

ORDER AND DISORDER IN NATURE, SCIENCE, AND RELIGION

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A key to understanding the interrelations of physics in nature, of physics as a science, of biology in nature, of biology as a science lies in examining their concept of order and disorder. We have been living through a century of change in our ideas about how determinacy and contingency, design and chance, order and chaos fit together to make up the world. These changes, in turn, shape religion in its account of both science and nature.

Astrophysics and nuclear physics are describing a universe "fine-tuned" for life, although physics has also found a universe with indeterminacy at its most fundamental levels. Meanwhile, evolutionary and molecular biology seem to be discovering that the history of life is a random walk with much struggle and chance, although they have also found that, in this seemingly random walk, over millennia, order is built up a negentropic slope, attaining in Earth's natural history the most complex and highly ordered phenomena known in the universe, such as ecosystems, organism, and—most of all—the human mind.

But this disorder mixed with order has not only been found in what science studies. It has been revealed within the discipline of science itself. Science was, when I first studied it in mid-century, alleged to be the most rational and orderly of human pursuits; but, in recent decades, science too is seen to have its contingencies, its disorder, even its anarchy. The theological world, at least in my Calvinist rearing, was the scene of divine predestination and providence, as rigorous as ever was any scientific determinism; but that view too now has few defenders. Theologically, we live in a more open world; God writes history in the interplay of order and disorder.

1. Order in Physics

Physics has made dramatic discoveries at astronomical and submicroscopic ranges, remote from ordinary, native-range experience. The universe (this universe at least) originated twenty billion years ago in a "big bang" and has since been expanding. From the primal burst of energy, elementary particles formed, and afterward hydrogen, the

simplest element, which serves a fuel for the stars. In the stellar furnaces all the heavier atoms were forged. Some stars subsequently exploded (supernovae). The heavier elements were collected to form, in our case, the solar system and planet Earth.

In the last twenty years physics has discovered that startling interrelationships are required for these creative processes to work. Recent theory interrelates the two levels; astronomical phenomena such as the formation of galaxies, stars, and planets depend critically on the microphysical phenomena, such as the charges on particles and their energy transformations. In turn, the mid-range scales, where the known complexity mostly lies (in ecosystems or human brains), depend on the interacting microscopic and astronomical ranges. If the scale of the universe were much reduced, there would not have been enough time for elements to form. If the expansion rate of the universe had been a little faster or slower, then the universe would already have recollapsed or the galaxies and stars would not have formed.

Change slightly the strengths of any of the four forces that hold the world together (the strong nuclear force, the weak nuclear force, electromagnetism, gravitation—forces that range over forty orders of magnitude), change critical particle masses and charges, and the stars would burn too quickly or too slowly, or atoms and molecules, including water, carbon, and oxygen, or amino acids (building blocks of life) would not form or remain stable.

These results have been summarized as the "anthropic principle" (an unfortunately anthropocentric term), which argues that the universe has been "fine-tuned" from the start and in its fundamental construction for the subsequent construction of stars, planets, life, and mind. There are nontheological, naturalistic ways of interpreting these discoveries, but a plausible interpretation is divine design. Theologians and philosophers have often been wary of design arguments, remembering William Paley, his fine-tuned watch, and the many telling criticisms of such arguments. Nevertheless the physical world is resembling a fine-tuned watch

again, and now many quantitative calculations support the argument.

Astrophysicists and microphysicists have joined to discover that, in the explosion that produced our universe, what seem to be widely varied facts really cannot vary widely, indeed that many of them can hardly vary at all, and have the universe develop life and mind. We find a single blast (the big bang) fine-timed to produce a world that produces us, when any of a thousand other imaginable blasts would have yielded nothing. Our arrival entitles us to suspect a Friend behind the blast,

When we consider the first seconds of the big bang, writes astronomer Bernard Lovell, "it is an astonishing reflection that at this critical early moment in the history of the universe, all of the hydrogen would have turned into helium if the force of attraction between protons—that is, the nuclei of the hydrogen atoms—had been only a few percent stronger. . . . No galaxies, no stars, no life would have emerged. It would have been a universe forever unknowable by living creatures. A remarkable and intimate relationship between man, the fundamental constants of nature and the initial moments of space and time seems to be an inescapable condition of our existence"¹

Cosmologists B J. Carr and MX Rees conclude, "Many interrelations between different scales that at first sight seem surprising are straightforward consequences of simple physical arguments. But several aspects of our Universe—some of which seem to be prerequisites for the evolution of any form of life—depend rather delicately on apparent 'coincidences' among the physical constants. . . . The Universe must be as big and diffuse as it is to last long enough to give rise to life"²

Astronomer Fred Hoyle reports that his atheism was shaken by his own discovery that in the stars carbon just manages to form and then just avoids complete conversion into oxygen. If one level had varied half a percent, life would have been impossible. "Would you not say to yourself, . . . 'Some supercalculating intellect must have designed the properties of the carbon atom, otherwise the chance of my finding such an atom through the blind forces of nature would be utterly minuscule'?" Of course you would. . . . The carbon atom is a fix. . . . A common sense interpretation of the facts suggests that a superintellect has monkeyed with the physics. . . . The numbers one calculates from the facts seem to me so overwhelming as to put this conclusion almost beyond question."³

"Somebody had to tune it very precisely," concludes Marek Demianski, a Polish cosmologist.⁴ Stephen Hawking, the Einstein of the second half of our century, agrees: "The odds against a universe like ours coming out of something like the Big Bang are enormous. I think there are clearly religious implications".⁵ How the various physical processes are "fine-tuned to such stunning accuracy is surely one of the great mysteries of cosmology," remarks physicist P.C.W. Davies. "Had this exceedingly delicate tuning of values been even slightly upset, the subsequent structure of the universe would have been totally different." "Extraordinary physical coincidences and apparently accidental cooperation . . . offer compelling evidence that something is 'going on' . . . A hidden principle seems to be at work."⁶

Physicist Mike Corwin concludes: "This 20-billion-year journey seems at first glance tortuous and convoluted, and our very existence appears to be the merest happenstance. On closer examination, however, we will see that quite the opposite is true—intelligent life seems predestined from the very beginning. . . . Any significant change in the initial conditions would have ruled out the possibility of life evolving later. . . . Yet here we are, alive and aware, in a universe with just the right ingredients for our existence."⁷

Physicists cannot do experiments revising the universe, but they have been doing thought experiments to see whether another one would be more congenial. Such *if-then* experiments conclude that the universe is mysteriously right for producing life and mind. No mechanism for life has ever been conceived that does not require elements produced by thermonuclear combustion. The stars are the furnaces in which all but the very lightest elements are forged, exploding as supernovae and dispersing this matter, subsequently regathered and forming planets and persons. Humans are composed of fossil stardust! In this historical perspective, astronomical nature is the precondition of the rational self.

