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SCIENCE

The Nonprevalence of Humanoids

We can learn more about life from terrestrial forms than we can from hypothetical extraterrestrial forms.

George Gaylord Simpson

The possibility that life exists elsewhere than on earth has excited human imagination since antiquity. In our own days it has become the principal basis for a whole school of writing: science fiction, which remains mere entertainment even though some of its devotees do make an unjustified claim that it should be taken more seriously. There has also long been discussion that was scientific, at least in the sense that it was by professional scientists who did not intend to write fiction. Even in the nineteenth century there was serious, if not invariably sober, discussion of the view that life exists not only elsewhere but even everywhere in the cosmos.

There is, then, nothing new in the fact that this subject is being widely discussed and publicized [(*1*)]. What is new is that the usual speculation and philosophizing are now accompanied by extensive (and incidentally expensive) research programs, by concrete plans for exploration, and by development of pertinent instrumentation. Although the interested scientists have by no means stopped talking, they are now, and for the first time in history, also acting. Our major space agency, NASA, has a "space bioscience" program. Biologists meeting under the auspices of the National Academy of Sciences have agreed that their "first and . . . foremost [task in space science] is the search for extraterrestrial life" (*2*). The existence of this movement is as familiar to the reader of the newspapers as to those of technical publications. There is even increasing recognition of a new science of extraterrestrial life, sometimes called *exobiology*—a curious development in view of the fact that this "science" has yet to demonstrate that its subject matter exists!

Another curious fact is that a large proportion of those now discussing this biological subject are not biologists. Even when biochemists and biophysicists are involved, the accent is usually on chemistry and physics and not on biology, strictly speaking. It would seem obvious that organic evolution has a crucial bearing on the subject, which is essentially a problem in evolutionary systematics. Surely, then, it is odd that evolutionary biologists and systematists have rarely been consulted and have volunteered little to the discussion. A possible reason for this blatant omission was suggested long ago by an evolutionary systematist, W. D. Matthew [(*3*)], who wrote that, "[Physical scientists] are accustomed to hold a more receptive attitude . . . toward hypotheses that cannot be definitely disproved . . . [while] the [evolutionary and systematic] biologist . . . is compelled . . . to leave out of consideration all factors that have not something in the way of positive evidence for their existence."

Matthew also remarked that, "To admit the probability of extra-mundane life opens the way to all sorts of fascinating speculation in which a man of imaginative temperament may revel free from the checks and barriers of earthly realities." Both of his points are illustrated delightfully and without conscious humor by a contemporary leader in exobiology who wrote in 1962, "We do not really know [what the atmosphere of Venus is like], and we are thus not severely limited in our conclusions"! (exclamation point mine).

As an evolutionary biologist and systematist, I believe that we should make ourselves heard in this field. Since part of our role must be to point out "the checks and barriers of earthly realities," we may at times seem merely to be spoilsports, but we do have other contributions as well.

Three Major Questions

Exobiology has three major questions: "What kind of life?" "Where?" "How may it have evolved?" Each question in turn involves two complex, distinct fields of inquiry. Confusion of these fields frequently distorts judgment and confuses argument.

The alternative fields as to the kind of life are "life as we know it" and "life as we do not know it." Life as we know it obviously cannot be confined in this context to actual terrestrial species, but implies only a more general similarity. It must, at least, involve a carbon chemistry reacting in aqueous media and with such fundamental organic compounds as amino acids, carbohydrates, purine-pyrimidine bases, fatty acids, and others. It must almost

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certainly also involve the combination and polymerization of those or similar fundamental molecules into such larger molecules or macromolecules as proteins, polysaccharides, nucleic acids, and lipids. Life as we do not know it might be based on some multivalent element other than carbon, on some medium (perhaps even solid or gaseous) other than liquid water, and then necessarily on quite different kinds of compounds.

If we did encounter such systems or organisms, we might well fail to recognize them as living or might have to revise our conception of what life is. Here on earth, in spite of a border zone between, and enormous diversities within, each realm, we can recognize two kinds of configurations of matter, one living and one not. (Under "configuration" I mean to include not only chemical composition but also organization or anatomy in the fullest sense and energy states and transactions.) "Life as we do not know it," if recognized at all, might have to be recognized as a third fundamental kind of configuration and not, strictly speaking, as life. There has been considerable speculation along such lines, some of it diverting in a science-fictional sort of way. Yet there is not a scrap of evidence that "life as we do not know it" actually exists or even that it *could* exist—evidence, for example, in the form of detailed specifications for a natural system that might exhibit attributes of life without the basis of life as we do know it. (Computers and other artifacts that mimic some features of the life of their makers are not really pertinent to this question.) Here, at least, further consideration will be given only to life as we know it, to the minimal extent of depending on similar biophysical and biochemical substrates.

