

13 Generating Life on Earth: Five Looming Questions

Holmes Rolston III

Events on Earth stand in marked contrast with events on other planets, such as the gases that swirl around Jupiter, or the winds that blow on Venus. On Earth, climatological and geomorphological processes continue in the Pleistocene period more or less like they did in the Precambrian. But Earth history is quite different because in biology — unlike physics, chemistry, geomorphology, or astronomy — something can be learned. Once upon a time, signals appeared! Where once there was matter, energy, and where these remain, there is information, symbolically encoding life. There is a new state of matter, neither liquid nor gaseous nor solid, but vital. With the passing of cold and warm fronts or the uplifting and eroding of mountains, there is no natural selection. Nothing is competing, nothing is surviving, reproducing, nothing has adapted fit. To come into being, to survive, an organism needs to gain, to use, to transmit relevant information.

If we ourselves are to gain the information we wish about this generating of vital information, we need to figure out five big unknowns.

Creating Information

In nature, in the Newtonian view there were two metaphysical fundamentals: matter and energy. Einstein reduced these two to one: matter-energy. In matter in motion, there is conservation of matter, also of energy; neither can be created nor destroyed, although each can take diverse forms, and one can be transformed into the other. In the biological sciences, the novelty is that matter-energy enters into rich information states. The biologists still claim two metaphysical fundamentals: matter-energy and information. They can

do so listening to a founder of cybernetics. Norbert Wiener insists: "Information is information, not matter or energy" (1948:155).

In physics and chemistry, throughout natural history, matter has been structurally transformed by energy, sometimes with impressive results, as with the construction of the higher elements in the stars or the composition of crystals, rocks, mountains, rivers, canyons on Earth. There are mathematical kinds of information (bitmaps). There is also a sense in which historical information is present, passively, on the surface of the moon. A geologist can read off from the way that craters are overlaid on each other which of the impacts came first. But the really spectacular constructions that are manifest in biological diversity and complexity do not appear without the simultaneous genesis of active information about how to compose, maintain, and communicate these vital structures and processes. This advanced, proactive information is recorded in the genes, and such information, unlike matter and energy, can be created and destroyed.

In living things, concludes Manfred Eigen, this is "the key-word that represents the phenomenon of complexity: information. Our task is to find an algorithm, a natural law that leads to the origin of information. . . . Life is a dynamic state of matter organized by information" (1992:12, 15). Bernd-Olaf Küppers agrees: "The problem of the origin of life is clearly basically equivalent to the problem of the origin of biological information" (1990:170). George C. Williams is explicit:

Evolutionary biologists have failed to realize that they work with two more or less incommensurable domains: that of information and that of matter. . . . Matter and information [are] two separate domains of existence, which have to be discussed separately in their own terms. The gene is a package of information, not an object. . . . Maintaining this distinction between the medium and the message is absolutely indispensable to clarity of thought about evolution. (In Brockman 1995:43)

John Maynard Smith says: "Heredity is about the transmission, not of matter or energy, but of information. . . . The concept of information is central both to genetics and evolution theory" (1972:28). Together with his colleague, Eörs Szathmáry, he analyzes "the major transitions in evolution" with the resulting complexity, asking "how and why this complexity has increased in the course of evolution." "Our thesis is that the increase has depended on a small number of major transitions in the way in which genetic information is transmitted between generations." Critical innovations have included the origin of the genetic code itself, the origin of eukaryotes from prokaryotes, mei-

otic sex, multicellular life, animal societies, and language, especially human language (1995:3).

The most spectacular thing about planet Earth, says Richard Dawkins, is this “information explosion,” even more remarkable than a supernova among the stars (1995:145). And, adds, Klaus Dose:

More than 30 years of experimentation on the origin of life in the fields of chemical and molecular evolution have led to a better perception of the immensity of the problem of the origin of life on Earth rather than its solution. . . . We do not actually know where the genetic information of all living cells originates. (1988:348)

When sodium and chlorine are brought together under suitable circumstances, anywhere in the universe, the result will be salt. This capacity is inlaid into the atomic properties; the reaction occurs spontaneously. Energy inputs may be required for some of these results, but no information input is needed. When nitrogen, carbon, and hydrogen are brought together under suitable circumstances anywhere in the universe, with energy input, the spontaneous result may be amino acids, but it is not hemoglobin molecules or lemurs — not spontaneously. The know-how, so to speak, to make salt is already in the sodium and chlorine, but the know-how to make hemoglobin molecules and lemurs is not secretly coded in the carbon, hydrogen, and nitrogen. The essential characteristic of a biological molecule, contrasted with a merely physicochemical molecule, is that it contains vital information. Its conformation is functional. With the typical protein, enzyme, lipid, or carbohydrate this is structural, keyed by the coding in DNA, and interlocked with an information producer-processor (the organism) that can transcribe, incarnate, metabolize, and reproduce it.

In the course of evolutionary history, one would be disturbed to find matter or energy spontaneously created, but ought we not be equally disturbed to find information appearing *ex nihilo*? Nature has spontaneously assembled itself as an open cybernetic system several billion years long and gaining spectacular diversity and complexity. Life is a river that runs uphill, and even if it nowhere runs uphill very steeply (if we look at its incremental assembly bit by bit), the river as a whole runs far uphill. Each living creature in the stream is quite highly ordered. Some forces are present that suck order in superseding steps out of disorder. Organisms must be constructed along a long negentropic pathway. This requires the continual introduction of information not previously present. Though no new matter or energy is needed, if there are to be generated these on-going evolutionary constructions, making niche-step by niche-step these

dramatic structural/functional climbs, new information is needed in enormous amounts. The usual turn here is to conclude that nature is self-organizing (autopoiesis), though, since no “self” is present, this is better termed spontaneously-organizing. Nature is spontaneously auto-cybernetic. An autopoietic, autocybernetic process can be just a name, like “soporific” tendencies, used to label this mysterious genesis of more out of less, a seemingly scientific name that is really a sort of mystic chant over a miraculously fertile universe. Any metaphysically adequate account needs a ground of this information.

Contingent versus Inevitable Creativity

Contemporary biologists are divided across a spectrum whether this creative cybernetic evolutionary history is entirely contingent or quite probable, even inevitable. If life on Earth is a one-off event, sheer contingency, we need not expect it elsewhere. If life is intrinsic to the physics and chemistry, we should expect it elsewhere. If we find some trends, some mixture of the inevitable and the contingent, we will not only wonder what to expect elsewhere but what to make of discovering ourselves here on Earth. Such trends, which are a *sine qua non* of historical interpretation, are neither absolute laws nor mere contingencies; they are never directly observable and may be difficult to detect in a limited span of time or range of observation. They show up statistically, but statistics deals poorly with cybernetically developing trends, with sometimes critical initiating discoveries, such as when photosynthesis, or neurons, or endoskeletons appeared.

There are eminent biologists — though they tend to be molecular biologists rather than paleontologists — who find Earth’s evolutionary history to be inevitable, at least in outline, and therefore predictable. Christian de Duve, a Nobel prizewinner, concludes: “Life was bound to arise under the prevailing conditions, and it will arise similarly wherever and whenever the same conditions obtain. There is hardly any room for ‘lucky accidents’ in the gradual, multistep process whereby life originated.” After life arises there is contingency as to its directions and species, but this is “constrained contingency” so that the general trends in the development of life — cellular organisms, multicellular organisms, solar energized organisms, increasingly diverse and complex organisms, and intelligent organisms — are likewise inevitable. “Life and mind emerge not as the results of freakish accidents, but as natural manifestations of matter, written into the fabric of the universe. I view this universe [as] . . . made in such a way as to generate life and mind, bound to give birth to thinking beings” (1995:xv-xvi, xviii).

“This universe breeds life inevitably,” concludes George Wald, another Nobel laureate (1974:9). Life is an accident waiting to happen, because it is blueprinted into the chemicals, rather as sodium and chlorine are preset to form salt, only much more startlingly so because of the rich implications for life and because of the openness and information transfer also present in the historical life process. Whatever place dice-throwing plays in its appearance and maturation, life is something arranged for in the nature of things. The dice are loaded.

