way of thinking about kinds in biology, can spread to other phenomena and other disciplines, as we shall see. There are persistent problems both inside and outside biology that readily dissolve once we adopt the Darwinian perspective on what makes a thing the sort of thing it is, but the tradition-bound resistance to this idea persists.

2. NATURAL SELECTION—AN AWFUL STRETCHER

It is an awful stretcher to believe that a peacock's tail was thus formed; but, believing it, I believe in the same principle somewhat modified applied to man.

—CHARLES DARWIN, letter quoted in Desmond and Moore 1991, p. 553

Darwin's project in *Origin* can be divided in two: to prove *that* modern species were revised descendants of earlier species—species had evolved—and to show *how* this process of "descent with modification" had occurred. If Darwin hadn't had a vision of a mechanism, natural selection, by which this well-nigh-inconceivable historical transformation could have been accomplished, he would probably not have had the motivation to assemble all the circumstantial evidence that it had actually occurred. Today we can readily enough imagine proving Darwin's first case—the brute historic fact of descent with modification—quite independently of any consideration of Natural selection or indeed any other mechanism for bringing these brute events about, but for Darwin the idea of the mechanism was both the

hunting license he needed, and an unwavering guide to the right questions to ask.[1]

The idea of natural selection was not itself a miraculously novel creation of Darwin's but, rather, the offspring of earlier ideas that had been vigorously discussed for years and even generations (for an excellent account of this intellectual history, see R. Richards 1987). Chief among these parent ideas was an insight Darwin gained from reflection on the 1798 *Essay on the Principle of Population* by Thomas Malthus, which argued that population explosion and famine were inevitable, given the excess fertility of human beings, unless drastic measures were taken. The grim Malthusian vision of the social and political forces that could act to check human overpopulation may have strongly flavored Darwin's thinking (and undoubtedly has flavored the shallow political attacks of many an anti-Darwinian), but the idea Darwin needed from Malthus is purely logical. It has nothing at all to do with political ideology, and can be expressed in very abstract and general terms.

Suppose a world in which organisms have many offspring. Since the offspring themselves will have many offspring, the population will grow and grow ("geometrically") until inevitably, sooner or later—surprisingly soon, in fact—it must grow too large for the available resources (of food, of space, of whatever the organisms need to survive long enough to reproduce). At that point, whenever it happens, not all organisms will have offspring. Many will die childless. It was Malthus who pointed out the mathematical inevitability of such a crunch in *any* population of long-term reproducers— people, animals, plants (or, for that matter, Martian clone-machines, not that such fanciful possibilities were discussed by Malthus). Those populations that reproduce at less than the replacement rate are headed for extinction unless they reverse the trend. Populations that maintain a stable population over long periods of time will do so by settling on a rate of overproduction of offspring that is balanced by the vicissitudes encountered. This is obvious, perhaps, for houseflies and other prodigious breeders, but Darwin drove the point home with a calculation of his own: "The elephant is reckoned to be the slowest breeder of all known animals, and I have taken some pains to estimate its probable minimum rate of natural increase:... at the end of the fifth century there would be alive fifteen million elephants, descended from the first pair" (*Origin,* p. *64*).[2] Since elephants have been around for millions

1. This has often happened in science. For instance, for many years there was lots of evidence lying around in favor of the hypothesis that the continents have drifted—that Africa and South America were once adjacent and broke apart—but until the mechanisms of plate tectonics were conceived, it was hard to take the hypothesis seriously.

2. This sum as it appeared in the first edition is wrong, and when this was pointed out, Darwin revised his calculations for later editions, but the general principle is still unchallenged.

of years, we can be sure that only a fraction of the elephants born in any period have progeny of their own.

So the normal state of affairs for any sort of reproducers is one in which more offspring are produced in any one generation than will in turn reproduce in the next. In other words, it is almost always crunch time.[3] At such a crunch, which prospective parents will "win"? Will it be a fair lottery, in which every organism has an equal chance of being among the few that reproduce? In a political context, this is where invidious themes enter, about power, privilege, injustice, treachery, class warfare, and the like, but we can elevate the observation from its political birthplace and consider in the abstract, as Darwin did, what would—must—happen in nature. Darwin added two further logical points to the insight he had found in Malthus: the first was that at crunch time, if there was significant variation among the contestants, then any advantages enjoyed by any of the contestants would inevitably bias the sample that reproduced. However tiny the advantage in question, if it was actually an advantage (and thus not absolutely invisible to nature), it would tip the scales in favor of those who held it. The second was that *if* there was a "strong principle of inheritance"—if offspring tended to be more like their parents than like their parents' contemporaries—the biases created by advantages, however small, would become amplified over time, creating trends that could grow indefinitely. "More individuals are born than can possibly survive. A grain in the balance will determine which individual shall live and which shall die,—which variety or species shall increase in number, and which shall decrease, or finally become extinct" *{Origin,* p. 467).

What Darwin saw was that if one merely supposed these few general conditions to apply at crunch time—conditions for which he could supply ample evidence—the resulting process would *necessarily* lead in the direction of individuals in future generations who tended to be better equipped to deal with the problems of resource limitation that had been faced by the individuals of their parents' generation. This fundamental idea—Darwin's dangerous idea, the idea that generates so much insight, turmoil, confusion, anxiety—is thus actually quite simple. Darwin summarizes it in two long sentences at the end of chapter 4 of *Origin*.

> If during the long course of ages and under varying conditions of life, organic beings vary at all in the several parts of their organization, and I

3. A familiar example of Malthus' rule in action is the rapid expansion of yeast populations introduced into fresh bread dough or grape juice. Thanks to the feast of sugar and other nutrients, population explosions ensue that last for a few hours in the dough, or a few weeks in the juice, but soon the yeast populations hit the Malthusian ceiling, done in by eir own voraciousness and the accumulation of their waste products—carbon dioxide (which forms the bubbles that make the bread rise, and the fizz in champagne) and alcohol being the two that we yeast-exploiters tend to value.

think this cannot be disputed; if there be, owing to the high geometric powers of increase of each species, at some age, season, or year, a severe struggle for life, and this certainly cannot be disputed; then, considering the infinite complexity of the relations of all organic beings to each other and to their conditions of existence, causing an infinite diversity in structure, constitution, and habits, to be advantageous to them, I think it would be a most extraordinary fact if no variation ever had occurred useful to each being's own welfare, in the same way as so many variations have occurred useful to man. But if variations useful to any organic being do occur, assuredly individuals thus characterized will have the best chance of being preserved in the struggle for life; and from the strong principle of inheritance they will tend to produce offspring similarly characterized. This principle of preservation, I have called, for the sake of brevity, Natural Selection. *[Origin,* p. 127.]

This was Darwin's great idea, not the idea of evolution, but the idea of evolution *by natural selection,* an idea he himself could never formulate with sufficient rigor and detail to prove, though he presented a brilliant case for it. The next two sections will concentrate on curious and crucial features of this summary statement of Darwin's.

3. DID DARWIN EXPLAIN THE ORIGIN OF SPECIES?

Darwin did wrestle brilliantly and triumphantly with the problem of adaptation, but he had limited success with the issue of diversity— even though he titled his book with reference to his relative failure: the origin of species.

—STEPHEN JAY GOULD 1992a, p. 54

Thus die grand fact in natural history of the subordination of group under group, which, from its familiarity, does not always sufficiently strike us, is in my judgment fully explained.

—CHARLES DARWIN, *Origin,* p. 413

Notice that Darwin's summary does not mention speciation at all. It is entirely about the adaptation of organisms, the *excellence* of their design, not the diversity. Moreover, on the face of it, this summary takes the diversity of species *as an assumption:* "the infinite [sic] complexity of the relations of all organic beings to each other and to their conditions of existence." What makes for this stupendous (if not actually infinite) complexity is the presence at one and the same time (and competing for the same living space) of so many different life forms, with so many different needs and strategies. Darwin

doesn't even purport to offer an explanation of the origin of the *first* species, or of life itself; he begins in the middle, supposing many different species with many different talents already present, and claims that starting from such a mid-stage point, the process he has described will inevitably hone and diversify the talents of the species already existing. And will that process create still further species? The summary is silent on that score, but the book is not. In fact, Darwin saw his idea explaining both great sources of wonder in a single stroke. The generation of adaptations and the generation of diversity were different aspects of a single complex phenomenon, and the unifying insight, he claimed, was the principle of natural selection.

Natural selection would inevitably produce *adaptation,* as the summary makes clear, and under the right circumstances, he argued, accumulated adaptation would create speciation. Darwin knew full well that explaining variation is not explaining speciation. The animal-breeders he pumped so vigorously for their lore knew about how to breed *variety* within a single species, but had apparently never created a new *species,* and scoffed at the idea that their particular different breeds might have a common ancestor. "Ask, as 1 have asked, a celebrated raiser of Hereford cattle, whether his cattle might not have descended from longhorns, and he will laugh you to scorn." Why? Because "though they well know that each race varies slightly, for they win their prizes by selecting such slight differences, yet they ignore all general arguments and refuse to sum up in their minds slight differences accumulated during many successive generations" *(Origin,* p. 29).