The dichotomy in discussing the "Where?" of possible extraterrestrial life is between our own solar system and presumed similar planetary systems anywhere else in the universe. We have extensive observational data on the planets of our system and a reasonable expectation of learning much more. Many facts have been learned over the years by earth-based astronomical methods. Recently rocketry and telemetry have given us closer looks at the moon and at Venus and promise to give us many additional facts. Human visits to the moon and the closer planets, at least, make no evident further demands on our theoretical knowledge and require only a reasonable extrapolation of our technical potentialities into the near future. Here, then, we have actual observational data to work with, and the promise of many more.

Not so for any planetary systems that may exist outside our own. Statements in both the scientific and the popular literature that there are millions of such systems suitable for life and probably inhabited may give the impression that we know that they do exist. In fact we know no such thing in any way acceptable as sober science. There are no direct observational data whatever. It is inherent in any acceptable definition of science that statements that cannot be checked by observation are not really *about* anything —or at the very least they are not science. As long as we do not confuse what we are saying with reality, there is no reason why we should not discuss what we hope or expect to observe, but it is all too easy to take conjecture and extrapolation too seriously. It is not impossible that our descendants may some day make pertinent direct observations on other planetary systems, but that is far beyond our present capabilities or any reasonable extrapolation from them. With our present techniques, the only way we could obtain direct knowledge of life outside our solar system would be by receiving signals from someone or something out there. That point is involved in the third question, the directly evolutionary one, and its two major fields of enquiry: the origin of life and its subsequent history. Here is my main topic, to which I will return at length.

Within Our Solar System

First it is necessary to refer briefly to the environmental conditions and possible evidence of life on the only planets for which we have any actual data, the planets of our own solar system. Apart from a few eccentrics, astronomers have long since agreed that life as we know it is now quite impossible on any extraterrestrial body in our solar system except Venus and Mars (see, for example, *4*). Opinion regarding Venus has been divided, but telemetry from the recent Venus probe seems to confirm beyond doubt the previous view that Venus is far too hot for life as we know it (*5*). Although somewhat equivocal, such evidence as we have on the composition of the Venusian atmosphere also seems to be unfavorable on balance (see, for example, *6*). It would appear, then, that Venus can now be ruled out as a possible abode of recognizable life.

The evidence for Mars is also highly equivocal, but it does not at present entirely exclude the possibility of life there. Temperatures are rigorous and there is little or no free oxygen. Obviously neither man nor any of our familiar animals and plants could possibly live in the open on Mars. Simple microorganisms have, however, been grown in conditions possibly similar to those that just might exist on Mars (*7*). This possibility depends in part on the usual belief that the so-called ice caps of Mars are indeed composed of water and that the atmosphere is mainly nitrogen with some carbon dioxide. Both beliefs have been authoritatively challenged by Kiess, Karrer, and Kiess [(*8*)], who maintain that the caps are N_2O_4. That and the accompanying concentrations of oxides of nitrogen in the atmosphere would make Mars lethal to life as we know it. In any case, there is increasing doubt that enough water exists on Mars to sustain any form of life.

Direct evidence for life on Mars has also been claimed. The old idea that the so-called canals of Mars were made by intelligent beings no longer merits sober consideration. It is, however, well known that there are dark areas on Mars that show seasonal changes in position and in apparent color. It has been claimed repeatedly that these areas must be covered with some form of plant life, and that idea received significant support when it was discovered that their infrared spectrum has a band similar to that of some organic compounds (*9*). However, similar absorption can also be caused by oxides of nitrogen and by a variety of inorganic carbonates (partly unpublished work cited by Calvin, *10*). The question remains open, and plans to make direct observations by space probe are going forward (see *11*). These plans depend on the further doubtful proposition that there may be microorganisms on Mars that can be grown by the same methods used here to grow microorganisms in laboratories.

The only other direct evidence for extraterrestrial life worthy of serious consideration is derived from meteorites. It has been claimed that some of these contain hydrocarbons of organic origin and even actual fossils of microorganisms (see *12*). If confirmed, these observations would indicate that life (now extinct) had occurred on a planet of our system that has since been disrupted. However, further investigation strongly suggests that the materials observed are in part inorganic and in the remaining part terrestrial contaminants (*13*). The most favorable possible verdict is "Not proven."

