CHANCE AND THE LIFE GAME

by A. R. Peacocke

There is an element of "necessity" in the universe, the givenness, from our point of view, of certain of its basic features: the fundamental constants, the nature of the fundamental particles (and so of atoms, and so of molecules, and so of complex organizations of molecules), the physical laws of the interrelation of matter, energy, space, and time. We are in the position, as it were, of the audience before the pianist begins his extemporizations—there is the instrument, there is the range of available notes, but what tune is to be played and on what principle and in what forms is it to be developed?

CHANCE

Given the limiting features which constitute our necessity, how are the potentialities of the universe going to be made manifest? Jacques Monod's answer is that it is by "chance"; indeed man's emergence in the "unfeeling immensity of the universe" is said to be "*only* by chance."[1] So the question to which we turn is that of the roles of chance and necessity, or "law," in the evolutionary process, in particular in the origin and development of living forms, and of the implications of this balance-and-interplay for discourse about belief in God as Creator.[2] It will transpire that, by and large, I agree that chance, appropriately defined, is the means whereby the potentialities of the universe are actualized but that from this I shall draw conclusions different from those of Monod.

Chance in Literature. Chance often has been apotheosized into a metaphysical principle threatening the very possibility of finding meaning in human life, as recognized in the bitter comment of the author of Ecclesiastes: "Time and Chance govern all."[3] In the ancient Greek myths Chance reigned in Chaos, that state of affairs

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which preceded the Cosmos we now inhabit. Thus John Milton, in this, as ever, as much classical pagan as Christian poet:

> Chaos umpire sits,
> And by decision more embroils the fray,
> By which he reigns; next him high arbiter
> Chance governs all.[4]

Chaos was the mythical state of affairs which preceded the emergence of the world order, of Cosmos, which was thought to manifest itself in the totality of natural phenomenon. Chaos was apparently a transitional stage and in one of the myths was represented as a dark and windy chasm. It is into this chasm which many of Charles Darwin's contemporaries peered, and it was the fearfulness of this vision of a universe, no more ordered than the roulette tables of a Monte Carlo saloon, which induced the anguish Alfred Tennyson expressed in *In Memoriam*—published in 1850 and written between 1833 (after the death of his friend Arthur Hallam) and 1849, that is, well before the publication of the *Origin of Species*. The specter of a Nature ringing its changes of chance and death regardless of human welfare and aspirations had been conjured long before Darwin by the lengthening, through geology, of the time scale of the earth, with all its vicissitudes and apparent catastrophes, and by the growing conviction that species came into existence, flourished, and died:

> The wish, that of the living whole
> No life may fail beyond the grave,
> Derives it not from what we have
> The likest God within the soul?
>
> Are God and Nature then at strife,
> That Nature lends such evil dreams?
> So careful of the type she seems,
> So careless of the single life;
>
> That I, considering everywhere
> Her secret meaning in her deeds,
> And finding that of fifty seeds
> She often brings but one to bear,
>
> I falter where I firmly trod,
> And falling with my weight of cares
> Upon the great world's altar-stairs
> That slope thro' darkness up to God.
>
> I stretch lame hands of faith, and grope
> And gather dust and chaff, and call
> To what I feel is Lord of all,
> And faintly trust the larger hope.
>
> . . . .

"So careful of the type?" but no.
  From scarped cliff and quarried stone
  She cries, "A thousand types are gone:
I care for nothing, all shall go.

"Thou makest thine appeal to me:
  I bring to life, I bring to death:
  The spirit does but mean the breath:
I know no more." And he, shall he,

Man, her last work, who seem'd so fair,
  Such splendid purpose in his eyes,
  Who roll'd the psalm to wintry skies,
Who built him fanes of fruitless prayer,

Who trusted God was love indeed
  And love Creation's final law—
  Tho' Nature, red in tooth and claw
With ravine, shriek'd against his creed—

Who loved, who suffer'd countless ills,
  Who battled for the True, the Just,
  Be blown about the desert dust,
Or seal'd within the iron hills?

No more? A monster then, a dream.
  A discord. Dragons of the prime,
  That tare each other in their slime,
Were mellow music match'd with him.

O life as futile, then, as frail!
  O for thy voice to soothe and bless!
  What hope of answer, or redress?
Behind the veil, behind the veil.[5]

So—even before Darwin—men were disturbed by this ancient fear of chaos ruled by chance, and Tennyson echoed this—being, as Thomas Carlyle described him, "a man solitary and sad, as certain men are, dwelling in an element of gloom—carrying a bit of Chaos about him, in short, which he is manufacturing into a Cosmos."[6] The publication of Darwin's ideas gave an impetus to the anguish of those already despairing of finding meaning or purpose in the universe. It was this mood and judgment which provoked the Bertrand Russell of the 1920s to his famous peroration:

That Man is the product of causes which had no prevision of the end they were achieving; that his origin, his growth, his hopes and fears, his loves and beliefs, are but the outcome of accidental collocations of atoms; that no fire, no heroism, no intensity of thought and feeling, can preserve an individual life beyond the grave; that all the labours of the ages, all the devotion, all the inspiration, all the noonday brightness of human genius, are destined to extinction in the vast death of the solar system, and that the whole temple of

Man's achievement must inevitably be buried beneath the debris of a universe in ruins—all these things, if not quite beyond dispute, are yet so nearly certain that no philosophy which rejects them can hope to stand. Only within the scaffolding of these truths, only on the firm foundation of unyielding despair, can the soul's habitation henceforth be safely built.[7]

Clearly to attribute the processes of the universe to "chance" can trigger off in sensitive men a profound sense of despair at the meaninglessness of all life, and of human life in particular. Such an emotive word warrants closer analysis, for there are more precise meanings which may be given to it in the context of the sciences. It is, of course, to these uses that Monod refers, but such a reference inevitably sets ringing much more emotional bells.