But no universe can provide several billion years of stellar cooking time, unless it is several billion light years across. *If* we cut the size of the universe from 10^{22} to 10^{11} stars, *then* that much smaller but still galaxy-sized universe might first seem roomy enough, but it would run through its entire cycle of expansion and recontraction in about one year! *If* the matter of the universe were not so relatively homogeneous as it is, *then* large portions of the universe would be so dense that they would

already have undergone gravitational collapse. Other portions would be so thin that they could not give birth to galaxies and stars. On the other hand, if it were entirely homogeneous, then the chunks of that make development possible could not assemble.⁸

If the universe were not expanding, *then* it would be too hot to support life. If the expansion rate of the universe had been a little faster or slower, *then* connections would have shifted so that the universe would already have recollapsed or so that galaxies and stars could not have formed. The extent and age of the universe are not obviously an outlandish extravagance. Indeed, this may be the most economical universe in which life and mind can exist—so far as we can cast that question into a testable form in physics.

Sometimes we marvel that it had to be that way. Sometimes we marvel that it could have been otherwise but was not so. Sometimes it is not too clear whether these startling interconnections are necessary or contingent, and we do not know how developing theory will revise the necessities and contingencies of these connections. But in the end it hardly matters. So far as these connections are improbable, we seem to need a guiding hand in ongoing superintendence; so far as they are necessary the guiding hand seems to have been there from the start.

Astrophysicists John D. Barrow and Joseph Silk calculate that "small changes in the electric charge of the electron would block any kind of chemistry."⁹ A fractional difference and there would have been nothing. It would be so easy to miss, and there are no hits in the revised universes we can imagine, and yet this universe is a delicate, intricate hit. We are marveling through it all how cosmology on the grandest scale and atomic theory on the minutest scale are not irrelevant to what is now taking place in human affairs, with even the further hint that there must be some great Cause adequate great effect.

The point is not that the whole Universe is necessary to produce Earth and *Homo sapiens*. That would be myopic pride; and this is an unfortunate suggestion in the term "anthropic principle." The issue is richness of potential, not anthropocentrism. There is no need to insist that everything else in the has some relevance to our being here.

God may have overdone the creation in pure exuberance, and why should the parts irrelevant to us trouble us?

These anthropic necessities and contingencies, by tandem turns on their respective upstrokes, integrate into a governing gestalt that detects Something, Someone behind the scenes arranging for the show. The physical world is (shades of Bishop Paley!) a fine-tuned watch again, and this time many quantitative calculations support the argument. The forms that matter and energy take seem strangely suited to their destiny.

2. Disorder in Physics

Yet there is also disorder in physics, for quantum physics has found what most physicists interpret as indeterminism at the submicroscopic level. That indeterminism in the atomic world ordinarily has no import for our native ranges of experience. Any uncertainty will always be statistically masked out. A macro-determinism remains, despite a micro-indeterminism. Despite the atomic uncertainties, we can still have clocks accurate to millionths of a second, because the averages are that reliable. Stochastic processes at lower levels are compatible with determinate processes at upper levels. The atomic indeterminacies imply nothing for human affairs or for a broad scope worldview.

But then again, perhaps there are sometimes gross random effects. In fact, we have not far to seek for evidence that molecular and even atomic phenomena are often amplified. In biochemistry and genetics, events at the phenotypic level are profoundly affected by events launched at the genotypic level. Such events may sometimes be affected by quantum events, as when random radiation affects genetic point mutations or crossing over. This in turn may affect enzyme functions or regulatory molecules, as when allosteric enzymes, which amplify processes a million times, are in turn regulated by modifier molecules, of which there may be only a few copies in a cell, copies made from a short stretch of DNA, where a few atomic changes can have a dramatic real-life effect. A single base pair altered can shift a whole reading frame. Indeed, by the usual evolutionary account, the entire biological tale is an amplification of increments, where microscopic mutations are edited over by macroscopic selective processes. These increments are most finely resolved into molecular evolutions, and these have an indeterminate dimension.

If we turn from the *random* element of indeterminacy to the *interaction* phenomenon also present, we gain a complementary picture. We are given a nature which is not just indeterminate in

random ways but which is plastic enough for an organism to work its program on, for a mind to work its will on. Indeterminacy does not in any straightforward way yield either function, purpose, or freedom, as critics of too swiftly drawn conclusions here are right to observe. Yet physics is, as it were, leaving room in nature for those emergent levels of structure and experience that operate despite the quantum indeterminacies and even because of them. We gain space for the higher phenomena which physics had elected to leave out.

Consider the phenomenon of organism. A laboratory apparatus that physicists have fabricated can constitute the conditions under which some phenomena appear, and within those conditions, we can further coagulate this outcome and not that one, from among the superposed quantum states. So the actual phenomena that come to pass are interaction phenomena, as well as are they, in other ways, random phenomena. Likewise, an organismic "apparatus," though it has naturally evolved, has evolved to the point where it can constitute the conditions under which the phenomena with which it interacts appear. Within this interaction, it can coagulate affairs this way and not that way, in accord with its cellular and genetic programs. The macromolecular system of the living cell, like the physicist's apparatus, is influencing by its interaction patterns the behavior of the atomic systems.

This is probably going on in a much more sophisticated way than it does in the relatively crude physicist's machinery which converts the atomic events into a photographic trace or a Geiger counter click. The organism converts the phenomena into life. This is taking place with instrumental control much closer to the atomic level in a pervasive, systematically integrated way in the organism, while in the bulky physicist's apparatus we can manipulate processes and fabricate the materials of our instruments directly at the gross macroscopic levels only, very indirectly at the molecular levels. But the organism is fine-tuned at the molecular level to nurse its way through the quantum states by electron transport, proton pumping, selective ion permeability, DNA encoding, and the like. The organism via its genetic information and biochemistries participates in forming the course of the microevents that constitute its passage through the world. The organism is responsible, in part, for the microevents, and not the other way round.