There is, then, no clear evidence of life anywhere else in our solar system. Wishful thinking, to which scientists are not immune, has obviously played a part here. The possibility is not excluded, but, on what real evidence we have, the chance of finding life on other planets of our system is slim.

Outside Our Solar System

It bears repeating that there are no observational data whatever on the existence, still less on the possible environmental conditions, of planets suitable for life outside our solar system. Any judgment on this subject depends on extrapolations from what we know of the earth and its life and from astronomical data that do not include direct observation. There are, indeed, considerable grounds for such extrapolations, but they still contain a large subjective element and have a strong tendency to go over into sheer fantasy.

There are four successive probabilities to be judged: the probability that suitable planets do exist; the probability that life has arisen on them; the probability that such life has evolved in a predictable way; and the probability that such evolution would lead eventually to humanoids (as defined in the next paragraph). The thesis I shall now develop, admittedly subjective and speculative but extrapolated from evidence, is that the first probability is fair, the second far lower but appreciable, the third exceedingly small, and the fourth almost negligible. Each of these probabilities depends on that preceding it, so that they must be multiplied together to obtain the over-all probability of the final event, the emergence of humanoids. The product of these probabilities, each a fraction, is probably not significantly greater than zero.

(Before proceeding, I should define "humanoid" for those not as addicted as I am to science fiction. A humanoid, in science-fiction terminology adaptable to the present also somewhat fanciful subject, is a natural, living organism with intelligence comparable to man's in quantity and quality, hence with the possibility of rational communication with us. Its anatomy and indeed its means of communication are not defined as identical with ours. An android, on the other hand, is a nonliving machine, servomechanism, or robot constructed in more or less human external shape and capable of performing some manlike actions.)

The first point, as to the existence of earthlike planets, need not detain us long. The astronomers seem to be in complete agreement that planets that are or have been similar to the earth when life arose here probably exist in large numbers (see *4*, *14*, *15*). Indeed the number of stars in the accessible universe (discernible by light or radio telescopy) is so incredibly enormous that even if the chances of any one of them having such a planet were exceedingly small, the probability that *some* of them do would be considerable. As a basis for further consideration, we may, then, reasonably postulate that conditions such as proved propitious to the origin of life on earth may have existed also outside our solar system.

The Origin of Life

The next question is: "How did life arise on earth, and is it probable or perhaps inevitable that it would arise elsewhere under similar conditions? This is largely in the field of the biochemists, and they certainly have not neglected it. The literature is enormous. Enough of it for our purposes is summarized or cited in the recent works of Oparin [(*16*)], Florkin [(*17*)], Calvin [(*18*)], and Ehrensvärd [(*19*)]. There are wide differences of opinion as to the particular course followed, but here again there is near unanimity on the essential points. Virtually all biochemists agree that life on earth arose spontaneously from nonliving matter and that it would almost inevitably arise on sufficiently similar young planets elsewhere.

That confidence is based on chemical experience. If atoms of hydrogen and oxygen come together under certain simple and common conditions of energy, they always deterministically combine to form water. Formation of more complex molecules requires correspondingly more complex concatenations of circumstances but is still deterministic in what seems to be a comparatively simple way. That has, indeed, been demonstrated in the laboratory. If energy such as would be available on a young planet is put into a mixture of the simplest possible compounds of hydrogen, oxygen, carbon, and nitrogen, such as also could well occur on a young planet, amino acids and other building blocks of the essential complex organic molecules are formed. The crucial experiment was that of Miller [(*20*)]. A large amount of later work, mostly noted in the books cited above, has confirmed and extended those results. The further synthesis of the building blocks into the macromolecules, especially nucleic acids and proteins, essential for life has not yet been accomplished under realistically primitive conditions. Nevertheless it is reasonable to assume that those steps, too, would occur deterministically, inevitably, if given enough time under conditions likely to hold on some primitive planets. It is also clear that there has indeed been enough time, for the earth is now definitely known to be more than three billion years old, and planets still older could well exist in this and other galaxies.