When the predecessors of DNA and RNA appear, enormously complex molecules appear bearing the possibility of genetic coding and information, these are conserved, writes Melvin Calvin, yet another Nobel laureate, “not by accident but because of the peculiar chemistries of the various bases and amino acids. . . . There is a kind of selectivity intrinsic in the structures.” The evolution of life, so far from being random, is “a logical consequence” of natural chemistries (1975:176, 169). To continue with Nobel prizewinners, Manfred Eigen concludes “that the evolution of life . . . must be considered an *inevitable* process despite its indeterminate course” (1971:519; 1992). Life is destined to come as part of the narrative story, although the exact routes it will take are open and subject to historical vicissitudes. Stuart Kauffman agrees: “I believe that the origin of life was not an enormously improbable event, but law-like and governed by new principles of self-organization in complex webs of catalysts” (1993:xvi; 1995).

Life originated at start-up events and then kept on further generating. Perhaps we can gain some clue about the nature of the evolutionary start-up from what happened afterward over the subsequent millennia. David Raup and John Sepkoski graph marine invertebrates and vertebrates, an overall rise, with climbs and drops, especially at times of catastrophic extinctions, from zero to perhaps 750 families (Fig. 1 on p. 200) (Raup and Sepkoski 1982). During the relatively flat part of the marine curve, life moves onto the land and greatly diversifies there, from the Silurian Period onward, not shown in this graph. That requires also considerable evolution of complexity, since the terrestrial environment is more demanding.

Plants develop steadily on the land masses, graphed by Karl Niklas (Fig. 2 on p. 200). For animals, it is in the vertebrates, most of all, that advance is difficult to deny (Fig. 3 on p. 201) (Niklas 1986). Norman D. Newell graphed the numbers of all families, terrestrial and marine, vertebrate and invertebrate, increasing through evolutionary time (Fig. 4 on p. 202) (Newell 1963). Rather interestingly, Sean Nee and Robert M. May find that the catastrophic extinctions do not much suppress these trends. Even in the most extreme cases, “approximately 80 percent of the tree of life can survive even when approximately 95

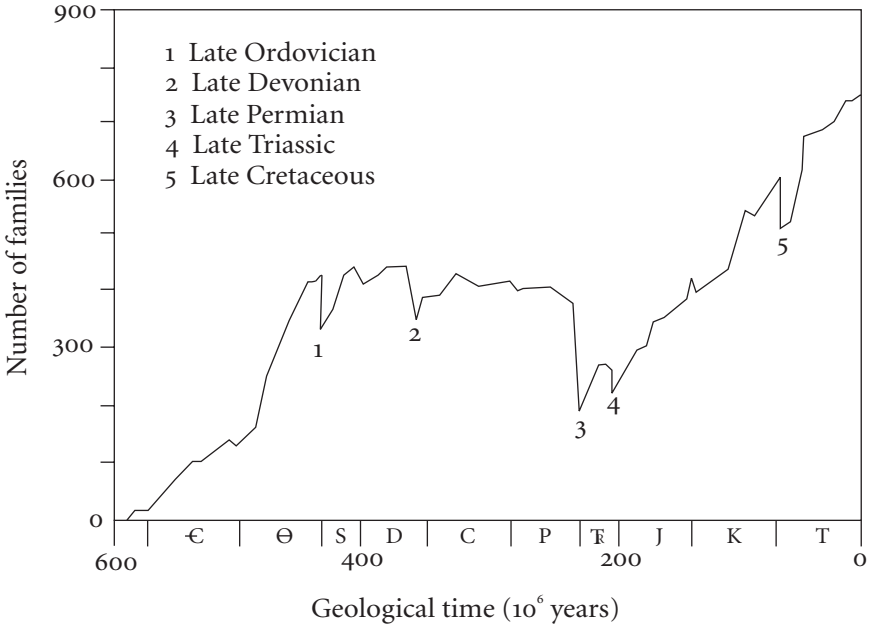


Fig. 1. Standing diversity through time for families of marine vertebrates and invertebrates, with catastrophic extinctions (Raup and Sepkoski, 1982)

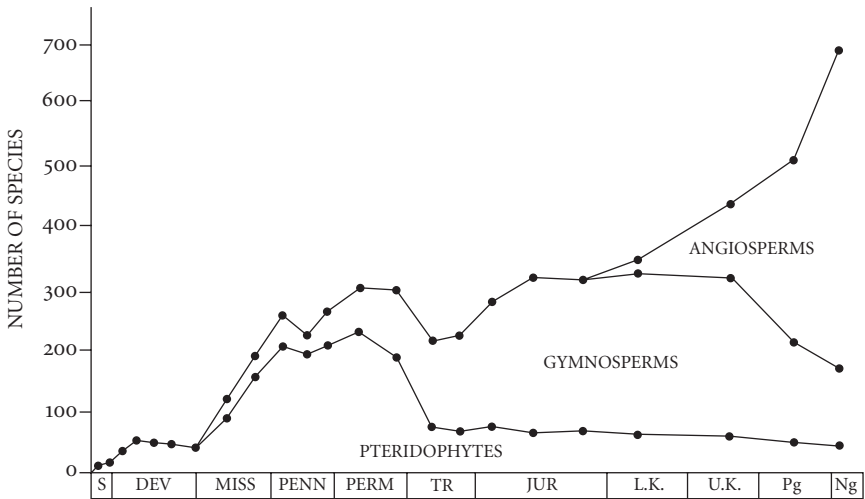


Fig. 2. Species diversity changes in vascular plants (Niklas, 1986)

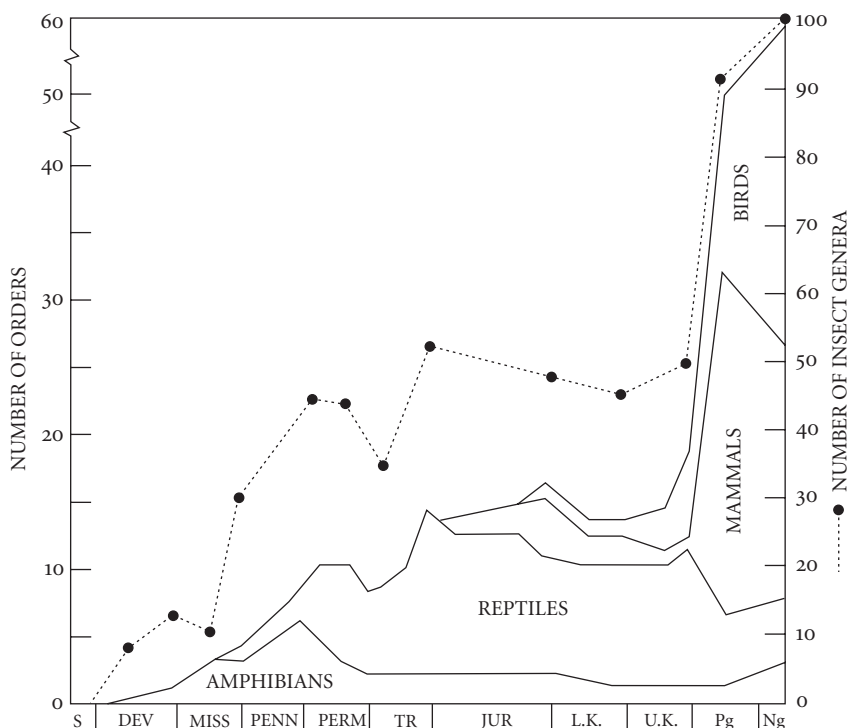


Fig. 3. Changes in the composition of vertebrate orders and numbers of insect genera (Niklas, 1986)

percent of species are lost.” To use their metaphor, mass extinction cuts off the twigs of the tree of life (the species) but the main branches (the families, orders, classes) persist in species that do survive. “Much of the tree of life may survive even vigorous pruning” (Fig. 5 on p. 202) (Nee and May 1997; Myers 1997).

A graph of increasing complexity is more difficult to produce. Nevertheless increases in capacities for sentience (ears, eyes, noses, antennae), increases in capacities for locomotion (muscles, fins, legs, wings), increases in capacities for manipulation (arms, hands, opposable thumbs), increases in neural networks with control centers, brains, surpassing mere genetic and enzymatic control, increases in capacities for acquired learning (feedback loops, synapses, memory banks), increases in capacities for communication and language acquisition) — all these take increased complexity. Nothing seems more evident over the long ranges than that complexity has increased; in the Precambrian there were microbes; in the Cambrian Period trilobites were the highest life form; the Pleistocene Period produced persons.

