Holmes Rolston, III, *Genes, Genesis and God*
Cambridge: Cambridge University Press, 1999
Chapter 1, pp. 1-53.

Chapter 1

Genetic Values: Diversity and Complexity in Natural History

Any account of genesis on Earth must place genes on the scene of global natural history. Nothing is more central to the contemporary neo-Darwinian view than an emergence over time of diversity and complexity, and genes are critical in this historic composition. Yet these developing phenomena, evident and indisputable though they are as fact of the matter, are subject to vigorous dispute about what is going on, a scientific issue laden with deeper philosophical significance.

1. NATURAL HISTORY: DIVERSITY AND COMPLEXITY

Something is learned across evolutionary history: how to make more diverse and more complex kinds. These 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. Even on Earth there is no such learning with the passing of cold and warm fronts; they just come and go. With the rock cycle, orogenic uplift, erosion, and uplift again, there is no natural selection. Nothing is competing, nothing is surviving, nothing has adapted fit. Climatological and geomorphological agitations continue in the Pleistocene period more or less as they did in the Precambrian. But the life story is different, because in biology, unlike physics, chemistry, geomorphology, or astronomy, something can be learned.

In result, where once there were no species on Earth, there are today five to ten million. On average and environmental conditions permitting, the numbers of life forms start low and end high. Seeking a philosophy of biology, Ernst Mayr realizes that many life-forms do not progress and that "higher" is a troublesome word. Still, he is forced to ask:

> And yet, who can deny that overall there is an advance from the prokaryotes that dominated the living world more than three billion years ago to the eukaryotes, with their well-organized nucleus and chromosomes as well as cytoplasmic organelles; from the single-celled eukaryotes to plants and animals with a strict division of labor among their highly specialized organ systems; and, within the animals, from ectotherms that are at the mercy of climate to the warm-blooded 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? (1991, p. 62; 1988, pp. 251-252)

Edward O. Wilson concludes his study of the diversity of life:

> Biological diversity embraces a vast number of conditions that range from the simple to the complex, with the simple appearing first in evolution and the more complex later. Many reversals have occurred along the way, but the overall average across the history of life has moved from the simple and few to the more complex and numerous. During the past billion years, animals as a whole evolved upward in body size, feeding and defensive techniques, brain and behavioral complexity, social organization, and precision of environmental control – in each case farther from the nonliving state than their simpler antecedents did.
>
> More precisely, the overall averages of these traits and their upper extremes went up. Progress, then, is a property of the evolution of life as a whole by almost any conceivable intuitive standard, including the acquisition of goals and intentions in the behavior of animals. It makes little sense to judge it irrelevant. … In spite of major and minor temporary declines along the way, in spite of the nearly complete turnover of species, genera, and families on repeated occasions, the trend in biodiversity has been consistently upward. (1992, pp. 187 and 194)

John Bonner, in a detailed study of the evolution of complexity, summarizes his findings:

> There has... been an extension of the upper limit of complexity during the course of evolution. ... There has also been an increase in the complexity of animal and plant communities, that is, there has been an increase in the number of species over geological time, and this has meant an increase in species diversity

> in any one community. ... One can conclude that evolution usually progresses by increases in complexity. ... As evolution proceeded on the surface of the earth, there has been a progressive increase in size and complexity. (1988, pp. 220, 228, and 245)

E. C. Pielou concludes a long study of diversity, "Thus worldwide faunal diversification has increased since life first appeared in a somewhat stepwise fashion, through the development and exploitation of adaptations permitting a succession of new modes of life" (1975, p. 149). Life appears in the seas; moves onto the land, then into the skies. Terrestrial communities developed from the Silurian onward. In the Tertiary there was a marked increase in diversity due to the rise of warm-blooded vertebrates (mammals and birds), more than making up for the decrease in reptiles and amphibians. When vertebrates took to the air, there was introduced an entirely new mode of life.

There were setbacks, notably in the Permian-Triassic and again in the wave of mammal extinctions in the middle (pre-Pleistocene) Quaternary. But there was recovery. Many factors figure in, including climates and continental drift. Sometimes, the change due to organic evolution is overwhelmed by the change due to climatic cooling or drying out. The change due to organic evolution may be accelerated or decelerated by continental drift; continents fused together may provide a bigger area that supports more species, or they may provide more competition that eliminates species that previously evolved on separated continents. If the tectonic plates drift together and form a supercontinent, the supercontinent may saturate with species and suppress further speciation (some think), and if afterward the continents drift apart, this may add to the provinciality of the world and facilitate by isolation the evolution of diversity. On the whole, organic evolution has "the result that the present diversity of the world's plants and animals is (or was just before our species appeared) probably greater than it has ever been before" (Pielou 1975, p. 150).

George Gaylord Simpson, after surveying the fossil record extensively and noting that there are exceptions, concludes: "The evidence warrants considering general in the course of evolution . . . a tendency for life to expand, to fill in all available spaces in the liveable environments, including those created by the process of that expansion itself. ... The total number and variety of organisms existing in the world has shown a tendency to increase markedly during the history of life" (1967, pp. 242, and 342). R. H. Whittaker finds, despite "island" and other local saturations and equilibria, that on continental scales and for most groups "increase of species diversity... is a self-augmenting evolutionary process without any evident limit." There is a natural tendency toward increased "species packing" (1972, p. 214). This is also called "bootstrapping in ecosystems," feed-forward loops that generate new niches that reinforce each other and open up new opportunities for species specialization (Perry et al. 1989). M. J. Benton, in a quantitative analysis of the fossil record, concludes "that the diversity of both marine and continental life increased exponentially since the end of the Precambrian" (1995, p. 52).

Complexity and diversity can sometimes be independent variables: beetles or grasses can become more diverse without becoming more complex. But the two are not always unrelated. Cumulatively over the millennia, as a result of the genetic capacity to acquire, store, and transmit new information, complexity can increase. There are advantages in specialized cells or organs, the efficiencies of the division of labor, which couples more complex and more diverse forms of life. In some situations, diversity increase has the result of stimulating complexity. A diverse environment is heterogeneous, and species are favored that are multiadaptable, and not just well adapted to one homogeneous environment. Such adaptability requires complexity, capacities to search out better environments and migrate to them, and, once there, abilities to invade successfully, to prey on or resist predation by – or to find and share resources with – the different kinds of organisms that can live in both wet and dry, cold and hot, grassland and forested environments. Complexity sometimes helps in dealing with the challenges and opportunities offered by diversity. Complexity helps in tracking changing environments.

Reptiles can survive in a broader spectrum of humidity conditions than can amphibians, mammals in a broader spectrum of temperature than can reptiles. Once there was no smelling, swimming, hiding, defending a territory, gambling, making mistakes, or outsmarting a competitor. Once there were no eggs hatching, no mothers nursing young. Once there was no instinct, no conditioned learning. Once there was no pleasure, no pain. But all these capacities got discovered by the genes. Once there was no capacity to make intentional reference, but this capacity arose, as when vervet monkeys learned to give different alarm calls to indicate the approach of different predators: leopards, eagles, snakes. Once there was no metameric segmentation, as in worms; once there was no pentameric segmentation, as in starfish. But all these phenomena appear, gradually, but eventually, without precedent if one looks further along their developmental lines.

J. W. Valentine, after a long survey of evolutionary history, concludes for marine environments that both complexity and diversity increase through time. First, with regard to diversity:

> A major Phanerozoic trend among the invertebrate biota of the world's shelf and epicontinental seas has been towards more and more numerous units at all levels of the ecological hierarchy. This has been achieved partly by the progressive partitioning of ecospace into smaller functional regions, and partly by the invasion of previously unoccupied biospace. At the same time, the expansion and contraction of available environments has controlled strong but secondary trends of diversity. ... The biosphere has become a splitter's paradise. (Valentine 1969, p. 706)

When the landmasses fragment, speciation is favored; when they coalesce, previously endemic offshore marine faunas and floras merge and decimate each other in competition. So there are ups and downs in numbers of families and species, due to the contingencies of drift; nevertheless, biologically, the trend is up. Complexity also increases:

> A sort of moving picture of the biological world with its selective processes that favor increasing fitness and that lead to "biological improvement" is projected upon an environmental background that itself fluctuates. ... The resulting ecological images expand and contract, but, when measured at some standardized configuration, have a gradually rising average complexity and exhibit a gradually expanding ecospace. (Valentine 1973, p. 471)

This double tendency in the biological system is disrupted but not overwhelmed by continental drift.