Two Meanings of "Chance." For our present purposes we can distinguish usefully two meanings of "chance."

1. When we toss a coin we say that the chances of it coming down heads or tails are even. We mean that in any long run of tossing of coins 50 percent will come down "heads" and 50 percent "tails" to a proportional accuracy which increases with the number of throws we make. But we also know that, had we sufficient knowledge of the exact values of the relevant parameters, the laws of mechanics would enable us in fact to say in any particular toss which way the coin would fall. In practice we cannot have all the information needed to analyze these multiple causes, and all we can know is that their net effect is equally likely to produce "heads" as "tails" after any individual tossing. So to apply "chance" in this context is simply to recognize our ignorance of the multiple parameters involved. It is a confession of our partial ignorance, partial because we do know enough from the symmetry of the problem to say that in any long run of such tossings there will be an equal number of heads and tails uppermost at the end of the process. The use of the word "chance" in this context does not imply a denial of causality in the sequence of events.

2. A second use of the word "chance" is that of the intersection of two otherwise unrelated causal chains. Suppose that when you leave the building in which you are reading these pages, as you step onto the pavement you are struck on the head by a hammer dropped by a man repairing the roof. From this accidental collision many consequences might follow for your mental life and for the welfare of your families. In ordinary parlance we would say it was due to "pure chance." The two trains of events—your leaving the building at the time you did and the dropping of the hammer—are each within themselves explicable as causal chains. Yet there is no connection between these two causal chains except their point of intersection, and *when* the hammer hits

you on the head could not have been predicted from within the terms of reference of either chain taken by itself. In this case causality is again not denied, but because there is no cross connection between the two causal chains we could not, unlike the previous case of the tossing of a coin, make any accurate prediction of the chance of it happening. (The second instance is sometimes more properly called "accident," and some authors distinguish between chance and accident in this sense.)

Much more needs to be said (and indeed is said in the vast literature on the mathematical theory of probability); at least this initial simple analysis serves to show that when, in ordinary parlance, some event is said to be "due to chance" this phrase is really not giving an explanation of the event in question or saying what its cause is but is simply acting as a stop card. It is saying in effect "the event in question has many multiple causes or seems to have been the result of the intersection of unrelated causal chains, so that we cannot attribute any *particular* cause to it." It is therefore a phrase to be avoided in our discussions. No doubt the phrase "due to chance" has acquired currency because many of the laws in natural science are statistical in character. They do not take the form of statements to the effect that event or situation *A* will be followed by event or situation *B* but rather of the form that *A* will be followed by *B*,′ *B*,″ and *B*‴ with different respective probabilities. Whether this incomplete knowledge of the consequence of *A* arises from a fundamental absence of causality in the old sense or is the consequence of the incompleteness of our knowledge of the operative multiple causes (as in the coin-tossing example) will depend on the particular situation. The first of these two alternatives, a fundamental absence of causality, sometimes is called "pure chance," but any event whose cause has not yet been discovered may be viewed either as a pure chance event that possesses no cause or as a complex event of cause as yet unknown.[8] Indeed the very notion of pure chance, of uncaused events, in the sense of absolutely unqualified disorder, is self-contradictory as well as running counter to a basic assumption of scientists in their, not unsuccessful, work.

The Life Game

Until the recent past, chance and law often have been regarded as alternatives for interpreting the natural world. But I hope enough has been said now to show that at many levels (from those of fundamental particles up to living organisms and indeed in the processes of coalescence that occur in cloud and in galaxy formation) the interplay between these principles is more subtle and complex than the simple dichotomies of the past would allow. For any particular state of a system we have to weigh carefully what the evidence is about their respective roles in determining its present behavior and for interpreting its past. The origin and development of living organisms is no exception, and we now must consider some interpretations of the life game which have emerged from scientific work of the last three decades—I refer to the ideas of Monod, Ilya Prigogine, and M. Eigen, and their colleagues.

Mutations and Evolution. Monod contrasts the "chance" processes which bring about mutations in the genetic material of an organism and the "necessity" of their consequences in the well-ordered, replicative, interlocking mechanisms which constitute that organism's continuity as a living form.[9] He points out, as has been well known in principle for years, though the detailed chemical account has been forthcoming only in the last few decades, that mutations in the genetic material, or DNA, are the results of chemical or physical events, and their locations in the molecular apparatus carrying the genetic information are entirely random with respect to the biological needs of the organism. Thus one causal chain is a chain of events, which may be the chemical modification of one of the nucleotide bases in DNA or its disintegration through absorption of a quantum of ultraviolet or cosmic radiation. These changes in the nucleotide bases, and so in the information which the DNA is carrying, are incorporated into the genetic apparatus of the organisms (the "genome"—a system of transmissible genes of the organisms constituted by its DNA) only if they are not lethal and if, on interacting with its environment, they have a higher rate of reproduction than before. This sequence represents a second causal chain—the interplay between the genetic constitution (and behavior) of a living organism and the pressures to which it is subjected by the environment that includes not only physical features but also the biological pressures of food resources and predators. These two causal chains are entirely independent, and it is in the second sense of chance that Monod is correct in saying that evolution depends on chance. It also qualifies for this description, in the other sense of chance, since in most cases we are not now in a position to specify all the factors which led to the mutated organisms being selected and, even less, the mechanism by which mutation was induced in the first place. (Indeed this latter is at the submolecular level at which quantum considerations begin to operate and is probably fundamentally precluded from any exactly predictive operation.)

