*The Cosmic Blueprint*

## *Also by Paul Davies*

---

*The Mind of God*
*The Matter Myth* (with J. Gribbin)
*Are We Alone?*
*The Last Three Minutes*
*About Time*
*The Fifth Miracle* (titled *The Origin of Life* in the UK edition)
*How to Build a Time Machine*
*The Big Questions*
*More Big Questions*
*The Runaway Universe*
*Other Worlds*
*The Edge of Infinity*
*God and the New Physics*
*Superforce*

### Student Texts

*Space and Time in the Modern Universe*
*The Forces of Nature*
*The Search for Gravity Waves*
*The Accidental Universe*
*Quantum Mechanics* (with D. Betts)

### Technical

*The Physics of Time Asymmetry*
*Quantum Fields in Curved Space* (with N. D. Birrell)
*The New Physics*
*Science and Ultimate Reality* (with J. Barrow & C, Harper)

# *The* COSMIC *Blueprint*

New Discoveries
in Nature's Creative Ability
to Order the Universe

*Paul Davies*

Templeton Foundation Press
Philadelphia & London

Templeton Foundation Press
300 Conshohocken State Road, Suite 550
West Conshohocken, PA 19428
www.templetonpress.org

Originally published by Simon and Schuster
Templeton Foundation Press Paperback Edition 2004


*Templeton Foundation Press helps intellectual leaders and others learn about science research on aspects of realities, invisible and intangible. Spiritual realities include unlimited love, accelerating creativity, worship, and the benefits of purpose in persons and in the cosmos.*

Library of Congress Cataloging in Publication Data

Davies, P. C. W.
Cosmic blueprint : new discoveries in nature's creative ability to order the universe / Paul Davies. -- Templeton Foundation Press pbk. ed.
p. cm.
Includes bibliographical references and index.
ISBN 1-932031-66-9 (pbk. : alk. paper)
I. Force and energy. 2. Matter. 3. Self-organizing systems. 4. Cosmology.
I. Title.
QC73.D383 2004
531'.6--dc22

2004002604

Printed in the United States of America

04 05 06 07 08 8 7 6 5 4 3 2 1

And whether or not it is clear to you, no doubt the universe is unfolding as it should.

*Max Ehrmann*

# *Contents*

# *Preface to the 2004 Edition*

From a casual glance about us, the physical world appears to be completely incomprehensible. The universe is so complicated, its structures and processes so diverse and fitful, there seems to be no reason why human beings should ever come to understand it. Yet the entire scientific enterprise is founded on the audacious assumption—accepted as an act of faith by scientists—that beneath the baffling kaleidoscope of phenomena that confront our inspection lies a hidden mathematical order. More than this. Science proceeds on the basis that the underlying order in nature can, at least in part, be grasped by the human intellect.

Following three centuries of spectacular progress, the scientific frontier may conveniently be divided into three broad categories: the very large, the very small and the very complex. The first category deals with cosmology, the overall structure and evolution of the universe. The second is the realm of subatomic particle physics and the search for the fundamental building blocks of matter. In recent years these two disciplines have begun to merge, with the realization that the big bang that started the universe off about 14 billion years ago would have released enormous energy, fleetingly exposing the ultimate constituents of matter. Cosmologists suppose that the large scale structure of the universe owes its origin to super-energetic subnuclear processes in the first split-second of its existence. In this way, subatomic physics helps shape the overall properties of the universe. Conversely, the manner in which the universe came to exist served to determine the number and properties of the fundamental particles of matter that were coughed out of the big bang. Thus the large determines the small even as the small determines the large.

By contrast, the third great frontier of research—the very complex—remains in its infancy. Complexity is, by its very nature, complicated, and so hard to understand. But what is becoming clear is that complexity does not always amount to messy, idiosyncratic complication. In many cases, beneath the surface of chaotic or complicated behaviour simple mathematical principles are at work. The advent of ever-greater computational power has led to an increasing understanding of the different types of complexity found in nature, and a growing belief in the existence of distinct laws of complexity that complement, but do not violate, the familiar laws of physics.

The first edition of this book was published in the 1980s, when chaos theory had received wide publicity. Although the roots of chaos theory date back a century or more, it came to prominence with the realization that chaos is a general feature of dynamical systems, so that randomness and unpredictability afflict not just the weather and biodiversity, but even such everyday systems as the stock market. Today, scientists accept that chaos theory describes just one among a diverse range of complex behaviours found in nature, and that a full understanding of complexity involves far more than simply identifying the difference between regular and irregular behaviour.