The further diversification into species would occur, Darwin argued, because if there was a variety of heritable skills or equipment in a population (of a single species), these different skills or equipment would tend to have different payoffs for different subgroups of the population, and hence these subpopulations would tend to diverge, each one pursuing its favored sort of excellence, until eventually there would be a complete parting of the ways. Why, Darwin asked himself, would this divergence lead to separation or clumping of the variations instead of remaining a more or less continuous fan-out of slight differences? Simple geographical isolation was part of his answer; when a population got split by a major geological or climatic event, or by haphazard emigration to an isolated range such as an island, this discontinuity in the environment ought to become mirrored eventually in a discontinuity in the useful variations observable in the two populations. And once discontinuity got a foothold, it would be self-reinforcing, all the way to separation into distinct species. Another, rather different, idea of his was that in intraspecific infighting, a "winner take all" principle would tend to operate:

For it should be remembered that the competition will generally be most severe between those forms which are most nearly related to each other inhabits, constitution and structure. Hence all the intermediate forms

between the earlier and later states, that is between die less and more improved state of a species, as well as the original parent-species itself, will generally tend to become extinct. *[Origin,* p. 121.]

He formulated a variety of other ingenious and plausible speculations on how and why the relentless culling of natural selection would actually create species boundaries, but they remain speculations to this day. It has taken a century of further work to replace Darwin's brilliant but inconclusive musings on the mechanisms of speciation with accounts that are to some degree demonstrable. Controversy about the mechanisms and principles of speciation still persists, so in one sense neither Darwin nor any subsequent Darwinian has explained the origin of species. As the geneticist Steve Jones (1993) has remarked, had Darwin published his masterpiece under its existing title today, "he would have been in trouble with the Trades Description Act because if there is one thing which *Origin of Species* is not about, it is the origin of species. Darwin knew nothing about genetics. Now we know a great deal, and although the way in which species begin is still a mystery, it is one with the details filled in."

But the fact of speciation itself is incontestable, as Darwin showed, building an irresistible case out of literally hundreds of carefully studied and closely argued instances. That is how species originate: by "descent with modification" from earlier species—not by Special Creation. So in another sense Darwin undeniably did explain the origin of species. Whatever the mechanisms are that operate, they manifestly begin with the emergence of variety within a species, and end, after modifications have accumulated, with the birth of a new, descendant species. What start as "well-marked varieties" turn gradually into "the doubtful category of subspecies; but we have only to suppose the steps in the process of modification to be more numerous or greater in amount, to convert these... forms into well-defined species" *(Origin,* p. 120).

Notice that Darwin is careful to describe the eventual outcome as the creation of "well-defined" species. Eventually, he is saying, the divergence becomes so great that there is just no reason to deny that what we have are two different species, not merely two different varieties. But he declines to play the traditional game of declaring what the "essential" difference is:

... it will be seen that I look at the term species, as one arbitrarily given for the sake of convenience to a set of individuals closely resembling each other, and that it does not essentially differ from the term variety, which is given to less distinct and more fluctuating forms. *[Origin,* p. 52.]

One of the standard marks of species difference, as Darwin fully recognized, is reproductive isolation—there is no interbreeding. It is interbreeding that reunites the splitting groups, mixing their genes and "frustrating" the process of speciation. It is not that anything *wants* speciation to happen, of course (Dawkins 1986a, p. 237), but if the irreversible divorce that marks speciation is to happen, it must be preceded by a sort of trial separation period in which interbreeding ceases for one reason or another, so that the parting groups can move further apart. The criterion of reproductive isolation is vague at the edges. Do organisms belong to different species when they *can't* interbreed, or when they just *don't* interbreed? Wolves and coyotes and dogs are considered to be different species, and yet interbreeding does occur, and—unlike mules, the offspring of horse and donkey—their offspring are not in general sterile. Dachshunds and Irish wolfhounds are deemed to be of the same species, but unless their owners provide some distinctly unnatural arrangements, they are about as reproductively isolated as bats are from dolphins. The white-tailed deer in Maine don't in fact interbreed with the white-tailed deer in Massachusetts, since they don't travel that far, but they surely could if transported, and naturally they count as of the same species.

And finally—a true-life example seemingly made to order for philosophers—consider the herring gulls that live in the Northern Hemisphere, their range forming a broad ring around the North Pole.

As we look at the herring gull, moving westwards from Great Britain to North America, we see gulls that are recognizably herring gulls, although they are a little different from the British form. We can follow them, as their appearance gradually changes, as far as Siberia. At about this point in the continuum, the gull looks more like the form that in Great Britain is called the lesser black-backed gull. From Siberia, across Russia, to northern Europe, the gull gradually changes to look more and more like the British lesser black-backed gull. Finally, in Europe, the ring is complete; the two geographically extreme forms meet, to form two perfectly good species: die herring and lesser black-backed gull can be both distinguished by their appearance and do not naturally interbreed. [Mark Ridley 1985, p. 5]

"Well-defined" species certainly do exist—it is the purpose of Darwin's book to explain their origin—but he discourages us from trying to find a "principled" definition of the concept of a species. Varieties, Darwin keeps insisting, are just "incipient species," and what normally turns two varieties into two species is not the *presence* of something (a new essence for each group, for instance) but the *absence* of something: the intermediate cases, which used to be there—which were necessary stepping-stones, you might say—but have eventually gone extinct, leaving two groups that are *in fact* reproductively isolated as well as different in their characteristics.

Origin of Species presents an overwhelmingly persuasive case for Darwin's first thesis—the historical fact of evolution as the cause of the origin

of species—and a tantalizing case in favor of his second thesis—that the fundamental mechanism responsible for "descent with modification" was natural selection.[4] Levelheaded readers of the book simply could no longer doubt that species had evolved over the eons, as Darwin said they had, but scrupulous skepticism about the power of his proposed mechanism of natural selection was harder to overcome. Intervening years have raised the confidence level for both theses, but not erased the difference (Ellegard [1958] provides a valuable account of this history). The evidence for evolution pours in, not only from geology, paleontology, biogeography, and anatomy (Darwin's chief sources), but of course from molecular biology and every other branch of the life sciences. To put it bluntly but fairly, anyone today who doubts that the variety of life on this planet was produced by a process of evolution is simply ignorant—inexcusably ignorant, in a world where three out of four people have learned to read and write. Doubts about the power of Darwin's idea of natural selection to explain this evolutionary process are still intellectually respectable, however, although the burden of proof for such skepticism has become immense, as we shall see.

So, although Darwin depended on his idea of the mechanism of natural selection to inspire and guide his research on evolution, the end result reversed the order of dependence: he showed so convincingly that species *had* to have evolved that he could then turn around and use this fact to support his more radical idea, natural selection. He had described a mechanism or process that, according to his arguments, *could* have produced all these effects. Skeptics were presented with a challenge: Could they show that his arguments were mistaken? Could they show how natural selection would be incapable of producing the effects?[5] Or could they even describe

4. As is often pointed out, Darwin didn't insist that natural selection explained everything: it was the "main but not exclusive means of modification" *(Origin,* p. 6).

5. It is sometimes suggested that Darwin's theory is systematically irrefutable (and hence scientifically vacuous), but Darwin was forthright about what sort of finding it would take to refute his theory. "Though nature grants vast periods of time for the work of natural selection, she does not grant an indefinite period" *(Origin,* p. 102), so, if the geological evidence mounted to show that not enough time had elapsed, his whole theory would be refuted. This still left a temporary loophole, for the theory wasn't formulatable in sufficiently rigorous detail to say just how many millions of years was the minimal amount required, but it was a temporary loophole that made sense, since at least some proposals about its size could be evaluated independently. (Kitcher [1985a, pp. 162-65], has a good discussion of the further subtleties of argument that kept Darwinian theory from being directly confirmed or disconfirmed.) Another famous instance: "If it could be demonstrated diat any complex organ existed, which could not possibly have been formed by numerous, successive, slight modifications, my theory would absolutely break down" (*Origin,* p. 189). Many have risen to this challenge, but, as we shall see in chapter 11, there are good reasons why they have not succeeded in their attempted demonstrations.

another process that might achieve these effects? What *else* could account for evolution, if not the mechanism he had described?

This challenge effectively turned Hume's predicament inside out. Hume caved in because he could not imagine how anything other than an Intelligent Artificer could be the cause of the adaptations that anyone could observe. Or, more accurately, Hume's Philo imagined several different alternatives, *but Hume had no way of taking these imaginings seriously*. Darwin described how a Nonintelligent Artificer could produce those adaptations over vast amounts of time, and proved that many of the intermediate stages that would be needed by that proposed process had indeed occurred. Now the challenge to imagination was reversed: given all the telltale signs of the historical process that Darwin uncovered—all the brush-marks of the artist, you might say—could anyone imagine how any process *other* than natural selection could have produced all these effects? So complete has this reversal of the burden of proof been that scientists often find themselves in something like the mirror image of Hume's predicament. When they are confronted with a *prima facie* powerful and undismissable objection to natural selection (we will consider the strongest cases in due course), they are driven to reason as follows: I cannot (yet) see how to refute this objection, or overcome this difficulty, but since I cannot imagine how anything other than natural selection could be the cause of the effects, I will have to assume that the objection is spurious; *somehow* natural selection must be sufficient to explain the effects.