The molecular biology of recent years thus has been able to give a much more detailed picture of the process of interplay between mutation and environment. However, it does not really add anything new in principle to the debates of the last hundred years, for the essential crux in these debates was, and is, that the mechanism of variation was causally entirely independent of the processes of selection, so that mutations were regarded as purely random with respect to the selective needs of the organism long before the molecular mechanisms of transmission, and alteration, of genetic information were unraveled in the last two decades. This is the basis on which Monod stresses the rôle of chance: "Pure chance, absolutely free but blind, at the very root of the stupendous edifice of evolution: this central concept of modern biology is no longer one among other possible or even conceivable hypotheses. It is today the *sole* conceivable hypothesis, the only one compatible with observation and tested fact. And nothing warrants the supposition (or the hope) that conceptions about this should, or ever could, be revised."[10]

As mentioned earlier, Monod goes on to draw the conclusion that man, and so all the works of his mind and culture, are the products of pure chance and therefore without any cosmic significance. The universe must be seen not as a directionally ordered whole (a cosmos) but as a giant Monte Carlo saloon in which the dice have happened to fall out in a way which produced man. There is no general purpose in the universe and in the existence of life and so none in the universe as a whole. It need not, it might not, have existed—nor might man.

However, *pace* Monod, I see no reason why this randomness of molecular event in relation to biological consequence, that Monod rightly emphasizes, has to be raised to the level of a metaphysical principle interpreting the universe, for, as we already have seen, in the behavior of matter on a larger scale many regularities, which have been raised to the level of being describable as "laws," arise from the combined effect of random microscopic events which constitute the macroscopic. So the involvement of chance at the level of mutations does not, of itself, preclude these events manifesting a lawlike behavior at the level of populations of organisms and indeed of populations of biosystems that may be presumed to exist on the many planets throughout the universe which may support life. Instead of being daunted by the role of chance in genetic mutations as being the manifestation of irrationality in the universe, it would be more consistent with the observations to assert that the full gamut of the potentialities of living matter could be explored only through the agency of the rapid and frequent randomization which is possible at the molecular level of the DNA. In other words, the designation "chance" in this context refers to the multiple effects whereby the (very large) number of mutations is elicited that constitute the "noise" which, via an independent causal chain, the environment then selects for viability. This role of chance is what one would expect if the universe were so constituted as to be able to explore all the potential forms of organizations of matter (both living and nonliving) which it contains. Moreover, even if the present biological world were only one out of an already large number of possibilities, it must be the case that the potentiality of forming such a world is present in the fundamental constitution of matter as it exists in our universe. The original primeval cloud of fundamental particles must have had the potentiality of being able to develop into the complex molecular forms we call modern biological life. It is this that I find significant about the emergence of life in the universe, and the role of chance, in both its forms, seems to me neither repulsive nor attractive but simply what is required if all the potentialities of the universe, especially for life, were going to be elicited effectively. Furthermore, if we propose that the world owes its being to a Creator God then I see no reason why God should not allow the potentialities of his universe to be developed in all their ramifications through the operation of random events; indeed, in principle, this is the only way in which all potentialities, given enough time and space, might eventually be actualized. Or, to change the metaphor, it is as if chance is the search radar of God, sweeping through all the possible targets available to its probing.

To this extent I agree with W. G. Pollard when he says, "To Einstein's famous question expressing his abhorrence of quantum mechanics, 'Does God throw dice?', the Judeo-Christian answer is not, as so many have wrongly supposed, a denial, but a very positive affirmative."[11] The judgment expressed in this last sentence of Pollard is based on his view of Providence as the expression of God's will and purpose in the particularities of events in history. As he says, history, including biological history, is "a maze, a fabric of turning points, open at every step to new choices and new direction."[12] For Pollard, God expresses his will for the universe in those particular events, selected from among all the alternatives at any instant, which in fact have occurred and which then give rise to a succession of new particular events, each providing a turning point. I agree with Pollard about the statistical character of many scientific laws, the fact that alternative possibilities follow any particular event with varying probabilities attributed to each. But, apart from events at the level of the fundamental subatomic particles, these probabilities represent simply our ignorance of all the factors contributing to the situation (they do not imply any lack of causality in the situation itself and presumably any lack of knowledge of the outcome of the events in the mind of God), at least insofar as we are discussing systems below the level of that of consciousness and human self-consciousness. The assertion that any given situation or event can be followed only by a number of alternative situations or events each with its own probability is a statement about our ability to predict the outcome of these situations, in view of our own ignorance of many multiple causes or (in the case of genetic mutations) of intersecting, independent causal chains. It is not an assertion of a basic noncausality in the situation or event. Since Pollard denies that he means that God alters the natural probability of a pattern of events to achieve his purposes, I find it hard to find any other meaning in "Providence," as he uses the term, than as a label or description of the particularity of the single, unique events which constitute history—and so, it seems to me, it is not capable of carrying the theological weight, in relationship to the biblical tradition, which he places on it.

Oddly enough Monod and Pollard have this in common—both regard the emergence and development of life as an improbable "surd" in a universe otherwise governed by the iron law of "necessity." Monod's response is to accept the "Absurd" in the spirit of French existentialism and to plead eloquently for the autonomy and validity of human values in themselves, more particularly those that are derived from the method of scientific objectivity. On the other hand Pollard, recognizing equally the unique character of the turning points in history, and in particular in biological evolution, attributes the uniqueness of the historical and biological sequence so constructed to "Providence."[13] This enables him to welcome the specific and distinctive character of any event as only one among several alternatives and at the same time to worship God for it. The danger of this move is that this worship has to be evoked whatever the event, and one may be inclined to select those events which are worthy of divine providence, on the basis of criteria derived from some other source, and reject those which are inconsistent with one's concept of God. The concept of the role of chance in biological evolution as eliciting the potentialities inherent in the created order seems to me not to require Monod's conclusion or to lead to the contradictions about the role of God in the universe which Pollard's entails.