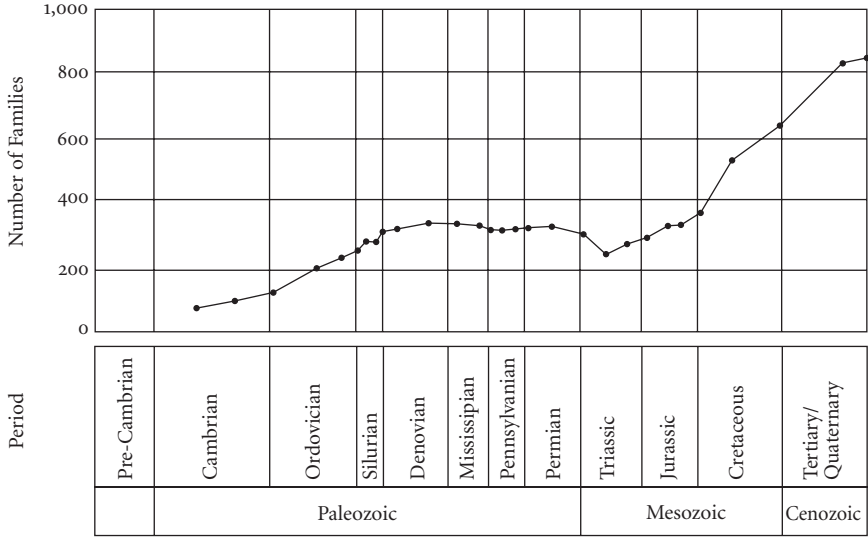


Fig. 4. Number of major families of fossil animals increasing through time (Newell, 1963)

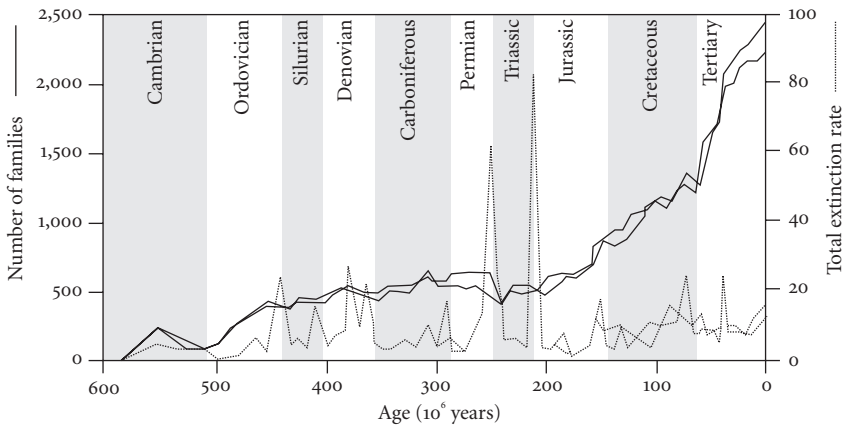


Fig. 5. Proliferation of number of families on Earth, continuing through major extinctions (Myers, 1997; Nee and May, 1997)

Ernst Mayr asks:

Who can deny that overall there is an advance from the procaryotes that dominated the living world more than three billion years ago to the eucaryotes with their well organized nucleus and chromosomes as well as cytoplasmic organelles; from the single-celled eucaryotes to metaphytes and metazoans with a strict division of labor among their highly specialized organ systems; within the metazoans from ectotherms that are at the mercy of climate to the warm-blooded endotherms, and within the endotherms from types with a small brain and low social organization to those with a very large central nervous system, highly developed parental care, and the capacity to transmit information from generation to generation? (Mayr 1988:251-252).

The lower forms remain too; there must be trophic pyramids, food chains. There cannot be higher forms, all by themselves. These must be superposed on lower forms, embedded in communities. So there can seem only change, not progress, if one looks at the monocots and dicots, the crustaceans and flatworms. But if we are to have the whole story of what is going on, we must look at the uppermost forms. These do seem to get built up over time.

Simon Conway Morris, a prominent Cambridge paleontologist, has been quite outspoken about how “life . . . is full of inherencies.” “Life shows a kind of homing instinct” (2003:8, 20). Looking back across Earth’s natural history and wondering if things might have been otherwise, searching the possibilities for “evolutionary counterfactuals,” “possibly . . . we shall discover in the end that there are none. And, despite the almost crass simplicity of life’s building blocks, perhaps we can discern inherent within this framework the inevitable and pre-ordained trajectories of evolution?” (2003:24).

True, much in evolutionary history can seem contingent, if one considers only the fortunes of this or that lineage, which is typically the focus of analysis. The history begins to look different when one considers the evolution of skills, irrespective of what lineage they happen to be in. Assuming more or less the same earthbound environments, if evolutionary history were to occur all over again, things would be different. Still, there would again be plants and animals; photosynthesis or something like it; primary producers and secondary consumers; predators and prey; parasites and hosts; autotrophs and heterotrophs; ecosystemic communities; cells and membranes; birth or hatching; seeds reproducing; coding and coping; natural selection; sight; mobility with fins, limbs, or wings; smell; hearing; convergence; and parallelism. Life would evolve in the sea, spread to the land and the air.

Play the tape of history again. If played just once more, the differences would strike us first. Leigh Van Valen continues: “Play the tape a few more times, though. We see similar melodic elements appearing in each, and the overall structure may be quite similar. . . . When we take a broader view, the role of contingency diminishes. Look at the tape as a whole. It resembles in some ways a symphony, although its orchestration is internal and caused largely by the interactions of many melodic strands” (Van Valen 1991:48).

Maynard Smith agrees that complexity has increased, but, to the contrary, finds no cause to think it would happen again. “There is nothing in neo-Darwinism which enables us to predict a long-term increase in complexity.” But he goes on to suspect that this is not because there is no such long-term increase, but that Darwinism is inadequate to explain it. We need “to put an arrow on evolutionary time” but get no help from evolutionary theory.

It is in some sense true that evolution has led from the simple to the complex: prokaryotes precede eukaryotes, singled-celled precede many-celled organisms, taxes and kineses precede complex instinctive or learnt acts. I do not think that biology has at present anything very profound to say about this. . . . We can say little about the evolution of increasing complexity. (1972:89, 98-99).

Contrary to de Duve, Eigen, Calvin, Conway Morris, or Kauffman, Maynard Smith and Eörs Szathmáry find “no reason to regard the unique transitions as the inevitable result of some general law”; to the contrary, these events might not have happened at all (1995:3).

Evolutionary history wanders in the first place because of atomic and molecular chance, unrelated to the needs of the organism. Selection is operating over this chance, but that selection does not introduce any ordered direction, because it is not selection for advancement, only selection for survival. The biggest events (the coming of mammals and humans) not less than the smallest events (the microscopic mutations) are accidental or random with respect to anything the theory can predict or retrospectively explain. It might first seem that in one part of the theory, the supply side, internal to the organism, one finds randomness, but that in another part of the theory, the retention side, external to the organism, one might find progress, because the “better” are selected. From among the myriad trials that come momentarily into existence, the fittest are selected to stay. The new events occur at random with respect to their direction, but are preserved for the direction they take.

But when we look more closely at even the retention side — so this claim runs — randomness is equally present there. There is no direction in the

microevolution (random variants), and no direction in the macroevolution either (selection headed nowhere), a twice-compounded randomness. Selection is for survival, yes; but there is only changing genetics that records changing morphology and behavior that tracks drifting environments. This does give local trends (hair growing whiter as environments grow colder). But there is no covering law, or trend, enabling one to say that microbes, or mammals, or humans could statistically be expected. They just occur as historical events, and the theory is surprised by them, although in retrospect they are consistent with the theory. Among the equally fit, some are more complex, some less so, and while survival might have been possible without advancing complexity, there is nevertheless advancing complexity in some few forms, consistent with, but not required by, the principle of natural selection.

Stephen Jay Gould spent his career “denying that progress characterizes the history of life as a whole, or even represents an orienting force in evolution at all” (1996:3). “We are the accidental result of an unplanned process . . . the fragile result of an enormous concatenation of improbabilities, not the predictable product of any definite process” (1983:101-102). “Natural selection is a theory of *local* adaptation to changing environments. It proposes no perfecting principles, no guarantee of general improvement” (1977:45). Natural selection provides no reason to believe in “innate progress in nature”; none of the local adaptations are “progressive in any cosmic sense” (1977:45). “Almost every interesting event of life’s history falls into the realm of contingency” (1989:290).