Before anyone jumps on this and pronounces that I have just conceded that Darwinism is just as much an unprovable faith as natural religion, it should be borne in mind that there is a fundamental difference: having declared their allegiance to natural selection, these scientists have then proceeded to take on the burden of showing how the difficulties with their view could be overcome, and, time and time again, they have succeeded in meeting the challenge. In the process, Darwin's fundamental idea of natural selection has been articulated, expanded, clarified, quantified, and deepened in many ways, becoming stronger every time it overcame a challenge. With every success, the scientists' conviction grows that they must be on the right track. It is reasonable to believe that an idea that was ultimately false would surely have succumbed by now to such an unremitting campaign of attacks. That is not a conclusive proof, of course, just a mighty persuasive consideration. One of the goals of this book is to explain why the idea of natural selection appears to be a clear winner, even while there are unresolved controversies about how it can handle some phenomena.

publication of *Origin,* "I would give absolutely nothing for the theory of Natural Selection, if it requires miraculous additions at any one stage of descent ... If I were convinced that I required such additions to the theory of natural selection, I would reject it as rubbish..." (F. Darwin 1911, vol. 2, pp. 6-7).

According to Darwin, then, evolution is an algorithmic process. Putting it this way is still controversial. One of the tugs-of-war going on within evolutionary biology is between those who are relentlessly pushing, pushing, pushing towards an algorithmic treatment, and those who, for various submerged reasons, are resisting this trend. It is rather as if there were metallurgists around who were disappointed by the algorithmic explanation of annealing. "You mean that's all there is to it? No submicroscopic Superglue specially created by the heating and cooling process?" Darwin has convinced all the scientists that evolution, like annealing, *works*. His radical vision of *how* and *why* it works is still somewhat embattled, largely because those who resist can dimly see that their skirmish is part of a larger campaign. If the game is lost in evolutionary biology, where will it all end?

CHAPTER 2: *Darwin conclusively demonstrated that, contrary to ancient tradition, species are not eternal and immutable; they evolve. The origin of new species was shown to be the result of "descent with modification." Less conclusively, Darwin introduced an idea of how this evolutionary process took place: via a mindless, mechanical—algorithmic—process he called "natural selection." This idea, that all die fruits of evolution can be explained as the products of an algorithmic process, is Darwin's dangerous idea.*

CHAPTER 3: *Many people, Darwin included, could dimly see* that *his idea of natural selection had revolutionary potential, but just what did it promise to overthrow? Darwin's idea can be used to dismantle and then rebuild a traditional structure of Western thought, which I call die Cosmic Pyramid. This provides a new explanation of the origin, by gradual accumulation, of all the Design in the universe. Ever since Darwin, skepticism has been aimed at his implicit claim that the various processes of natural selection, in spite of their underlying mindlessness, are powerful enough to have done all the design work that is manifest in the world.*

CHAPTER THREE

Universal Acid

1. EARLY REACTIONS

Origin of man now proved. —Metaphysics must flourish. —He who understands baboon would do more towards metaphysics than Locke.

—CHARLES DARWIN, in a notebook not intended for publication, in P. H. Barrett et al. 1987, D26, M84

His subject is die 'Origin of Species,' & not die origin of Organization; & it seems a needless mischief to have opened the latter speculation at all.

—HARRIET MARTINEAU, a friend of Darwin's, in a letter to Fannie Wedgwood, March, 13, 1860, quoted in Desmond and Moore 1991, p. 486

Darwin began his explanation in the middle, or even, you might say, at the end. starting with the life forms we presently see, and showing how the patterns in today's biosphere could be explained as having arisen by the process of natural selection from the patterns in yesterday's biosphere, and so on, back into the very distant past. He started with facts that everyone knows: all of today's living things are the offspring of parents, who are the offspring of grandparents, and so forth, so everything that is alive today is a branch of a genealogical family, which is itself a branch of a larger clan. He went on to argue that, if you go back far enough, you find that all the branches of all the families eventually spring from common ancestral limbs, so that there is a single Tree of Life, all the limbs, branches, and twigs united by descent with modification. The fact that it has the branching organization of a tree is crucial to the explanation of the sort of process involved, for such

a tree *could* be created by an automatic, recursive process: first build an *x,* then modify *x's* descendants, then modify those modifications, then modify the modifications of the modifications— If Life is a Tree, it could all have arisen from an inexorable, automatic rebuilding process in which designs would accumulate over time.

Working backwards, starting at or near "the end" of a process, and solving the next-to-last step before asking how *it* could have been produced, is a tried and true method of computer programmers, particularly when creating programs that use recursion. Usually this is a matter of practical modesty: if you don't want to bite off more than you can chew, the right bite to start with is often the finishing bite, if you can find it. Darwin found it, and then very cautiously worked his way back, skirting around the many grand issues that his investigations stirred up, musing about them in his private notebooks, but postponing their publication indefinitely. (For instance, he deliberately avoided discussing human evolution in *Origin;* see the discussion in R. J. Richards 1987, pp. 160ff.) But he could see where all this was leading, and, in spite of his near-perfect silence on these troubling extrapolations, so could many of his readers. Some loved what they thought they saw, and others hated it.

Karl Marx was exultant: "Not only is a death blow dealt here for the first time to 'Teleology' in the natural sciences but their rational meaning is empirically explained" (quoted in Rachels 1991, p. 110). Friedrich Nietzsche saw—through the mists of his contempt for all things English—an even more cosmic message in Darwin: God is dead. If Nietzsche is the father of existentialism, then perhaps Darwin deserves the title of grandfather. Others were less enthralled with the thought that Darwin's views were utterly subversive to sacred tradition. Samuel Wilberforce, Bishop of Oxford, whose debate with Thomas Huxley in June 1860 was one of the most celebrated confrontations between Darwinism and the religious establishment (see chapter 12), said in an anonymous review:

> Man's derived supremacy over the earth; man's power of articulate speech; man's gift of reason; man's free-will and responsibility ...—all are equally and utterly irreconcilable with the degrading notion of the brute origin of him who was created in the image of God __ [Wilberforce 1860.]

When speculation on these extensions of his view arose, Darwin wisely chose to retreat to the security of his base camp, the magnificently provisioned and defended thesis that began in the middle, with life already on the scene, and "merely" showed how, once this process of design accumulation was under way, it could proceed without any (further?) intervention from any Mind. But, as many of his readers appreciated, however comforting this modest disclaimer might be, it was not really a stable resting place.

Did you ever hear of universal acid? This fantasy used to amuse me and some of my schoolboy friends—I have no idea whether we invented or inherited it, along with Spanish fly and saltpeter, as a part of underground youth culture. Universal acid is a liquid so corrosive that it will eat through *anything!* The problem is: what do you keep it in? It dissolves glass bottles and stainless-steel canisters as readily as paper bags. What would happen if you somehow came upon or created a dollop of universal acid? Would the whole planet eventually be destroyed? What would it leave in its wake? After everything had been transformed by its encounter with universal acid, what would the world look like? Little did I realize that in a few years I would encounter an idea—Darwin's idea—bearing an unmistakable likeness to universal acid: it eats through just about every traditional concept, and leaves in its wake a revolutionized world-view, with most of the old landmarks still recognizable, but transformed in fundamental ways.

Darwin's idea had been born as an answer to questions in biology, but it threatened to leak out, offering answers—welcome or not—to questions in cosmology (going in one direction) and psychology (going in the other direction). If redesign could be a mindless, algorithmic process of evolution, why couldn't that whole process itself be the product of evolution, and so forth, *all the way down?* And if mindless evolution could account for the breathtakingly clever artifacts of the biosphere, how could the products of our own "real" minds be exempt from an evolutionary explanation? Darwin's idea thus also threatened to spread *all the way up,* dissolving the illusion of our own authorship, our own divine spark of creativity and understanding.

Much of the controversy and anxiety that has enveloped Darwin's idea ever since can be understood as a series of failed campaigns in the struggle to contain Darwin's idea within some acceptably "safe" and merely partial revolution. Cede some or all of modern biology to Darwin, perhaps, but hold the line there! Keep Darwinian thinking out of cosmology, out of psychology, out of human culture, out of ethics, politics, and religion! In these campaigns, many battles have been won by the forces of containment: flawed applications of Darwin's idea have been exposed and discredited, beaten back by the champions of the pre-Darwinian tradition. But new waves of Darwinian thinking keep coming. They seem to be improved versions, not vulnerable to the refutations that defeated their predecessors, but are they sound extensions of the unquestionably sound Darwinian core idea, or might they, too, be perversions of it, and even more virulent, more dangerous, than the abuses of Darwin already refuted?

Opponents of the spread differ sharply over tactics. Just where should the protective dikes be built? Should we try to contain the idea within biology itself, with one post-Darwinian counterrevolution or another? Among those who have favored this tactic is Stephen Jay Gould, who has offered several different revolutions of containment. Or should we place the barriers far-

ther out? To get our bearings in this series of campaigns, we should start with a crude map of the pre-Darwinian territory. As we shall see, it will have to be revised again and again to make accommodations as various skirmishes are lost.