Since Monod and Pollard made their contributions, there have been developments in theoretical biology which cast new light on the interrelation of chance and law in the origin and evolution of life. In these developments it is possible to see more clearly that Monod was able to analyze, in his consideration of the mutations of the genetic material and their consequences for natural selection, the way in which chance processes can operate in a law-regulated system to produce new forms of organized and information-carrying systems of the kind which life requires. To these more recent ideas we must now turn.[14]

Thermodynamics of Living Organisms and Dissipative Systems. Prigogine and his colleagues at Brussels, who were already well known for their development and extension of the theories of thermodynamics to irreversible processes not previously covered by the classical approaches, have turned their attention increasingly to the analysis of living systems. The underlying problem here is one which emerged in full force in the nineteenth century. In biology we observe, in the course of geological time, increases in organization with the emergence of structures of greater and greater functional and structural complexity. But in the general course of natural events there is an increase in disorder with time; in the more precise terminology of thermodynamics and statistical mechanics, there is an irreversible increase in entropy (which is related logarithmically to a measure of disorder) of any isolated system such that it will tend more and more to a state of equilibrium and maximum disorder. How can biological systems swim, as it were, against the entropic stream, always enhancing their structural order at the expense of their surroundings? Formally this question may be answered by pointing out that biological organisms maintain their structure and order at the expense of the free energy of compounds which they consume and, by returning heat to their environment, in fact eventually produce a greater increase in entropy than the decrease that occurs in the living organisms themselves. So the laws of thermodynamics are not contravened by active, living, biological systems.

However, this still does not answer the question of how it was that such highly ordered systems as living organisms ever could have come into existence in a world in which irreversible processes always tend to lead to an increase in entropy, in disorder. We know that in systems near to equilibrium any fluctuations away from that state will be damped down, and the system will tend to revert back to its equilibrium state. What Prigogine and his colleagues have been able to show is that there exists a class of steady-state systems, "dissipative structures," which by taking in matter and energy can maintain themselves in an ordered, steady state far from equilibrium. In such states there can occur, under the right conditions, fluctuations which no longer are dampened and which are amplified so that the system changes its whole structure to a new ordered state in which it again can become steady and imbibe energy and matter from the outside and maintain its new structured form. This instability of dissipative structures has been studied by these workers who have set out more precisely the thermodynamic conditions for a dissipative structure to move from one state to a new state which is more ordered than previously. It turns out that these conditions are not so restrictive that no systems can ever possibly obey them. Indeed a very large number of systems, such as those of the first living forms of matter which must have involved complex networks of chemical reactions, are very likely to do so, since they are nonlinear in the relationship between the forces and fluxes involved (which is one of the necessary conditions for these fluctuations to be amplified).

Many model systems can be cited. I shall confine myself to two, one purely physical and the other more chemical. The physical situation is that which simply arises when one heats a fluid layer from the bottom so that there is a gradation of temperature from a high temperature at the bottom of the heated vessel to a lower temperature at the top. At first, when the temperature gradient is small, heat is transferred simply by conduction, and the fluid as a whole remains at rest. But at a critical value of the temperature gradient, internal convective motion appears spontaneously, and groups of molecules start moving together in concert. Indeed the cooperativity of motion between these molecules is extremely high, and a regular pattern of hexagonal "cells" can be found within the moving fluid. This seems quite contrary to the Boltzmann principle and to the randomization of the movements of molecules which seems inherent to the second law. The point is that this system is a long way from equilibrium, and it can be shown that at certain conditions of viscosity, and so on, which themselves depend on temperature, the system ceases to be linear and "order through fluctuations" may occur with the production of a new structure resulting from an instability.

Even more striking is the observation of order through fluctuations in chemical systems. Chemical networks can be of a very high degree of complexity through incorporating one or more autocatalytic steps, and they are often nonlinear (in the sense above) when not close to equilibrium. Then various kinds of oscillating reactions and other features can occur. One of the most striking of these is the so-called Zhabotinsky reaction (the oxidation of malonic acid by bromate in the presence of cerium ions in solution). With the right combination of solution conditions, and at constant temperature, one observes the transformation of an original homogeneous reaction mixture into a series of pulsing waves of concentration of cerium ions, moving up and down the tube, until eventually a steady state is reached. In this there are static, banded layers of alternating high and low concentrations of ceric ions. From an originally homogeneous system a highly ordered structure has appeared through the fluctuations that are possible in a nonlinear system far removed from equilibrium. What has happened is that fluctuations in such a system have been amplified and, through the ordinary laws of chemical kinetics, a new structure has appeared which is ordered at first in time and then finally in space—a new kind of alliance of chance and law. Under the conditions of this reaction the structural formation has a probability of unity provided the initial fluctuation arises from within the system, and the causal chain leading to this fluctuation, although it cannot be discerned by ourselves, must be itself the result of lawlike processes occurring at the microlevel. Because of the discovery of these dissipative systems, and of the possibility of order through fluctuations, it is now possible, on the basis of these physicochemical considerations, to regard as highly probable the emergence of those ordered and articulated molecular structures which are living. Instead of them having only an inconceivably small chance of emerging in the "primeval soup" on the surface of the earth before life appeared, we now see that ordered dissipative structures of some kind will appear in due course. To this extent the emergence of life was inevitable, but the form it was to take remained entirely open and unpredictable, at least to us. Prigogine and G. Nicolis go further:

> We . . . begin to understand, in quantitative terms, the role of the statistical element in the description of a [dissipative] system. . . . we are led to a first parallelism between dissipative structure formation and certain features occurring in the early stages of biogenesis and the subsequent evolution to higher forms. The analogy would even become closer if the model we discuss has further critical points of unstable transition. One would then obtain a hierarchy of dissipative structures, each one enriched further by the information content of the previous models through the "memory" of the initial fluctuations which created them successively.[15]

But how can a molecular population have information content, and how can it store a "memory"? It is to problems of this kind that Eigen and his colleagues at Göttingen have directed their attention.

