Letters

Life on Other Planets: Some Exponential Speculations

G. G. Simpson's "The nonprevalence of humanoids" (21 Feb., p. 769) brings up a basic matter of scientific procedure and philosophy. What is the investigator to assume when he does not know? The answer to this question is important, because it determines the nature of his continuing research.

As far as astronomy is concerned, a general point of view has developed during the past few centuries. Although people once thought differently, there appears to be nothing extraordinary about the sun or about the general region which includes the Milky Way galaxy. In lieu of direct evidence to the contrary, it seems reasonable enough to view our section of the universe as if it were a fair sample of the total universe. The sun is currently at a recognized stage in stellar evolution, a stage through which all stars of a certain type pass in their middle age. Another stage may be the formation of planets, a possibility supported by some theoretical considerations although not by observation. So we are not compelled to regard our situation as exceptional, at least from an astronomical standpoint.

Simpson suggests that things may be different as far as biological phenomena are concerned. In the course of making a case for the nonprevalence of humanoids he also makes a case for the nonprevalence of evolution. He concedes a "considerable probability, perhaps even inevitability, in the progression from dissociated atoms to macromolecules" but believes the odds to be enormous against further developments: "Evolution must frequently or usually have ended at that pre-organismal stage."

The question is whether one can arrive at such conclusions merely by multiplying improbabilities. Only the observed existence of numerous stars refutes the notion that the birth of a star must be an improbably rare event. The event depends upon a concatenation of random events: a sufficient concentration of gases, conditions under which the gases will contract *in situ* instead of being swept away, a delicate equilibrium between contracting gravitational forces and thermal forces which tend to produce expansion, and so on. But stars are being born and probably planets with them, and so we seek new hypotheses when highly improbable things tend to happen too often. (After all, the odds against life's developing spontaneously on earth were once considered overwhelming, until it was realized that this is precisely what must have happened.)

On the basis that there is nothing special about our section of the universe, it is plausible to assume that life has appeared and is appearing throughout the universe—whether it is life as we know it, or life as we do not know it. Although observations cannot prove this assumption once and for all, they may have a powerful impact on it. For example, suppose that we found cellular life on Mars. In that case, it would be clear that similar principles had governed the appearance of life in two rather different environments, and arguments based on pyramiding improbabilities would be somewhat weakened.

Whether or not humanoids have evolved elsewhere, one thing is certain. The humanoid *Homo sapiens* has already evolved to a point where he thrives on challenges. He is actively engaged in studying life on earth; he will soon be seeking life on other planets. Sufficient funds should be available for both endeavors.

John Pfeiffer
New Hope, Pennsylvania

Simpson takes exception to my use, in a book review (*1*), of the word "opportunistic" to denote the opposite extreme to a "deterministic" view of evolution. I do not wish to defend either term, having used them with hesitation after considering others that seemed less apt; but I think I should comment on what I had hoped to imply, since it bears on Simpson's article.

Accepting the concept of mutation and natural selection, we see life evolving as a series of chance events and "choices" among the results of these. Since each choice is predicated upon the cumulative result of previous choices, such a process entails an exponential increase in order and decrease in probability. Loose analogy might be had to the operation of a computer, where choice of alternatives contributes bits of negentropy. In such procedure all alternative (unsuccessful) choices are thrown away so far as the record is concerned, which therefore may give the impression that the direction of evolution was preordained. Such a (deterministic?) view encourages finalistic and teleological thinking.

Recognizing that each choice involves alternative possibilities (opportunities?) one adopts a more "probabilistic" view, but expects, since each choice is predicated upon (determined by?) the existing situation, that a thread of continuity must run through the whole of evolution, as is manifest, for example, in the common biochemical makeup of all species. That there were many different possibilities to choose from is indicated by the million or so species of organisms that have evolved; in terms of modern thinking about natural selection, it seems conservative to estimate that a thousand mutations have been involved in each of these, so the number of choices made in arriving at the present array of forms of life on earth might be around 10^9.