Michael Ruse surveys the conclusions of evolutionary biologists at great length. “A major conclusion of this study is that some of the most significant of today’s evolutionists are Progressionists, and . . . we find (absolute) progressivism alive and well in their work” (1996:536). Nevertheless, they are all wrong, because, biased, they are reading progress into the evolutionary record. They have slipped into “pseudo-science.” “For nigh two centuries, evolution functioned as an ideology, as a secular religion, that of Progress” (1996:526). The fashionable account at the moment is that the British read progress into nature from their cultural gestalt. Scientists continue to do this because we humans have an innate disposition to long for order. That biases us to read progress into a Darwinian nature, when the truth of the matter is that Darwinian nature is disorderly, not progress. Today, argues Ruse, the more “mature” scientists, unbiased, have “expelled progress” from evolutionary history (1996:534). “Evolution is going nowhere — and rather slowly at that” (1986:203).

But then one has also to conclude that all those Nobel laureates are immature scientists! Perhaps a better conclusion to draw at this point (despite

Ruse, and puzzling about the Nobel laureates) is that there isn't any conclusion. Maybe we do not even know whether we humans are competent to make such a judgment. We do not know where the information that is generating life is coming from; we do not know whether its arrival was contingent, necessary, improbable, or probable.

Possibility Space: Omnipresent versus Emerging

We do not know how or when generating such information became possible. We do know, of course, that it did become possible, since here we are. For scientists, the question is about the generating the actual out of the possible. Metaphysicians also need to generate those possibilities. Once again, metaphysicians and scientists are located along a spectrum. On one end of this spectrum, all the possibilities are always there, front-loaded (as it were) into the system. From the Big Bang on there is a world of infinite possibilities. On another account, along the spectrum, new possibilities appear during the circumstances of evolutionary history. That certainly seems the case in human history. We regularly say that new possibilities open up; we mean that opportunities once not there came into being.

Perhaps there are degrees of possibility. Possibilities are of various kinds. With originating life, the developing possibility route is not so much logical, or empirical, or even physical; it is historical. Science does not handle historical explanations very competently, especially where there are emergent novelties; science prefers law-like explanations in which there are no surprises. One predicts, and the prediction comes true. If such precision is impossible, science prefers statistical predictions, probabilities. One predicts, and, probably, the prediction comes true. Biology, meanwhile, though prediction is often possible, is also full of unpredictable surprises — like calcium endoskeletons in vertebrates after millennia of diatomaceous silica and chitinous arthropod exoskeletons. As life becomes more complex, it becomes more historical.

There is no induction (expecting the future to be like the past) by which one can expect, even probably, trilobites later from prokaryotes earlier, or dinosaurs still later by extrapolating along a regression line (a progression line!) drawn from prokaryotes to trilobites. There are no humans invisibly present (as an acorn secretly contains an oak) in the primitive eukaryotes, to unfold in a law-like or programmatic way. The ancient ancestral forms are not proto-vertebrates, or pre-terrestrials, nor are gymnosperms about-to-be angiosperms, as though the descendant forms were latent among the functions of the predecessors. Originating events often become what they become only

retrospectively: Vertebrates began (possibly) with the notochords of primitive chordates.

Nevertheless, there is the epic story: eukaryotes, trilobites, dinosaurs, primates, swarms of wild creatures in seas and on land, followed by humans who come late in the story. What makes the critical difference in evolutionary history is increase in the information possibility space, which is not something inherent in the precursor materials, nor even in the evolutionary system.

The accounts by Calvin, Wald, Eigen, Conway Morris, and Kauffman suggest that the possibilities are always there, latent in the physics and chemistry. De Duve puts it this way: “The universe has given life and mind. Consequently, it must have had them, potentially, ever since the Big Bang” (2002:298). But of course all such possibilities are seen only retrospectively. If, *per impossibile*, some scientist had under observation the elementary particles forming after the first three minutes, nothing much in them suggests anything specific about the coding for life that would take place, fifteen billion years later, on Earth. After Earth forms, the lifeless planet is irradiated by solar energy, as are other planets as well. In orogeny and erosion, or the shifting of the tectonic plates, the possibilities of building geological structures seem always to be there.

At the microscopic levels, quantum physics depicts an open system and nested sets of possibilities; but, at first, all the atoms and molecules take non-living tracks. There really isn’t much in the physics and chemistry of atoms and molecules, prior to their biological assembling, that suggests that they possess, pushed down inside them, any tendencies to order themselves up to life. The order does not seem to be arising “bottom up.” Only later, do some atoms and molecules begin to take living tracks, called forth as interaction phenomena when cybernetic organisms appear.

From a more comprehensive view, if there is some “inside order” to matter that makes it prolife, perhaps it is distributed over the whole system and not just in capacities in the particles. Such order would be “top down.” But, despite the anthropic principle, such order is not generally evident in the systemic astronomy, since far the vastest parts of the universe are lifeless. Nor, on Earth, are the meteorological or geomorphological systems all that suggestive of inevitable life. They mostly seem kaleidoscopic variations on geophysical and geochemical processes. Even after things have developed as far as the building blocks of life, there is nothing in a “thin hot soup” of disconnected amino acids to predict that they will arrange for DNA molecules in which to record the various discoveries of structures and metabolisms specific to the diverse forms of life, dinosaurs or lemurs.

When, in biology there open up entirely unprecedented levels of achieve-

ment and power, we do not conclude that such possibilities are possessed inside the atoms and molecules apart from their systemic location, since atoms and molecules would not even be collected into a hot soup except for the Earth-world in which this is possible, nor can this or that sequence of DNA code for anything unless there is an environment in which to behave this way or that, with a niche to fill. All these events may come naturally, but they are still quite a surprise. Recent microbiology has been revealing their enormous complexity. We do not know that life, if it occurs on some other planet, being there also built of the same atoms, must select these same biochemistries, although the amino acids found on meteorites and the prebiotic molecules guessed to be present in interstellar dust clouds can suggest that the potential for life is omnipresent in matter.

Making this survey, can one insist that the probabilities must always have been there, or at least the possibilities? Can one claim that what did actually manage to happen must always have been probable, or, minimally, improbably possible all along the way? Push this to extremes, as one must do, if one claims that all the possibilities are always there, latent in the dust, latent in the quarks. Such a claim becomes pretty much an act of speculative faith, not in present actualities, since one knows that these events have taken place, but faith in past probabilities always being omnipresent. Is the claim some kind of induction or deduction, or most-plausible-case conclusion from present actualities? Speculation about such possibilities always being there is easy, provided one does not have to specify any of the details. But this perennial and vast library of possibilities is mostly imaginary.

For in fact, on Earth, there really isn't anything in rocks that suggests the possibility of *Homo sapiens*, much less the American Civil War, or the World Wide Web, and to say that all these possibilities are lurking there is simply to let possibilities float in from nowhere. Unbounded possibilities that one posits ad hoc to whatever one finds has in fact taken place — possibilities of any kind and amount desired in one's metaphysical enthusiasm — can hardly be said to be a scientific hypothesis. Alfred North Whitehead cautions against this as a metaphysical mistake (1978:46). This is hardly even a faith claim with sufficient warrant. It is certainly equally credible, and more plausible, and no less scientific, or metaphysical, to hold that new possibility spaces open up en route. But one will need an explanation adequate to this effect.

Karl Popper concludes that science discovers "a world of propensities," open to historical innovation, the possibility space ever enlarging.

In our real changing world, the situation and, with it, the possibilities, and thus the propensities, change all the time. . . . This view of propensities al-

lows us to see in a new light the processes that constitute our world: the world process. The world is no longer a causal machine — it can now be seen as a world of propensities, as an unfolding process of realizing possibilities and of unfolding new possibilities. . . . New possibilities are created, possibilities that previously simply did not exist. . . . Especially in the evolution of biochemistry, it is widely appreciated that every new compound creates new possibilities for further new compounds to synthesize: possibilities which previously did not exist. The possibility space . . . is growing. . . . Our world of propensities is inherently creative. (1990:17-20)

The result is the evolutionary drama. “The variety of those [organisms] that have realized themselves is staggering.” “In the end, we ourselves become possible” (1990:26, 19).