The organism has to flow through the quantum states, but the organism selects the quantum states that achieve for it an informed flow-through. The

information within the organism enables it to act as a preference sieve through the quantum states, by interaction sometimes causing quantum events, sometimes catching individual chance events which serve its program, and thereby the organism maintains its life course. The organism is a whole that is program laden, a whole that executes its lifestyle in dependence on this looseness in its parts. There is a kind of downward causation which complements an upward causation, and both feed on the openness, if also the order, in the atomic substructures. The microscopic indeterminism provides a looseness through which the organism can steer itself by taking advantage of the fluctuations at the micro-levels.

Life makes matter count. It loads the dice. The throttling and interrupting of events is not by physical processes which preset or break up biological events; the throttling and interrupting is much the other way around. Biological events are superintending physical ones. The organism is "telling nature where to go." Biological nature takes advantage of physical nature.

3. Disorder in Biology

Bigscale biology is a stark contrast to bigscale physics—at first at least. Evolutionary history has located the secret of life in natural selection operating over incremental variations across enormous timespans, with the fittest selected to survive. The process is prolific, but not fine-tuned. To the contrary, evolutionary history can seem make-shift and "tinkering."¹⁰ Natural selection is thought to be blind, both in the genetic variations bubbling up without regard to the needs of the organism, some few of which by chance are beneficial, and also in the evolutionary selective forces, which select for survival, without regard to advance.

The evolutionary history resulting from natural selection is often said to be a *random walk*. A random walk is illustrated by a child's penny hike, one where she flips a penny at each corner to see which way she will go. If life is kept moving by a survival urge, with random flips over direction, and the options selected most likely to keep it moving (= surviving), then one can see why life will keep moving but not why it will move directionally toward complexity or sentience. The principle predicts that there will be survivors, but not that there will be any advancement.

There is a kind of macroscopic randomness that results from the microscopic randomness. So far

from being a directionally ordered whole, or having headings anywhere in its major or minor currents, the evolutionary course rather wanders. It wanders in the first instance due to atomic and molecular chance (both relative and absolute) and, given these chancy mutational possibilities provided from the lower levels, it wanders in the second instance due to the nonselection for anything but mere survival, without bias toward progress, improvement, or complexity. Any ascent is accidental to the process. Biologists survey the staggering array of fossil and surviving life forms, see it as full of struggling, chance, zigzag, and groping omnidirectionality, some trials happening to work, most failing, a very few of them eventuating in the ascent of neural forms. Latter day grass plants, or crustaceans, or beetles, are no better, no worse than those of the geological past, just different.

Curiously, the astronomers who in an earlier era saw the lavish universe as blind and wasteful have now argued that the universe is anthropic, formed from the outset with those constants and potentials that are right for life. But when we reach biology (after fifteen billion years of astronomical and geomorphic developments) the biologists think the upslope progress of life, once it arrives, all to be random.

The geneticist Jacques Monod, wrote:

Chance *alone* is at the source of every innovation, of all creation in the biosphere. Pure chance, absolutely free but blind, at the root of this stupendous edifice of evolution: this central concept of modern biology is no longer one among the other possible or even conceivable hypotheses. It today is the *sole* conceivable hypothesis, the only one that squares with observed and tested fact. And nothing warrants the supposition—or the hope—that on this score our position is likely ever to be revised. . . . When one ponders on the tremendous journey of evolution over the past three billion years or so, the prodigious wealth of structures it has engendered, and the extraordinarily effective telenomic performances of living beings, from bacteria to man, one may well find oneself beginning to doubt again whether all this could conceivably be the product of an enormous lottery presided over by natural selection, blindly picking the rare winners from among numbers drawn at utter random.

Nevertheless,

a detailed review of the accumulated modern evidence (shows) that this conception alone is compatible with the facts. . . . The ancient covenant is in pieces; man at last knows that he is alone in the universe's unfeeling immensity, out of which he emerged only by chance.¹¹

Harvard paleontologist Stephen Jay Gould agrees: "We are the accidental result of an unplanned process. . . the fragile result of an enormous concatenation of improbabilities, not the predictable product of any definite process."¹² "Almost every interesting event of life's history falls into the realm of contingency."¹³ In this sense, the biggest events too (the coming of mammals and men), not less than the smallest events (the microscopic mutations), are accidental or random with respect to anything that natural selection theory can predict or retrospectively explain. One has no covering law, or trend, enabling one to say that microbes, or mammals, or men could statistically be expected.

Is there any order in the ascent of life? Since life is evidently a highly ordered event, since presently living organisms in ecosystems on Earth, humans included, are the most complex things known in the universe, and since there has been the phenomenal evolution of increasing order over the millennia of natural history, many critics complain that if natural selection theory cannot give account of this composition of order, then it cannot do enough explanatory work. The most striking feature of all, the ascent of life, becomes an anomaly, that is, something which cannot be predicted, derived, or given account of out of the theoretical model. Although one does get from the theory a description of what has happened and a semicausal account of why it should keep moving and vary, one is not getting *any explanation of all* why it must or did ascend, but rather the assurance that there is not any overall orthoselection, not even in those episodes where simple forms eventuated in complex ones.

We can say that if life starts out simply, there is nowhere to go but up. So some development of complexity is not surprising. But life does not steadily and irreversibly have to go up. "Nowhere to go but up" is true at the launching, but not thereafter. There is down, stable, and out, and many forms take these routes. The evolutionary process

might have achieved a few simple, reliable forms, needing little modification, and stagnated thereafter, as has sometimes happened in little changing habitats. Nothing in the theory makes probable a continual ascent, since, at every point in time, the probabilities of descent, stagnation, and ascent are equally great. Nothing says that the better adapted are more complex. Nothing tracks ascent.

The theory explains the events that do occur, but in such a way that it does not explain why a great many other events did not occur in the stead of each, and if, moreover, one of these alternatives had occurred, the very same explanatory theory would have been invoked to explain the alternative. That is, the theory, without being false, is incomplete, because it is not supplying enough orderly innovating principle. How can we get more order into biology?

4. Order in Biology

What most needs to be explained is not the disorder, but the negentropic ascent. Biology must posit some constructive forces that give a slope to evolution. The random walk account seems blind to overwhelmingly evident, longstanding evolutionary trends across three to four billion years. The physical world overall moves thermodynamically downhill, despite some negentropic eddies, but now in bioscience we need an overall upslope force, or set of forces, a sort of biogravity that accounts not only for a survival drive but for the assembling and conservation of more advanced forms. Across a slope, of course, one can still gradually wander up or down, but there will be cumulative directionality. Now, with the passage of time and trials, there will, by ever more probability, be ever more salient constructions of life.