Just as the sciences of the large and small have begun to merge, so has the study of the very complex begun to overlap with that of the microworld. The most exciting developments are taking place at the interface of biological, chemical and computational systems. The acronym BINS has been coined for 'bio-info-nano systems'. These refer to the realm of molecular machines (so-called nanotechnology, on the scale of one-billionth of a metre) and information-processing systems, of which the living cell is a classic natural example. In the last decade, a central goal of this field has been the attempt to build a quantum computer. This is a device designed to exploit quantum weirdness to process information. The power of quantum systems is that they may exist in many different configurations simultaneously. An atom, for example, might be both excited and unexcited at the same time. By attaching information to certain special quantum states, physicists hope to process it exponentially faster than in a conventional computer. If this quest succeeds—and the research is still in its infancy—it will transform not only the investigation of complexity, but our very understanding of what is meant by the term.

In Chapter 12 I toy with the idea that quantum mechanics may hold the key to a better appreciation of biological complexity—the thing that distinguishes life from complex inanimate systems. Since formulating these early ideas in the original edition of this book, I have developed the subject in greater depth, and readers are referred to my book *The Fifth Miracle* (re-titled *The Origin of Life* in the UK) for more on quantum biology. It is my belief that quantum nano-machines will soon blur the distinction between the living and the nonliving, and that the secret of life will lie with the extraordinary information processing capabilities of living systems. The impending merger of the subjects of information, computation, quantum mechanics and nanotechnology will lead to a revolution in our understanding of bio-systems.

Many of the puzzles I wrote about in 1988, such as the origin of life, remain deeply problematic, and there is little I wish to add. The one field that has advanced spectacularly in the intervening years, however, is cosmology. Advances in the last decade have transformed the subject from a speculative backwater to a mainstream scientific discipline. Consider, for example, the data from a satellite called the Wilkinson Microwave Anisotropy Probe, or WMAP, published in 2003. Newspapers across the world carried a picture showing a thermal map of the sky built up painstakingly from high Earth orbit. In effect, it is a snapshot of what the universe looked like 380,000 years after its birth in a hot big bang. The searing heat that accompanied the origin of the universe has now faded to a gentle afterglow that bathes the whole universe. WMAP was designed to map that dwindling primordial heat, which has been travelling almost undisturbed for over 13 billion years. Enfolded in the blobs and splodges of the map are the answers to key cosmic questions, such as how old the universe is, what it is made of and how it will die. By mining the map for data, scientists have been able to reconstruct an accurate account of the universe in unprecedented detail.

Perhaps the most significant fact to emerge from the results of WMAP, and many ground-based observations, is the existence of a type of cosmic antigravity, now dubbed 'dark energy'. The story goes back to 1915, when Einstein published his general theory of relativity. This work of pure genius offered a totally new description of gravity, the force that keeps our feet on the ground, and acts between all bodies in the universe, trying to pull them together. But this universal attraction presented Einstein with a headache. Why, he asked, doesn't the universe just collapse into a big heap, dragged inward by its own colossal weight? Was there something fundamentally wrong with his new theory?

Today we know the answer. The universe hasn't collapsed (at least yet) because the galaxies are flying apart, impelled by the power of the big bang. But in 1915 nobody knew the universe was expanding. So Einstein set out to describe a static universe. To achieve this he dreamed up the idea of antigravity. This hitherto unknown force would serve to oppose the weight of the universe, shoring it up and averting collapse. To incorporate antigravity into his theory of relativity, Einstein tinkered with his original equations, adding an extra term that has been cynically called 'Einstein's fudge factor'.

It was immediately obvious that antigravity is like no other known force. For a start, it had the peculiar property of increasing with distance. This means we would never notice its effects on Earth or even in the solar system. But over cosmic dimensions it builds in strength to a point where, if the numbers are juggled right, it could exactly balance the attractive force of gravity between all the galaxies.