But — the reply comes — since all those things did come in subsequent evolutionary and cultural history, their possibilities must have been there all along. You were not listening when we discovered that matter is self-organizing, autopoietic. That posits enormous capacities, there from the start; and nothing in the historical drama ought to take us by all that much surprise one who believes in self-organizing nature. Thomas R. Cech, a molecular biologist and Nobel laureate, reviews the origin of life:

If intrinsic to these small organic molecules is their propensity to self-assemble, leading to a series of events that cause life forms to originate, that is perhaps the highest form of creation that one could imagine. . . . At least from the perspective of a biologist, I have given an account of how possibilities did, in times past, become actual. When this happened, life originated with impressive creativity, and it does not seem to me that possibilities floated in from nowhere; they were already present, intrinsic to the chemical materials. (1995:33).

Suppose that a meteorite lands on Earth, releasing some iron atoms as the incandescent meteor crashes into the ground. Suppose some of those iron atoms make their way into my diet, and into my blood. Would not such meteoric iron, from outer space, work just as well as any terrestrial iron atom carrying oxygen to my brain? Does that not mean that such iron atoms have had from time immemorial the capacity for entering into cognitive processes? Passively perhaps, if overtaken by mind, but actively there is no such self-contained potential. A single atom of iron has no such possibilities within itself at all. To claim that it does is like saying that ink and paper have all the possibilities of the Library of Congress latent within the bottle and secretly coded in the paper

pulp fibers. Entering into thinking processes becomes a possibility for such an extraterrestrial iron atom only with its encounter with (only relative to) the systemic company of enormous amounts of information.

One can insist that it must always have been possible to put carbon atoms into organic cells and silicon atoms into computers, since we humans do that now somatically and technologically — and the atoms are no different from what they have been for billions of years. But it may have always been possible to do this *with* these atoms, providing that one had the know-how to do such things, but not possible lacking such information. Such information has to become possible. That is a different claim from claim that it has always been possible *for* carbon and silicon to self-organize into organism and computers.

We know that water, as a polar molecule, has various features that have turned out to be fortunate for supporting life. But you can know all about the polarity of water, and nothing known there leads you to predict lipid bilayers later on, built with their hydrophobic heads and hydrophilic tails and used to make membranes that enclose the life structures. In the forest, a scientist encounters a tree, the wood functioning to hold the leaves up to the sun. But what new can we do with wood? We can build a violin and play music. This gives us no cause to claim that a violin is lurking in the possibility space of the tree with its wood.

Seeds sprout plants. Earth sprouts biodiversity. Michael Polanyi says: “From a seed of submicroscopic living particles — and from inanimate beginnings lying beyond these — we see emerging a race of sentient, responsible and creative beings. The spontaneous rise of such incomparably higher forms of being testifies directly to the operations of an orderly innovating principle” (1964:386-387). But the problem with the metaphor of a “seed” is that we now know what is in a seed: DNA coding the species of life. Neither in carbon and oxygen atoms nor in the geomorphology of planet Earth is there any such information seeded in, neither for making trilobites and dinosaurs, or for *Homo sapiens* sprouting myriad cultures, sprouting ethics, science, and religion.

Enthusiastic metaphysicians will reply that all actual events materialize in a global possibility space. The possibility space is always there. There is no such thing as the creation of possibilities that were not there. New doors may open but only into rooms that previously existed, albeit unoccupied and with no furniture. One does not need to get possibilities from nowhere because there are infinite possibilities everlastingly, or at least since the Big Bang. The proof of this lies in what has subsequently happened. But surely the possibility space of serious alternatives does enlarge and shrink. There are times of opportunity, in which taking one direction opens up new possibilities, and

taking another shuts them out. Along the way, new possibility space for genetic engineering is brought into the picture, and this is linked with the appearance of new information.

Co-option Generating Novel Possibilities

Something seems to be introducing layer by layer new possibilities of order, not just unfolding some latent order already there in the startup set-up. The biological constructions are historical, but they are not simply linear combinatorial processes. True, in the DNA molecules the coding is linear, and the changes are incremental in the linear sequences. But these changes also involve reassorting blocks that reshuffle to produce surprises. A few changes in the linear sequence produce quite different folding patterns at tertiary and quaternary levels in the finished protein. Novel possibilities open up whole new regions of search space; old molecules recombine to learn new tricks in unprecedented circumstances. Evolution improvises.

Such composition is not linear because it requires co-option: “An existing gene (and its product) is recruited to a new function” (Conway Morris 2000:9). For example, lens crystallins used in eyes first evolved in an altogether different role, as heat stress proteins. Surprisingly, they get used to make eye lenses (Wistow 1993). Darwin had already noted this: “The swimbladder in fishes . . . shows us clearly the highly important fact that an organ originally constructed for one purpose, namely flotation, may be converted into one for a wholly different purpose, namely, respiration” (Darwin 1968:220-221).

Hearing evolved from cells in the side of an aquatic vertebrate’s body that were sensitive to pressure, helpful to a swimming animal, an original use that has been lost from the reptiles onward. These cells were co-opted to become the hair cells in mammalian ears. That required constructing the external, middle, and inner ears, with small bones co-opted and modified to amplify sound, vibrating an oval area on the cochlea of the inner ear. This jiggles the microscopic hairs (stereocilia) on the ends of the hair cells. These cells synapse with neurons. The hairs are sensitive to movements as small as 0.3 nanometers (about the diameter of a large atom). Mechanical movement of the cilia opens and closes ion channels letting sodium ions into the cell, and this constitutes an electric current, which triggers the synapsizing, producing perceptible noise, over a volume differential of a trillion times from softest to loudest.

Animals need to know frequencies as well as volume, and here the firing

frequencies of the usual synaptic transmissions can track frequencies at the lower ranges, but the higher frequencies are too fast for this method. So ears improvise something else. There has further evolved a basilar membrane packed with hair cells and rolled up in the cochlea (about the size of a pea) that, using different widths and stiffness of the membrane, can differentiate how far along it a traveling wave will go, and so the auditory system responds to different frequencies ending up at different places on the membrane. There is a tonotopic map on the basilar membrane of the frequencies being heard. Further, on the basilar membrane, there is a system of outer hair cells that amplify the inner hair cells. With this the ear can detect frequencies up to 20,000 hertz. A trained musician can distinguish between a tone of 1,000 Hz and another of 1,001 Hz, which requires that the musician detect a difference of only 1 microsecond in the sound wavelengths.

But where is the sound coming from? That too is useful information. Animals have two ears, and the differential travel time of sound from the source to the slightly separated ears, can be used to locate the sound. But again, this only works in the range 20-2,000 hertz, above which frequency the wavelength is too short to figure location out this way. There is not enough interaural time. So another way is improvised. One ear is in the shadow of the sound, compared to the other. Now the auditory system sends the signals to the superior olive nucleus in the mid-brain, and there the sound from one ear is compared to the sound from the other for the intensity differential resulting from the sound shadow, and the location of higher frequency sounds is computed. Persons can locate a sound source in the horizontal plane with a precision of 2 degrees (Bear et al. 2001: ch. 11). Meanwhile, a spin-off from this auditory system is the vestibular system, co-opted to maintain bodily balance.

One could say that such complex ears were latent in the possibility space of pressure cells, which were latent in the possibility space of carbon, oxygen, nitrogen atoms. But an equally plausible account is that co-options opened up new possibility space, and the new genetic information achieved proves of value in an evolutionary search for better environmental information (heard in the ears). With continuing co-option, these vertebrate ears open up the possibility of animal communication — and, in due course and much later, of human language, which makes culture possible, with its cumulative transmission of ideas orally communicated from mind to mind.

Spoken language requires simultaneously the evolution of genes for speech and such genes, differentiating humans from other primates, arose at a highly critical period in our evolution. The FOXP2 gene, called a speech gene, arose less than 200,000 years ago and became the subject of strong selection, making language and culture possible. Acetylcholine, an ancient mol-

ecule was around for millennia doing other things in plants and bacteria; when nerves appear it gets co-opted for use in synaptic transmission, which makes mental life possible. Ideas pass from mind to mind, and for this hearing is more important than sight — at least until the invention of writing. Millennia later, written language (needing those eyes and their crystallins) transforms cultures by making possible the transmission of thoughts non-orally, across centuries and peoples. Printing makes possible massive public communication, followed by radio, television, electronic communication, the internet. Escalating co-option drives the information explosion.