There will be increases of both diversity and complexity. Edward O. Wilson, after a survey of evolutionary natural history, concludes, "Progress, then, is a property of the evolution of life as a whole by almost any conceivable intuitive standard, including the acquisition of goals and intentions in the behavior of animals." "In spite of major and minor temporary declines along the way, in spite of the nearly complete turnover of species, genera, and families on repeated occasions, the trend in biodiversity has been consistently upward."¹⁴

Ernst Mayr, an evolutionary biologist, though he greatly dislikes any suggestions of teleology, is forced to concede that there is evolutionary progress. Many life forms do not progress, "higher" is

a troublesome word in biology. "And yet, who can deny that overall there is an advance from the pro-caryotes that dominated the living world more than three billion years ago to the eucaryotes with their well organized nucleus and chromosomes as well as cytoplasmic organelles; from the single-celled eucaryotes to metaphytes and metazoans with a strict division of labor among their highly specialized organ systems; within the metazoans from ectotherms that are at the mercy of climate to the warm-blooded endotherms, and within the endotherms from types with a small brain and low social organization to those with a very large central nervous system, highly developed parental care, and the capacity to transmit information from generation to generation?"¹⁵

John Maynard Smith, another evolutionary biologist, says, "There is nothing in neo-Darwinism which enables us to predict a long-term increase in complexity." But he goes on to suspect that this is not because there is no such long-term increase, but that Darwinism is inadequate to explain it. We need "to put an arrow on evolutionary time" but get no help from evolutionary theory, "It is in some sense true that evolution has led from the simple to the complex: procaryotes precede eucaryotes, single-celled precede many-celled organisms, taxes and kineses precede complex instinctive or learnt acts. I do not think that biology has at present anything very profound to say about this."¹⁶

Thermodynamics need be nowhere violated, because there is a steady "downhill" flow of energy, but some of this energy comes to pump a long route uphill. Philosopher of science Michael Polanyi finds that "there is a cumulative trend of changes tending towards higher levels of organization, among which the deepening of sentience and the rise of thought are the most conspicuous. . . . From a seed of submicroscopic living particles—and from inanimate beginnings lying beyond these—we see emerging a race of sentient, responsible and creative beings. The spontaneous rise of such incomparably higher forms of being testifies directly to the operations of an orderly innovating principle."¹⁷

When we envision an orderly innovating principle, the randomizing element begins to look different. It does not need to be taken away, at least not all of it, but it can remain as openness and possibility. Again in biology, as before in physics, what we get is a world of infinite possibilities, one in which there is a superposition of possible mutation states over actual ones, but also one where many of

the possibilities become briefly actual, real mutants, and then a fractional few stay actual (survive). Once again, but at a higher level, microscopic possibilities are edited "from above" in accord with the needs of the macroscopic organism. Further, organisms are edited so that from many options, the well-adapted survive, and this results, among other things, in advancing ecosystemic and evolutionary creativity. There is an editing on the basis of fitness, which stretches on into advancement. Here we are going to emphasize not the shuffling but the overall sorting.

Beginning with chemical evolution, where complex living forms are constructed from simple building blocks of amino acids, onward after a coding evolves in DNA and RNA to transmit discoveries over generations, we have the steady nentropic climb. But to have life assemble this way, there must be a sort of push-up, lock-up effect. Thermodynamicists have recently been surprised at what happens in certain mathematical and statistico-deterministic systems previously thought to "run down" over time, a surprise coinciding with that of biologists at what happens in evolutionary ecosystems as these randomly, and yet not so randomly, build themselves up over time. So there seem to be occasional places on the evolutionary upslope where thermodynamics favors advancement.

By shaking a tray of printers type, one can get a few short words, which are destroyed as soon as they are composed. But if sentences begin to appear (an analogue of the long, symbolically coded DNA molecules and the polypeptide chains), and form into a poem or a short story (an analogue of the organism), one can be quite sure there are some formative, even irreversible, constraints on the sorting and shaking which are catching the up-thrusts and directionally organizing them. It hardly seems coherent to hold that nonbiological materials are randomly the more and more derandomized across long structural sequences and thus ordered up to life. That is quite as miraculous as walking on water. It seems rather that life is an accident waiting to happen, because it is blueprinted into the chemicals, rather like sodium and chlorine are preset to form salt, only much more startlingly so because of the rich implications for life and because of the openness and information transfer also present in the historical life process. Life is not an accident, whatever place randomness plays in its appearance and maturation. It is something arranged for in the nature of things.

When these enormously complex molecules appear, predecessors of DNA and RNA, bearing the possibility of genetic coding and information, they are conserved, writes biochemist Melvin Calvin, "not by accident but because of the peculiar chemistries of the various bases and amino acids. . . . There is a kind of selectivity intrinsic in the structures."¹⁸ Peculiar chemistries indeed! With an *intrinsic* selectivity that filters and forces the process upslope, toward ever greater molecular complexity and at length to an informational molecule! If it can be said to exist here at the molecular incubation of life, natural selection is of the fittest (meta-stable) but these are just those structures nearer and nearer to biological molecules. Such selection combines with these peculiar chemistries forced toward biochemistries, with the result that the biological consequence, the evolution of life, so far from being random, is "a logical consequence"¹⁹ of natural principles. We seem almost to be saying that life is the earthen destiny of these chemicals.

"This universe breeds life inevitably," concludes George Wald, an evolutionary biochemist.²⁰ Quantum physics gives us an open system and nested sets of possibilities; but, while some atoms and molecules take living tracks, called forth as interaction phenomena by the cybernetic organism, most atoms and molecules take nonliving tracks. If there is some "inside order" to matter that makes it pro-life, it is in the whole system and not just in the particles. Even there the "selectivity intrinsic in the structures" does not rule out a universe of myriad options, only some of which are realized.

Meanwhile, we do posit a primitive planetary environment in which the formation of living things had a high probability, or, in other words a pregnant Earth. Here we may not so much need interference by a supernatural agency, as rather the recognition of a marvelous endowment of matter with a propensity toward life. Yet we may still need something to superintend the possibilities. Once again, it is not just the necessities, nor the contingencies, but the prolife mixing of the two that impresses us. It is not just the atomic or astronomical physics, found universally, but the middle-range earthen system, found rarely, with its zest for complexity which is so remarkable.

Here there is a mixture of inevitability and openness, so that one way or another, given the conditions and constants of physics and chemistry, together with the biased earthen environment, life will somehow both surely and surprisingly appear.