It was a neat idea, but short-lived. It crumbled in the 1920s when Edwin Hubble found that the universe is expanding. When Einstein met Hubble in 1931 he immediately realised that antigravity is unnecessary, and abandoned it, called it 'the biggest blunder of my life'. After this debacle, antigravity was firmly off the cosmological agenda. When I was a student in the 1960s it was dismissed as repulsive in both senses of the word. But as so often in science, events took an unexpected turn. Just because antigravity wasn't needed for its original purpose didn't logically mean it was nonexistent, and in the 1970s the idea popped up again in an entirely different context. For forty years physicists had been puzzling over the nature of empty space. Quantum mechanics, which deals with processes on a subatomic scale, predicted that even in the total absence of matter, space should be seething with unseen, or dark, energy. Einstein's famous formula $E=mc^2$ implies that this dark energy should possess mass, and as a result it should exert a gravitational pull. Put simply, quantum mechanics implies that even totally empty space has weight.

At first sight this seems absurd. How can space itself—a vacuum—weigh anything? But since it's impossible to grab a bit of empty space and put it on a pair of scales, the claim isn't easy to test. Only by weighing the universe as a whole can the weight of its (very considerable) space be measured. Weighing the universe is no mean feat, but as I shall shortly discuss, it can be done.

Before getting into the question of how much a given volume of space weighs, a tricky aspect of dark energy needs to be explained. Space doesn't just have weight, it exerts a pressure too. In Einstein's theory, pressure as well as mass generates a gravitational pull. For example, the Earth's internal pressure contributes a small amount to your body weight. This is confusing, because pressure pushes outward, yet it creates a gravitational force that pulls inwards. When it comes to dark energy, the situation is reversed—its pressure turns out to be negative. Put simply, space sucks. And just as pressure creates gravity, so sucking creates *antigravity*. When the sums are done, the conclusion is startling: space sucks so hard, its antigravity wins out. The upshot is that dark energy precisely mimics Einstein's fudge factor!

In spite of this amazing coincidence, few scientists took up the cause of dark energy. Theorists hoped it would somehow go away. Then in 1998 came a true bombshell. Astronomers in Australia and elsewhere were doing a head count of exploding stars. From the light of these so-called supernovae they could work out the distances the explosions occurred. It soon became clear that these violent events were situated too far away to fit into the standard model of a universe that started out with a big bang and then progressively slowed its expansion over time. The only explanation seemed to be that, some time in the past, the pace of expansion had begun to pick up again, as if driven by a mysterious cosmic repulsion. Suddenly dark energy was back in vogue.

The results from such surveys, together with those of WMAP, indicate that only about 5 percent of the universe is made of normal matter such as atoms. About a quarter consists of some sort of dark matter yet to be identified, but widely believed to be exotic subatomic particles coughed out of the big bang. The lion's share of the universe is in the form of dark energy. To put a figure to it, the empty space of the observable universe weighs in at about a hundred trillion trillion trillion trillion tonnes, far more than all the stars combined. Large this may be, but to place it in context, the weight of the space inside a car is a few trillion-trillionths of a gram.

Theorists have no idea why the amount of dark energy weighs in at just the value it does. Indeed, they remain divided whether the dark energy is just Einstein's antigravity or some more complicated and exotic phenomenon. Whatever its explanation, dark energy probably seals the fate of the cosmos. As time goes on and the pace of cosmic expansion accelerates, so the galaxies will be drawn farther and farther apart, speeding up all the time. Eventually, even the galaxies near our own Milky Way (or what's left of it) will be receding faster than light, and so will be invisible. If nothing acts to change this trend, the ultimate state of the universe will be dark, near-empty space for all eternity. It is a depressing thought.

There is a glimmer of hope, however. The same physical processes that triggered the inflationary burst at the birth of the universe could, in principle, be re-created. With trillions of years to worry about it, our descendants in the far future might figure out a way to produce a new big bang in the laboratory, in effect creating a baby universe. Theory suggests that this new universe will balloon out, generating its own space and time as it goes, and will eventually disconnect itself from the mother universe. For a while, mother and baby will be joined by an umbilical cord of space, offering a bridge between the old universe and the new. Our descendants might be able to scramble into the new universe, and embark on a new cycle of cosmic evolution and development. This would be the ultimate in emigration: decamping to a brand-new cosmos, hopefully customised for bio-friendliness!

The dark energy idea has drifted in and out of favour for over seven decades. If the astronomical evidence is to be believed, it is now on again for good. Though dark energy predicts the demise of the universe, it might also contain the basis for cosmic salvation. If so, Einstein's greatest mistake could yet turn out to be his greatest triumph. And if the laws of the universe really are a sort of cosmic blueprint, as I suggest, they may also be a blueprint for survival.