Often, though not always, there is gene duplication, and one copy serves the former function; the new copy can be modified in exploratory directions. There are remarkable forks off the preexisting pathways, which served some other function (and may continue to do this). Things get recruited for new roles. Previously disconnected parts working along unrelated pathways are co-opted off and put together to start serving a novel function, perhaps only slightly well at the first. Radically different selection pressures begin to work in new directions that are completely unanticipated when they occur. Once launched, the novel functions may improve steadily and completely transform the course of natural and human history.

Perhaps it all takes place by slight modifications of a precursor system. These incremental changes keep “bootstrapping” on themselves and hence the self-organization. But these slight modifications are sometimes made in new, unprecedented directions. The co-opting modification is not improving the initial function but angles off in a new direction. The change is not iterative; it is metamorphic. Co-option breaks up channelized and entrenched developmental lines (more and better pressure cells) and opens up new directions (hearing at a distance, meaningful sounds). Restriction enzymes, one of the most important features of genetic innovation, and a principal tool in genetic engineering, were first invented by bacteria to cut their parasites into pieces. They turned out to be useful for organisms to cut their own genomes into pieces and reshuffle them in the search for co-options.

Complex operating systems in both nature and culture cannot be designed from scratch at the start, but they have to evolve by additions to previous versions and, with co-option, these previous constructions come eventually to fulfill functions that had nothing to do with their initial construction. One can say, well, it just happens this way. But a metaphysician needs an explanation for the arriving possibilities.

Evolutionists can make *ex post facto* explanations. After the events have taken place, the paleontologist can say, well this is what happened, and this is what resulted. But prior to the events, if asked what would be the result, if

such and such happened, one could never, from the knowledge of the constituent parts, say in advance what the results would be. Much less could one predict that such results had to happen. Perhaps one will say, since it has so often happened in evolutionary history, that there must be some tendency in biological nature to co-opt, a disposition to improvise, to be opportunistic. But where is such tendency located? Hardly from “bottom up” in the precursor materials. Hardly either from “top down” in the planetary system.

Maybe the possibilities lie somewhere in the mid-scale genetics. Simon Conway Morris builds much of his case for inevitable evolution on repeated convergences, such as the evolution of marsupials in Australia parallel to the evolution of placentals worldwide. (He has an index of five pages of convergences, 2003:457-461.) “Convergence occurs because of ‘islands’ of stability, analogous to ‘attractors’ in chaos theory” (2003:127). “The details of convergence actually reveal many of the twists and turns of evolutionary change as different starting points are transformed towards common solutions via a variety of well-trodden paths” (2003:144). Within the cell Conway Morris notices “some of the proteins being recruited in quite surprising ways from some other function elsewhere in the cell” (2003:111). “Evolution is a past master at co-option and jury-rigging: redeploying existing structures and cobbling them together in sometimes quite surprising ways. Indeed, in many ways that *is* evolution” (2003:238).

But does this add up to making the whole life story more or less inevitable? Some events are “quite surprising” indeed. About 2.7 billion years ago eucaryotes developed from the ongoing procaryote line. Much later, but before plants and animals had diverged, by endosymbiosis what were once-independent organisms fused into other, larger and quite different organisms to become mitochondria transferred into the pre-plant/animal line, and became the powerhouse organelles for all subsequent life. There emerges a new kind of system where the organism has highly efficient and specialized power modules (the mitochondria) something not possible to either of the precedents before they interacted, criss-crossed, synthesized and transformed each other. The “information” about how to do this was not present before in the preceding organisms, but now there has appeared new “information” (coded in the revised DNA in the nucleus and the residual DNA in the mitochondrion) that makes this new, high-powered form of life possible.

About 1.6 billion years ago the plant and animal lines diverged; and later still, by another remarkable endosymbiosis, plastids, once free-living, made the lateral transfer into the plant line to become the chloroplasts critical for the capture of solar energy. Again, new, higher-powered forms of life are possible, both in the plants and in the animals that feed on plants (Dyall et al.

2004) Perhaps one can say that endosymbiosis is likely to occur, there are frequently “mobile elements” that transpose and reshape evolution (Kazazian 2004). But is there any “inherency” in the earliest microbial life making inevitable or even probable these two especially vital endosymbioses, both thought to initiate as singularities, and both dramatically changing the history of life on Earth? One can say that evolution is disposed to exciting serendipity. In such cases of co-opted emergence, repeatedly compounding, something that is genuinely new pops out, pops up. The novelty is, of course, based on the precedents, but there is genuine novelty not present in any of the precedents. What emerged required the precedents, but the presence of the prior organisms did not determine or make inevitable these results. There are critical turning points in the history of life that hinge on events more idiographic (unique, one-off events) than nomothetic (law like, inevitable, repeatable trends). Things get recruited for new roles. Novel possibilities open up whole new regions of search space; old molecules recombine to learn new tricks.

Sometimes the explanatory account is by laws applied to initial conditions, and the same laws again reapplied to the resulting outcomes, now treated as further initial conditions. But sometimes, with co-options, endosymbioses, lateral genetic transfers, mutations, the outcomes are not just further sets of initial conditions. The novel outcomes revise the previous laws; the rules of the game change, and the future is like no previous past. One can say that all this surprising serendipity is somehow “inherent” from the start; but the explanatory power of such a claim is rather vague. The main idea in co-option is the unpredictable and unexpected; co-option is as revolutionary as it is evolutionary.

Environmental and structural constraints remain, but the constraints are not what they were before, now that the organism is equipped with these new potential capacities. The amount of information in an organism is transforming into its capacity for self-reformation, though the self-reformation is also provoked, evoked by environmental challenge and stress. The self-organizing becomes self-transcending.

Was all that resulted all along present in the possibility spaces of all the predecessor organisms? Maybe some of the possibility was within one organism, some within the other. Isn't it equally plausible to believe that new possibility space appeared with the co-option of the mitochondria and chloroplast predecessor organisms to novel functions? Some achievements that are genuinely new pop up. These are based on the precedents, but there is novelty not present in either of the precedents. What emerged required the precedents, but the presence of the prior organisms, which became precedents, did not require or determine these results. Biologists, a century back, used to call such

events “saltations.” Physicists, pressed for words from their discipline, might call it a “quantum leap.” Maybe we need a new term: “cybernetic leap.” Biologists inclined toward chance may call this “tinkering” (Jacob 1977). Biologists impressed with the results will call it evolutionary “exploring.” One needs a metaphysics for such co-option because there appear new ontological levels, both actual and possible (sight where before was only heat stress protection; language where before was only skin pressure sensibility; sight and language opening up the possibility of writing/reading). Co-option is the key to historical creativity.

Retrospectively, of course, after these novelties happen, the historian can trace the steps by which events happened. One can claim that the possibilities were always there; one can with equal plausibility claim that new possibility space has opened up en route in the course of natural history. Prospectively, if one could stand at each present moment, at each “now” over the course of evolution, there is always the great unknown. There is the generation of new possibility space in which information breakthroughs become possible. The pivotal element in a metaphysics of such evolutionary biology is the future, not the past, not even the present. Past and present are necessary but never sufficient for the future. In that sense our accounts will always be insufficient, incomplete, before this capacity for future innovation.

Anthropic Biology?

A number of physicists and astronomers have argued that the universe has been “fine-tuned” from the start and in its fundamental character for the subsequent construction of stars, planets, life, and mind. These results have been summarized as the “anthropic principle” (an unfortunately anthropocentric term; “biophilic principle” would have been better) (Barrow and Tipler, 1986; Leslie, 1990). Startling interrelationships are required for the cosmological processes to work; astronomical phenomena depend critically on the microphysical phenomena. In turn, the mid-range scales, where the known complexity mostly lies, in Earth’s biodiversity or in human brains, depend on the interacting microscopic and astronomical ranges.

Biology has seemed a stark contrast — at first at least. Biology has also developed at ranges of the very small and of big-scale history. Molecular biology, discovering DNA, has decoded life; and evolutionary history has located the unfolding of life in natural selection operating over incremental genetic variations across enormous time spans, with the fittest selected to survive. The process is prolific, but biology is more “pushy” about life than is it “fine-

tuned.” Indeed, as we have seen, biologists are quite mixed about how to mix inevitability and contingency in the overall events of natural history. This “pushy” evolution is also “bushy,” incessantly generating species, diversity — new branches and twigs on a bush. Incidentally, perhaps evolution will generate complexity, but — so many claim — there is no tendency toward progress. At this point, one would be radical indeed to suppose that biology is anthropic, headed for the generation of human beings. Recalling, and redoubling, Michael Ruse’s phrase, that would be super-pseudo-science: humans arrogantly supposing themselves to be the destiny of all earlier, all other life on Earth.