These summary conclusions can be illustrated in graph form, in a series of graphs that provocatively illustrate at once the vicissitudes and the progress of evolutionary history. Valentine graphs diversity in kinds of marine invertebrates (Fig. 1.1). There are steep climbs and drops, with a rise overall from 0 to 450 families.[1]

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[1] Numbers of genera and species cannot be reliably estimated from the fossil record.

Figure 1.1. Diversity level of families of well-skeletonized shelf invertebrates. Reprinted with permission from *Evolutionary Paleoecology of the Marine Biosphere,* by James W. Valentine, Prentice-Hall, 1973, p. 387. This graph also appeared in James W. Valentine, "Patterns of Taxonomic and Ecological Structure of the Shelf Benthos during Phanerozoic Time," *Palaeontology,* vol. 12, part 4,1969, p. 692.

Raup and Sepkoski (1982) add the marine vertebrates and graph a rise, again with climbs and drops, especially at times of catastrophic extinctions, from 0 to perhaps 750 families (Fig. 1.2). A common interpretation of the somewhat flat midportion of the graph (Ordovician to Permian periods) is that Earth's tectonic plates were configured to fuse the landmasses, resulting in a saturation of kinds of species that had at that point evolved on the continental shelves. Since marine life is primarily on the continental shelves, it may be

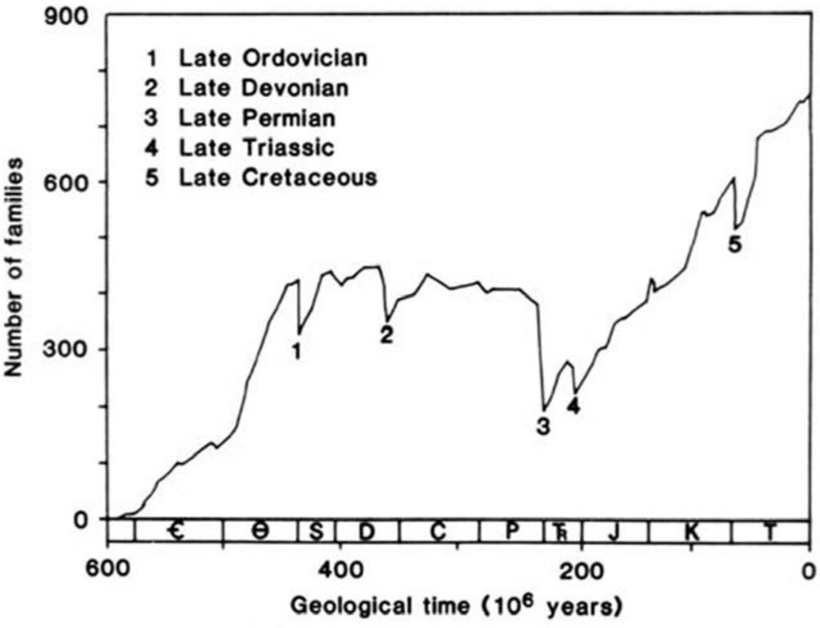

Figure 1.2. Standing diversity through time for families of marine vertebrates and invertebrates, with catastrophic extinctions. Reprinted with permission from David M. Raup and J. John Sepkoski, Jr., "Mass Extinctions in the Marine Fossil Record," *Science* 215 (19 March 1982): 1501-1503, p. 1502. Copyright 1982 American Association for the Advancement of Science.

especially susceptible to contingencies in continental drift. Also, during this relatively flat part of the marine curve, life moves onto the land and greatly diversifies there, from the Silurian period onward (not shown in these graphs). That requires also considerable evolution of complexity, since the terrestrial environment is more demanding.

Plants develop steadily on the landmasses, with species turnover resulting in increased diversity. Andrew H. Knoll graphs (Fig. 1.3) this record for local ecosystems over evolutionary time. In the Paleozoic there is a general rise, and after that a plateau. "The history of diversity within floras from subtropical to tropical mesic floodplains is marked by several periods of rapid increase separated by extended periods of more or less unchanging taxonomic richness." After the mid-Mesozoic, with the rise of the angiosperms (flowering plants), there is a steady climb in regional floras. Knoll concludes "that spe-

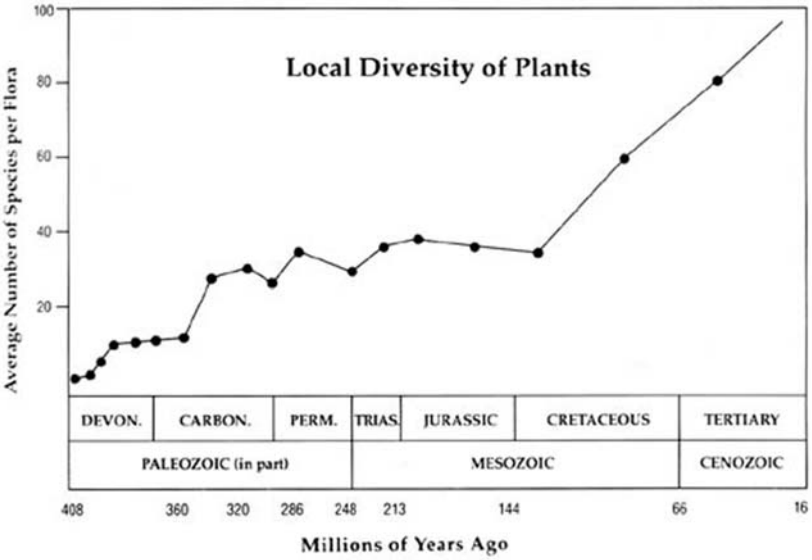

Figure 1.3 . Average number of plant species found in local floras. From *The Diversity of Life* by Edward O. Wilson. Copyright © 1992 by Edward O. Wilson. Reprinted by permission of Harvard University Press. This graph is adapted from Andrew H. Knoll, "Patterns of Change in Plant Communities Through Geological Time," from *Community Ecology*, Jared Diamond and Ted J. Case, eds. Copyright © 1986, by Harper Collins Publishers. Reprinted by permission of Addison-Wesley Educational Publishers.

cies numbers within subtropical to tropical communities have been rising continually since the Cretaceous and that a plateau has yet to be established" (1986, pp. 140 and 132).

For animals, the story of terrestrial life may be less contingent than that in marine shelves, since terrestrial animal species are quite mobile and have often crossed land bridges between the continents, resulting in a different pace of competition and selection for different traits. It is in the vertebrates, most of all, that advance is difficult to deny. The sea, though required for the inception of life and though long an environment for diverse forms of life, is not an environment that has ever produced big brains; dramatic cerebral evolution has always been terrestrial, because the more challenging land environment seems to demand more neural power. Even today the "minds" in the sea (whales, dolphins) were once formed on land and returned to the sea. In the global picture, complementing the marine one, if

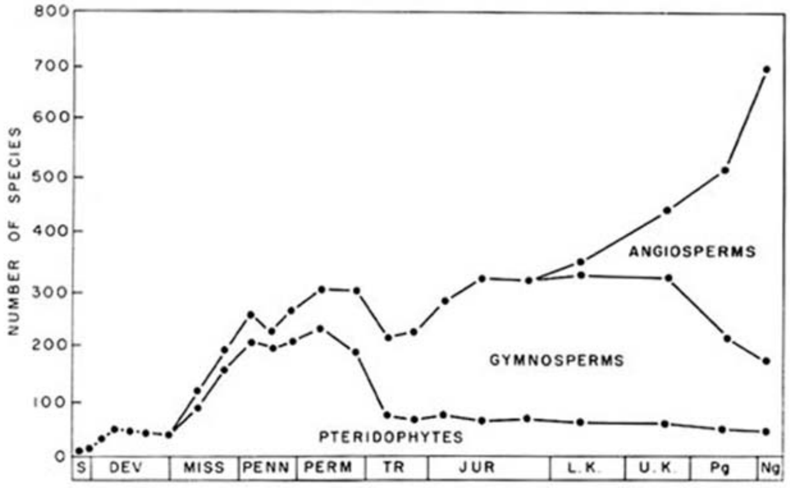

Figure 1.4. Species diversity changes in vascular plants. Reprinted with permission from K. J. Niklas, "Large Scale Changes in Animal and Plant Terrestrial Communities," in D. M. Raup and D. Jablonski, eds, *Patterns and Processes in the History of Life,* Springer-Verlag, 1986, p. 385.

one examines the top trophic rungs for complexity and if one adds the increases of diversity cumulating in both marine and terrestrial environments, the increase of complexity and diversity will be still more evident.