Paul Davies
Sydney, January 2004

# *Preface to the First Edition*

The creation of the universe is usually envisaged as an abrupt event that took place in the remote past. It is a picture reinforced both by religion and by scientific evidence for a 'big bang'. What this simple idea conceals, however, is that the universe has never ceased to be creative.

Cosmologists now believe that immediately following the big bang the universe was in an essentially featureless state, and that all the structure and complexity of the physical world we see today somehow emerged afterwards. Evidently physical processes exist that can turn a void—or something close to it—into stars, planets, crystals, clouds and people.

What is the source of this astonishing creative power? Can known physical processes explain the continuing creativity of nature, or are there additional organizing principles at work, shaping matter and energy and directing them towards ever higher states of order and complexity?

Only very recently have scientists begun to understand how complexity and organization can emerge from featurelessness and chaos. Research in areas as diverse as fluid turbulence, crystal growth and neural networks is revealing the extraordinary propensity for physical systems to generate new states of order spontaneously. It is clear that there exist *self-organizing* processes in every branch of science.

A fundamental question then presents itself. Are the seemingly endless varieties of natural forms and structures, which appear as the universe unfolds, simply the accidental products of random forces? Or are they somehow the inevitable outcome of the creative activity of nature? The origin of life, for example, is regarded by some scientists as an extremely rare chance event, but by others as the natural end state of cycles of self-organizing chemical reactions. If the richness of nature is built into its laws, does this imply that the present state of the universe is in some sense predestined? Is there, to use a metaphor, a 'cosmic blueprint'?

These deep questions of existence are not, of course, new. They have been asked by philosophers and theologians for millennia. What makes them especially germane today is that important new discoveries are dramatically altering the *scientists*' perspective of the nature of the universe. For three centuries science has been dominated by the Newtonian and thermodynamic paradigms, which present the universe either as a sterile machine, or in a state of degeneration and decay. Now there is the new paradigm of the creative universe, which recognizes the progressive, innovative character of physical processes. The new paradigm emphasizes the collective, cooperative and organizational aspects of nature; its perspective is synthetic and holistic rather than analytic and reductionist.

This book is an attempt to bring these significant developments to the attention of the general reader. It covers new research in many disciplines, from astronomy to biology, from physics to neurology—wherever complexity and self-organization appear. I have tried to keep the presentation as non-technical as possible, but inevitably there are some key sections that require a more careful treatment. This is especially true of Chapter 4, which contains a number of technical diagrams. The reader is urged to persevere, however, for the essence of the new paradigm cannot be properly captured without some mathematical ideas.

In compiling the material I have been greatly assisted by my colleagues at the University of Newcastle upon Tyne, who do not, of course, necessarily share my conclusions. Particular thanks are due to Professor Kenneth Burton, Dr Ian Moss, Dr Richard Rohwer and Dr David Tritton. I should like to thank Dr John Barrow, Professor Roger Penrose and Professor Frank Tipler for helpful discussions.

P.D.

*The Cosmic Blueprint*

# 1

# *Blueprint for a Universe*

> God is no more an archivist unfolding an infinite sequence he had designed once and forever. He continues the labour of creation throughout time.
>
> —*Ilya Prigogine*[1]

## The origin of things

Something buried deep in the human psyche compels us to contemplate creation. It is obvious even at a casual glance that the universe is remarkably ordered on all scales. Matter and energy are distributed neither uniformly nor haphazardly, but are organized into coherent identifiable structures, occasionally of great complexity. From whence came the myriads of galaxies, stars and planets, the crystals and clouds, the living organisms? How have they been arranged in such harmonious and ingenious interdependence? The cosmos, its awesome immensity, its rich diversity of forms, and above all its coherent unity, cannot be accepted simply as a brute fact.

The existence of *complex* things is even more remarkable given the generally delicate and specific nature of their organization, for they are continually assailed by all manner of disruptive influences from their environment that care nothing for their survival. Yet in the face of an apparently callous Mother Nature the orderly arrangement of the universe not only manages to survive, but to prosper.

There have always been those who choose to interpret the harmony and order of the cosmos as evidence for a metaphysical designer. For them, the existence of complex forms is explained as a manifestation of the designer's creative power. The rise of modern science, however, transformed the rational approach to the problem of the origin of things. It was discovered that the universe has not always been as it is. The evidence of geology, palaeontology and astronomy suggested that the vast array of forms and structures that populate our world have not always existed, but have *emerged* over aeons of time.