2. DARWIN'S ASSAULT ON THE COSMIC PYRAMID

A prominent feature of Pre-Darwinian world-views is an overall top-to-bottom map of things. This is often described as a Ladder; God is at the top, with human beings a rung or two below (depending on whether angels are part of the scheme). At the bottom of the Ladder is Nothingness, or maybe Chaos, or maybe Locke's inert, motionless Matter. Alternatively, the scale is a Tower, or, in the intellectual historian Arthur Lovejoy's memorable phrase (1936), a Great Chain of Being composed of many links. John Locke's argument has already drawn our attention to a particularly abstract version of the hierarchy, which I will call the Cosmic Pyramid:

God
Mind
Design
Order
Chaos
Nothing

(Warning: each term in the pyramid must be understood in an old-fashioned, pre-Darwinian sense!)

Everything finds its place on one level or another of the Cosmic Pyramid, even blank nothingness, the ultimate foundation. Not all matter is Ordered, some is in Chaos; only some Ordered matter is also Designed; only some Designed things have Minds, and of course only one Mind is God. God, the first Mind, is the source and explanation of everything underneath. (Since everything thus *depends on* God, perhaps we should say it is a chandelier, hanging from God, rather than a pyramid, supporting Him.)

What is the difference between Order and Design? As a first stab, we might say that Order is mere regularity, mere pattern; Design is Aristotle's *telos,* an exploitation of Order for a purpose, such as we see in a cleverly designed artifact. The solar system exhibits stupendous Order, but does not (apparently) have a purpose—it isn't/or anything. An eye, in contrast, is *for* seeing. Before Darwin, this distinction was not always clearly marked. Indeed, it was positively blurred:

> In the thirteenth century, Aquinas offered the view that natural bodies [such as planets, raindrops, volcanos] act as if guided toward a definite goal or end "so as to obtain the best result." This fitting of means to ends implies, argued Aquinas, an intention. But, seeing as natural bodies lack consciousness, they cannot supply that intention themselves. "Therefore some intelligent being exists by whom all natural things are directed to their end; and this being we call God." [Davies 1992, p. 200.]

Hume's Cleanthes, following in this tradition, lumps the adapted marvels of the living world with the regularities of the heavens—it's *all* like a wonderful clockwork to him. But Darwin suggests a division: Give me Order, he says, and time, and I will give you Design. Let me start with regularity—the mere purposeless, mindless, pointless regularity of physics—and I will show you a process that eventually will yield products that exhibit not just regularity but purposive design. (This was just what Karl Marx thought he saw when he declared that Darwin had dealt a death blow to Teleology: Darwin had *reduced* teleology to nonteleology, Design to Order.)

Before Darwin, the difference between Order and Design didn't loom large, because in any case it all came down from God. The whole universe was His artifact, a product of His Intelligence, His Mind. Once Darwin jumped into the middle with his proposed answer to the question of how Design could arise from mere Order, the rest of the Cosmic Pyramid was put in jeopardy. Suppose we accept that Darwin has explained the Design of the bodies of plants and animals (including our own bodies—we have to admit that Darwin has placed us firmly in the animal kingdom). Looking up, if we concede to Darwin our bodies, can we keep him from taking our minds as well? (We will address this question, in many forms, in part III.) Looking down, Darwin asks us to give him Order as a premise, but is there anything to keep him from stepping down a level and giving himself an algorithmic account of the origin of Order out of mere Chaos? (We will address this question in chapter 6.)

The vertigo and revulsion this prospect provokes in many was perfectly expressed in an early attack on Darwin, published anonymously in 1868:

> In the theory with which we have to deal, Absolute Ignorance is the artificer; so that we may enunciate as the fundamental principle of the whole system, that, IN ORDER TO MAKE A PERFECT AND BEAUTIFUL MACHINE, IT IS NOT REQUISITE TO KNOW HOW TO MAKE IT. This proposition will be found, on careful examination, to express, in condensed form, the essential purport of the Theory, and to express in a few words all Mr. Darwin's meaning; who, by a strange inversion of reasoning, seems to think Absolute Ignorance fully qualified to take the place of Absolute Wisdom in all the achievements of creative skill. [MacKenzie 1868.]

Exactly! Darwin's "strange inversion of reasoning" was in fact a new and wonderful way of thinking, completely overturning the Mind-first way that

John Locke "proved" and David Hume could see no way around. John Dewey nicely described the inversion some years later, in his insightful book *The Influence of Darwin on Philosophy:* "Interest shifts ... from an intelligence that shaped things once for all to the particular intelligences which things are even now shaping" (Dewey 1910, p. 15). But the idea of treating Mind as an effect rather than as a First Cause is too revolutionary for some—an "awful stretcher" that their own minds cannot accommodate comfortably. This is as true today as it was in 1860, and it has always been as true of some of evolution's best friends as of its foes. For instance, the physicist Paul Davies, in his recent book *The Mind of God,* proclaims that the reflective power of human minds can be "no trivial detail, no minor by-product of mindless purposeless forces" (Davies 1992, p. 232). This is a most revealing way of expressing a familiar denial, for it betrays an ill-examined prejudice. Why, we might ask Davies, would its being a by-product of mindless, purposeless forces make it trivial? Why couldn't the most important thing of all be something that arose from unimportant things? Why should the importance or excellence of *anything* have to rain down on it from on high, from something more important, a gift from God? Darwin's inversion suggests that we abandon that presumption and look for sorts of excellence, of worth and purpose, that can emerge, bubbling up out of "mindless, purposeless forces."

Alfred Russel Wallace, whose own version of evolution by natural selection arrived on Darwin's desk while he was still delaying publication of *Origin,* and whom Darwin managed to treat as codiscoverer of the principle, never quite got the point.[1] Although at the outset Wallace was much more forthcoming on the subject of the evolution of the human mind than Darwin was willing to be, and stoutly maintained at first that human minds were no exception to the rule that all features of living things were products of evolution, he could not see the "strange inversion of reasoning" as the key to the greatness of the great idea. Echoing John Locke, Wallace proclaimed that "the marvelous complexity of forces which appear to control matter, if not actually to constitute it, are and must be mind-products" (Gould 1985, p. 397). When, later in his life, Wallace converted to spiritualism and exempted human consciousness altogether from the iron rule of

1. This fascinating and even excruciating story has been well told many times, but still the controversies rage. Why did Darwin delay publication in the first place? Was his treatment of Wallace generous or monstrously unfair? The unsettled relations between Darwin and Wallace are not just a matter of Darwin's uneasy conscience about how he handled Wallace's innocent claim-jumping correspondence; as we see here, the two were also separated by vast differences in insight and attitude about the idea they both discovered. For particularly good accounts, see Desmond and Moore 1991; Richards 1987, pp. 159-61.

evolution, Darwin saw the crack widen and wrote to him: "I hope you have not murdered too completely your own and my child" (Desmond and Moore 1991, p. 569).

But was it really so inevitable that Darwin's idea should lead to such revolution and subversion? "It is obvious that the critics did not wish to understand, and to some extent Darwin himself encouraged their wishful thinking" (Ellegard 1956). Wallace wanted to ask what the *purpose* of natural selection might be, and though this might seem in retrospect to be squandering the fortune he and Darwin had uncovered, it was an idea for which Darwin himself often expressed sympathy. Instead of reducing teleology all the way to purposeless Order, why couldn't we reduce all mundane teleology to a single purpose: God's purpose? Wasn't this an obvious and inviting way to plug the dike? Darwin was clear in his own mind that the variation on which the process of natural selection depended *had* to be unplanned and undesigned, but the process itself might have a purpose, mightn't it? In a letter in I860 to the American naturalist Asa Gray, an early supporter, Darwin wrote, "I am inclined to look at everything as resulting from *designed* [emphasis added] laws, with the details whether good or bad, left to the working out of what we may call chance" (F. Darwin 1911, vol. 2, p. 105).

Automatic processes are themselves often creations of great brilliance. From today's vantage point, we can see that the inventors of the automatic transmission and the automatic door-opener were no idiots, and their genius lay in seeing how to create something that could do something "clever" without having to think about it. Indulging in some anachronism, we could say that, to some observers in Darwin's day, it seemed that he had left open the possibility that God did His handiwork by designing an automatic design-maker. And to some of these, the idea was not just a desperate stopgap but a positive improvement on tradition. The first chapter of Genesis describes the successive waves of Creation and ends each with the refrain "and God saw that it was good." Darwin had discovered a way to eliminate this retail application of Intelligent Quality Control; natural selection would take care of that without further intervention from God. (The seventeenth-century philosopher Gottfried Wilhelm Leibniz had defended a similar hands-off vision of God the Creator.) As Henry Ward Beecher put it, "Design by wholesale is grander than design by retail" (Rachels 1991, p. 99). Asa Gray, captivated by Darwin's new idea but trying to reconcile it with as much of "is traditional religious creed as possible, came up with this marriage of convenience: God *intended* the "stream of variations" and *foresaw* just how the laws of nature He had laid down would prune this stream over the eons. As John Dewey later aptly remarked, invoking yet another mercantile metaphor, "Gray held to what may be called design on the installment plan" (Dewey 1910, p. 12).