In the composition of the floras and faunas, certain forms can later be less numerous than before, but, climatic conditions permitting, overall biodiversity gradually and sometimes rather spectacularly rises (Fig 1.4 and Fig. 1.5). Here too the later-coming forms are often more complex than the earlier ones they replace. Mammals with their warm blood and higher energy requirements develop metabolisms and behavioral skills not present in cold-blooded reptiles and amphibians. Angiosperms advance over, and may displace, gymnosperms. Fortunately for overall biodiversity, these earlier groups, in reduced numbers (and with species turnover), continue to enrich present faunas and floras.

Norman D. Newell has graphed the numbers of all families, terrestrial and marine, vertebrate and invertebrate, increasing through evolutionary time (Fig. 1.6).

It is difficult to produce a graph of increasing complexity, since

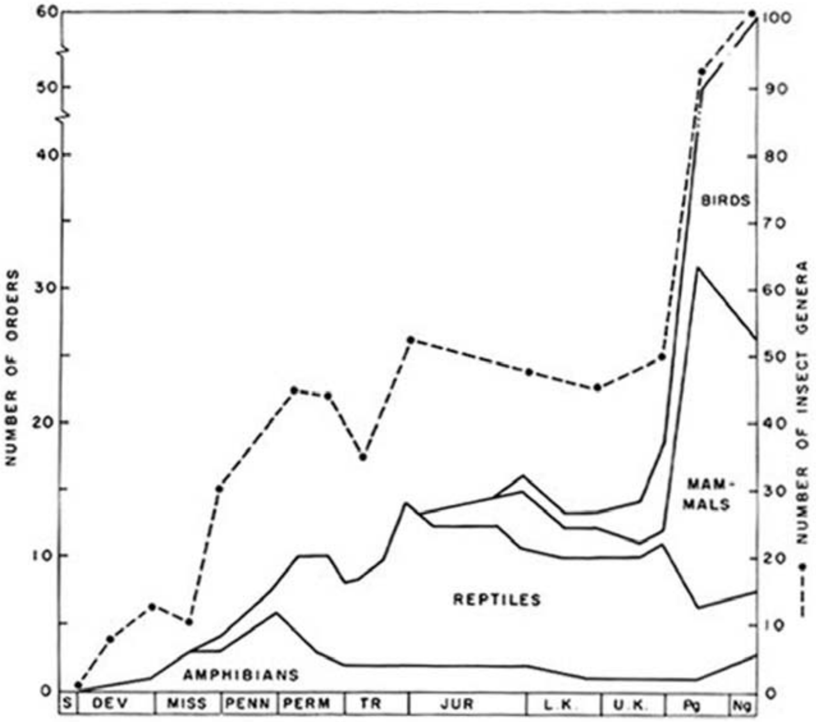

Figure 1.5. Changes in the composition of vertebrate orders and numbers of insect genera. Reprinted with permission from K.J. Niklas, "Large Scale Changes in Animal and Plant Terrestrial Communities," in D. M. Raup and D. Jablonski, eds., *Patterns and Processes in the History of Life,* Springer-Verlag, 1986, p. 390.

complexity (unlike a numerical count of families) may not be any single thing to graph. There is unlikely to be any single parameter measuring it that always increases (progresses?) over the course of natural history. Nor does complexity always coincide with advancement, because sometimes complexity is a disadvantage. The overspecialized frequently become extinct. Nevertheless increases in capacities for centralized control (neural networks with control centers, brains surpassing mere genetic and enzymatic control), 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 capacities for acquired learning (feedback loops, synapses, mem-

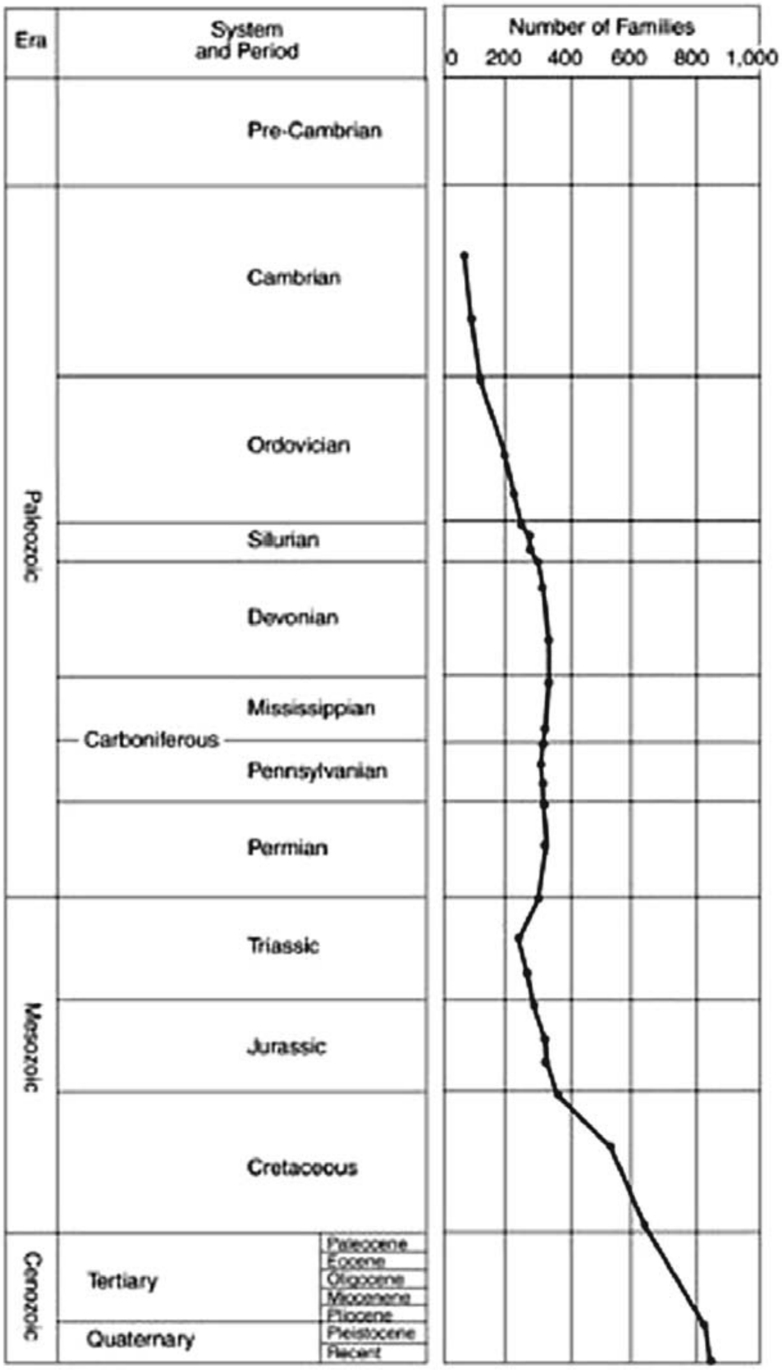

Figure 1.6. Number of major families of fossil animals increasing through time. Reprinted with permission from Norman D. Newell, "Crises in the History of Life," *Scientific American,* 208 (no. 2, February 1963): 76-92, p. 80.

ory banks), increases in capacities for communication and language acquisition - all these take increased complexity. Nothing seems more evident over the long range than that complexity has increased; in the Precambrian there were microbes; in the Cambrian period trilobites were an advanced life-form; the Pleistocene period produced persons.

Trends, which are a sine qua non of historical interpretation, 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 even statistics deals poorly with developing cybernetic trends, where there is information buildup with trial and error learning making critical discoveries (such as photosynthesis, neurons, endoskeletons).