Scientists have recently come to realize that none of the objects and systems that make up the physical world we now perceive existed in the beginning. Somehow, all the variety and complexity of the universe has arisen since its origin in an abrupt outburst called the big bang. The modern picture of Genesis is of a cosmos starting out in an utterly featureless state, and then progressing step by step—one may say unfolding—to the present kaleidoscope of organized activity.

## Creation from nothing

The philosopher Parmenides, who lived 1500 years before Christ, taught that 'nothing can come out of nothing'. It is a dictum that has been echoed many times since, and it forms the basis of the approach to creation in many of the world's religions, such as Judaism and Christianity. Parmenides' followers went much farther, to conclude that there can be no real change in the physical world. All apparent change, they asserted, is an illusion. Theirs is a dismally sterile universe, incapable of bringing forth anything fundamentally new.

Believers in Parmenides' dictum cannot accept that the universe came into existence spontaneously; it must either always have existed or else have been created by a supernatural power. The Bible states explicitly that God created the world, and Christian theologians advance the idea of creation *ex nihilo*—out of literally nothing. Only God, it is said, possesses the power to accomplish this.

The problem of the ultimate origin of the physical universe lies on the boundary of science. Indeed, many scientists would say it lies beyond the scope of science altogether. Nevertheless, there have recently been serious attempts to understand how the universe could have appeared from nothing without violating any physical laws. But how can something come into existence uncaused?

The key to achieving this seeming miracle is quantum physics. Quantum processes are inherently unpredictable and indeterministic; it is generally impossible to predict from one moment to the next how a quantum system will behave. The law of cause and effect, so solidly rooted in the ground of daily experience, fails here. In the world of the quantum, spontaneous change is not only permitted, it is unavoidable.

Although quantum effects are normally restricted to the microworld of atoms and their constituents, in principle quantum physics should apply to everything. It has become fashionable to investigate the quantum physics of the entire universe, a subject known as quantum cosmology. These investigations are tentative and extremely speculative, but they lead to a provocative possibility. It is no longer entirely absurd to imagine that the universe came into existence spontaneously from nothing as a result of a quantum process.

The fact that the nascent cosmos was apparently devoid of form and content greatly eases the problem of its ultimate origin. It is much easier to believe that a state of featureless simplicity appeared spontaneously out of nothing than to believe that the present highly complex state of the universe just popped into existence ready-made.

The amelioration of one problem, however, leads immediately to another. Science is now faced with the task of explaining by what physical processes the organized systems and elaborate activity that surround us today emerged from the primeval blandness of the big bang. Having found a way of permitting the universe to be self-creating we need to attribute to it the capability of being *self-organizing*.

An increasing number of scientists and writers have come to realize that the ability of the physical world to organize itself constitutes a fundamental, and deeply mysterious, property of the universe. The fact that nature has *creative power,* and is able to produce a progressively richer variety of complex forms and structures, challenges the very foundation of contemporary science. 'The greatest riddle of cosmology,' writes Karl Popper, the well-known philosopher, 'may well be . . . that the universe is, in a sense, creative.'[2]

The Belgian Nobel prize–winner Ilya Prigogine, writing with Isabelle Stengers in their book *Order Out of Chaos,* reaches similar conclusions:[3] 'Our universe has a pluralistic, complex character. Structures may disappear, but also they may appear.' Prigogine and Stengers dedicate their book to Erich Jantsch, whose earlier work *The Self-Organizing Universe* also expounds the view that nature has a sort of 'free will' and is thereby capable of generating novelty:[4] 'We may one day perhaps understand the self-organizing processes of a universe which is not determined by the blind selection of initial conditions, but has the potential of partial self-determination.'

These sweeping new ideas have not escaped the attention of the science writers. Louise Young, for example, in lyrical style, refers to the universe as 'unfinished', and elaborates Popper's theme:[5] 'I postulate that we are witnessing—and indeed participating in—a creative act that is taking place throughout time. As in all such endeavours, the finished product could not have been clearly foreseen in the beginning.' She compares the unfolding organization of the cosmos with the creative act of an artist: '. . . involving change and growth, it proceeds by trial and error, rejecting and reformulating the materials at hand as new potentialities emerge'.

In recent years much attention has been given to the problem of the so-called 'origin of the universe', and popular science books on 'the creation' abound. The impression is gained that the universe was created all at once in the big bang. It is becoming increasingly clear, however, that creation is really a continuing process. The existence of the universe is not explained by the big bang: the primeval explosion merely started things off.