It is not unusual to find such metaphors, redolent of capitalism, in evolutionary explanations. Examples are often gleefully recounted by those critics and interpreters of Darwin who see this language as revealing—or should we say betraying—the social and political environment in which Darwin developed his ideas, thereby (somehow) discrediting their claim to scientific objectivity. It is certainly true that Darwin, being an ordinary mortal, was the inheritor of a huge manifold of concepts, modes of expression, attitudes, biases, and visions that went with his station in life (as a Victorian Englishman might put it), but it is also true that the economic metaphors that come so naturally to mind when one is thinking about evolution get their power from one of the deepest features of Darwin's discovery.

3. THE PRINCIPLE OF THE ACCUMULATION OF DESIGN

The key to understanding Darwin's contribution is *granting* the premise of the Argument from Design. What conclusion ought one to draw if one found a watch lying on the heath in the wilderness? As Paley (and Hume's Cleanthes before him) insisted, a watch exhibits a tremendous amount of *work done*. Watches and other designed objects don't just happen; they have to be the product of what modern industry calls "R and D"—research and development—and R and D is costly, in both time and energy. Before Darwin, the only model we had of a process by which this sort of R-and-D work could be done was an Intelligent Artificer. What Darwin saw was that in principle the same work could be done by a different sort of process that *distributed* that work over huge amounts of time, by thriftily conserving the design work that had been accomplished at each stage, so that it didn't have to be done over again. In other words, Darwin had hit upon what we might call the Principle of Accumulation of Design. Things in the world (such as watches and organisms and who knows what else) may be seen as products embodying a certain amount of Design, and one way or another, that Design had to have been created by a process of R and D. Utter undesignedness—pure chaos in the old-fashioned sense—was the null or starting point.

A more recent idea about the difference—and tight relation—between Design and Order will help clarify the picture. This is the proposal, first popularized by the physicist Erwin Schrodinger (1967), that Life can be defined in terms of the Second Law of Thermodynamics. In physics, order or organization can be measured in terms *of heat differences* between regions of space time; *entropy* is simply disorder, the opposite of order, and according to the Second Law, the entropy of any isolated system increases with time. In other words, things run down, inevitably. According to the

Second Law, the universe is unwinding out of a more ordered state into the ultimately disordered state known as the heat death of the universe.[2]

What, then, are living things? They are things that defy this crumbling into dust, at least for a while, by not being isolated—by taking in from their environment the wherewithal to keep life and limb together. The psychologist Richard Gregory summarizes the idea crisply:

> Time's arrow given by Entropy—the loss of organization, or loss of temperature differences—is statistical and it is subject to local small-scale reversals. Most striking: life is a systematic reversal of Entropy, and intelligence creates structures and energy differences against the supposed gradual 'death' through Entropy of the physical Universe. [Gregory 1981, p. 136.]

Gregory goes on to credit Darwin with the fundamental enabling idea: "It is the measure of the concept of Natural Selection that increases in the complexity and order of organisms in biological time can now be understood." Not just individual organisms, but the whole process of evolution that creates them, thus can be seen as fundamental physical phenomena running contrary to the larger trend of cosmic time, a feature captured by William Calvin in one of the meanings of the title of his classic exploration of the relationship between evolution and cosmology, *The River That Flows Uphill: A Journey from the Big Bang to the Big Brain* (1986).

A *designed* thing, then, is either a living thing or a part of a living thing, or the artifact of a living thing, organized in any case in aid of this battle against disorder. It is not impossible to oppose the trend of the Second Law, but it is costly. Consider iron. Iron is a very useful element, essential for our bodily health, and also valuable as the major component of steel, that wonderful building material. Our planet used to have vast reserves of iron ore, but they are gradually being depleted. Does this mean that the Earth is running out of iron? Hardly. With the trivial exception of a few tons that have recently been launched out of Earth's effective gravitational field in the form of space-probe components, there is just as much iron on the planet today as there ever was. The trouble is that more and more of it is scattered about in the form of rust (molecules of iron oxide), and other low-grade, low-concentration materials. In principle, it could all be recovered, but that would take enormous amounts of energy, craftily focused on the particular project of extracting and reconcentrating the iron.

It is the organization of just such sophisticated processes that constitutes

2. And where did the initial order come from? The best discussion I have encountered of "is good question is "Cosmology and the Arrow of Time," ch. 7 of Penrose 1989.

the hallmark of life. Gregory dramatizes this with an unforgettable example. A standard textbook expression of the directionality imposed by the Second Law of Thermodynamics is the claim that you can't unscramble an egg. Well, not that you absolutely can't, but that it would be an extremely costly, sophisticated task, uphill all the way against the Second Law. Now consider: how expensive would it be to make a device that would take scrambled eggs as input and deliver unscrambled eggs as output? There is one ready solution: put a live hen in the box! Feed it scrambled eggs, and it will be able to make eggs for you—for a while. Hens don't normally strike us as near-miraculously sophisticated entities, but here is one thing a hen can do, thanks to the Design that has organized it, that is still way beyond the reach of the devices created by human engineers.

The more Design a thing exhibits, the more R-and-D work had to have occurred to produce it. Like any good revolutionary, Darwin exploits as much as possible of the old system: the vertical dimension of the Cosmic Pyramid is retained, and becomes the measure of how much Design has gone into the items at that level. In Darwin's scheme, as in the traditional Pyramid, Minds do end up near the top, among the most designed of entities (in part because they are the self-redesigning things, as we shall see in chapter 13). But this means that they are among the most advanced *ejfects* (to date) of the creative process, not—as in the old version—its cause or source. Their products in turn—the human artifacts that were our initial model—must count as more designed still. This may seem counterintuitive at first. A Keats ode may seem to have some claim to having a grander R and D pedigree than a nightingale—at least it might seem so to a poet ignorant of biology—but what about a paper clip? Surely a paper clip is a trivial product of design compared with any living thing, however rudimentary. In one obvious sense, yes, but reflect for a moment. Put yourself in Paley's shoes, but walking along the apparently deserted beach on an alien planet. Which discovery would excite you the most: a clam or a clam-rake? Before the planet could make a clam-rake, it would have to make a clam-rake-maker, and that is a more designed thing by far than a clam.

Only a theory with the logical shape of Darwin's could *explain* how designed things came to exist, because any other sort of explanation would be either a vicious circle or an infinite regress (Dennett 1975). The old way, Locke's Mind-first way, endorsed the principle that it takes an Intelligence to make an intelligence. This idea must have always seemed self-evident to our ancestors, the artifact-makers, going back to *Homo habilis,* the "handy" man, from whom *Homo sapiens,* the "knowing" man, descended. Nobody ever saw a spear fashion a hunter out of raw materials. Children chant, "It takes one to know one," but an even more persuasive slogan would seem to be "It takes a greater one to make a lesser one." Any view inspired by this slogan immediately faces an embarrassing question, however, as Hume had

noted: If God created and designed all these wonderful things, who created God? Supergod? And who created Supergod? Superdupergod? Or did God create Himself? Was it hard work? Did it take time? Don't ask! Well, then, we may ask instead whether this bland embrace of mystery is any improvement over just denying the principle that intelligence (or design) must spring from Intelligence. Darwin offered an explanatory path that actually honored Paley's insight: real work went into designing this watch, and work isn't free.

How much design does a thing exhibit? No one has yet offered a system of design quantification that meets all our needs. Theoretical work that bears on this interesting question is under way in several disciplines,[3] and in chapter 6 we will consider a natural metric that provides a neat solution to special cases—but in the meantime we have a powerful intuitive sense of different amounts of design. Automobiles contain more design than bicycles, sharks contain more design than amoebas, and even a short poem contains more design than a "Keep Off the Grass" sign. (I can hear the skeptical reader saying, "Whoa! Slow down! Is this supposed to be uncon-troversial?" Not by a long shot. In due course I will attempt to justify these claims, but for the time being I want to draw attention to, and build on, some familiar—but admittedly unreliable—intuitions.)

Patent law, including the law of copyright, is a repository of our practical grasp of the question. How much novelty of design counts as enough to justify a patent? How much can one borrow from the intellectual products of others without recompense or acknowledgment? These are slippery slopes on which we have had to construct some rather arbitrary terraces, codifying what otherwise would be a matter of interminable dispute. The burden of proof in these disputes is fixed by our intuitive sense of how much design is too much design to be mere coincidence. Our intuitions here are very strong and, I promise to show, sound. Suppose an author is accused of plagiarism, and the evidence is, say, a single paragraph that is almost identical to a paragraph in the putative source. Might this be just a coincidence? It depends crucially on how mundane and formulaic the paragraph is, but most paragraph-length passages of text are "special" enough (in ways we will soon explore) to make independent creation highly unlikely. No reasonable jury would require the prosecutor in a plagiarism case to demonstrate exactly the causal pathway by which the alleged copying took place. The defendant would clearly have the burden of establishing that his work was, remarkably, an independent work rather than a copying of work already done.

A similar burden of proof falls on the defendant in an industrial-espionage

3. For accessible overviews of some of the ideas, see Pagels 1988, Stewart and Golubitsky 1992, and Langton et al. 1992.

case: the interior of the defendant's new line of widgets looks suspiciously similar in design to that of the plaintiff's line of widgets—is this an innocent case of convergent evolution of design? Really the only way to prove your innocence in such a case is to show clear evidence of actually having done the necessary R-and-D work (old blueprints, rough drafts, early models and meckups, memos about the problems encountered, etc.). In the absence of such evidence, but also in the absence of any physical evidence of your espionage activities, you would be convicted—and you'd deserve to be! Cosmic coincidences on such a scale just don't happen.