The lower forms remain, too; there must be trophic pyramids, food chains. Even the microbes have a remarkable diversity (Service 1997). There cannot be higher forms, all by themselves. They must be superposed on lower forms, embedded in communities. So there can seem only changing diversity, not increased complexity, if one looks at the monocots and dicots, the crustaceans and flatworms. Perhaps one should not expect much progress in the invertebrates, not much past that in the arthropods. In all the understories, which must remain occupied if there is to be a biotic community, there is mainly turnover, perhaps with some increased fitness for survival. But if we are to have the whole story of what is going on, one must look at the uppermost forms. These do seem to get built up over time.

A word recently coined by Humberto R. Maturana and Francisco J. Varela to describe such phenomena in nature is "autopoiesis" *(autos,* self, and *poiein,* to produce) (Maturana and Varela 1980). The idea, however, is an old one: "The earth produces of itself [Greek: automatically]" (Mark 4.28). The "auto" here should not be taken to posit a "self," but rather an innate principle of the spontaneous origination of order, that is, of genesis. That, we recall, is the root meaning of the word "nature," to generate or give birth. Organisms, which do have somatic selves, are self-organizing, but so are species lines, in which such organismic selves are contained. Ecosystems are spontaneously organizing: the species get arranged into interdependencies; novel niches appear and species arise to fill them. Even the planet, globally, is a prolific system.

Stuart Kauffman concludes a long study of the origins of order in evolutionary history: "Since Darwin, biologists have seen natural selection as virtually the sole source of that order. But Darwin could not have suspected the existence of self-organization, a recently discovered, innate property of some complex systems. ...Selection has molded, but was not compelled to invent, the native coherence of ontogeny, or biological development. ... We may have begun to understand evolution as the marriage of selection and self-organization" (1991, summarizing Kauffman 1993; 1995; Rosen 1991; Salthe 1993). Analyzing computer, mathematical, and biological models, Kauffman finds that natural selection can drive ordered systems to the edge of chaos because that is where the greatest possibility for self-organization, and survival in changing environments, occurs. "Evolution has tuned adaptive gene regulatory systems to the ordered region and perhaps to near the boundary between order and chaos." "Networks on the boundary between order and chaos may have the flexibility to adapt rapidly and successfully" (Kauffman 1991). If so, we will not be surprised to find that in these "poised systems" creativity is often entwined with chance and chaos. The construction of order is most probable at the edge of disorder.

> Evolution is a complex combinatorial optimization process in each of the coevolving species in a linked ecosystem, where the landscape of each actor deforms as the other actors move. Within each organism, conflicting constraints yield a rugged fitness landscape graced with many peaks, ridges, and valleys. . . . Such order has beauty and elegance, casting an image of permanence and underlying law over biology. Evolution is not just "chance caught on the wing." It is not just a tinkering of the ad hoc, of bricolage, of contraption. It is emergent order honored and honed by selection. (1993, p. 644)

Francisco J. Ayala concludes, "Progress has occurred in nontrivial senses in the living world because of the creative character of the process of natural selection" (1974, p. 353). Theodosius Dobzhansky says:

> Nobody has been able to propose a satisfactory definition of what counts as evolutionary progress. Nevertheless, viewing evolution of the living world as a whole, from the hypothetical primeval self-reproducing substance to higher plants, animals and man, one cannot avoid the recognition that progress, or advancement, or rise, or ennoblement, has occurred. ... Seen in retrospect, evolution as a whole doubtless had a general direction, from simple to complex, from dependence on to relative inde-

> pendence of the environment, to greater and greater autonomy of individuals, greater and greater development of sense organs and nervous systems conveying and processing information about the state of the organism's surroundings, and finally greater and greater consciousness. (1974, pp. 310-311)

If in natural history we define progress as "increase in the ability to gather and process information about the environment" (Ayala 1988, p. 92; 1974, p. 344), then again and again, evolution produces phenomena that rise above the former levels with breakthroughs in achievement and power. Evolutionary progress is the systemic generation of increased richness in value, such as diverse species, each of value in itself; or more complex skills, such as the capacity for acquired learning; or better adaptation for survival, such as thicker fur in a cooling climate. Such breakthroughs might not be something that one can catch in graph form; they might not be something that rises in steady ascent on a landscape where there are hills up and down, and circuitous ways up, over, down, and around them, even tunnels and bridges, where organisms manage to survive in a convoluted and adventurous world. Narratives are not statistical affairs; narrative plots do not plot well on line graphs. But narratives may be required to tell the progressing story of increasing diversity and complexity in natural history.

In nature there are, if we consult physics and chemistry, two kinds of things, matter and energy, but if we consult biology there is a third kind of thing: information. All three are required for the genesis so evident in Earthen natural history. At this level, neither matter nor energy can be created or destroyed, though, at the more fundamental levels of atomic and astronomical physics, the one can be transformed into the other. Matter throughout natural history has been energetically structurally transformed. This happens in physics and chemistry 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. But the really spectacular constructions that are manifest in biological diversity and complexity do not appear without the simultaneous genesis of information how to compose and maintain such structures and processes. It is this information that is recorded in the genes, and such information, unlike matter and energy, can be created and destroyed. Such genetic information is the key to all progress in biological nature. Making sense of that genesis, with its results alike in nature and in culture, from both scientific and philosophical perspectives is the task that lies ahead of us. Does the epic have any plot?

2. CONTINGENT NATURAL HISTORY?

We noted that this developing diversity and complexity, evident though both are, are subject to diverse interpretations. Despite the conclusions of the various scientists already cited, and on the basis of the textbook theory of natural selection, hardnosed scientists are reluctant to see any progress[2] in the evolutionary epic, because this theory, as usually interpreted, does not entitle them to see any. John Maynard Smith says, "There is nothing in neo-Darwinism which enables us to predict a long-term increase in complexity." But he goes on to suspect that this is not because there is no such long-term increase, but that Darwinism is inadequate to explain it. We need "to put an arrow on evolutionary time" but get no help from evolutionary theory.

> It is in some sense true that evolution has led from the simple to the complex: prokaryotes precede eukaryotes, single-celled precede many-celled organisms, taxes and kineses precede complex instinctive or learnt acts. I do not think that biology has at present anything very profound to say about this. ... We can say little about the evolution of increasing complexity. (1972, pp. 89 and 98-99)[3]

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[2] The idea of progress, say the postmodernists and others, is an ideological illusion, historically generated in Enlightenment Europe, and, in such discussions as we are engaged in here, superimposed by some scientists onto natural history, though denied by others. Such imposing is myth making to bolster up the good feelings of dominant Europeans about their connections with natural history, which is otherwise rather fearful, red in tooth and claw. See Ruse (1996). Readers will have to judge, if they can find within themselves the capacity to critique such allusions of illusion, whether (for example) the graphs used here, all made by scientists, are illusion-making projections. If not, do they reveal anything discovered about objective, nonhuman natural history, and what has been created ("projected") by evolutionary forces, even though perhaps not adequately explained by natural selection theory?

[3] Darwin was pulled both ways. He concluded *On the Origin of Species*, "As natural selection works solely by and for the good of each being, all corporeal and mental endowments will tend to progress towards perfection" (1859, 1964, p. 489). "The inhabitants of each successive period in the world's history have beaten their predecessors in the race for life, and are, in so far, higher in the scale of nature; and this may account for that vague yet ill-defined sentiment, felt by many pa-

The received theory says only that the better adapted survive, and (despite the use of the word "better") this adaptation leaves entirely open the question whether the survivors are better in any sense involving progressive worth. It does not even say that the survivors must be more complex, perceptive, sentient, specialized, or that the ecosystems in which later-coming forms are components will be more diverse or stable than the earlier ones. Later-coming grasses are not any better than earlier, now extinct ones; they are just different. Some life-forms (cockroaches, marine shellfish) survive over long periods little changed from their ancestors. In other cases, surviving life-forms have lost organs – eyes, legs, wings – and become parasites. (It does seem, though, that such parasites typically depend on whatever skills they lose remaining in their hosts.) In climates growing colder or drier fewer species may live there later. There are fewer dinosaurs now than in Cretaceous times, fewer birds than in Pleistocene times.