It is still a far cry from the essential preliminary formation of proteins, nucleic acids, and other large organic molecules to their organization into a system alive in the full sense of the word. This is the step, or rather the great series of steps, about which we now know the least even by inference and extrapolation. A fully living system must be capable of energy conversion in such a way as to accumulate negentropy, that is, it must produce a less probable, less random organization of matter and must cause the increase of available energy in the local system rather than the decrease demanded in closed systems by the second law of thermodynamics. It must also be capable of storing and replicating information, and the replicated information must eventually enter into the development of a new individual system like that from which it came. The living system must further be enclosed in such a way as to prevent dispersal of the interacting molecular structures and to permit negentropy accumulation. At the same time selective transfer of materials and energy in both directions between organism and environment must be possible. Systems evolving toward life must become cellular individuals bounded by membranes.

The simplest true organisms have all those characteristics and more, but they are very far from being simple in microscopic and submicroscopic organization. Less organized associations of organic macromolecules, such as are seen today in the viruses, cannot perform all those feats on their own and therefore cannot be meaningfully viewed as primitive and true forms of life.

If evolution is to occur and organisms are to progress and diversify, still more is necessary. Living things must be capable of acquiring new information, of alteration in their stored information, and of its combination into new but still integrated genetic systems. Indeed it now seems that these processes, summed up as mutation, recombination, and selection, must already be invoked in order to get from the stage of loose macromolecules to that of true organisms, or cellular systems. There must be some kind of feedback and encoding leading to increased and diversified adaptation of the nascent organisms to the available environments. Basically such adaptation is the ability to reproduce and to maintain or increase continuous populations of individuals by acquiring, converting, and organizing materials and energy available from existing environments. These processes of adaptation in populations are decidedly different in degree from any involved in the prior inorganic synthesis of macromolecules. They also seem to be quite different in kind, but that is partly a matter of definition and is also obscured by the fact that they must have arisen gradually on the basis of properties already present in the inorganic precursors. In any case, something new has definitely been added in these stages of the origin of life. It requires an attitude of hope if not of faith to assume that the acquisition of organic adaptability was deterministic or inevitable to the same degree or even in the same sense in which that was probably true of the preceding, more simply chemical origin of the necessary macromolecules.

By that I do not mean to say that material causality has been left behind or that some mysterious vitalistic element has been breathed into the evolving systems. All must still be proceeding without violation of physical and chemical principles. Those principles must, however, now be acting in different ways because they are involved in holistic, organic, increasingly complex, multimolecular systems that far transcend simple chemical bonding. It is here that one must stop taking for granted the expectations and extrapolations of the chemist and can obtain further enlightenment only from the biologist as such, that is, the student of whole organisms as they exist in reproducing populations and in communities adapted to environments.

Given ample time and rather simple circumstances not likely to be unique in the universe, there does seem to be considerable probability, perhaps even inevitability, in the progression from dissociated atoms to macromolecules. The further organization of those molecules into cellular life would seem, on the face of it, to have a far different, very much lower order of probability. It is not impossible, because we know it did happen at least once. Nevertheless that event is so improbable that even if macromolecules have arisen many times in many places, it would seem that evolution must frequently or usually have ended at that preorganismal stage. Only the astronomical assurance that there may be many millions of earth-like planets permits us to assume that the origin of true, that is of cellular, life may have happened more than once. In the observable universe the lowest recent estimate for earthlike planets by a competent astronomer is, as far as I know, that of Shapley [(*15*)], who considers 100 million a highly conservative figure. On that basis it is reasonable to speculate that life has arisen repeatedly in the universe, even though we do not know and perhaps will never know whether that is a fact.

Here brief consideration may be given to the idea that once life had arisen somewhere, organisms in a state of cryptobiosis (*21*) might have spread by "cosmozoan" transport from one planet to another. That possibility was especially urged by Arrhenius [(*22*)], following the still earlier, curious speculation of Richter and others that life may be coextensive with the whole cosmos both in space and in time. It now appears extremely improbable but not quite impossible that any organism, even encapsulated and in a cryptobiotic state of entirely suspended metabolism, could survive the radiation hazards in space without artificial shielding (*23*). Furthermore, passage from one solar system to another at any speed attainable by natural means (e.g., by the pressure of light) would require vastly more time than any established or probable duration of the cryptobiotic state, which is not known to have lasted longer than about fifty years in microorganisms or about a thousand years in any organisms (*21*). A conservative conclusion would be that it is extremely improbable, almost to the point of impossibility, that any form of life has ever traveled by natural means from one planetary system to another. Such travel between earth and Mars, within the same planetary system, is still improbable, but the possibility is not absolutely ruled out.