After a long study of the possibility of the evolution of biological molecules capable of self-organization, Manfred Eigen, a thermodynamicist, concludes "that the evolution of life . . . must be considered an *inevitable* process despite its indeterminate course."²¹ Life is destined to come as part of the narrative story, yet the exact routes it will take are open and subject to historical vicissitudes.

Hidden behind the word *random* is a constructive freedom, a resourcefulness in options tossed up for many diverse directions of movement. The mix of stability and mutation is not perfect, but it is impressive in view of the historical successes of evolution across billions of years. On the one hand, before deleterious or neutral mutations, misfits, monstrosities, and extinct lines, we may think that nature does trashy work. But on the other hand, these trials and ancestral forms are subject to optimizing pressures and tested for their performances. What nature conserves is the best of *its* constructions within a particular ecological niche.

The evolutionary process, so far from being irrational, is a prototype of the only kind of rationality that we know. It is not babel, but there is a logic to it, not only to its information conservation, but to its random exploration and problem-solving. Imagination is as necessary as is logic for rationality. Mutation scans for new "ideas," and natural selection throws out the trash and saves the gems. Evolutionary achievement is a rudimentary form of cognition. In terms of human imagination and logic, it is not always a waste but sometimes an index of creativity to cast forth a thousand ideas so as to sort out the single best one. Perhaps we would not want human life to operate any other way. God lets these creatures too (so to speak) figure things out for themselves.

The speciation process is drifting, but it is drifting through an information search, and edited for its discoveries of information. This editing is for survival, but it also scans and produces new arrivals on a climb toward complexity, sentience, and, eventually, mind. It is the production of errors that produces knowledge. The whole system is a context of instruction.

Natural selection, by this revised account, is not so much blind to development as does it at crucial points of innovation and turnings in the upper levels of its systems; it "sees" those mutations that are superior and selects them. It tends in that direction, even though it does not intend it. Thus the seeming random element can be put in a more

intelligible gestalt, where it becomes a precondition of epistemic development.

Recent accounts do not make the genes out to be blind and random, so much as a problem solving process. The genetically originated novelties are formed in a shuffle that, while blind to the organismic needs, is far from chaotic and only more or less random. The genetic system is a system that generates and tests. Any and all variations are not equally probable. Genetic and enzymatic controls on the variation process limit the range of trials. There are different mutation rates at different genetic locations. Mutators and antimutators increase or trim the mutation rates as a function of population stresses. Specific mutations are nondirected, but the rate and place at which they occur is partially regulated. There is some tendency for genes to sort in pretested blocks. Repair mechanisms snip out certain genetic errors, and thus eliminate some variation. The genetic program has the capacity (if we may put it so) to "reject" some of the random recombinants on the basis of information already present in the genetic coding. Individual genetic sets are adept at pumping out their own disorder.²² But they do not pump out all novelty; that would cease evolutionary development and lead to extinction. There is a shake-up of the genes under environmental stress, so that the fastest evolution toward variant forms, often more highly organized forms, takes place almost explosively after major geologic crises.

Contemporary geneticists are insisting that we misperceive this process if we think of it as being blind. Though not deliberated in the conscious sense, it is cognitive, somewhat like computers, which, likewise without felt experience, can run problem-solving programs. There is a vast array of sophisticated enzymes to cut, splice, digest, rearrange, mutate, reiterate, edit, correct, translocate, invert, and truncate particular gene sequences. The geneticist John H. Campbell writes, "Cells are richly provided with special enzymes to tamper with DNA structure," enzymes that biologists are extracting and using for genetic engineering. But this "engineering" is already going on in spontaneous nature.

"Gene-processing enzymes also engineer comparable changes in genes *in vivo*. Cells deliberately manipulate the structures of their gene molecules for phenotypic and possible evolutionary goals. . . . We have discovered enzymes and enzyme pathways for almost every conceivable change in the structure of genes. The scope for self-engineering of multi-

gene families seems to be limited only by the ingenuity of control systems for regulating these pathways." These pathways may have "governors" that are "extraordinarily sophisticated." "Self-governed genes are 'smart' machines in the current vernacular sense. Smart genes suggests smart cells and smart evolution, ... the promise of radically new genetic and evolutionary principles."²³ Such engineering of "selves" is not deliberate in the conscious sense, but rather in the programmed sense of a computer on problem-solving search (Latin: *de-liberatio*, well weighed), that is, systematically ventured and tested.

In fact, in certain kinds of problem-solving searches, so far from disparaging the blind groping of genes under natural selection pressures, computer scientists may deliberately (now in the conscious sense) seek to imitate a similar process on their unconscious computers. Some sophisticated computer programs use what are called "genetic algorithms." An "algorithm" is a set of instructions or rules that is repeated to solve a problem. In simpler computing programs these algorithms can be precisely and logically specified. But in more complex programs, they cannot, because they are not known. Nor can there be random searches because all possible solutions to a problem are so numerous that it would take a computer millions of years to check them all.

"Genetic" algorithms involve combining and recombining partial solutions to a problem in order to generate improved solutions. The model for such programs is biological, sexual mating and strings of genes on chromosomes that can be shuffled and selected. The underlying metaphor is natural selection. Scientists may want to program a computer to search for the optimal set of values to solve certain multi-valued problems where the values interact with each other, such as solving certain sets of mathematical equations, or detecting patterns against a background of noise, or predicting the weather, or scheduling the most effective work and meeting times for many dozens of employees in a manufacturing plant, each of whom has different time slots available, different pay scales, and each of which contributes different skills to the production process, and many of which have to operate together or sequentially.

The computer will generate at random some "bit strings," or "genotypes," analogous to information coded on chromosomes, which are possible values in solution. These sequences are its initial "population." It will then test members of the population

for effectiveness at a solution, rank them for what the computer scientists call their "fitness," and select the fittest. The computer will then generate new possible solutions, stimulating variations on the highest ranking ones, inhibiting the lower ranking ones, evaluate the new possibilities for their "fitness," and put them in competition with the previous, partially effective solutions. The computer also "mates" the various solutions, that is, cuts up and splices portions of bit strings that seem to code the most effective values, and then tests these "offspring" for their fitness.

Even in large and complicated search spaces, genetic algorithms tend to converge on solutions that are globally optimal or nearly so. Simple bit strings can encode complicated structures, and reiterated transformations of partial solutions have a striking power to improve them.²⁴ Computer searches for optimal solutions that would take a computer an estimated billion years, if done completely at random, can be accomplished by genetic algorithms in a few hours. Genetic problem solving, then, does not seem so tinkering, jury-rigged, and blind. To the contrary, it is remarkably like what some of the smartest scientists are doing.