By this account, whether in fertile or harsh environments, species are simply buffeted about by their changing environment. If the environment just drifts through tectonic changes, climatic changes, continental drift, and so on, then neither can the life-forms that inhabit such an environment have direction. At the molecular, genotypic level, those species that survive do so on the basis of random variations, ventured from below and unrelated to the needs of the organism. At the molar, phenotypic level, species must be "better" adapted, but if the environment that they track better is drifting, then they do not progress toward complexity or diversity, or anything else: they just track drift – the species are as aimless as the geomorphic processes. The only form of progress that natural selection can promote is progress in capacity to survive, and that is an indepen-

laeontologists, that organisation on the whole has progressed" (1859, 1964, p. 345; cf. 1872a, 1962, p. 355; 1874,1895, pp. 145 and 619).

On the other hand, "After long reflection, I cannot avoid the conviction that no innate tendency to progressive development exists" (Darwin 1872b), and Darwin penned himself a memo: "Never use the words *higher* and *lower"* (Darwin 1858, p. 114).

Darwin lived in an age that thought highly of progress and his interpretation of natural history may be colored by his cultural era. His belief in progress may have waned in later life. One can, of course, defend progress in natural history whether or not belief in cultural progress is in or out of style.

dent variable with regard to increasing complexity or increasing diversity.

Evolution takes place wherever there is any change in gene frequency. If so, it may be said that such change has nothing to do with the selection of the advanced. There is just wandering up or down the ranges of life's complexity, across less or more of the ranges of life's diversity. There are local trends (cushion plants in alpine environments; thick leaves in deserts; repeated evolution of horns), but natural selection theory is unable to predict any long-term or big-scale outcomes. From the point of view of the theory, this resulting increasing diversity and complexity are contingent.

Despite Maynard Smith's modest conclusion that biology has little to say about these longer-range trends in evolutionary history, others draw the stronger conclusion that evolutionary history is a random walk. With Maynard Smith, biology has no explanation; with Jacques Monod the explanation is pure chance:

> Chance *alone* is at the source of every innovation, of all creation in the biosphere. Pure chance, absolutely free but blind, at the very root of this stupendous edifice of evolution: this central concept of modern biology is no longer one among other possible or even conceivable hypotheses. It today is the *sole* conceivable hypothesis, the only one that squares with observed and tested fact. And nothing warrants the supposition – or the hope – that on this score our position is likely ever to be revised. . . .
>
> When one ponders on the tremendous journey of evolution over the past three billion years or so, the prodigious wealth of structures it has engendered, and the extraordinarily effective teleonomic performances of living beings, from bacteria to man, one may well find oneself beginning to doubt again whether all this could conceivably be the product of an enormous lottery presided over by natural selection, blindly picking the rare winners from among numbers drawn at utter random. [Nevertheless,] a detailed review of the accumulated modern evidence [shows] that this conception alone is compatible with the facts. ... Man knows at last that he is alone in the universe's unfeeling immensity, out of which he emerged only by chance. (Monod 1972, pp. 112-113, 138, and 180)

Stephen Jay Gould agrees, emphasizing the philosophical implications of what biological science has found: "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, pp. 101-102). "Natural selection is a theory of *local* adaptation to changing environments. It proposes no perfecting principles, no guarantee of general improvement" (1977a, p. 45). Natural selection provides no reason to believe in "innate progress in nature"; none of the local adaptations is "progressive in any cosmic sense" (1977a, p. 45).

"There are no intrinsic trends towards increasing (or decreasing) diversity. Ecological roles are, in a sense, 'preset' by the nature of environments and the topological limits to species packing; they are filled soon after the Cambrian explosion. Thereafter, inhabitants change continually, but the roles remain" (1977b, p. 19). As in a rotating kaleidoscope, there is change without development, steady turnover, but not really different from the astronomical panorama of the cycling planets and revolving galaxies. The system is without value heading. Any values are produced by luck. "Almost every interesting event of life's history falls into the realm of contingency" (1989, p. 290). That is "a claim about the nature of *reality"* "denying that progress characterizes the history of life as a whole, or even represents an orienting force in evolution at all" (1996, p. 3).

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, p. 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" (p. 526). In fact, he argues, today more "mature" scientists, unbiased, have "expelled progress" from evolutionary history (p. 534). "Evolution is going nowhere - and rather slowly at that" (Ruse 1986, p. 203).

Evolutionary history wanders in the first place because of atomic and molecular chance, unrelated to the needs of the organism. There is selection operating over this chance, of course, but that selection does not introduce any ordered direction into the chance variation, 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. In the genes, there is record keeping. 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 reflects 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 men 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 although 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.

We can say that if life starts out simply, there is nowhere to go but up. So some development of diversity and complexity is not surprising. But life does not steadily and irreversibly have to go up. "Nowhere to go but up" is true at the launching, but not thereafter. There are down, stable, and out, and many forms take these routes. The evolutionary process might have achieved a few simple, reliable forms, needing little modification, and stagnated thereafter, as has sometimes happened in little-changing habitats. Nor is there any account of why the life process, if it happens to ascend, will not happen to descend, earlier more complex, later simpler, devolution after evolution, since up or down is immaterial to survival. Life might have gone extinct; many life-forms did. Nor does it help here to appeal to time to guarantee complexity. Time does nothing to cure randomness, not unless there is some further principle (that natural selection does not supply) that locks in the upstrokes.

We nowhere here wish to deny that there is contingency in natural history; to the contrary we will enlist this in the service of the genesis of value. But is this the whole story? 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. But 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 Earth-bound environments, if evolutionary history were to occur all over again, things would be different. Still, there would likely again be organisms reproducing, genotypes and phenotypes, natural selection over variants, multicellular organisms with specialized cells, membranes, organs; there would likely be plants and animals: photosynthesis or some similar means of solar energy capture in primary producers such as plants, and secondary consumers with sight, and other sentience such as smell and hearing; mobility with fins, limbs, and wings, such as in animals. There would be predators and prey, parasites and hosts, autotrophs and heterotrophs, ecosystemic communities; there would be convergence and parallelism. Coactions and cooperations would emerge. Life would probably evolve in the sea, spread to the land and the air.

Play the tape of history again; the first time we replayed it the differences would strike us. 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)

One clue, already supplied by Kauffman, may lie in realizing that genetic creativity is stimulated at "the boundary between order and chaos." At such a boundary, interpreters who prefer to emphasize the chaos can face in that direction and see only the contingency. But in a more complete account, one needs also to see the order maintained at the edge of chaos. Indeed, this is an order generated in such an environment, and, more profoundly still, made possible by it. Life at such a boundary needs, above all, information, for it is such information by which it can form, or inform, matter and energy into the living molecules by which life is generated, regenerated, and maintained. In this prolific natural history, normal extinction and turnover are essential to the creative process.

Even atypical extinction rates are incorporated into the creative process. Niles Eldredge reviews the geological epochs of accelerated extinction to find that they are also times of accelerated speciation, as though to endorse Kauffman's claim that creativity is increased at the boundary between chaos and order:

> The particularly compelling aspect of this account is that the factors underlying species extinction – namely, habitat disruption, fragmentation and loss – are the very same as those conventionally cited as causes of speciation. Thus the causes of extinction may also serve as the very wellspring of the evolution of new species. (Eldredge 1995a, p. 79)

This effect can be coupled with the finding by geneticists that at times of stress, genetic mutation rates are increased.[4]

There have also been a few (perhaps five, as numbered in Fig. 1.2) rare but devastating catastrophic extinctions. These decimated diversity, presumably also with adverse results on complexity. The late Permian and late Cretaceous extinctions are the most startling. Each catastrophic extinction is succeeded by a recovery. Although natural events, these extinctions so deviate from the trends that many paleontologists look for causes external to the evolutionary ecosystem. If caused by supernovae, collisions with asteroids/ oscillations of the solar system above and below the plane of the galaxy/ or other extraterrestrial upsets, such events are accidental to the evolutionary ecosystem. If the causes were more terrestrial – cyclic changes in climates or continental drift – the biological processes that characterize Earth nevertheless prove to have powers of recovery. Uninterrupted by accident, or even interrupted so, the biological forces steadily increase the numbers of species.