The same burden of proof now reigns in biology, thanks to Darwin. What I am calling the Principle of Accumulation of Design doesn't logically *require* that all design (on this planet) descend via one branch or another from a single trunk (or root or seed), but it says that since each new designed thing that appears must have a large design investment in its etiology somewhere, the cheapest hypothesis will always be that the design is largely copied from earlier designs, which are copied from earlier designs, and so forth, so that actual R-and-D innovation is minimized. We know for a fact, of course, that many designs have been independently re-invented many times—eyes, for instance, dozens of times—but every case of such convergent evolution must be proven against a background in which most of the design is copied. It is logically possible that all the life forms in South America were created independently of all the life forms in the rest of the world, but this is a wildly extravagant hypothesis that would need to be demonstrated, piece by piece. Suppose we discover, on some remote island, a novel species of bird. Even if we don't *yet* have direct confirmatory evidence that this bird is related to all the other birds in the world, that is our overpoweringly secure default assumption, after Darwin, because birds are very special designs.[4]

So the fact that organisms—and computers and books and other artifacts—are effects of very special chains of causation is not, after Darwin, a merely reliable generalization, but a deep fact out of which to build a theory. Hume recognized the point—"Throw several pieces of steel together, without shape or form; they will never arrange themselves to compose a watch"—but he and other, earlier, thinkers thought they had to ground this deep fact in Mind. Darwin came to see how to distribute *it* in vast spaces of Nonmind, thanks to his ideas about how design innovations could be conserved and reproduced, and hence accumulated.

The idea that Design is something that has taken work to create, and

4. Note, by the way, that it would not follow *logically* that the bird was related to other birds if we found that its DNA was almost identical in sequence to that of other birds! "Just a coincidence, not plagiarism," would be a logical possibility—but one that nobody would take seriously.

hence has value at least in the sense that it is something that might be conserved (and then stolen or sold), finds robust expression in economic terms. Had Darwin not had the benefit of being born into a mercantile world that had already created its Adam Smith and its Thomas Malthus, he would not have been in position to find ready-made pieces he could put together into a new, value-added product. (You see, the idea applies to itself very nicely.) The various sources of the Design that went into Darwin's grand idea give us important insights into the idea itself, but do no more to diminish its value or threaten its objectivity than the humble origins of methane diminish its BTUs when it is put to use as a fuel.

4. THE TOOLS FOR R AND D: SKYHOOKS OR CRANES?

The work of R and D is not like shoveling coal; it is somehow a sort of "intellectual" work, and this fact grounds the other family of metaphors that has both enticed and upset, enlightened and confused, the thinkers who have confronted Darwin's "strange inversion of reasoning": the apparent attribution of intelligence to the very process of natural selection that Darwin insisted was *not* intelligent.

Was it not unfortunate, in fact, that Darwin had chosen to call his principle "natural *selection*" with its anthropomorphic connotations? Wouldn't it have been better, as Asa Gray suggested to him, to replace the imagery about "nature's Guiding Hand" with a discussion of the different ways of winning life's race (Desmond and Moore 1991, p. 458)? Many people just didn't get it, and Darwin was inclined to blame himself: "I must be a very bad explainer," he said, conceding: "I suppose 'natural selection' was a bad term" (Desmond and Moore 1991, p. 492). Certainly this Janus-faced term has encouraged more than a century of heated argument. A recent opponent of Darwin sums it up:

> Life on Earth, initially thought to constitute a sort of prima facie case for a creator, was, as a result of Darwin's idea, envisioned merely as being the outcome of a process and a process mat was, according to Dobzhansky, "blind, mechanical, automatic, impersonal," and, according to de Beer, was "wasteful, blind, and blundering." But as soon as these criticisms [sic] were leveled at natural selection, the "blind process" itself was compared to a poet, a composer, a sculptor, Shakespeare—to the very notion of creativity that the idea of natural selection had originally replaced. It is clear, I think, that there was something very, very wrong with such an idea. [Bethell 1976.]

Or something very, very right. It seems to skeptics like Bethell that there is something willfully paradoxical in calling the process of evolution the blind watchmaker" (Dawkins 1986a), for this takes away with the left hand

("blind") the very discernment, purpose, and foresight it gives with the right hand. But others see that this manner of speaking—and we shall find that it is not just ubiquitous but irreplaceable in contemporary biology—is just the right way to express the myriads of detailed discoveries that Darwinian theory helps to expose. There is simply no denying the breathtaking brilliance of the designs to be found in nature. Time and again, biologists baffled by some apparently futile or maladroit bit of bad design in nature have eventually come to see that they have underestimated the ingenuity, the sheer brilliance, the depth of insight to be discovered in one of Mother Nature's creations. Francis Crick has mischievously baptized this trend in the name of his colleague Leslie Orgel, speaking of what he calls "Orgel's Second Rule: Evolution is cleverer than you are." (An alternative formulation: Evolution is cleverer than Leslie Orgel!)

Darwin shows us how to climb from "Absolute Ignorance" (as his outraged critic said) to creative genius without begging any questions, but we must tread very carefully, as we shall see. Among the controversies that swirl around us, most if not all consist of different challenges to Darwin's claim that he can take us all the way to *here* (the wonderful world we inhabit) from *there* (the world of chaos or utter undesignedness) in the time available without invoking anything beyond the mindless mechanicity of the algorithmic processes he had proposed. Since we have reserved the vertical dimension of the traditional Cosmic Pyramid as a measure of (intuitive) designedness, we can dramatize the challenge with the aid of another fantasy item drawn from folklore.

> *skyhook,* orig. Aeronaut. An imaginary contrivance for attachment to the sky; an imaginary means of suspension in the sky. *[Oxford English Dictionary.}*

The first use noted by the *OED* is from 1915: "an aeroplane pilot commanded to remain in place (aloft) for another hour, replies 'the machine is not fitted with skyhooks.' " The skyhook concept is perhaps a descendant of the *dens ex machina* of ancient Greek dramaturgy, when second-rate playwrights found their plots leading their heroes into inescapable difficulties, they were often tempted to crank down a god onto the scene, like Super-man, to save the situation supernaturally. Or skyhooks may be an entirely independent creation of convergent folkloric evolution. Skyhooks would be wonderful things to have, great for lifting unwieldy objects out of difficult circumstances, and speeding up all sorts of construction projects. Sad to say, they are impossible.[5]

5. Well, not quite impossible. Geostationary satellites, orbiting in unison with the Earth's rotation, are a kind of real, nonmiraculous skyhook. What makes them so valuable—what makes them financially sound investments—is that we often do want very much to attach something (such as an antenna or a camera or telescope) to a place high in the sky. Satellites are impractical for *lifting,* alas, because they have to be placed so high in the sky. The idea has been carefully explored. It turns out that a rope of the strongest artificial fiber yet made would have to be over a hundred meters in diameter at the top—it could taper to a nearly invisible fishing line on its way down—just to suspend its own weight, let alone any payload. Even if you could spin such a cable, you wouldn't want it falling out of orbit onto the city below!

There are cranes, however. Cranes can do the lifting work our imaginary skyhooks might do, and they do it in an honest, non-question-begging fashion. They are expensive, however. They have to be designed and built, from everyday parts already on hand, and they have to be located on a firm base of existing ground. Skyhooks are miraculous lifters, unsupported and insupportable. Cranes are no less excellent as lifters, and they have the decided advantage of being real. Anyone who is, like me, a lifelong onlooker at construction sites will have noticed with some satisfaction that it sometimes takes a small crane to set up a big crane. And it must have occurred to many other onlookers that in principle this big crane could be used to enable or speed up the building of a still more spectacular crane. Cascading cranes is a tactic that seldom if ever gets used more than once in real-world construction projects, but in principle there is no limit to the number of cranes that could be organized in series to accomplish some mighty end.

Now imagine all the "lifting" that has to get done in Design Space to create the magnificent organisms and (other) artifacts we encounter in our world. Vast distances must have been traversed since the dawn of life with the earliest, simplest self-replicating entities, spreading outward (diversity) and upward (excellence). Darwin has offered us an account of the crudest, most rudimentary, stupidest imaginable lifting process—the wedge of natural selection. By taking tiny—the tiniest possible—steps, this process can gradually, over eons, traverse these huge distances. Or so he claims. At no point would anything miraculous—from on high—be needed. Each step has been accomplished by brute, mechanical, algorithmic climbing, from the base already built by the efforts of earlier climbing.

It does seem incredible. Could it really have happened? Or did the process need a "leg up" now and then (perhaps only at the very beginning) from one sort of skyhook or another? For over a century, skeptics have been trying to find a proof that Darwin's idea just can't work, at least not *all the way*. They have been hoping for, hunting for, praying for skyhooks, as exceptions to what they see as the bleak vision of Darwin's algorithm churning away. And time and again, they have come up with truly interesting challenges—leaps and gaps and other marvels that do seem, at first, to need

skyhooks. But then along have come the cranes, discovered in many cases by the very skeptics who were hoping to find a skyhook.