Cultural evolution, although taking place by a much different mechanism, also involves choices (*2*); and it would seem that since his debut as a toolmaker Man has added easily a million or so facets to his culture. And back of the first replicating systems that could begin to evolve by natural selection lies a stretch of "chemical" evolution, where choices must have been made, although the mechanism is again much different. Choice of one of two possible optical isomers is an obvious example, but it seems probable that many more led up to and followed this one. When one considers the unlikeliness of a primordial thin soup—from which so many think life to have emerged—as a place for the dehydration concerned in joining both amino acids and nucleotides into long polymers, one begins to suspect a quite special sequence of situations and events (*3*). It may be noted that we have no way of putting this or any other negentropic process into dimensions used in studying chemical reactions in the laboratory (*4*).

Taking all these things into consideration, the total number of choices might be raised considerably above the figure mentioned, although it might still be well below the estimates of astronomers regarding the number of habitable planets. But since order is related exponentially to number of choices, Man may be very much less probable than this number suggests. Moreover, it is possible that astronomers underestimate the specificity of the conditions on earth that have permitted Man to evolve (*5*).

Obviously speculations along this line may enjoy great freedom; but is this not the more reason for viewing them from as many angles as possible, rather than from single disciplines? Long-shot chances have their place in science, but even at the race track the odds and the size of the stake are taken into account. I think, like Simpson, that there are good gambles to be taken close to home, and that some of these might even lead to clearer ideas of the odds of finding what we seek in space.

Several years before Sputnik I stated my position regarding the probable uniqueness of Life and of Man in the last pages of a book (*5*) that has since been revised without change in this particular regard. Further mulling over has not altered my view that we have here on earth something so precious that we should be extremely careful not to jeopardize it by incautious acts.

HAROLD F. BLUM
National Cancer Institute,
Bethesda, Maryland

References

1. H. F. Blum, *Science* **139**, 398 (1963).
2. ———, *Am. Scientist* **51**, 32 (1963).
3. ———, *ibid.* **49**, 474 (1961).
4. ———, *Synthese* **15**, 115 (1963).
5. ———, *Time's Arrow and Evolution* (Harper Torchbook, New York, 1962; first published by Princeton Univ. Press, Princeton, N.J., 1951).

Simpson has been wise to reprove the excessive investment in problems of extraterrestrial life likely to remain intractable, in our time, to experimental or even theoretical treatment. The article is so salutary that one hesitates to blunt its impact by any objection whatever. Yet Simpson's argument does leave uneasy feelings, not so much because it is based on a very particular philosophy of science as because this outlook is purported to stem inevitably from, or attach especially to, the nature of life phenomena. I refer to the empiricist notion that a discipline comes into being when a subject matter presents itself naively to the senses.

While it is true that there are now no data for "exobiology," the problem of the dispersion of life in the universe is a legitimate one for *biology*. It is an oversimplification to state that propositions about unobservables are scientifically meaningless. Such exaggeration leads Simpson to the strained footnote to the effect that a dark companion to a star inferred from gravitational perturbations is more fictitious than a planet identified from a spot on a photographic plate. Propositions can be declared meaningless on their face only if they are about entities undetectable *in principle*. As to practice, new instrumentation reveals former unobservables almost every year, many of which were discussed theoretically prior to detection.

Simpson implies, therefore, that biology inherently does not deal with principles of such generality, that—in modern language—its laws are not Lorentz-invariant, that it is tied to the universe's local irregularities. The principal reason for so relegating biology to a descriptive and historical status is that unsystematic variability is a necessary term in the theory of natural selection. The neo-Darwinian theory is, indeed, a generalization comparable in scope to Newton's law of gravitation. Nevertheless, particularly in view of experience with Newton's law, natural selection as an analytic principle should not be identified with the speciation it was designed to give an account of. It is not inconceivable that genetic variability will be found to follow systematic rules when the point of view is enlarged from the ecological to the terrestrial and hence to the cosmic scale.