The Origin of Living Molecular Systems. The work of Eigen, which first appeared in a magnificent paper published in 1971, has now been developed in a wider context and in a most attractive form, as *Das Spiel*, a book at present available only in its German edition.[16] In these studies Eigen and his colleagues examine the changes in time of a population of a system of replicating biological macromolecules, each capable of carrying the information required to make a copy of itself (as can DNA). The virtue of these investigations is that they show how the determinism of the physicochemical laws of kinetics can be linked with the random, time-dependent ("stochastic") processes which must be evoked when one is concerned with only a finite number of kinds of macromolecule. In the first stage of their study the application of the laws of chemical kinetics by themselves gives a deterministic account, which shows how any population of such macromolecules must move inevitably to the situation in which a particular macromolecule with the highest "selective value" (which Eigen is able to define precisely and independently in physical terms) dominates the population. However, this deterministic account of the selection process gives only mean values and applies only to great numbers of macromolecules. In fact there occur two processes which are inherently subject to chance: The occurrence of a specific mutant is an elementary event subject to quantum-mechanical uncertainty; and the growth in numbers of a particular molecular species is subject to statistical fluctuations—for if the last remaining representative of one kind of information macromolecule decomposed before being copied it would become extinct.

This is nicely illustrated by a model "selection game" in which one starts with a box containing ten balls of ten different colors and a separate supply of balls of all these same ten colors. Then alternate the following moves: (*A*) Pick a ball at random from the box and return it to the box together with another ball of the same color (net numerical effect: +1); (*B*) take out a ball, again at random, and discard it (net numerical effect: −1). The total number of balls in the box remains at ten after any number of repetitions of $A + B$ ($= +1 - 1$), but the range of colors narrows down surprisingly rapidly. For once the last representative of a given color is irrevocably removed by *B* it can never again be built up by *A*. So although the chances of the number of a given color being increased or decreased remain equal, the time course of the operation of chance is such that one color eventually predominates in the box.

The treatment of Eigen and his colleagues is highly mathematical and is based on the theory of games and of stochastic processes, but Eigen has been able also to illustrate the principles involved by inventing actual games which the novice can play (with, e.g., octahedral dice!). They have been able to delineate fairly precisely what kind of combination of chance and law (the rules of the game) will allow such a population of information-carrying macromolecules both to develop into one "dominant species," as it were, and at the same time to maintain enough inherent flexibility to evolve into new forms if conditions change.

They have carried these investigations further to see what kind of self-organizing cycles of macromolecules would most likely be able to be viable and self-reproducing given the known properties of proteins and nucleic acids and have been able to devise a suitable "hypercycle" which involves both kinds of macromolecule in an autocatalytic cyclic sequence. Although it may not represent exactly the way in which such self-reproducing systems emerged, this hypercycle shows that at least it is possible in principle for it to happen with quite a high degree of probability. Their treatment demonstrates that natural selection of the fittest, at the macromolecular level at least, is no tautology; it is not a question simply of affirming the "survival of the survivor," as some have gibed at Darwinism. (There are inherent molecular properties which will enable a certain macromolecule to be the fittest to survive.) He concludes

> that the evolution of life, if it is based on a derivable physical principle, must be considered an *inevitable* process despite its indeterminate course.... The models treated ... and the experiments discussed earlier ... indicate that it is not only inevitable "in principle" but also sufficiently probable within a realistic span of time. It requires appropriate environmental conditions (which are not fulfilled everywhere) and their maintenance. These conditions have existed on Earth and must still exist on many planets in the universe. There is no temporal restriction to the continuation of the evolutionary process, as long as energy can be supplied.[17]

According to this analysis, although the emergence of living systems may be "inevitable," it is nevertheless "indeterminate," for it is impossible to trace back the precise historical route or to predict the exact course of development, beyond certain time limits, as a consequence of the involvement of fluctuation, that is, of random processes, in the development of the population of informational macromolecules.

Chance and Law as Creative. From the interaction of genetic mutations and natural selection, from the role of so-called chance events, in the emergence and development of life, many (as we saw) who have reflected on the processes of biological evolution have concluded that they are "due to chance" and therefore of no significance for man's understanding of the universe and of his place in it. But the works of Prigogine and Eigen and their collaborators now show how subtle the interplay of chance and law, of randomness and determinism, can be in the processes which lead to the emergence of living structures. These studies demonstrate that the interplay of chance and law is in fact creative, for it is the combination of the two which allows new forms to emerge and evolve. Furthermore, the character of this interplay of chance and law appears now to be of a kind which makes it "inevitable" both that living structures should emerge and that they should evolve—given the physical and chemical properties of the atomic units (and presumably therefore of subatomic particles) in the universe we actually have. One obtains the impression that the universe has potentialities which are becoming actualized by the joint operation, in time, of chance and law, of random time-dependent processes in a framework of lawlike determined properties—and that these potentialities include the possibility of biological, and so of human, life.

Chance and the Doctrine of Creation

I have tried to give a fair account of one aspect—the interplay of chance and law in the life game—of our present scientific perspective on the world and to draw out its general implications, so far without much reference to a theism which conceives of a Creator God. I have tried negatively to show that the deduction (e.g., of Monod) from this picture, that the quest for meaning for man in the cosmos is hopeless, is not warranted by the role of chance in evolution—both as Monod conceived it and, even more clearly, in the form the more thermodynamic and kinetic work of Prigogine and Eigen has indicated.

Relevance of the Life Game. However, man does not stop his questioning as soon as the latest brick has been definitively added to the edifice of science. He never stops asking questions about himself and the cosmos and its meaning to him. The questions he asks are perennial, going back to the dawn of human self-consciousness, but the context to which the answers are now referred cannot but be that of the world view created by the sciences. So we are inevitably involved in thinking again what the assertion that there is a God who is Creator really can mean in this new context. What images are going to be appropriate to any continued theistic affirmation?