David M. Raup, the paleontologist who has best documented these catastrophic extinctions, has also reflected philosophically on them. He finds it striking that, though seemingly catastrophic, these periodic cutbacks prepare the way for more complex diversity later on. Evolution can tend to stagnate, unless there are crises and upsets (an insight also reached independently by Kauffman). The cata-

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[4] See Section 4.

strophic extinctions first seem quite a bad thing, an unlucky disaster. But in fact they were good luck. Indeed, were it not for them we humans would not be here, nor would any of the mammalian complexity. Life on Earth is quite resilient in its capacity to track shifting environments, and, though there is lots of turnover, normal geological processes lack the power to cause significant extinctions in major groups that are widespread. But just such a resetting of natural history is productive – rarely but periodically. We should think twice before judging these catastrophic extinctions to be a bad thing. Raup explains:

> Without species extinction, biodiversity would increase until some saturation level was reached, after which speciation would be forced to stop. At saturation, natural selection would continue to operate and improved adaptations would continue to develop. But many of the innovations in evolution, such as new body plans or modes of life, would probably not appear. The result would be a slowing down of evolution and an approach to some sort of steady state condition. According to this view, the principal role of extinction in evolution is to eliminate species and thereby reduce biodiversity so that space – ecological and geographic – is available for innovation. (1991, p. 187)

Raup argues for what he calls "extinction-driven evolution." Natural selection fosters diversity, but natural selection acting steadily and without interruption would saturate and stagnate natural history. Extinctions subtract from the biodiversity but at the same time provide the space for more innovative biocomplexity. This is not only true of the normal extinction turnover, but is especially true during catastrophic extinctions. There is a big shakeup; this is, if you like, at random; it is, we must say, catastrophic, but we must also say that the system is creatively stimulated by the catastrophe. The result is innovation beyond stagnation. The randomness is integrated into the creative system. Catastrophic extinction, though quite rare, "has been the essential ingredient in producing the history of life that we see in the fossil record" (1991, p. 189).

The storied character of natural history is increased, not diminished, by the catastrophic extinctions and by the element of chance operating during normal extinction turnover. Once "we thought that stable planetary environments would be best for evolution of advanced life," but now we think instead that "planets with enough environmental disturbance to cause extinction and thereby promote speciation" are required for such evolution (Raup 1991, p. 188). So large-scale fluctuations are vital to the dynamics of large systems.

Although it was once thought that much biodiversity was lost in the catastrophic extinctions, more recent studies suggest a different picture. Sean Nee and Robert M. May find, on the basis of a mathematical analysis of fossil extinctions: "A large amount of evolutionary history can survive an extinction episode. . . . A substantial proportion of the tree of life could survive even such a large extinction as occurred in the Late Permian." Some paleontologists have figured that up to 95 percent of marine (though not land) species perished in this extinction, though this is now thought to be an overestimate. But even if this had been so, "approximately 80 percent of the tree of life can survive even when approximately 95 percent of species are lost." Mass extinction more often cuts off the twigs of the tree of life (the species), so to speak, than the main branches (the families, orders, classes), which persist in species that do survive. "Much of the tree of life may survive even vigorous pruning" (1997, pp. 692-694; Myers 1997).

In fact, as Raup claims, the pruning results in vigorous regrowth and the production of entire, new branches of life; the main achievements of evolutionary history persist through the pruning. Put in graph form (Fig. 1.7), the major extinctions in species make only transient dips in the proliferation of the number of families on Earth over evolutionary history, combining the results of graphs such as that by Newell (Fig. 1.6) with that by Raup and Sepkoski (Fig. 1.2). The conclusion that life proliferates and elaborates over time seems inescapable. The secret lies in the genes, to which we next turn.

3. SEARCHING GENES

Living organisms must track drifting environments, sometimes chaotic environments, but the life process is drifting through an information search and locking onto discoveries. It is cybernetic or hereditary, as geomorphic processes are not; there is no cumulation of information in the hydrologic, climatological, orogenic cycles, but there is in the birth, life, death, genetic cycles. That is why biology is historical in ways impossible in physics or geophysics. Genesis becomes genetic, and, later, neural.

P. T. Saunders and M. W. Ho (1976) argue that there is an increase in the amount of genetic information stored in the organism. Kimura

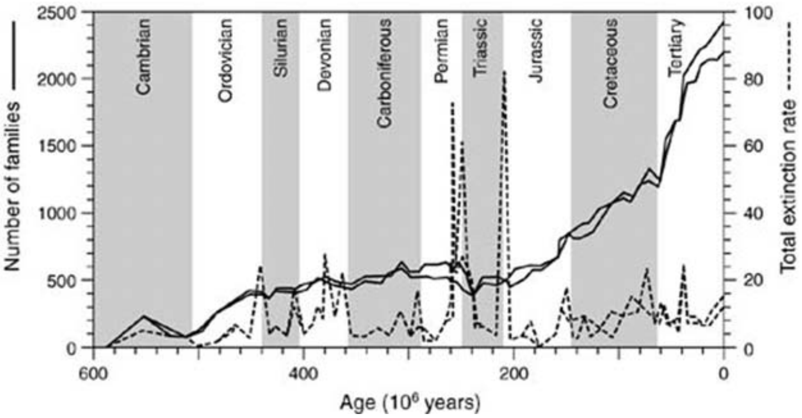

Figure 1.7. Proliferation of number of families on Earth, continuing through major extinctions. The double lines in both the number of families and the extinction rate represent maximum and minimum estimates (Benton 1995). Reprinted with permission from Norman Myers, "Mass Extinction and Evolution," *Science* 278 (24 October 1997): 597-598, p. 598. Copyright 1997 American Association for the Advancement of Science.

(1961) estimates that the higher organisms have accumulated genetic information from the Cambrian to the present at an average rate of 0.29 bit per generation. Generation times differ widely; genetic information involves quality as well as quantity; some of it is redundant. There is at present no way of reliably measuring the amount of significant genetic information in any one organism or species. Although both complexity and information resist quantification, the two are related and there does seem to be increased ability to gather and to process information about the environment, not as a general characteristic of life but as an achievement at the top trophic levels[5] (Nitecki 1988; McShea 1991).

One must understand genes as a phenomenon of searching, using variations generated in the encounter of the organism with changing environments to do this. The perpetuated gene, coding for a form of life, is only part of the story. "The role recognized by modern biology for an individual organism … is to transmit its genes to future generations to the maximum possible extent" (Williams 1988, pp. 385-

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[5] McShea finds a clear consensus among evolutionary biologists that there has been increasing complexity over evolutionary time, though he suspects this arises from cultural bias interpreting the fossil evidence. Ruse agrees (1996).

386; 1993). This is its inbuilt program, but there is also the playing out of this program in the ecosystem with, its interactions, checks and balances, creativity over time, and fuller history. Genes promote the survival of their kind, and ecosystems supply a satisfactory place for that to occur, so that there are repeated turnovers of individuals – birth, death, birth, death – and persistence of the kind over millennia. But what also and even more often happens is the arrival of new kinds. On the big scale it is not individual organisms that survive; it is not even species. There is speciation, the generation of new kinds, not simply reproduction to the maximum possible extent of existing kinds. There is historical development; superposed on survival. Organisms have powers that transcend their own self-defensive powers; they actualize themselves, but they actualize much more. There is descent with modification, and this sometimes results in ascent with modification.

The first microbes sought only to make more microbes to the maximum possible extent, but some transformed into trilobites, who sought to make trilobites to the maximum possible extent, but some transformed into lizards, who sought to make more lizards to the maximum possible extent, but some transformed into warblers. In the fuller narrative, genes evolve, develop, and code organisms that sometimes remain in their places, sometimes go extinct, but sometimes pass over into something else. The perpetuated gene is where information, the memory of the past with which the organism faces the future, is stored. The story is of selves preserving their self-identity, and, further, the story is of transformation as much as of evolutionary stability. The genes are the locus of this innovative evolutionary change.

Organisms in the world run on self-interest, but, as the world story runs on, genes are caught up in genesis, in the production of new ranges, orders, and kinds of selves – metazoans beyond protozoans, conditioned behavior beyond instinct, neurons where before was only stimulus-response, brains where before were only neurons, experience where before was only biochemical vitality, personality where before was only animal experience. The genes conserve order but also introduce novelty. Genes code a coping, and the coping is a defense of these values gained and dynamically transformed over time. What is conserved is what has proved valuable, tested, and transmitted intergenerationally. In result, with exploratory variations, what is selected is promising and seminal. Natural history is a story of how significant values endure through a context of suffering, stress, perpetual perishing and regeneration.