Subsequent Evolution of Postulated Life Forms

We now turn to the subsequent evolution of postulated life forms once life has appeared on a planet, and we again move to a different order of probability. We have only a single sample on which to base judgment. Paleobiologists have shown us the general course followed by evolution on this planet. Neobiologists have shown in great, although still incomplete, detail the outcome of that process at one point in time, the present. Although these are far from being the only accomplishments of systematists, they are in themselves so important for current problems as to justify intensified research on this enormous subject.

The problem of extrapolating from this unique sample is to decide whether it is inevitable, probable, improbable, or impossible for life of independent origin to have followed a similar or identical course. Opinions have indeed varied from one end to the other of that scale. I believe that a reasonable choice among those opinions is possible, and furthermore that many, even most, of those who have recently considered the subject have made a wrong choice. Review of recent literature on exobiology, almost all of it by physical scientists and biochemists (or molecular biologists), shows that most of them have *assumed,* usually without even raising the question, that once life arose anywhere its subsequent course would be much as it has been on earth. Now, the only really sound basis for such an assumption would be the opinion that the course followed by evolution on earth is its only possible course, that life cannot evolve in any other way. In a review of two books in which that assumption is made, Blum [(*24*)] has called this the "deterministic" point of view as contrasted with an "opportunistic" one. The choice of terms is not a happy one, if only because it is demonstrable that evolution fully deterministic in the philosophical sense would not necessarily, indeed would almost surely not, follow similar courses on different planets. Nevertheless, the two schools of thought do exist and what Blum calls the deterministic one is more commonly followed in current exobiological speculations.

There are here underlying problems of philosophy and indeed also theology. Those problems have been discussed in previous chapters (especially 9, 10, and 11) and need little further attention here. The pertinent *scientific* questions are: If the processes of evolution are the same everywhere as they are here on earth, will they elsewhere lead to the same material results, including men or humanoids? Just how inevitable is that outcome?

Those questions can be followed up in two different but related ways. First, we can examine the course of evolution here on earth to see whether in fact it has proceeded as if directed toward a goal or an inevitable outcome. Second, we can investigate the mechanisms or processes of evolution in order to judge whether and under what conditions their outcome was limited to a course eventuating in some kind of humanoid, that is, in ourselves in the terrestrial example. Those approaches have also been discussed in previous [chapters] (especially 4, 8, and 12) and need only summaries at this point.

The fossil record shows very clearly that there is no central line leading steadily, in a goal-directed way, from a protozoan to man. Instead there has been continual and extremely intricate branching, and whatever course we follow through the branches there are repeated changes both in the rate and in the direction of evolution. Man is the end of one ultimate twig. The housefly, the dog flea, the apple tree, and millions of other kinds of organisms are similarly the ends of others. Moreover, we do not find that life has simply expanded, branching into increasing diversity, until the organisms now living had evolved. On the contrary, the vast majority of earlier forms of life have become extinct without issue. Usually their places in the economy of nature have then been taken by other organisms of quite different origin. In some cases, their places seem simply to have remained empty for shorter or longer periods.

Neither in its over-all pattern nor in its intricate detail can that record be interpreted in any simply finalistic way. If evolution is God's plan of creation—a proposition that a scientist as such should neither affirm nor deny—then God is not a finalist. But this still does not fully answer the particular question we are pursuing here. The whole nonfinalistic pattern *might* have been followed nearly enough on a planet of some other star to produce humanoids there also. We must turn then to the causal elements and limitations inherent in the process for further judgment of the probability of such an outcome.

Each new organism develops in accordance with a figurative message, coded information, received from its one or two parents. Evolution occurs only if there are changes in that information in the course of generations. Such changes in individuals occur for the most part in two ways, although each takes numerous and sometimes complicated forms: mutations, which introduce new elements into the message, and recombinations, which put these elements into new associations and sequences. In a stricter sense mutations are any changes within the code carried by a nucleic acid. Recombinations involve rearrangements of the various code units and particularly new associations of units from different sources. The latter sources of variation are sexual, and sexlike processes occur in even the most primitive living organisms although they have been secondarily lost in a relatively small number of both plants and animals.

In themselves, these processes are not adaptive; they have no direct relevance to fitting organisms into the economy of nature, permitting their survival and further evolution. Since most (but not all) evolutionary changes are adaptive and progressive evolution does occur, these processes alone cannot be the whole story. They are necessary for evolution, but something else must also be involved. There must be some interaction between organisms and environment and from this there must be some kind of feedback into the genetic code. The feedback is by natural selection and it occurs in populations through successive generations, not in individuals in their lifetimes. That is the whole point of natural selection: that it does feed back from environment to genetic code in such a way as to maintain or change the message in adaptive ways. It does this because, by and large, the better adapted organisms have more offspring. The more adaptive genetic messages thus tend to spread through the population in the course of generations. Also, in more complex ways that I need not go into here, new code combinations adaptive for the population as a whole are thus brought into being.