It is time for some more careful definitions. Let us understand that a *skyhook* is a "mind-first" force or power or process, an exception to the principle that all design, and apparent design, is ultimately the result of mindless, motiveless mechanicity. A *crane,* in contrast, is a subprocess or special feature of a design process that can be demonstrated to permit the local speeding up of the basic, slow process of natural selection, *and* that can be demonstrated to be itself the predictable (or retrospectively explicable) product of the basic process. Some cranes are obvious and uncon-troversial; others are still being argued about, very fruitfully. Just to give a general sense of the breadth and application of the concept, let me point to three very different examples.

It is now generally agreed among evolutionary theorists that *sex* is a crane. That is, species that reproduce sexually can move through Design Space at a much greater speed than that achieved by organisms that reproduce asexually. Moreover, they can "discern" design improvements along the way that are all but "invisible" to asexually reproducing organisms (Holland 1975). This cannot be the *raison d'etre* of sex, however. Evolution cannot see way down the road, so anything it builds must have an immediate payoff to counterbalance the cost. As recent theorists have insisted, the "choice" of reproducing sexually carries a huge *immediate* cost: organisms send along only 50 percent of their genes in any one transaction (to say nothing of the effort and risk involved in securing a transaction in the first place). So the *long-term* payoff of heightened efficiency, acuity, and speed of the redesign process—the features that make sex a magnificent crane—is as nothing to the myopic, local competitions that must determine which organisms get favored in the very next generation. Some other, short-term, benefit must have maintained the positive selection pressure required to make sexual reproduction an offer few species could refuse. There are a variety of compelling—and competing—hypotheses that might solve this puzzle, which was first forcefully posed for biologists by John Maynard Smith (1978). For a lucid introduction to the current state of play, see Matt Ridley 1993- (More on this later.)

What we learn from the example of sex is that a crane of great power may exist that was not created *in order to exploit* that power, but for other reasons, although its power as a crane may help explain why it has been maintained ever since. A crane that was obviously created to be a crane is *genetic engineering*. Genetic engineers—human beings who engage in recombinant-DNA tinkering—can now unquestionably take huge leaps through Design Space, creating organisms that would never have evolved by "ordinary" means. This is no miracle—*provided that genetic engineers (and the artifacts they use in their trade) are themselves wholly the products of*

earlier, slower evolutionary processes. If the creationists were right that mankind is a species unto itself, divine and inaccessible via brute Darwinian paths, then genetic engineering would not be a crane after all, having been created with the help of a major skyhook. I don't imagine that any genetic engineers think of themselves this way, but it is a logically available perch, however precarious. Less obviously silly is this idea: if the bodies of genetic engineers are products of evolution, but their *minds* can do creative things that are irreducibly nonalgorithmic or inaccessible by all algorithmic paths, then the leaps of genetic engineering might involve a skyhook. Exploring this prospect will be the central topic of chapter 15.

A crane with a particularly interesting history is theBaldwin-Effect, named for one of its discoverers, James Mark Baldwin (1896), but more or less simultaneously discovered by two other early Darwinians, Conwy Lloyd Morgan (famed for Lloyd Morgan's Canon of Parsimony [for discussion, see Dennett 1983]) and H. F. Osborn. Baldwin was an enthusiastic Darwinian, but he was oppressed by the prospect that Darwin's theory would leave Mind with an insufficiently important and originating role in the (redesign of organisms. So he set out to demonstrate that animals, *by dint of their own clever activities in the world,* might hasten or guide the further evolution of their species. Here is what he asked himself: how could it be that individual animals, by solving problems in their own lifetimes, could change the conditions of competition for their own offspring, making those problems easier to solve in the future? And he came to realize that this was in fact possible, under certain conditions, which we can illustrate with a simple example (drawn, with revisions, from Dennett 1991a).

Consider a population of a species in which there is considerable variation at birth in the way their brains are wired up. Just one of the ways, we may suppose, endows its possessor with a Good Trick—a behavioral talent that protects it or enhances its chances dramatically. The standard way of representing such differences in fitness between individual members of a population is known as an "adaptive landscape" or a "fitness landscape" (S. Wright 1931). The altitude in such a diagram stands for fitness (higher is better), and the longitude and latitude stand for some factors of individual design—in this case, features of brain-wiring. Each different way a brain might be wired is represented by one of the rods that compose the land-scape—each rod is a different *genotype*. The fact that just one of the com-binations of features is any good—that is, any better than run-of-the-mill—is illustrated by the way it stands out like a telephone pole in the desert.

As figure 3.1 makes clear, only one wiring is favored; the others, no matter how "close" to being the good wiring, are about equal in fitness. So such an isolated peak is indeed a needle in the haystack: it will be practically invis-ible to natural selection. Those few individuals in the population that are lucky enough to have the Good Trick genotype will typically have difficulty

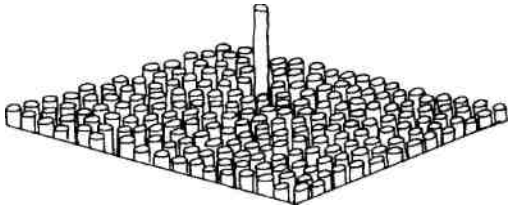

FIGURE 3.1

passing it on to their offspring, since under most circumstances their chances of finding a mate who also has the Good Trick genotype are remote, and a miss is as good as a mile.

But now we introduce just one "minor" change: suppose that although the individual organisms *start out* with different wirings (whichever wiring was ordered by their particular genotype or genetic recipe)—as shown by their scatter on the fitness landscape—they have some capacity to adjust or revise their wiring, depending on what they encounter during their lifetimes. (In the language of evolutionary theory, there is some "plasticity" in their *phenotypes*. The phenotype is the eventual body design created by the genotype in interaction with environment. Identical twins raised in different environments would share a genotype but might be dramatically different in phenotype.) Suppose, then, that these organisms can end up, after exploration, with a design different from the one they were born with. We may suppose their explorations are random, but they have an innate capacity to recognize (and stay with) a Good Trick when they stumble upon it. Then those individuals who begin life with a genotype that is closer to the Good Trick genotype—fewer redesign steps away from it—are more likely to come across it, and stick with it, than those that are born with a faraway design.

This head start in the race to redesign themselves can give them the edge in the Malthusian crunch—if the Good Trick is so good that those who never learn it, or who learn it "too late," are at a severe disadvantage. In populations with this sort of phenotypic plasticity, a near-miss is *better* than a mile. For such a population, the telephone pole in the desert becomes the summit of a gradual hill, as in figure 32; those perched near the summit, although they start out with a design that serves them no better than others, will tend to discover the summit design in short order.

In the long run, natural selection—redesign at the genotype level—will tend *to follow the lead* o/and *confirm* the directions taken by the individual organisms' successful explorations—redesign at the individual or phenotype level.

The way I have just described the Baldwin Effect certainly keeps Mind to

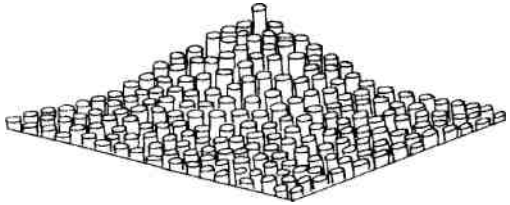

FIGURE 3.2

a minimum, if not altogether out of the picture; all it requires is some brute, mechanical capacity to stop a random walk when a Good Thing comes along, a minimal capacity to "recognize" a tiny bit of progress, to "learn" something by blind trial and error. In fact, I have put it in *behavioristic* terms. What Baldwin discovered was that creatures capable of "reinforcement learning" not only do better individually than creatures that are entirely "hard-wired"; their species will *evolve faster* because of its greater capacity to discover design improvements in the neighborhood.[6] This is not how Baldwin described the effect he proposed. His temperament was the farthest thing from behaviorism. As Richards notes:

> The mechanism conformed to ultra-Darwinian assumptions, but nonetheless allowed consciousness and intelligence a role in directing evolution. By philosophic disposition and conviction, Baldwin was a spiritualistic metaphysician. He felt the beat of consciousness in the universe; it pulsed through all the levels of organic life. Yet he understood the power of mechanistic explanations of evolution. [R.J. Richards 1987, p. 480.][7]

The Baldwin Effect, under several different names, has been variously described, defended, and disallowed over the years, and recently independently rediscovered several more times (e.g., Hinton and Nowland 1987).

6. Schull (1990), is responsible for the perspective that allows us to see species as variably capable of "seeing" design improvements, thanks to their variable capacities for phenotypic exploration (for commentary, see Dennett 1990a).

7. Robert Richards' account of the history of the Baldwin Effect (1987, especially pp. 480-503 and discussion later in that book) has been one of the major provocations and guides to my thinking in this book. What I found particularly valuable (see my review, Dennett 1989a) was that Richards not only shares with Baldwin and many other Darwinians a submerged yearning for skyhooks—or at least a visceral dissatisfaction with theories that insist on cranes—but also has the intellectual honesty and courage to expose and examine his own discomfort with what he is obliged to call "ultra-Darwinism." Richards' heart is clearly with Baldwin, but his mind won't let him bluster, or try to paper °ver the cracks he sees in the dikes that others have tried to erect against universal acid.