Christopher Wills, an evolutionary molecular biologist, concludes, "There is an accumulated wisdom of the genes that actually makes them better at evolving (and sometimes makes them better at not evolving) than were the genes of our distant ancestors. . . . This wisdom consists both of the ways that genes have become organized in the course of evolution and the ways in which the factors that change the genes have actually become better at their task."²⁵ Jeremy Campbell concludes, "The lesson of information theory is that choice and constraint can coexist as partners, enabling a system, be it a living organism, a language, or a society, to follow the arrow not of entropy but of history. This is the arrow which distinguishes past from future, by moving away from the simple, the uniform and the random, and toward the genuinely new, the endlessly complex products of nature and mind."²⁶

5. Order and Disorder in Science

Nevertheless, what goes on in evolutionary biology may still seem in considerable contrast to the operation of scientists doing their science. Scientists routinely state the nature of the problem that needs to be attacked. They start by reviewing what others have learned, do their research, and, in

a standard conclusion to a scientific article, suggest what research needs to be done next. Models and paradigms in science focus our attention on likely revisions (mutations of the theory), so that what the scientist attends to is not random but focused. A scientist is guided by heuristic rules that track in likely directions. Science is directed by a research program. Is not science therefore a high rational process, quite different from evolutionary natural history?

The evolutionary and innovative part of the process seems random and blind, when we contrast genetic exploration with scientific exploration. Incremental blind trials (making a mutation at random in the cogs and wheels of a watch) fail with high probability, but deliberated trials (replacing a gear that is failing frequently with one made of stronger alloy) often succeed because they are made with an overview of the whole and an analysis of where the problem area is located. Blind trial and error is devoid of any gestalt that controls educated guesses about what improvements in theory or practices might work and why. Incremental, deliberated experiments are controlled from the top down, holistically, by an overall pattern that is partially already in place or envisioned. By contrast, an incremental genetic mutation that bubbles up from below is at random with regard to the whole. Scientists do grope, but they can and must grope for an overall pattern in terms of which they can structure a theoretical understanding, form a set of laws or an integrated theory. Scientists can put the apparatus they wish to build on the drawing boards and build it up by careful design, step by step, and nature does not do it that way.

But the engineering form of creativity, appropriate for artifacts and machines, may not always be the better form. Creative development with vitality is regularly incremental and alive each step of the way. A mature person can only be made out of a fertilized ovum, vital developmental step by vital developmental step. Scientists do not engineer their artifacts this way, but scientists (philosophers or theologians) can themselves only be made out of newborn infants, incrementally over decades. The way to think of this required historical development may not be, somewhat pejoratively, to term it piecemeal modification or make-shift tinkering. Rather we are dealing with development along a story line. Lives have to be narrated, not engineered. Scientists may engineer their artifacts, but the lives of scientists (and all human persons) have to be biographies. Life has its revolutions and

conversions, its dramatic crises; still it has to be lived incrementally and vitally day by day. Robots can be assembled and switched on; but persons have to be assembled while they are living. That may be the nature of all self-generation.

Genetic vitality is in fact a rather sophisticated problem solving process; many achievements there are not yet possible for scientists to duplicate. Genetic creativity is quite startling in what it has produced: many millions of species all the way from microbes to persons, coded for coping in all kinds of environments. So we are too swift if we think that there is no research program in the genes. And, likewise, we are too swift if we think that there is no trial and error in scientific problem solving, no groping about in the dark.

When R.E. Monro, a molecular biologist, reflected over the development of biology he concluded: "An essential characteristic of scientific research, in its more revolutionary aspect is that the scientist is searching for the unknown or, in other words, he does not know what he is searching for."²⁷ The cybernetics theorist Herbert A. Simon compares scientific problem solving with natural selection, to find that, on the cutting edges of science, "the process ordinarily involves much trial and error. Various paths are tried; some are abandoned, others are pushed further, Before a solution is found, many paths of the maze may be explored. The more difficult and novel the problem, the greater is likely to be the amount of trial and error required to find a solution. At the same time, the trial and error is not completely random or blind; it is, in fact, rather highly selective. . . . Human problem solving, from the most blundering to the most insightful, involves nothing more than varying mixtures of trial, and error and selectivity."²⁸

Baruj Benacerraf, reflecting over his career in immunology, for which he was awarded a Nobel prize, agreed: "After more than 40 years in research and over 600 publications, I have learned that discoveries are determined primarily by chance observations and are conditioned by past experience and advances in technology."²⁹ The published research papers describe an orderly, deliberated, simplified logic of discovery, proceeding from problem analysis to experiment, to data collection, analysis, and conclusions, but this is often a story that never happened. What did happen is far more complex, wandering, provisional, tentative, exploratory, lucky.³⁰

The *justification* of variants, the testing of them, can sometimes be highly selective, but the *discovery*

of variants, the generation of them, cannot be very selective, and is perhaps not selective at all when one is really stymied about where to go next. In the midst of a search, novel ideas are often just stumbled upon by accident. Luigi Galvani happened to cause a spark near a frog specimen, which happened to cause the leg to jump, and electricity was discovered. Alexander Flemming happened to notice a Petri dish of staphylococci, which happened to be contaminated by a mold, and penicillin was discovered. Henri Becquerel was experimenting with fluorescence, incited by sunlight, wondering if the sunlight could also induce X-rays. Bored during a series of cloudy days, he happened to put wrapped photographic plates in a drawer with potassium uranyl sulfate (containing uranium), to discover that they became fogged. Thereby he discovered natural radioactivity, destroyed the nineteenth-century conception of atomic structure, and launched twentieth-century nuclear physics.

The story of science, like so many good narratives, is the story of searching, but often too it is the story of lucky turns of events in puzzling situations, of surprising directions of resolution when conflict deepens. Generate and test is standard scientific procedure, not only when computer scientists set up genetic algorithms, but regularly when they undertake research programs. Normally a scientist does want to search the nearby space for possibilities of development. On the other hand, in more radical research, a systematic search is a waste of time if you are nowhere near the zone of good answers, in which case a little random probing around in supposedly wild places may be a useful heuristic. New ideas may be recombinations of old ideas, but they may come from places entirely out of the range of the old theory. When you go beyond the range of what is already known or suspected, you proceed blindly. There is now a kind of random trial and error, with most of the ideas worthless or irrational, but the occasional bubbling up of one that has promise. That rare, lucky idea is locked onto by rational selection, and science turns in hitherto unanticipated directions.