Now we must ask: How can the universe, having come into being, subsequently bring into existence totally new things by following the laws of nature? Put another way: What is the source of the universe's creative potency? It will be the central question of this book.

## The whole and its parts

To most people it is obvious that the universe forms a coherent whole. We recognize that there are a great many components that go together to make up the totality of existence, but they seem to hang together, if not in cooperation, then at least in peaceful coexistence. In short, we find order, unity and harmony in nature where there might have been discord and chaos.

The Greek philosopher Aristotle constructed a picture of the universe closely in accord with this intuitive feeling of holistic harmony. Central to Aristotle's philosophy was the concept of *teleology* or, roughly speaking, final causation. He supposed that individual objects and systems subordinate their behaviour to an overall plan or destiny. This is especially apparent, he claimed, in living systems, where the component parts function in a cooperative way to achieve a final purpose or end product. Aristotle believed that living organisms behave as a coherent whole because there exists a full and perfect 'idea' of the entire organism, even before it develops. The development and behaviour of living things is thus guided and controlled by the global plan in order that it should successfully approach its designated end.

Aristotle extended this animistic philosophy to the cosmos as a whole. There exists, he maintained, what we might today term a *cosmic blueprint*.

The universe was regarded as a sort of gigantic organism, unfurling in a systematic and supervised way towards its prescribed destiny. Aristotelian finalism and teleology later found its way into Christian theology, and even today forms the basis of Western religious thought. According to Christian dogma, there is indeed a cosmic blueprint, representing God's design for a universe.

In direct opposition to Aristotle were the Greek atomists, such as Democritus, who taught that the world is nothing but atoms moving in a void. All structures and forms were regarded as merely different arrangements of atoms, and all change and process were thought of as due to the rearrangement of atoms alone. To the atomist, the universe is a machine in which each component atom moves entirely under the action of the blind forces produced by its neighbours. According to this scheme there are no final causes, no overall plan or end-state towards which things evolve. Teleology is dismissed as mystical. The only causes that bring about change are those produced by the shape and movement of other atoms.

Atomism is not suited to describe, let alone explain, the order and harmony of the world. Consider a living organism. It is hard to resist the impression that the atoms of the organism *cooperate* so that their collective behaviour constitutes a coherent unity. The organized functioning of biological systems fails to be captured by a description in which each atom is simply pushed or pulled along blindly by its neighbours, without reference to the global pattern. There was thus already present in ancient Greece the deep conflict between holism and reductionism which persists to this day. On the one hand stood Aristotle's synthetic, purposeful universe, and on the other a strictly materialistic world which could ultimately be analysed as, or reduced to, the simple mechanical activity of elementary particles.

In the centuries that followed, Democritus' atomism came to represent what we would now call the scientific approach to the world. Aristotelian ideas were banished from the physical sciences during the Renaissance. They survived somewhat longer in the biological sciences, if only because living organisms so distinctly display teleological behaviour. However, Darwin's theory of evolution and the rise of modern molecular biology led to the emphatic rejection of all forms of animism or finalism, and most modern biologists are strongly mechanistic and reductionist in their approach. Living organisms are today generally regarded as purely complex machines, programmed at the molecular level.

The scientific paradigm in which all physical phenomena are reduced to the mechanical behaviour of their elementary constituents has proved extremely successful, and has led to many new and important discoveries. Yet there is a growing dissatisfaction with sweeping reductionism, a feeling that the whole really is greater than the sum of its parts. Analysis and reduction will always have a central role to play in science, but many people cannot accept that it is an exclusive role. Especially in physics, the synthetic or holistic approach is becoming increasingly fashionable in tackling certain types of problem.

However, even if one accepts the need to complement reductionism with a holistic account of nature, many scientists would still reject the idea of a cosmic blueprint as too mystical, for it implies that the universe has a purpose and is the product of a metaphysical designer. Such beliefs have been taboo for a long time among scientists. Perhaps the apparent unity of the universe is merely an anthropocentric projection. Or maybe the universe behaves *as if* it is implementing the design of a blueprint, but nevertheless is still evolving in blind conformity with purposeless laws?

These deep issues of existence have accompanied the advance of knowledge since the dawn of the scientific era. What makes them so pertinent today is the sweeping nature of recent discoveries in cosmology, fundamental physics and biology. In the coming chapters we shall see how scientists, in building up a picture of how organization and complexity arise in nature, are beginning to understand the origin of the universe's creative power.