Still, despite their evolutionary origins, humans are a radically new kind of species on Earth, and somehow we got here. What is quite surprising in humans is not so much that they have intelligence generically, for many other animals have specific forms of a generic intelligence. Nor is it that humans have intelligence with subjectivity, for there are precursors of this too in the primates. The surprise is that this intelligence becomes reflectively self-conscious and builds cumulative transmissible cultures. An information explosion gets pinpointed in humans. Humans alone have “a theory of mind”; they know that there are ideas in other minds, making linguistic cultures possible. The final looming question is: What kind of explanations does science offer for this appearance and emergence of humans? Is biology anthropic?

Animal brains are already impressive. In a cubic millimeter (about a pinhead) of mouse cortex there are 450 meters of dendrites and one to two kilometers of axons. Human brains multiply the cortex in mice three thousand times. This cognitive development has come to a striking expression point in the hominid lines leading to *Homo sapiens*, going from about 300 cubic centimeters of cranial capacity in chimpanzees to 1,400 in humans. The connecting fibers in a human brain, extended, would wrap around the Earth forty times. In body structures generally, such as blood or liver, humans and chimpanzees are 95 percent to 98 percent identical in their genomic DNA sequences and the resulting proteins.

But this is not true in their brains. “Changes in protein and gene expression have been particularly pronounced in the human brain. Striking differences exist in morphology and cognitive abilities between humans and their closest evolutionary relatives, the chimpanzees.” So concludes a team of molecular biologists and evolutionary anthropologists from the Max-Planck Institutes in Germany (Enard et al. 2002). The puzzle is how so little genetic difference can make such an enormous brain-power difference. “This is one of the major questions that those of us interested in our own biology would like

to ask. What does that 1.5% difference look like?" asks Francis Collins, Director of the National Human Genome Research Institute (in Gibbons 1998).

Some trans-genetic threshold seems to have been crossed. The human brain is of such complexity that descriptive numbers are astronomical and difficult to fathom. A typical estimate is 10^{12} neurons, each with several thousand synapses (possibly tens of thousands). Each neuron can "talk" to many others. This network, formed and reformed, makes possible virtually endless mental activity. The result of such combinatorial explosion is that the human brain is capable of forming more possible thoughts than there are atoms in the universe. On a cosmic scale, humans are minuscule atoms, but on a complexity scale, humans are the most sophisticated of known natural products. In our hundred and fifty pounds of protoplasm, in our three-pound brain is more operational organization than in the whole of the Andromeda galaxy.

Genes make the kind of human brains possible that facilitate an open mind. But when that happens, these processes can also work the other way around. Minds employ and reshape their brains to facilitate their chosen ideologies and lifestyles. Our ideas and our practices configure and reconfigure our own sponsoring brain structures. Michael Merzenich, a neuroscientist, reports his increasing appreciation of "what is the most remarkable property of our brain: its capacity to develop and to specialize its own processing machinery, to shape its own abilities, and to enable, through hard brainwork, its own achievements" (Merzenich 2001:418).

In the vocabulary of neuroscience, we have "mutable maps" in our cortical representations, formed and reformed by our deliberated changes in thinking and resulting behaviors. For example, with the decision to play a violin well and with resolute practice, string musicians alter the synaptic connections and thereby the structural configuration of their brains to facilitate fingering the strings with one hand and drawing the bow with the other (Elbert et al. 1995). The human brain is as open as it is wired up. Our minds shape our brains.

Does this fit into the evolutionary picture? Maybe, but not without a looming question. Conway Morris asks whether "intelligence is some quirky end point of the evolutionary process or whether in reality it is more-or-less inevitable, an emergent property that is wired into the biosphere, whether "given time, evolution will inevitably lead not only to the emergence of such properties as intelligence?" (2003:148). His answer: "We may be unique, but paradoxically those properties that define our uniqueness can still be inherent in the evolutionary process. In other words, if we humans had not evolved then something more-or-less identical would have emerged sooner or later" (2003:196). "The science of evolution does not belittle us. . . . Something like

ourselves is an evolutionary inevitability, and our existence also reaffirms our one-ness with the rest of Creation” (2003:xv-xvi).

Conway Morris simultaneously finds, however, that “what evolution cannot do is see into the future diversification as far as the envelope of possibilities is concerned, although it can be equally sure that a great deal of what does one day evolve will have emerged in parallel circumstances in other times and places” (2003:307). In evolutionary biology “we can only retrodict and not predict” (2003:12). At this point Conway Morris seems to want it both ways: both inevitability and openness in natural history. The account seems to be that, despite these inherencies and inevitabilities, they can only be known *ex post facto*. If some extra-terrestrial biologists had had Earth under observation back in the pre-Cambrian, the headings of natural history were not then predictable. They would not have known what the future was to be. But after these inherencies home in, converge on intelligent life, after these surprises do happen, biologists, terrestrial or extra-terrestrial can see that they had to happen, more or less as they did.

Humans evolved *out of* origins in natural history, but they seem to have done just that: to have made exodus from determination by genetics and natural selection and to have passed into a mental and social realm with new freedoms. Richard Lewontin puts it this way:

Our DNA is a powerful influence on our anatomies and physiologies. In particular, it makes possible the complex brain that characterizes human beings. But having made that brain possible, the genes have made possible human nature, a social nature whose limitations and possible shapes we do not know except insofar as we know what human consciousness has already made possible. . . . History far transcends any narrow limitations that are claimed for either the power of the genes or the power of the environment to circumscribe us. . . . The genes, in making possible the development of human consciousness, have surrendered their power both to determine the individual and its environment. They have been replaced by an entirely new level of causation, that of social interaction with its own laws and its own nature. (1991:123).

The genes outdo themselves; this is unexpected co-option taken at a pitch. Despite finding other kinds of progress undeniable in the evolutionary record, Ernst Mayr reflects on the evolution of intelligence: “An evolutionist is impressed by the incredible improbability of intelligent life ever to have evolved” (1988:69). Mind of the human kind seems to require incredible opening up of new possibility space.

J. Craig Venter and over two hundred coauthors, reporting on the completion of the Celera Genomics version of the human genome project, caution in their concluding paragraph:

In organisms with complex nervous systems, neither gene number, neuron number, nor number of cell types correlates in any meaningful manner with even simplistic measures of structural or behavioral complexity. . . . Between humans and chimpanzees, the gene number, gene structural function, chromosomal and genomic organization, and cell types and neuroanatomies are almost indistinguishable, yet the development modifications that predisposed human lineages to cortical expansion and development of the larynx, giving rise to language culminated in a massive singularity that by even the simplest of criteria made humans more complex in a behavioral sense. . . . The real challenge of human biology, beyond the task of finding out how genes orchestrate the construction and maintenance of the miraculous mechanism of our bodies, will lie ahead as we seek to explain how our minds have come to organize thoughts sufficiently well to investigate our own existence. (Venter et al. 2001:1347-1348)

Stuart Kauffman ponders this ongoing co-option of what he calls “pre-adaptations,” adaptations previously used for some other function:

Consider the concept of Darwinian pre-adaptation, the idea that a feature that was selected for one purpose turns out to be useful for a second purpose. . . . Do you think you could ever say ahead of time what all possible Darwinian pre-adaptations are? . . . We can never say ahead of time what the relevant variables are in the evolution of the biosphere. This means the biosphere keeps inventing new functionalities and we can't say ahead of time what they are. That's a radical new kind of failure to predict. It's not quantum uncertainty, and it's not chaos theory. Still, it's the kind of uncertainty that seems central. Life keeps inventing things. (Kauffman 2002)

He calls this “the mystery of the emergence of novel functionalities in evolution where none existed before: hearing, sight, flight, language. Whence this novelty? I was led to doubt that we could prestate the ‘configuration space’ of a biosphere. . . . Life is doing something far richer than we may have dreamed, literally, something incalculable” (2000:5, 7).