This feedback is basic for our present enquiry because it places definite limitations on the possible course of evolution. We can be quite sure that if the environments of their ancestors had been very different from what they were, the organisms of today would also be very different. It is also clear that evolution must be opportunistic in the sense that it can work only with what is there. Mutations can occur only in quite definite ways depending on the existing nature of the coded message. Recombination can recombine only the code elements that do exist in given organisms. Selection can work only on variations actually present in a population. The cause of evolution thus includes all the genetic, structural, physiological, and behavioral states of populations right back to the origin of life.

Even slight changes in earlier parts of the history would have profound cumulative effects on all descendent organisms through the succeeding millions of generations. In spite of the enormous diversity of life, with many millions of species through the years, it represents only a minute fraction of the possible forms of life. The existing species would surely have been different if the start had been different and if any stage of the histories of organisms and their environments had been different. Thus the existence of our present species depends on a very precise sequence of causative events through some two billion years or more. Man cannot be an exception to this rule. If the causal chain had been different, *Homo sapiens* would not exist. (These causal limitations were discussed in more detail in the preceding chapter. [see also *25*])

Not Repeatable

Both the course followed by evolution and its processes clearly show that evolution is not repeatable. No species or any larger group has ever evolved, or can ever evolve, twice. Dinosaurs are gone forever. Nothing very like them occurred before them or will occur after them. That is so not only because of the action of selection through long chains of nonrepetitive circumstances, as I have just briefly noted. It is also true because in addition to those adaptive circumstances there is a more or less random element in evolution involved in mutation and recombination, which are stochastic, technically speaking. Repetition is virtually impossible for nonrandom actions of selection on what is there in populations. It becomes still less probable when one considers that duplication of what are, in a manner of speaking, accidents is also required. This essential nonrepeatability of evolution on earth obviously has a decisive bearing on the chances that it has been repeated or closely paralleled on any other planet.

The assumption, so freely made by astronomers, physicists, and some biochemists, that once life gets started anywhere, humanoids will eventually and inevitably appear is plainly false. The chance of duplicating man on any other planet is the same as the chance that the planet and its organisms have had a history identical in all essentials with that of the earth through some billions of years. Let us grant the unsubstantiated claim of millions or billions of possible planetary abodes of life; the chances of such historical duplication are still vanishingly small.

Even if, as I believe, any close approximation of *Homo sapiens* elsewhere in the accessible universe is effectively ruled out, the question is not quite closed. Manlike intelligence is, after all, a marvelous adaptation, especially in its breadth. It has survival value in a wide range of environmental conditions, and therefore, if it became possible at all, might be favored by natural selection even under conditions different from those on earth. There is, to be sure, another serious hitch here. Man may be going to use one wild aspect of his intelligence to wipe himself out. I do not believe that will occur, but no realist can now deny it as a possibility. If it did happen, the adaptiveness of human intelligence would have been short-lived indeed, and the argument from its apparent broad adaptiveness would be negatived.

Apart from that point, is there not some play, so to speak, in the causations of history? Even in planetary histories different from ours might not some quite different and yet comparably intelligent beings—humanoids in a broader sense—have evolved? Obviously these are questions that cannot be answered categorically. I can only express an opinion. Evolution is indeed a deterministic process to a high degree. The factors that have determined the appearance of man have been so extremely special, so very long continued, so incredibly intricate that I have been able hardly to hint at them here. Indeed they are far from all being known, and everything we learn seems to make them even more appallingly unique. If human origins were indeed inevitable under the precise conditions of our actual history, that makes the more nearly impossible such an occurrence anywhere else. I therefore think it extremely unlikely that anything enough like us for real communication of thought exists anywhere in our accessible universe.

"Extremely unlikely" is not "impossible," and those who like to dream may still dream that mankind is not alone in the universe. But here another point comes up to trouble us. What is the nature and value of that dream? Unless we know or can seriously hope to learn in fact of other humanoids, the dream remains a dream, a fantasy, a science-fiction *divertissement*, a poetic consolation with no substance of reality. Suppose the near-impossible were to be true. What are the chances that we could in fact learn of the existence of extraterrestrial humanoids and eventually communicate with them? With a feeling almost of sorrow, I must conclude that the chances are vanishingly small.