The vacillation shown by Simpson in granting the formation of macromolecules and protolife to be a systematic and probably generalizable process, while denying this character to biogenesis subsequent to the elaboration of genetic transmission, indicates a lingering vitalism. Such an orientation is not dictated by the subject matter of biology. We can be biologists and believe that when generalizations of the order of, say, the competitive-exclusion principle are arrived at, a new level of natural law might appear, derived from study of the terrestrial biosphere but encompassing matter in general. Biological principles might not only supplement physics and chemistry as regards a nook and cranny of the universe, but go on to reform them.

The chances that such discoveries will be made in the course of earthly rather than astral activities, however, seem eminently great. And Simpson's essay itself proves that he does not oppose mental bioprospecting of the worlds, which costs the taxpayer nothing.

MICHAEL F. HALASZ
1429 Severn Street,
Pittsburgh, Pennsylvania

. . . The following diversion in numerology, which is no more naive than calculations of the number of earthlike planets in the universe, is merely intended to temper the widely held faith that humanoids must necessarily arise on an appreciable proportion of as yet hypothetical earthlike planets:

Numbers associated with the magnitude of the universe, for example the estimates of from 10^8 to 10^{20} earthlike planets among up to 10^{21} stars within the observable universe (radius, 10^{10} light years $= 6 \times 10^{21}$ miles) overpower many people. In a diploid cell 10^{-12} gram of DNA can code for a sequence of about 10^8 of the 20 amino acids. Such an "information source" contains $20^{(10^8)} = 10^{(1.30 \times 10^8)} = 2^{(0.43 \times 10^8)}$ possible genetic "messages" (organisms?). The improbabilities associated with such a 0.43-billion-bit information source make even Eddington's "cosmical number," the supposed total number of protons and neutrons in the observable universe (approximately 2.4 $\times 10^{79}$), pale into insignificance.

If we consider each section of the DNA which codes each polypeptide of about 15,000 molecular weight as a "gene" or cistron, then there are 10^6 genes for each such organism. If we allow ten variants ("alleles" representing single amino acid substitutions along a polypeptide) with approximately equal adaptive value for each gene, and consider all colinear sequences of these as again representing adaptively equivalent phenotypes, then if this amount of diversity were the maximum that is likely to occur within a Mendelian population, the equal-likelihood probability of producing *any* member of *any* Mendelian population (species) is $10^{(10^6)} \times 10^{-(1.30 \times 10^8)} = 10^{-(1.29 \times 10^8)}$. Even if we suppose that all possible "chromosomal rearrangements" of such million kinds of nonallelic genes are adaptively equal and therefore represent members of other species with "equal evolutionary potential," the probability of producing *any* member of *any* such species, if all permutations are equally likely, is still only $10^6! \times 10^{-(1.29 \times 10^8)}$ or approximately $10^{-(1.23 \times 10^8)}$.

Since evolution is "opportunistic" and "deterministic," all permutations are *not* equally likely. Let's consider a hypothetical collection of 10^8 Mendelian populations, each of 10^6 sexual members at a time 3×10^9 years ago on earth. Let each organism have the coding for 10^6 polypeptides, and allow a mutation rate per gene per generation of 10^{-6}. Let the generation time equal one year. If there were 2×10^6 offspring per mating pair, and if two mutations per 2×10^6 offspring confer a sufficiently large selective advantage *in the given environment* so that their carriers are the only survivors among their sibs, then $10^6 \times 10^8 \times 3 \times 10^9 = 3 \times 10^{23}$ possible different "progressive" viable genotypes would have been produced "deterministically" and "opportunistically" out of a total of 3×10^{29} "tested by evolution."

This represents a tempo of evolution far exceeding that which could have occurred on earth or on any earthlike planet, yet only an infinitesimal proportion of the $10^{(1.23 \times 10^8)}$ possible genotypes with "different evolutionary potential" would have been sampled.