I earlier considered some of the complementary and reinforcing analogical models which have developed in the Judeo-Christian intellectual tradition to explicate God's relation to the world as Creator, models that avoid an excessive stress on transcendence, which becomes deism, or an excessive stress on immanence, which merges into pantheism.[18] How does the scientific picture of the interplay of chance and law that I have outlined bear upon these models? Clearly many authors, including myself, have stressed the continuity and unity of the created order and observed that God is *semper Creator*—he is creating at every moment of the world's existence in and through the self-perpetuating creativity of the very stuff of the world. Indeed it is possible to see the Logos, the creative outgoing Word of God, as most distinctively discerned in the creative self-transformation which occurs in all events and most particularly in man's personal response to the created order, to other men, and, John Cobb has argued, to God in Christ.[19]

Be that as it may, the new evidence about the roles of chance and law in the life game encourage us to add a further dimension, or set of metaphors, to our images and models of God's continuous activity in creation, for we now see more clearly than ever before the role in the eliciting of life, and so of man, of the interplay of random chance microevents with the "necessity" which arises from the stuff of this world having their particular given properties, that is, having one set of potentialities and not another.[20] These potentialities are written into creation by the Creator himself, and they are unveiled by chance exploring their gamut. "Gamut" is a musical term which has come to mean "the whole scale, range or compass of a thing," and perhaps I may be allowed to press the musical analogy further.[21]

The Music of Creation. God as Creator we now see as perhaps somewhat like a bell ringer, ringing all the possible changes, all the possible permutations and combinations he can out of a given set of harmonious bells, though it is God who creates the "bells" too. Or, perhaps better, he is more like a composer who, beginning with an arrangement of notes in an apparently simple tune, elaborates and expands it into a fugue by a variety of devices of fragmentation and reassociation; of turning it upside down and back to front; by overlapping these and other variations of it in a range of tonalities; by a profusion of patterns of sequences in time, with always the consequent interplay of sound flowing in an orderly way from the chosen initiating ploy (i.e., more technically, by inversion, stretto, and canon, etc.). Thus does a J. S. Bach create a complex and interlocking harmonious fusion of his seminal material, both through time and at any particular instant, which, beautiful in its elaboration, only reaches its consummation when all the threads have been drawn into the return to the home key of the last few bars—the key of the initial melody whose potential elaboration was conceived from the moment it was first expounded. In this kind of way might the Creator be imagined to unfold the potentialities of the universe which he himself has given it. He appears to do this by a process in which the creative possibilities, inherent by his own creative intention within the fundamental entities of that universe and their interrelations, become actualized within a temporal development shaped and determined by those self-same inherent potentialities that he conceived from the very first note. One cannot help recalling how, when the Lord answers Job out of the whirlwind, he averred that at creation "the morning stars sang together, and all the sons of God shouted for joy."[22]

The Dance of Creation. The music in creation has been a constant theme of the religions of India in particular.[23] It was indeed a correct and shrewd instinct on the part of A. Glansdorff and Prigogine to depict on the dust cover of their major work, expounding with much rigor the ideas of the Brussels school which I have briefly outlined, the South Indian representation, in bronze, of Shiva, the Creator-Destroyer, as Lord of the Dance of creation.[24] Within a fiery circle representing the action of material energy and matter in nature Shiva Nataraja (as "he" is called in this aspect of his being) dances the dance of wisdom and enlightenment to maintain the life of the cosmos and to give release to those who seek him. In one of his two right hands he holds a drum which touches the fiery circle and by its pulsating waves of sound awakens matter to join in the dance; his other right hand is raised in a protecting gesture of hope—"do not fear"—while one of the left hands brings destructive fire to the encircling nature, and this fire, by erasing old forms, allows new ones to be evoked in the dance. These bronze images are one of the profoundest representations in art of the "five activities of God" in overlooking, creating, evolving; in preservation and support; in destruction; in embodiment, illusion, and giving of rest; and in release, salvation, and grace.[25] Shiva is the Presence contained within Nature—the universal omnipresent Spirit dancing within and touching the whole arch of matter-nature with head, hands, and feet:

> His form is everywhere: all-pervading in His Shiva-Shakti
> Chidabaram [the center of the universe] is everywhere,
> everywhere His dance:
> As Shiva is all and omnipresent,
> Everywhere is Shiva's gracious dance made manifest.
> His five-fold dances are temporal and timeless.
> His five-fold dances are His Five Activities. . . .[26]

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> the grandeur of this conception itself as a synthesis of science, religion and art. . . . No artist of today, however great, could more exactly or more wisely create an image of that Energy which science must postulate behind all phenomena. If we would reconcile Time with Eternity, we can scarcely do so otherwise than by the conception of alternations of phase extending over vast regions of space and great tracts of time. Especially significant, then, is the phase alternation implied by the drum, and the fire which "changes" not destroys. These are but the visual symbols of the theory of the day and night of Brahma.

In the night of Brahma, Nature is inert, and cannot dance till Shiva wills it: He rises from His rapture, and dancing sends through inert matter pulsing waves of awakening sound, and lo! matter also dances appearing as a glory about Him. Dancing, He sustains its manifold phenomena. In the fullness of time, still dancing, he destroys all forms and names by fire and gives new rest. This is poetry: but none the less, science.[27]

The idea of the dance of creation is not absent from Western culture either—for example, in the ancient Cornish carol, the "General Dance," and in the well-known setting by Gustav Holst of the carol "Tomorrow Shall Be My Dancing Day," often sung in English parish churches and cathedrals in the Christmas season. The idea is reflected too in a sixteenth-century poem entitled "Orchestra, or, a Poem of Dancing" by Sir John Davies in which one of the suitors of Penelope, long bereft of Ulysses' presence, is depicted as trying to persuade her to dance:

Dancing, bright lady, then began to be
When the first seeds whereof the world did spring,
The fire air earth and water, did agree
By Love's persuasion, nature's might king,
To leave their first discorded combating
And in a dance such measure to observe
And all the world their motion should preserve.