Communication

In the present or any foreseeable state of our technology, the only way we could learn of other humanoids would be by their sending us a message or actually visiting us. That requires, in the first instance, that they must have developed manlike technology, which by no means follows automatically from the mere development of intelligence. (They *might* be intelligent enough to use their brains in better ways!) They must also have done so at just the right time, which involves another tricky point. Out of the billions of years of life on earth, there has been only an infinitesimal length of time, some sixty years, since man has been in a position either to send or to receive messages through outer space. How small the chance of coincidence that any other humanoid reached just this stage at just the right time!

Theoretically, the improbability of humanoids becomes a little less the farther out in space. If humanoids were on a planet a million light years away—and that is a very small distance in the vastness of the galaxies—a message to reach us now would have had to be sent precisely a million years ago. Improbability piled on improbability approaches impossibility. If again the apparently impossible happened, it would certainly be one of the most exciting events in history, but to what avail? The senders of the message would obviously be dead when we received it; their whole species might well be extinct. If, finally stretching the barest possibility to the utmost, we received a message from the relatively nearby stars, it would take years or more likely generations to send a message and receive a reply. Under those conditions the establishment of useful, intelligible intercommunication would still be impossible.

An actual visit to earth by extraterrestrial humanoids would require a technology extremely far advanced beyond ours. We do not, at present, even know that such a stage of technology is possible. All the difficulties previously noted, and more, here pile up. If such a feat is remotely possible and if humanoids are at all prevalent in the universe—the if's do tend to pile up, too, in this subject!—then one would think that we would have been visited by now. In spite of reports of flying saucers and little green men, which belong only in science fiction, the fact is that none have visited us. That would seem, indeed, a logical added reason to believe that humanoids are, to say the least, nonprevalent.

Conclusions

I cannot share the euphoria current among so many, even among certain biologists (some of them now ex-biologists converted to exobiologists). The reasons for my pessimism are given here only in barest suggestion. They will not, I know, convince all or indeed many. There are too many emotional factors and, to put it bluntly, selfish interests opposed to these conclusions. In fact I myself would like to be proved wrong, but a rational view of the evidence seems now to make the following conclusions logically inescapable:

1. There are certainly no humanoids elsewhere in our solar system.

2. There is probably no extraterrestrial life in our solar system, but the possibility is not wholly excluded as regards Mars.

3. There probably are forms of life on other planetary systems somewhere in the universe, but if so it is unlikely that we can learn anything whatever about them, even as to the bare fact of their real existence.

4. It is extremely improbable that such forms of life include humanoids, and apparently as near impossible as does not matter that we could ever communicate with them in a meaningful and useful way if they did exist.

I shall close this chapter with a plea. We are now spending billions of dollars a year and an enormously disproportionate part of our badly needed engineering and scientific manpower on space programs. The prospective discovery of extraterrestrial life is advanced as one of the major reasons, or excuses, for this. Let us face the fact that this is a gamble at the most adverse odds in history. Then if we want to go on gambling, we will at least recognize that what we are doing resembles a wild spree more than a sober scientific program.

To some it seems that the reward could be so great that facing any odds whatever is justified. The biological reward, if any, would be a little more knowledge of life. But we already have life, known, real, and present right here in ourselves and all around us. We are only beginning to understand it. We can learn more from it than from any number of hypothetical Martian microbes. We can, indeed, learn more about possible extraterrestrial life by studying the systematics and evolution of earthly organisms. Knowledge from enlarged programs in those fields is not a gamble because profit is sure.

My plea then is simply this: that we invest just a bit more of our money and manpower, say one-tenth of that now being gambled on the expanding space program, for this sure profit.