Does anthropic physics indicate that biology too must somehow be anthropic — only we cannot yet see how? Or does biology, finding a “massive singularity” (Venter) with the coming of humans, remain open to configura-

tion spaces that can never be predated, to a future in which new possibility space will be generated? We do know with absolute certainty that we are here, and with virtual certainty that elaborated biodiversity and biocomplexity has managed to happen on Earth. So there isn't any doubt about these results. Nor is there serious doubt that these results are wonderful. But biology still stutters how nature generates such a wonderland. More plainly put, the five looming questions are still unanswered.

* * *

At the end of our searching, there rises on the horizon a final looming question, a sixth suggested by wondering about these five. Does such an evolutionary generation of life on Earth leave possibility space for faith in God? Almost anything can happen in a world in which what we see around us has actually managed to happen. The universe has never yet proved as simple as we previously thought. Or less mysterious. The story is incredible, and true, progressively more so at every emergent level: a universe fifteen billion years old, exploding from a vacuum, fine-tuned from the start, immense in size, coming to a unique and most complex expression point in Earth, generating a natural history with rich biodiversity, at the apex of which we humans stand, finding out who and where we are, discovering that we humans ourselves confront an open future and have staggering, escalating possibilities for good and evil.

There does seem to be demanded a ground generating these possibilities that so surprisingly, if regularly, break previous records of attainment and power. We live on a wonderland Earth, and we ourselves are the apex of these wonders. Nothing now known in any of these sciences prevents our finding this Ground holy, praising Spirit in, with, and under nature.

References

- Barrow, John D., and Frank J. Tipler. 1986. *The Anthropic Cosmological Principle*. New York: Oxford University Press.
- Bear, Mark F., Barry W. Connors, and Michael A. Paradiso. 2001. *Neuroscience*. 2nd ed. Baltimore: Lippincott Williams and Wilkins.
- Brockman, John. 1995. *The Third Culture: Beyond the Scientific Revolution*. New York: Simon and Schuster.
- Calvin, Melvin. 1975. "Chemical Evolution." *American Scientist* 63:169-177.
- Cech, Thomas R. 1995. "The Origin of Life and the Value of Life." In Holmes Rolston III (ed.), *Biology, Ethics, and the Origins of Life*, 15-37. Boston: Jones and Bartlett.

- Conway Morris, Simon. 2000. "Evolution: Bringing Molecules into the Fold." *Cell* 100:1-11.
- Conway Morris, Simon. 2003. *Life's Solution: Inevitable Humans in a Lonely Universe*. Cambridge: Cambridge University Press.
- Darwin, Charles. 1968. [1859.] *The Origin of Species*. Baltimore: Pelican Books.
- Dawkins, Richard. 1995. *River out of Eden: A Darwinian View of Life*. New York: Basic Books, HarperCollins.
- de Duve, Christian. 1995. *Vital Dust: Life as a Cosmic Imperative*. New York: Basic Books.
- de Duve, Christian. 2002. *Life Evolving: Molecules, Mind, and Meaning*. Oxford: Oxford University Press.
- Dose, Klaus. 1988. "The Origin of Life: More Questions than Answers." *Interdisciplinary Science Reviews* 13:348-356.
- Dyall, Sabrina D., Mark T. Brown, and Patricia J. Johnson. 2004. "Ancient Invasions: From Endosymbionts to Organelles." *Science* 304:253-257.
- Eigen, Manfred. 1971. "Self-organization of Matter and the Evolution of Biological Macromolecules." *Die Naturwissenschaften* 58:465-523.
- Eigen, Manfred. 1992. [SUPPLY REFERENCE]
- Elbert, Thomas, et al. 1995. "Increased Cortical Representation of the Fingers of the Left Hand in String Players." *Science* 270 (13 October): 305-307.
- Enard, Wolfgang, et al. 2002. "Intra- and Interspecific Variation in Primate Gene Expression Patterns." *Science* 296 (12 April):340-343.
- Gibbons, Ann. 1998. "Which of Our Genes Make Us Human?" *Science* 281 (4 September):1432-1434.
- Gould, Stephen Jay. 1977. *Ever Since Darwin*. New York: W. W. Norton and Co.
- Gould, Stephen Jay. 1983. "Extemporaneous Comments on Evolutionary Hope and Realities." In Charles L. Hamrum (ed.), *Darwin's Legacy, Nobel Conference XVIII*, 95-103. San Francisco: Harper and Row.
- Gould, Stephen Jay. 1989. *Wonderful Life: The Burgess Shale and the Nature of History*. New York: W. W. Norton.
- Gould, Stephen Jay. 1996. *Full House: The Spread of Excellence from Plato to Darwin*. New York: Harmony Books.
- Jacob, François. 1977. "Evolution and Tinkering." *Science* 196:1161-1166.
- Kauffman, Stuart A. 1993. *The Origins of Order: Self-Organization and Selection in Evolution*. New York: Oxford University Press.
- Kauffman, Stuart A. 1995. *At Home in the Universe: The Search for Laws of Self-Organization and Complexity*. New York: Oxford University Press.
- Kauffman, Stuart A., 2000. "Prolegomenon to a General Biology." In *Investigations*, 1-22. Oxford: Oxford University Press.
- Kauffman, Stuart A. 2002. "Consciousness: It Blows My Mind." Metanexus Interview by Jill Neimark. Online at: http://www.metanexus.net/metanexus_online/show_article.asp?5605

- Kazazian, Haig H., Jr. 2004. "Mobile Elements: Drivers of Genome Evolution." *Science* 303:1626-1632.
- Küppers, Bernd-Olaf. 1990. *Information and the Origin of Life*. Cambridge, MA: MIT Press.
- Leslie, John, ed., 1990. *Physical Cosmology and Philosophy*. New York: Macmillan.
- Lewontin, Richard C. 1991. *Biology as Ideology: The Doctrine of DNA*. New York: HarperCollins Publishers.
- Maynard Smith, John. 1972. *On Evolution*. Edinburgh: University of Edinburgh Press.
- Maynard Smith, John, and Eörs Szathmáry. 1995. *The Major Transitions in Evolution*. New York: W. H. Freeman.
- Mayr, Ernst. 1988. *Toward a New Philosophy of Biology*. Cambridge, MA: Harvard University Press.
- Merzenich, Michael. 2001. "The Power of Mutable Maps." In Bear et al., *Neuroscience*, 418. 2nd ed. Baltimore: Lippincott Williams and Wilkins.
- Myers, Norman. 1997. "Mass Extinction and Evolution." *Science* 278:597-598.
- Nee, Sean, and Robert M. May. 1997. "Extinction and the Loss of Evolutionary History." *Science* 278:692-694.
- Newell, Norman D. 1963. "Crises in the History of Life." *Scientific American* 208/2 (February):76-92.
- Niklas, Karl J. 1986. "Large-Scale Changes in Animal and Plant Terrestrial Communities." In D. M. Raup and D. Jablonski (eds.), *Patterns and Processes in the History of Life*, 383-403. New York: Springer-Verlag.
- Polanyi, Michael. 1964. *Personal Knowledge*. New York: Harper and Row.
- Popper, Karl R. 1990. *A World of Propensities*. Bristol, UK: Thoemmes.
- Raup, David M., and J. John Sepkoski Jr. 1982. "Mass Extinctions in the Marine Fossil Record." *Science* 215:1501-1503.
- Ruse, Michael, 1986. *Taking Darwin Seriously*. Oxford: Basil Blackwell.
- Ruse, Michael. 1996. *Monad to Man: The Concept of Progress in Evolutionary Biology*. Cambridge, MA: Harvard University Press.
- Van Valen, Leigh M. 1991. "How Far Does Contingency Rule?" *Evolutionary Theory* 10:47-52.
- Venter, J. Craig, et al. 2001. "The Sequence of the Human Genome." *Science* 291 (16 February):1304-1351.
- Wald, George. 1974. "Fitness in the Universe: Choices and Necessities." In J. Oró et al. (eds.), *Cosmochemical Evolution and the Origins of Life*, 7-27. Dordrecht: D. Reidel.
- Weiner, Norbert. 1948. *Cybernetics*. New York: John Wiley.
- Whitehead, Alfred North. 1978. [1929.] *Process and Reality*, corrected edition. New York: Free Press.
- Wistow, Graeme. 1993. "Lens Crystallins: Gene Recruitment and Evolutionary Dynamism," *Trends in Biochemical Sciences* 18:301-306.