Clearly, unless a large proportion of genotypes with "different evolutionary potential" nonetheless should prove to have "*similar* evolutionary potential," only organisms related by descent from a common ancestor will have any appreciable chance of having "similar evolutionary potential." Restated, only if observation of the evolutionary record strongly indicates that *independent origin* and "convergent evolution" have occurred in connection with important humanoid characteristics does it at present make sense to give serious consideration to the occurrence of extraterrestrial humanoids.

If a "humanoid" is an organism which has a sophisticated data-processing and information-retrieval system and which, for adaptive purposes, can communicate *substantial* amounts of the information used within its data-processing system to other organisms of the same kind, then what is the evidence for independent origin and convergent evolution of *important* elements of such systems?

I believe we can discount the significance of such primitive "reflex arcs" among the higher plants as that of the Venus's-flytrap. The relationship of nervous tissues and systems among animals is almost certainly the result of parallel evolution based on descent from a common ancestor.

Sophisticated data processing has apparently depended upon the evolution of a complex visual apparatus, and it is therefore particularly relevant to ask whether the arthropod, molluscan, and chordate eyes are examples of independent origin, and whether the cephalopod and vertebrate eyes are samples of convergent evolution.

Cytological evidence indicates that visual receptors have a common cellular origin, representing the realization of the evolutionary potential indicated for the cilium among, for example, the euglenoids. Were there no living flagellated species with eye-spots, and were none of the electron-microscopic evidence on the structure of photoreceptors yet in, we might argue for independent origins of primary photoreceptors. Were there no living tupaioids ("tree shrews"), the marked similarity (almost identity) of the detailed sculpturing of the external ear (too soft to leave a fossil record) of some ceboids (New World monkeys) to that of some Old World monkeys and apes (and especially man), but dissimilarity to that of living lemuroids, lorisoids, tarsioids, and hapaloids (marmosets), might suggest convergent evolution determined by some obscure adaptive value special to the higher primates. *Tupaia glis* with its very human-like ears weakens that argument and instead spotlights "evolutionary conservatism" as well as "opportunism."

In the absence of knowledge concerning the structure of the "eyes" (if any) of possible extinct ancestral stocks of the arthropods, molluscs, annelids, echinoderms, and chordates, embryological, anatomical, and neurological evidence strongly favors independent origin and, in the case of the cephalopods and vertebrates, convergence. However, until a comprehensive "molecular evolutionary" study of living members of these groups has been made, or "missing links," living or fossil, are discovered, one would not want to hinge important arguments for support of Project Ozma or any substantial part of NASA's program on such evidence.

Extensive communication among members of a species seems to exist only among some social hymenoptera and some few vertebrates. Here the case for independent origin of the mechanisms in the two lines and of convergence growing out of the "deterministic potential" of the visual data-processing equipment seems quite convincing. Yet the scarcity of instances of such communication among the many species with such potential emphasizes how largely uncertain is the "determinism" of evolution. Since ours appears to be the only sophisticated communicating species on earth, it seems reasonable to favor Simpson's view that "humanoids are, to say the least, nonprevalent."

LEONARD ORNSTEIN
Division of Cell Biology, Mount Sinai Hospital, New York 29

The foregoing letters expand the discussion of extraterrestrial life in an interesting way, subject as it is to the different approaches of the discussants. I want to enter only one demurrer. Contrary to Halasz, there is neither "vacillation" nor "vitalism" in my opinion about the origin of cells from macromolecules. I hold this to be possible under physical laws but extremely improbable. To maintain that it is a "generalizable process" presumably would mean that it would *regularly* occur, that it is a necessary outcome of physical law under usual circumstances. That is, in my opinion, a gross fallacy, sufficiently exposed by its logically leading to the plainly false statement that anything that has ever occurred in history is "generalizable." A similar fallacy underlies belief that principles like that of ecological incompatibility (or "competitive exclusion") might represent "a new level of natural law." Such principles differ radically from natural laws not because they are biological rather than physical, but because they are contingent and historical rather than immanent. These matters are discussed at some length in other chapters of *This View of Life*, my book in which the *Science* article is one chapter.

GEORGE GAYLORD SIMPSON
Museum of Comparative Zoology, Harvard University