Nor can we assume that, though the context of discovery and generation has random elements, the context of justification, the testing, is admirably rational. Rare and right but unlucky ideas get launched only to be ignored by a scientific community unprepared to hear them. Much depends on the circumstances of launching, the sensitivities of initial referees and critics, the academic posts and laboratories that happen to be involved, editorial

and funding decisions, the wealth, health, and persuasiveness of the scientist-discoverer, perceived relevance of the discovery in applied science, ideological implications, contingencies of timing, and so on.

Theories get misjudged because scientists are flattered or jealous, because they are in too much hurry patiently to digest the evidence, or because they are distracted by peripheral interests and convictions. Mendel's work in genetics was ignored; an early molecular theory of gases by J. J. Waterson was said to be "nothing but nonsense" by the referee of the Royal Society, though it anticipated the work, years later, of the eminent physicists Joule, Clausius, and Clerk Maxwell.³¹ Alfred Wegener published a theory in 1915 that anticipated plate tectonics, and supported it with much geological research. But he was ridiculed by his colleagues and died in 1930 as an intellectual outcast. Half a century later his idea became the paradigm that made geology a unified science. Many discoveries have been stillborn or smothered; we know only those that survived by mix of plausibility, push, and luck. These human foibles serve to diminish the contrast between the rational in science and the contingent in nature.

Nevertheless, one way or another, on occasions there are profound redirections in science; and the really creative turns, hoped for and sought, are also unexpected. Deep revolutions have come in science (electricity, radioactivity) and are still coining, and when they come they will entail unforeseen changes in the way we think. Darwin's creative discovery of the theory of natural selection and the incremental evolution of species, replacing the previous paradigm of fixed species, has, over the last century, steadily been stretching into our whole worldview. Darwin was groping. What he found changed history. When, in the future, evolutionary theory is transcended, it will be by ideas that initially seem in the twilight zone.

We do not wish to deny, but rather to affirm, that there are forms of creativity available in science that are impossible genetically. Certainly science is a conscious process, being neural, while natural selection is nonconscious, being genetic. There is feedback and coupling in science that transcends any in biology. But both processes are cybernetic with elements of trial and error, such that the trials and errors are requisite to epistemic growth. When natural selection is elevated into rational selection there is a new chapter in the story of knowledge, but some themes are pervasive

throughout the whole epistemic adventure. There is a narrative continuity as well as an emergent novelty,

The element of trial and error is not entirely eliminated, nor does it seem that it can ever be. It is not that the groping is gone, but that it is deliberately systematic, whereas before it was only genetically systematic. There is still variation and retention of successful variants. And, when the theory itself runs into trouble, when a paradigm overthrow looms on the horizon, on the frontiers of thought and development, there is still scanning with much trial and error. Deliberative thought is the launching of many trial ideas, and the selective testing of these in experience.³² A vast number of these innovations are abandoned; very few of these ideas prove to add to our knowledge and are worthy to be transmitted to posterity. In that sense the entire scientific enterprise moves by throwing forward hypotheses on the forefront of experience, by testing these, and preserving only those few that succeed.

6. Order and Disorder in Religion

What response is religion to make to this mixture of order and disorder, permeating both nature and science? Does order out of disorder come also to permeate our concept of God, and of God's providence in the world? A generation or two back we might have confronted this as an antithesis: God or chance. Even today, as we have seen in astrophysics, microphysics, molecular biology, evolutionary biology, we find it incredible that the world's history is nothing but a random walk. But also today, we wonder whether we can be detecting, in D.J. Bartholomew's words, a "God of chance," that is a God who employs chance in the cause of creativity, as well as a God who also generates a fine-tuned universe.

For Bartholomew, a statistician, makes what he calls a "transition from a scientific perspective, to one which is primarily theological" and concludes, "Rather than accepting the common view that chance is inimicable to order and purpose, . . . it is actually conducive to the kind of world which one would expect a God such as Christians believe in to create. Instead of opposing God and chance, we shall contend that chance was God's idea and that he uses it to ensure the variety, resilience and freedom necessary to achieve his purposes."³³ There is a "subtle and surprising complementarity of chance and determinism." "Chance offers the potential

Creator many advantages which it is difficult to envisage being obtained in any other way." Bartholomew offers the "central thesis that a world of chance is not merely consistent with a theistic view, but, almost, required by it." This is "the splendid vision of God who conceived a world built on chance and from which he continues to fashion something of eternal value."³⁴

The lines between determinism and chance are not as clear as they once were. Some deterministic processes (the output of a random number generator in a computer, or mathematically chaotic systems) can be indiscernible from genuinely random ones. Random processes in particular events (a coin flipped) can quickly lead to high probabilities in the aggregate (fifty percent heads, fifty percent tails). Chaos is regularly mixed with order; there can be chance at one level and order at another. Open, directed order at one level can feed on the chance at another. Chance, when coupled with selection, allows novelty. The cumulating novelty is evolutionary and world history. But now we begin to see that it is not chance as such that is of value, nor is it only the statistical averaging of chance.

Once we said that if the world is by chance it is not godly. If it is godly, it is not by chance. But now we must reform our theology, stochastic processes are foundational in the world and consistent with divine design. And yet we reform our theology not just with statistics, but with narrative, "Only in a world with a sufficient degree of randomness is there enough flexibility to combine a broadly determined line of development with adequate room for the exercise of real freedom on the part of individuals."³⁵ If God were only God the Averager, then individuals would just rattle around in the statistics, and the norms, the normals would never change.

But contingencies can also bring in surprises, and it is not just averages that we want to notice, but innovations that make a critical difference. For a good story, God the Narrator, beyond God the Statistician, we need critical control at turning points. It is not merely statistical averages that make history; it is critical surprises, anomalous turns, new beginnings. Narratives do not fit regression curves; regression curves (as every statistician knows) cannot be extrapolated very far through history. Large historical outcomes can turn on thresholds at initiating points. We must detect God in the improbabilities as well as in the probabilities. We steadily get more out of less, order out of disorder, the improbable made more probable. Earlier

in the century, Einstein insisted that God does not dice, but now we learn that God does play but that the dice of God are loaded.

This is God's doing, and now the creative action, once reserved to God's special creation of species, and his providential predestination of events, must now be reallocated to include a vast self-creativity within the creatures, lured upslope over this long evolutionary process. The tracks (fossils) left on a sandy playground by a child whose father was teaching her to walk would seem erotic and meaningless to an outside observer, uninformed about what was going on. But they would in fact be the tracks of a significant and lovely process. The evolutionary advance, with *its* paleontological record, requires a still more sophisticated keying in to providential pathways. God has to be detected both in the averages and in the startling innovations. That is true first in nature and later in culture. Nothing is predestined and yet destiny permeates the whole.