An organism arrives in the world with a genotype, shaped by a long evolutionary history. The genotype is the past delivered to the present, en route to the future. Nor is it just the genetic past; the genotype is what it is because it records the macroscopic evolutionary past. This macroscopic past is not one that the organism has lived on its own; it is the interactant past that ancestors have lived with others of that species and of other species. The history of ancestral skin-out interactions is driving the skin-in biochemistries, morphological development, and instinctive behaviors, as the genotype unfolds into a phenotype. That past history is continued with a present chapter; the genotype becomes a phenotype as it projects this coded past onto the contemporary environment. The story is reenacted as natural selection acts again in the new organism, not on the genotype, but on the historically maturing phenotype, into which the local history is now incorporated. The organism copes, and natural selection evaluates and records that coping, coded now for the generation to come.

Karl Popper concludes:

> Animals, and even plants, are problem-solvers. And they solve their problems by the method of competitive tentative solutions and the elimination of error. . . . Just like theories, organs and their functions are tentative adaptations to the world we live in. … A new tentative solution – a theory, an organ, a new kind of behaviour – may discover a new virtual ecological niche and thus may turn a virtual niche into an actual one. New behaviour or organs may also lead to the emergence of new problems. And in this way, they [plants and animals] may influence the further course of evolution, including the emergence of new biological values. (1972, p. 145)

Survival of the fittest is a subroutine in spinning a bigger story. There is survival of the searchers.

4. SMART GENES

The claim that natural history is random often couples with a claim that the genes are "blind" (Dawkins 1986). This claim, though metaphor, has initial plausibility because there is no intentionality in the genes. They do not "see" where they are going. By the standard scientific accounts, random variations bubble up from the genetic level, and these genotypic variations are expressed in variant phenotypes. Organisms compete for a place in drifting environments, struggling to hold a place against other lives, and those few variations that are accidentally useful are selected; the most, harmful, are discarded. Further variations are neutral; to them even natural selection is blind, since they produce no differential survival rates. These can sometimes remain, though unselected. There can also be random genetic drift, variation in gene frequency from one generation to another due to chance fluctuations.

Such lack of intentionality, or "blindness," is frequently extrapolated to draw more philosophical conclusions. George Williams asserts: "The evolutionary process is immensely powerful and oppressive, ... it is abysmally stupid" (1988, p. 400; 1993). Charles Darwin exclaimed once that the process is "clumsy, wasteful, blundering, low, and horribly cruel"[6] (Darwin, quoted in de Beer 1962, p. 43). On the other hand, Donald J. Cram, accepting the Nobel prize for his work deciphering how complex and unique biological molecules recognize each other and interlock, concludes: "Few scientists acquainted with the chemistry of biological systems at the molecular level can avoid being inspired. Evolution has produced chemical compounds that are exquisitely organized to accomplish the most complicated and delicate of tasks." Organic chemists can hardly "dream of designing and synthesizing" such "marvels" (1988, p. 760).

We want to reconsider this alleged "blindness," both the science and the philosophical interpretations, in the light of how genes have in fact generated this prolific natural history. Nonintentional though the genetic processes may be, the genes do successfully both maintain their own kind and also steadily generate novelty. In this defense of life and in this search for innovations, might not genetic creativity in fact be a rather sophisticated problem-solving process? Talk of a genetic "strategy" has become commonplace among biologists, not thereby implying consciousness, but strongly suggesting a problem-solving skill.

Removing (or, if you like, shifting) the metaphor, more precisely

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[6] In other moods, Darwin can find the process impressive, beautiful, and quite creative. Also, see note 3.

the question is whether an organism is "informed" whether information is present as needed for the organism's competence in its ecological niche. Every organism has considerable information about how to make a way through the world. It has a "program" and in that sense a "blind" plant has know-how about the life it is set to defend. All biology is cybernetic; the information storage in deoxyribonucleic acid (DNA), the know-how for life, is the principal difference between biology and chemistry or physics. Past achievements are recapitulated in the present, with variations, and these results get tested today and then folded into the future (Campbell 1982; Wicken 1987).

Well, it may be replied, the stored information is not so blind, but the method of discovering any new genetic information is blind. Because genes do not "see" where they are going, the variations are accidental and groping, and for this "blind" is a convenient metaphor. As organisms move from earlier genetic achievements to the discovery of later ones, there are certainly elements of random exploration. But is that all there is to be said? Consider how these elements of trial and error are incorporated in a larger generative process.

In reproduction the genetically originated novelties are formed in a shuffle that, although from one perspective may be said to be blind to the organismic needs, is far from chaotic and is only more or less random. Any and all variations are not equally probable. Genetic and enzymatic controls on the variation process limit the range of trials. There are different mutation rates at different genetic locations. Mutators and antimutators increase or trim the mutation rates as a function of population stresses (Tamarin 1996, pp. 472-474; Cairns, Overbaugh and Miller 1988; Gardner and Snustad 1981, pp. 330-331). Specific mutations are nondirected, but the rate and place at which they occur are partially regulated. In that probabilistic sense, adaptive mutation takes place (Drake 1991). For example, an enzyme produced under stress conditions "not only enhances the absolute rate of genetic change, it also alters the spectrum of the resulting mutations." "Components exist for feedback between the generators of genetic diversity and the environment that selects among variants." "Natural selection acts beyond particular alleles. It also favors genetic metabolism that generates alleles with a high probability of passing the tests of environmental selection." The result, according to David S. Thaler, is "the evolution of genetic intelligence" (1994).

There is a tendency for genes to sort in pretested blocks, a sort of modular construction and reconstruction, facilitated by the organization of the DNA into exons, units of genetic material expressed in structures, and introns, intervening sequences, that allow exon shuffling, also with various enzymes to facilitate this (Tamarin 1996, pp. 262-263). Repair mechanisms proofread and snip out certain genetic errors, and thus eliminate some variation, altering the variation-versus-fidelity ratio by up to five orders of magnitude (Mary K. Campbell 1991, pp. 580-583; Friedberg 1985; Friedberg, Walker, and Siede 1995). The genetic program has the capacity to reject some of the random recombinants on the basis of information already present in the genetic coding. Individual genetic sets are adept at pumping out their own disorder. But they do not pump out all novelty; that would cease evolutionary development and lead to extinction. There is a shakeup of the genes under environmental stress, so that the fastest evolution toward variant forms, often more highly organized forms, takes place almost explosively after major geologic crises.[7]

Mutation is usually kept slight and conservative. Chaotic mutations that code for nothing do not even begin to produce the biomolecular units or subunits of proteins, enzymes, or lipids that were previously coded for in the unmutated gene. Other radical mutations that do produce structures, but nonfunctional ones, immediately abort. The only mutations that really get tested are those just incremental enough to fit cooperatively within the whole organismic organization, or, rarely and surprisingly, those with bigger, quantum leaps that still fit cooperatively enough to allow their trial in the life of a phenotype. So there is constraint as to what random variations are much or at all tested. On the one hand, changing environments, especially if they are unpredictably changing, will select the more evolvable species; the less evolvable will go extinct. On the other hand, what worked well in the past, or a variant rather much like it, will probably work well in the future.

Adaptation is imperfect; there are ways in which any organism could be better adapted, and the variants produced are not all equally and perfectly fitted. But if no improvement were possible, or the variants all equal, evolution would cease, natural selection would stop selecting for the better adapted ones, nor could life track changing environments. There must be room to make "mistakes" which

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[7] See the observations by David Raup and Niles Eldredge, discussed earlier.

are more like "retakes," taking another tack, zigzagging the direction a bit testing whether some of the trials are better informed methods of survival. Natural selection selects to leave the successful information in place, so far as this is possible under local genetic and ecological constraints. In this sense, it is the maladaptation that permits adaptation, the imperfection that drives the world toward perfection.