Although it has been regularly described and acknowledged in biology textbooks, it has typically been shunned by overcautious thinkers, because they thought it smacked of the Lamarckian heresy (the presumed possibility of inheritance of acquired characteristics—see chapter 11 for a detailed discussion). This rejection is particularly ironic, since, as Richards notes, it was intended by Baldwin to be—and truly is—an acceptable *substitute* for Lamarckian mechanisms.

> The principle certainly seemed to dispatch Lamarckism, while supplying that positive factor in evolution for which even staunch Darwinists like Lloyd Morgan longed. And to those of metaphysical appetite, it revealed that under the clanking, mechanical vesture of Darwinian nature, mind could be found. [R. J. Richards 1987, p. 487]

Well, not Mind—if by that we mean a full-fledged, intrinsic, original, skyhook-type Mind—but only a nifty mechanistic, behavioristic, crane-style mind. That is not nothing, however; Baldwin discovered an effect that genuinely increases the power—locally—of the underlying process of natural selection wherever it operates. It shows how the "blind" process of the basic phenomenon of natural selection can be abetted by a limited amount of "look-ahead" in the activities of individual organisms, which create fitness differences that natural selection can then act upon. This is a welcome complication, a wrinkle in evolutionary theory that removes one reasonable and compelling source of doubt, and enhances our vision of the power of Darwin's idea, especially when it is cascaded in multiple, nested applications. And it is typical of the outcome of other searches and controversies we will explore: the motivation, the passion that drove the research, was the hope of finding a skyhook; the triumph was finding how the same work could be done with a crane.

5. WHO'S AFRAID OF REDUCTIONISM?

> *Reductionism is a dirty word, and a kind of 'holistier than thou' self-righteousness has become fashionable.*
>
> —RICHARD DAWKINS 1982, p. 113

The term that is most often bandied about in these conflicts, typically as a term of abuse, is "reductionism." Those who yearn for skyhooks call those who eagerly settle for cranes "reductionists," and they can often make reductionism seem philistine and heartless, if not downright evil. But like most terms of abuse, "reductionism" has no fixed meaning. The central image is of somebody claiming that one science "reduces" to another: that

chemistry reduces to physics, that biology reduces to chemistry, that the social sciences reduce to biology, for instance. The problem is that there are both bland readings and preposterous readings of any such claim. According to the bland readings, it is possible (and desirable) to *unify* chemistry and physics, biology and chemistry, and, yes, even the social sciences and biology. After all, societies are composed of human beings, who, as mammals, must fall under the principles of biology that cover all mammals. Mammals, in turn, are composed of molecules, which must obey the laws of chemistry, which in turn must answer to the regularities of the underlying physics. No sane scientist disputes this bland reading; the assembled Justices of the Supreme Court are as bound by the law of gravity as is any avalanche, because they are, in the end, also a collection of physical objects. According to the preposterous readings, reductionists want to abandon the principles, theories, vocabulary, laws of the higher-level sciences, in favor of the lower-level terms. A reductionist dream, on such a preposterous reading, might be to write "A Comparison of Keats and Shelley from the Molecular Point of View" or "The Role of Oxygen Atoms in Supply-Side Economics," or "Explaining the Decisions of the Rehnquist Court in Terms of Entropy Fluctuations." Probably nobody is a reductionist in the preposterous sense, and everybody should be a reductionist in the bland sense, so the "charge" of reductionism is too vague to merit a response. If somebody says to you, "But that's so reductionistic!" you would do well to respond, "That's such a quaint, old-fashioned complaint! What on Earth did you have in mind?"

I am happy to say that in recent years, some of the thinkers I most admire have come out in defense of one or another version of reductionism, carefully circumscribed. The cognitive scientist Douglas Hofstadter, in *Godel Escher Bach,* composed a "Prelude ... Ant Fugue" (Hofstadter 1979, pp. 275-336) that is an analytical hymn to the virtues of reductionism in its proper place. George C. Williams, one of the pre-eminent evolutionists of the day, published "A Defense of Reductionism in Evolutionary Biology" (1985). The zoologist Richard Dawkins has distinguished what he calls hierarchical or gradual reductionism from precipice reductionism; he rejects only the precipice version (Dawkins 1986b, p. 74).[8] More recently the physicist Steven Weinberg, in *Dreams of a Final Theory* (1992), has written a chapter entitled "Two Cheers for Reductionism," in which he distinguishes between uncompromising reductionism (a bad thing) and compromising reductionism (which he ringingly endorses). Here is my own version. We must distinguish reductionism, which is in general a good

• See also his discussion of Lewontin, Rose, and Kamin's (1984) idiosyncratic version of reductionism—Dawkins aptly calls it their "private bogey"—in the second edition of *The Selfish Gene (1989),* p. 331.

thing, from *greedy reductionism,* which is not. The difference, in the context of Darwin's theory, is simple: greedy reductionists think that everything can be explained without cranes; good reductionists think that everything can be explained without skyhooks.

There is no reason to be compromising about what I call good reductionism. It is simply the commitment to non-question-begging science without any cheating by embracing mysteries or miracles at the outset. (For another perspective on this, see Dennett 1991a, pp. 33-39.) *Three* cheers for that brand of reductionism—and I'm sure Weinberg would agree. But in their eagerness for a bargain, in their zeal to explain too much too fast, scientists and philosophers often underestimate the complexities, trying to skip whole layers or levels of theory in their rush to fasten everything securely and neatly to the foundation. That is the sin of greedy reductionism, but notice that it is only when overzealousness leads to falsification of the phenomena that we should condemn it. In itself, the desire to reduce, to unite, to explain it all in one big overarching theory, is no more to be condemned as immoral than the contrary urge that drove Baldwin to his discovery. It is not wrong to yearn for simple theories, or to yearn for phenomena that no simple (or complex!) theory could ever explain; what is wrong is zealous misrepresentation, in either direction.

Darwin's dangerous idea is reductionism incarnate,[9] promising to unite and explain just about everything in one magnificent vision. Its being the idea of an *algorithmic* process makes it all the more powerful, since the substrate neutrality it thereby possesses permits us to consider its application to just about anything. It is no respecter of material boundaries. It applies, as we have already begun to see, even to itself. The most common fear about Darwin's idea is that it will not just explain but *explain away* the Minds and Purposes and Meanings that we all hold dear. People fear that once this universal acid has passed through the monuments we cherish, they will cease to exist, dissolved in an unrecognizable and unlovable puddle of scientistic destruction. This cannot be a sound fear; a *proper* reductionists explanation of these phenomena would leave them still standing but just demystified, unified, placed on more secure foundations. We might learn some surprising or even shocking things about these treasures, but unless our valuing these things was based all along on confusion or mistaken identity, how could increased understanding of them diminish their value in our eyes?[10]

9. Yes, incarnate. Think about it: would we want to say it was reductionism *in spirit?*

10. Everybody knows how to answer this rhetorical question with another: "Are you so in love with Truth at all costs that you would want to know if your lover were unfaithful to you?" We are back where we started. I for one answer that I love the world so much that I am sure I want to know the truth about it.

A more reasonable and realistic fear is that the greedy abuse of Darwinian reasoning might lead us to deny the existence of real levels, real complexities, real phenomena. By our own misguided efforts, we might indeed come to discard or destroy something valuable. We must work hard to keep these two fears separate, and we can begin by acknowledging the pressures that tend to distort the very description of the issues. For instance, there is a strong tendency among many who are uncomfortable with evolutionary theory to exaggerate the amount of disagreement among scientists ("It's just a theory, and there are many reputable scientists who don't accept this"), and I must try hard not to overstate the compensating case for what "science has shown." Along the way, we will encounter plenty of examples of genuine ongoing scientific disagreement, and unsettled questions of fact. There is no reason for me to conceal or downplay these quandaries, for no matter how they come out, a certain amount of corrosive work has already been done by Darwin's dangerous idea, and can never be undone.

We should be able to agree about one result already. Even if Darwin's relatively modest idea about the origin of species came to be *rejected* by science—yes, utterly discredited and replaced by some vastly more powerful (and currently unimaginable) vision—it would still have irremediably sapped conviction in any reflective defender of the tradition expressed by Locke. It has done this by opening up new possibilities of imagination, and thus utterly destroying any illusions anyone might have had about the soundness of an argument such as Locke's *a priori* proof of the *inconceivability* of Design without Mind. Before Darwin, this was inconceivable in the pejorative sense that no one knew how to take the hypothesis seriously. Proving it is another matter, but the evidence does in fact mount, and we certainly can and must take it seriously. So whatever else you may think of Locke's argument, it is now as obsolete as the quill pen with which it was written, a fascinating museum piece, a curiosity that can do no real work in the intellectual world today.

CHAPTER 3: *Darwin's dangerous idea is that Design can emerge from mere Order via an algorithmic process that makes no use of pre-existing Mind. Skeptics have hoped to show that at least somewhere in this process, a helping hand (more accurately, a helping Mind) must have been provided—a skyhook to do some of the lifting. In their attempts to prove a role for skyhooks, they have often discovered cranes: products of earlier algorithmic processes that can amplify the power of the basic Darwinian algorithm, making the process locally swifter and more efficient in a nonmiraculous way. Good reductionists suppose that all Design can be explained without skyhooks; greedy reductionists suppose it can all be explained without cranes.*