What theologians once termed an established order of creation is rather an order that dynamically creates, an order for creating. In nature, the older and newer accounts both concur that living creatures now exist where once they did not. But the manner of their coming into being has to be reassessed. God is not molding the inert material, craftsman-like, a divine carpenter or engineer. But God "from below" microscopically creates the energetic, prolife materials which bubble up trials. "From above," systematically and environmentally, God, the divine lure, via selectivity intrinsic in the processes coaxes forth living organisms and via natural selection selects the best adapted.

The watchmaker-design approach to the concept of a Creator, if appropriate in physics, may not be the model for biology, where more autonomy and self creativity is combined with the divine will for life, a divine parenting entwined with spontaneous creative process. Now the problem of nonpredictability in evolution looks rather different. Randomness seemed before a barrier, but it is now seen as confrontation with, even a carrier of, inventive creativity. The randomness so-called is hiding some innovative forces, which natural selection theory, unaided, is incompetent to detect. Randomness is there with and for creative results, In some veiled way, the meaning of randomness is creativity. A.R. Peacocke, a biologist and theologian, concludes, "Chance is the search radar of God, sweeping through all the possible targets available to its probing."³⁶

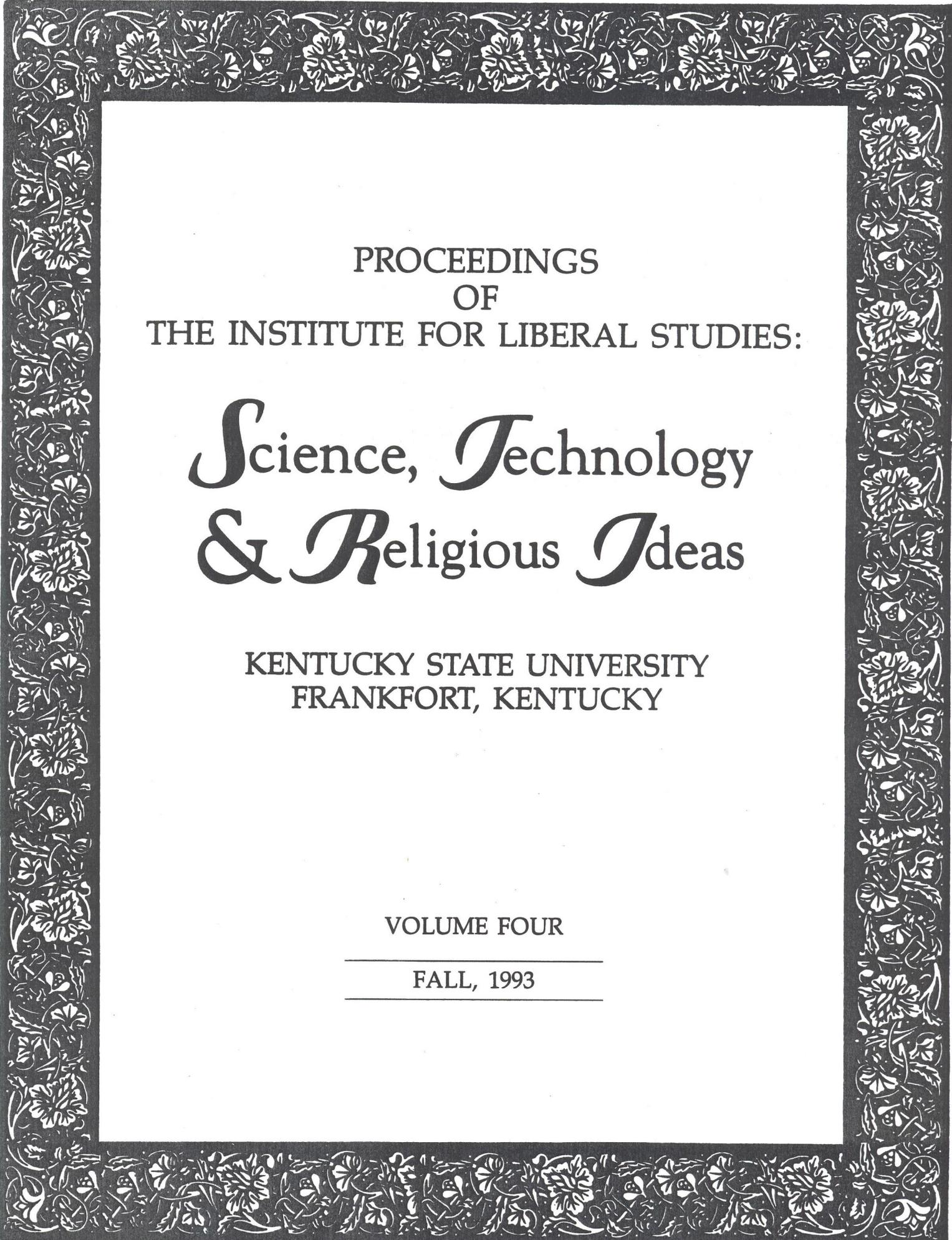
In the materializing of the quantum states, in the compositions of prebiotic molecules, in the genetic mutations, there are selective principles at work, as well as stabilities and regularities, which order the story and perpetuate a swelling wave over the transient particles. This portrays in some respects a loose teleology, a soft concept of creation, and yet one which permits genuine, though not ultimate, integrity and autonomy in the creatures. What comes to pass wells up from below, congealing out of the quantum states. But we gain with organism a further truth that the higher levels can also come to superintend the lower, responding to potentials presented there. But what is true of the individual organism can likewise be believed of the life process overall. We have in the life adventure an interaction phenomenon, where a prolife principle is overseeing the affairs of matter. When mind evolves, we continue with an interaction phenomenon, where a spiritual principle is overseeing the affairs of mind.

The molecular self-assembling is a sort of self-actualizing, but it is also a response to the brooding winds of the Spirit moving over the face of these earthen waters. "I would say," concluded anthropologist Loren Eiseley, "that if 'dead' matter has reared up this curious landscape of fiddling crickets, song sparrows, and wondering men, it must be plain even to the most devoted materialist that the matter of which he speaks contains amazing, if not dreadful powers, and may not impossibly be ... 'but one mask of many worn by the Great Face behind'."³⁷

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