Since when they still are carried in a round,
And changing come one in another's place;
Yet do they neither mingle nor confound,
But every one doth keep the bounded space
Wherein the dance doth bid it turn or trace.
This wondrous miracle doth Love devise,
For dancing is love's proper exercise.

Or if this all, which round about we see,
As idle Morpheus some sick brains hath taught,
Of individual notes compacted be,
How was this goodly architecture wrought?
Or by what means were they together brought?
They err that say they did concur by chance;
Love made them meet in a well-ordered dance![28]

The "Play" of God in Creation. Dancing involves play and joy, and the conception of the world process as the Lord Shiva's play is a prominent theme in the Hindu scriptures—"The perpetual dance is His play."[29] Indeed both of our images, of the writing of a fugue and of the execution of a dance, express the idea of God enjoying, of playing in, creation. Nor is this an idea new to Christian thought. The Greek fathers, so Harvey Cox argues, contended that the creation of the world was a form of play: "God did it they insisted out of freedom, not because he had to, spontaneously and not in obedience to some inexorable law of necessity. He did it, so to speak, 'just for the hell of it,'"[30] J. Moltmann calls this play the "theological play of the good will of God," which he later elaborates: "... God created the world neither out of his own essence nor by caprice. It did not have to be, but creation suits his deepest nature or else he would not enjoy it.... when we say that the creative God is playing, we are talking about a playing that differs from that of man. The creative God plays with his own possibilities and creates out of nothing that which pleases him."[31] No wonder that Dante could liken, in an unforgettable phrase, the angelic praises of the Trinity in paradise to the "laughter of the universe" ("un riso dell' universo").[32]

This understanding of why God should create the world at all finds an echo in the concept of *līlā* in some aspects of Indian thought.[33] According to this tradition of the *Vedanta Sutra*, the creative activity of God is his sport or play, *līlā*; the worlds are created by and for the enjoyment of God. In later devotional Hinduism, nature is the *līlā*, the cosmic play or dance, of the Lord: "The perfect devotee does not suffer; for he can both visualize and experience life and the universe as the revelation of that Supreme Divine Force (*sakti*) with which he is in love, the all-comprehensive Divine Being in its cosmic aspect of playful aimless display (*līlā*)—which precipitates pain as well as joy, but in its bliss transcends them both."[34] This represents the world-accepting strand in Indian religion (Tantra and popular Hinduism) in which "the world is the unending manifestation of the dynamic aspect of the divine, and as such should not be devaluated and discarded as suffering and imperfection, but celebrated, penetrated by enlightening insight, and experienced with understanding."[35] In the majestic sculptures, bronzes, and "expanding form" of the Indian aesthetic phenomenon, H. Zimmer claims, there is portrayed nature as "*Prakriti* herself (*natura naturans*, not the merely visible surface of thing) ... with no resistance to her charm—as She gives birth to the oceans of the worlds. Individuals—mere waves, mere moments, in the rapidly flowing, unending torrent of ephemeral forms—are tangibly present; but their tangibility itself is simply a gesture, an affectionate flash of expression on the otherwise invisible countenance of the Goddess Mother whose play (līlā) is the universe of her own beauty."[36]

The world order as the expression of the creative urge (*sakti*) of God is really his/her play, *līlā*, which is the motivation which prompts God to creation, preservation, and destruction. According to the idea of *līlā*, God is not constrained by any external agency or desire. God's creative activities are a spontaneous overflow of the fullness of his own joy and perfection—it is like that spontaneity and freedom which is experienced in human play and sport. The contemporary Indian proponent of an "integral philosophy," Sri Aurobindo, also takes up this theme (in the account of N. A. Nikam):

In relation to . . . the self-delight of the eternally self-existing being, the world, according to Sri Aurobindo, is not *maya* [in the "pejorative sense of cunning, fraud, or illusion"—a phenomenal and mutable, and so not fundamental and immutable, truth] but *līlā*,: i.e., a play, and joy of play, wherever this is found: 'the child's joy, the poet's joy, the actor's joy, the mechanician's joy. . ."; the cause and purpose of play is: "being ever busy with its own innumerable self-representations . . . Himself, the play, Himself the player, Himself the playground." There is behind all our experiences one reality, one indivisible conscious being, supporting our experiences by its inalienable delight. The delight of being is, or ought to be, therefore, our real response in all situations. The experience of pain, pleasure, and indifference, is only a superficial arrangement effected by the limited part of our selves, caused by what is uppermost in our waking consciousness. There is . . . a vast bliss behind our mental being.[37]

In conclusion the creative role of chance operating upon the lawful "necessities" which are themselves created has led us to accept models of God's activity which express God's gratuitousness and joy in creation as a whole and not in man alone. The created world then is seen as an expression of the overflow of the divine generosity. The model is, as we have seen, almost of God displaying the delight and sheer exuberance of play in the unceasing act of creation, as represented, in the Wisdom literature by the female personification of God's Wisdom present in the creation:

When he [the Lord] set the heavens in their place I [Wisdom] was
there,
when he girdled the ocean with the horizon,
when he fixed the canopy of clouds overhead
and set the springs of oceans firm in their place,
when he prescribed its limits for the sea
and knit together earth's foundations.
Then I was at his side each day,
his darling and delight,
playing in his presence continually,
playing on the earth, when he had finished it,
while my delight was in mankind.[38]

NOTES

1. Jacques Monod, *Chance and Necessity: An Essay on the Natural Philosophy of Modern Biology*, trans. Austryn Wainhouse (New York: Alfred A. Knopf, Inc., 1971); my italics.