References and Notes

1. In the spring of 1963 I gave lectures on this subject (but entitled "Life on Other Worlds") at six member institutions of the University Center of Virginia and at the University of Colorado. The present chapter, not printed before in any version, is based on those lectures but has been extensively revised.
   I have stressed that "there are no direct observational data whatever" on any planetary systems but our own. On 19 April 1963 the New York *Times* announced that Dr. van de Kamp of Swarthmore had discovered the third such planetary (or "solar") system. The apparent contradiction is a matter of definition of "direct observation" and "solar system" and really calls for no correction of my text. Three stars are inferred to have *unobserved* dark companions on the basis of perturbations of the stars' motions interpreted as due to gravitational influence of the companion. Whether or in what sense the dark companions are to be considered planets is not clear. Inferences as to size, radiation, and so on make them unlike any planets of our system and entirely unsuited for life.
   Since much of the material in this chapter is recent, controversial, and somewhat outside my own field, it has seemed wise to document it in more detail than other chapters. The following explicit citations are made in the text: *(2–25)*
2. H. H. Hess *et al.*, "A Review of Space Research," *Natl. Acad. Sci.–Natl. Res. Council Publ. No. 1079* (1962). Includes a chapter of 23 pages on biology, ostensibly prepared by or expressing the views of 26 "principal participants," two or three of whom are in fact organismal biologists.
3. W. D. Matthew, "Life in other worlds," *Science* **54**, 239 (1921).
4. F. Jackson and P. Moore, *Life in the Universe* (Norton, New York, 1962).
5. F. T. Barath, A. H. Barrett, J. Copeland, D. E. Jones, A. E. Lilley, "Mariner II: Preliminary reports on measurements of Venus. Microwave radiometers," *Science* **139**, 908 (1963).
6. C. Sagan, "Origin and planetary distribution of life," *Radiation Res.* **15**, 174 (1961).
7. E. Hawrylewicz, B. Gowdy, R. Ehrlich, "Micro-organisms under a simulated Martian environment," *Nature* **193**, 497 (1962).
8. C. C. Kiess, S. Karrer, H. K. Kiess, "A new interpretation of Martian phenomena," *Publ. Astron. Soc. Pacific* **72**, 256 (1960).
9. W. M. Sinton, "Further evidence of vegetation on Mars," *Science* **130**, 1234 (1959).
10. M. Calvin, "Communication: From molecules to Mars," *A.I.B.S. (Am. Inst. Biol. Sci.) Bull.* **12**, No. 5, 29 (1962).
11. G. V. Levin, A. H. Heim, J. R. Clendenning, M. F. Thompson, "Gulliver—a quest for life on Mars," *Science* **138**, 114 (1962).
12. B. Nagy, W. G. Meinschein, D. J. Hennessy, "Mass spectroscopic analyses of the Orgueil meteorite: Evidence for biogenic hydrocarbons," *Ann. N.Y. Acad. Sci.* **93**, 25 (1961).
13. E. Anders and F. W. Fitch, "Search for organized elements in carbonaceous chondrites," *Science* **138**, 1392 (1962).
14. F. Hoyle, *Frontiers of Astronomy* (Harper, New York, 1955).
15. H. Shapley, *Of Stars and Men* (Beacon, Boston, 1958).
16. A. I. Oparin, *The Origin of Life* (Oliver & Boyd, London, 3rd English ed., 1957); ———, "The origin of life on earth," *Reports on the International Symposium of August, 1957, in Moscow* (Academy of Sciences of the U.S.S.R., Moscow, 1959); ———, Ed., *The Origin of Life on the Earth* (Pergamon, London, 1960).
17. M. Florkin, Ed., *Some Aspects of the Origin of Life* (Pergamon, London, 1961).
18. M. Calvin, *Chemical Evolution* (Univ. of Oregon Press, Eugene, 1961).
19. G. Ehrensvärd, *Life: Origin and Development* (Univ. of Chicago Press, Chicago, 1962).
20. S. L. Miller, "Production of some organic compounds under possible primitive Earth conditions," *J. Am. Chem. Soc.* **77**, 2351 (1955).
21. D. Keilin, "The problem of anabiosis or latent life: History and current concept," *Proc. Roy. Soc. London* **B150**, 149 (1955).
22. S. Arrhenius, *Worlds in the Making* (Harper, New York, 1908).
23. P. Becquerel, "La suspension de la vie des spores des bactéries et de moisissures desséchées dans la vide vers le zéro absolu. Ses conséquences pour la dissémination et la conservation de la vie dans l'univers," *Compt. Rend.* **231**, 1392 (1950).
24. H. F. Blum, "Negentropy and living systems," *Science* **139**, 398 (1963).
25. G. G. Simpson, *The Meaning of Evolution* (Yale Univ. Press, New Haven, 1949); ———, "The history of life," in *The Evolution of Life*, S. Tax, Ed. (Univ. of Chicago Press, Chicago, 1960), pp. 117–180; ———, "Some cosmic aspects of organic evolution," in *Evolution und Hominisation*, G. Kurth, Ed. (Fischer, Stuttgart, 1962), pp. 6–20.