2. "Necessity" is the word used by Monod to denote the deterministic aspect of natural processes. But we need also to refer to the basic "givenness" of the features of the universe mentioned in the first sentence of this paper (i.e., the fundamental physical constants, the fundamental particles as well as the physical laws of the interrelation

of matter, energy, space, and time and of other physical features of the universe). Because of this wider reference I shall usually use the word "law" rather than "necessity" to refer to these "given" aspects of the universe that include the statistical, apparently deterministic laws governing the behavior of matter, at least above the subatomic level. These natural laws provide the rules according to which the life game is played.

3. Eccles. 9:11 (N.E.B.).

4. *Paradise Lost* 2:907-9.

5. *In Memoriam* 55, 56.

6. J. Slater, ed., *Correspondence of Emerson and Carlyle* (New York: Columbia University Press, 1964), p. 363 (Carlyle to Emerson, August 5, 1844).

7. Bertrand Russell, "A Free Man's Worship" (1903), in *Mysticism and Logic, and Other Essays* (London: Allen & Unwin, 1963), p. 41.

8. Cf. Ernest Nagel, *The Structure of Science* (London: Routledge & Kegan Paul, 1961), chap. 10.

9. Monod (n. 1 above).

10. Ibid., p. 110.

11. W. G. Pollard, *Chance and Providence* (London: Faber, 1958), p. 97.

12. Ibid., p. 72.

13. W. G. Pollard, "A Critique of Jacques Monod's *Chance and Necessity*," *Soundings* (Winter 1973), pp. 433-44.

14. For a brief account see my "Chance and Necessity in the Life-Game," *Trends in Biochemical Sciences* 2 (1977): 99-100, and for a more thorough exposition my "The Nature of Evolution of Biological Hierarchies," in *New Approaches to Genetics*, ed. P. W. Kent (London: Routledge & Kegan Paul, Oriel Press, 1978), pp. 245-304.

15. Ilya Prigogine and G. Nicolis, "Biological Order, Structure and Instabilities," *Quarterly Review of Biophysics* 4 (1971): 132.

16. M. Eigen, "The Self-Organization of Matter and the Evolution of Biological Macromolecules," *Naturwissenschaften* 58 (1971): 465-523; M. Eigen and P. Schuster, "The Hypercycle—A Principle of Natural Self-Organizations," ibid. 64 (1977): 541-65 and 65 (1978): 7-41; R. Winkler and M. Eigen, *Das Spiel* (Munich: R. Piper & Co. Verlag, 1975).

17. Eigen, "The Self-Organization of Matter," p. 519.

18. See my *Creation of the World of Science* (Oxford: Clarendon Press, 1979), chap. 1.

19. Ibid., chap. 6; John Cobb, *Christ in a Pluralistic Age* (Philadelphia: Westminster Press, 1971).

20. Peacocke, *Creation and the World of Science*, chap. 2.

21. *Oxford English Dictionary*, s.v. "Gamut."

22. Job 38:7. Cf. Johannes Kepler, for whom the cosmos was a spiritual harmony ("concentus intellectualis") which "pure spirits and in a certain way even God sense with no less enjoyment and pleasure than man experiences when listening to musical chords" (as quoted by Max Caspar, *Kepler*, trans. and ed. C. Doris Hellman [London: Abelard-Schumann, 1959], p. 95).

23. For a much wider treatment of Eastern thought and mysticism in relation to modern physics in particular see Fritjof Capra's *The Tao of Physics* (Berkeley, Calif.: Shambhala Publications, 1975) and my comments on this in appendix A to my *Creation and the World of Science*.

24. A. Glansdorff and Ilya Prigogine, *Thermodynamic Theory of Structure, Stability, and Fluctuations* (New York: Wiley-Interscience, 1971).

25. A. K. Coomaraswamy, *The Dance of Shiva* (London: Peter Owen, 1958), p. 70.

26. "The Vision of the Sacred Dance" (from Tirumular's *Tirumantrum*), as quoted by Coomaraswamy, p. 71.

27. Coomaraswamy, pp. 77-78.

28. John Davies (1569-1626), "Orchestra, or, a Poem on Dancing," in *Silver Poets of the 16th Century*, ed. G. Bullett (London: Everyman's Library, Dent, 1947), pp. 322-23. I am indebted to Mrs. Jane Brooke of Salisbury, England, for drawing my attention to this poem.

29. Tirumular, as quoted by Coomaraswamy, p. 74.
30. Harvey Cox, *The Feast of Fools* (Cambridge, Mass.: Harvard University Press, 1969), p. 151.
31. J. Moltmann, *Theology and Joy* (London: S.C.M. Press, 1973), pp. 38, 40-41. Again cf. Kepler's "As God the Creator played/ so He also taught nature, as His image, to play/ the very game/ which He played before her" (as quoted by Caspar [n. 22 above], p. 185).
32. *Il Paradiso*, canto 27, lines 4-5.
33. I am much indebted to Dr. J. Lipner, Saint Edmund House, Cambridge, England, and the Rev. J. S. Thekkumkal of Campion Hall, Oxford, England, and Dharmaram College, Bangalore, India, for introducing me to this concept. The latter kindly also allowed me to see a draft of the part on "Nature in Indian Thought" of his, as yet unpublished, thesis. These paragraphs owe much to his account.
34. H. Zimmer, *Philosophies of India*, ed. J. Campbell (London: Routledge & Kegan Paul, 1951), p. 571.
35. Ibid., p. 570.
36. Ibid., p. 593.
37. N. A. Nikam, "The Problem of Creation: Concepts of Māyā and Līlā," in *The Integral Philosophy of Sri Aurobindo*, ed. H. Chaudhuri and F. Spiegelberg (London: Allen & Unwin, 1960), p. 147. The quotations within this passage are from Sri Aurobindo's *The Life Divine* (Pondicherry: Sri Aurobindo International University Collection, 1955).
38. Prov. 8:27-31.