The challenge is to get as much versatility coupled with as much stability as is possible, but this is a matter of optimizing twin maxima. On the one hand there is selective advantage in using as much of past knowledge as is possible, even in keeping that which might be useful; on the other there is advantage in quickly breaking through to something new where this is required (with the risk of mis-takes this involves). Many variations are not eliminated but made recessive, transmitted by infrequently expressed genetic potential that is kept as versatility, subsequently favored if environments alter. The dominant/recessive phenomenon in genetics is a way of storing variability that is not usually expressed in a stable environment, but that is nevertheless there when the environment shifts. There may be a large number of such recessive alleles waiting in the population. Should these shifts come, the species is ready to deal with a broader range of environmental conditions than the usual environment requires (Ayala 1978).

When rabbits vary, whether through expression of variant alleles or through mutation, some are not immobile, and some travel at twice their previous velocity. Rather, some run a little faster, some a little slower, and the extra or reduced speed must integrate with benefits and costs to all the other vital rabbit metabolisms and behaviors. The variation that really emerges for natural selection to operate on is subject to prior constraint by the accomplished successes of the organism. The process is blind in that the particular variations are not generated by the needs of the organism, yet only those variations are tested that are more or less functional. Probing is restricted to the cutting edges. The organism typically only searches the nearby space for possible directions of development.

Contemporary geneticists are insisting that thinking of this process as being "blind" misperceives it. Species often move through likely possibility space much faster than would be expected on the "blind" assumption (and sometimes they do not). Genes in these species have substantial solution-generating capacities. Though not deliberated in the conscious sense, the process is cognitive, somewhat like that of computers, which, likewise without felt experience, can run problem-solving programs. There is a vast array of sophisticated enzymes to cut, splice, digest, rearrange, mutate, reiterate, edit, correct, translocate, invert, and truncate particular gene sequences. There is much redundancy (multiple and variant copies of a gene in multigene families) that shields the species from accidental loss of a beneficial gene, provides flexibility – both overlapping backup and unique detail – on which these enzymes can work.

John H. Campbell, a molecular geneticist, writes, "Cells are richly provided with special enzymes to tamper with DNA structure," enzymes that biologists are extracting and using for genetic engineering. But this "engineering" is already going on in spontaneous nature:

> Gene-processing enzymes also engineer comparable changes in genes in vivo. Cells deliberately manipulate the structures of their gene molecules for phenotypic and possibly evolutionary goals. . . .We have discovered enzymes and enzyme pathways for almost every conceivable change in the structure of genes. The scope for self-engineering of multigene families seems to be limited only by the ingenuity of control systems for regulating these pathways. (1983, pp. 408-409)

These pathways may have "governors" that are "extraordinarily sophisticated." "Self-governed genes are 'smart' machines in the current vernacular sense. Smart genes suggests smart cells and smart evolution. It is the promise of radically new genetic and evolutionary principles that is motivating today's study" (1983, pp. 410 and 414). Despite Campbell's use of "deliberately," biologists do not think that such self-engineering is deliberate in the conscious sense, but rather in the programmed sense of a computer on problem-solving search (Latin: *deliberatio,* well weighed), that is, systematically ventured and tested. "Smart" in the vernacular sense means "clever" or "ingenious," and that is beginning to seem a better metaphor for genes than that they are "blind." "Smart," like "selfish," could be a misleading metaphor, but something creative is going on. "Selection" has been usefully extended from human to natural selection; "information," from human to genetic affairs. "Cognitive" or "learning" capacities may not be restricted to organismic individuals.

In a study of whether species as historical lines, using various genetic strategies to solve problems, can be considered "intelligent" Jonathan Schull concludes:

> Plant and animal species are information-processing entities of such complexity, integration, and adaptive competence that it may be scientifically fruitful to consider them intelligent. . . . Plant and animal species process information via multiple nested levels of variation and selection in a manner that is surprisingly similar to what must go on in intelligent animals. As biological entities, and as processors of information, plant and animal species are no less complicated than, say, monkeys. Their adaptive achievements (the brilliant design and exquisite production of biological organisms) are no less impressive, and certainly rival those of the animal and electronic systems to which the term "intelligence" is routinely (and perhaps validly) applied today. (1990, p. 63)

Analogies with the artificial intelligence in computers are particularly striking. Such cognitive processing is not conscious, but that does not mean it is not intelligent, where there are clever means of problem solving in a phyletic lineage. Schull continues:

> Gene pools in evolving populations acquire, store, transmit, transform, and use vast amounts of fitness-relative information. ... The information-processing capacities of these massively parallel distributed processing systems surpasses that of even the most sophisticated man-made systems. . . . It seems likely that an evolving species is a better simulation of "real" intelligence than even the best computer program likely to be produced by cognitive scientists for many years. (1990, pp. 64 and 74)

So it seems that if we recognize that there are smart computers, we must also recognize that there are even smarter genes.

Phenotypes can be more or less labile, or plastic. What features they develop from a possible repertoire for which they are genetically endowed depends on what environments they find themselves in. *Nemoria* caterpillars that eat oak catkins grow body shapes that mimic the catkins; those that eat leaves develop body shapes that mimic twigs (Greene 1989). Insects sometimes survive in environments for which they are less than optimally adapted (feeding on a less nutritious plant). This genetically based plasticity enables phenotypes to handle changing environments, or to explore novel nearby environments, although not yet genetically changing. The plasticity itself is an adaptation for provisional trials, without yet solidifying these trial directions in genetic coding, not unless there is found some selection pressure that makes worthwhile fixing that behavior in genetic coding. The species tests various possibility spaces, and thereby hangs on until such time as better genes that equip it for more adequate performance in the shifting or novel environment (better capacities to digest the once less desirable plant, which may be increasing its numbers in the warming climate) do appear. Such plasticity allows better searching.

Augmenting this may be "maternal effects," whereby, at times, acquired characteristics are inherited for several generations (Landman 1991). Beetles eating seeds of the less desirable species, which have a harder seed coat, may, once some of them do break through the coat, lay bigger eggs that give their young a head start, enabling these young to eat their way into more of the seeds. Beetle larvae, otherwise genetically identical, whose mothers did not eat such plants and who were hatched from smaller eggs, can seldom survive on them, although they do quite well if feeding on the more desirable species (Fox, Thakar, and Mousseau 1997). That too enables species to occupy possibility spaces, until such time as genes do appear for a better adapted fit.

The protein-coding portions of the genes account for only about 3 percent of the DNA in the human genome; the other 97 percent encodes no proteins. Geneticists once thought this might be "junk DNA," but "geneticists are beginning to formulate a new view of the genome. Rather than being considered a catalogue of useful genes interspersed with useless junk, each chromosome is beginning to be viewed as a complex 'information organelle' replete with sophisticated maintenance and control systems." That summarizes the work of Eric Lander, from his research on the Human Genome Project. This DNA seems to be able to regulate and control somatic processes without even making protein enzymes, and molecular biologists misunderstood it until they realized this. Much of it is not waste at all, but it "is turning out to play vital roles in normal genome function" (Nowak 1994).

Not only does such problem solving take place, but the genes, over the millennia, get better at it. Christopher Wills concludes, "There is an accumulated wisdom of the genes that actually makes them better at evolving (and sometimes makes them better at not evolving) than were the genes of our distant ancestors. . . . This wisdom consists both of the ways that genes have become organized in the course of evolution and the ways in which the factors that change the genes have actually become better at their task" (1989, pp. 6-8). Blind genes accumulating wisdom? Perhaps the contingent variation is part of the wisdom in the process.

Is all this problem solving accidental to evolution? It would be a rather anomalous result of nothing but blind genes, driven to reproduce nothing but their own kind, if there had appeared novel kinds steadily over many millennia but only by drifting into them. The genes seek only survival, but the story is of arrivals. There seems to be something present in the environmental system in which these genes are embedded that not only irritates them, producing an agitated effort at competitive survival, but also induces them, sometimes, to pass over into something higher. Species increase their kind, but ecosystems increase kinds. Evolution tries out mutations, variations, and that means diversity and, sometimes, complexity. The graphs we have reviewed do not particularly look like graphs of genes (much less "selfish" genes) keeping themselves intact; they rather suggest a creative upflow of life transmitted across a long continuing turnover of kinds, across a long history that includes struggling toward more diverse and more complex forms of life.

5. GENETIC ALGORITHMS

In certain kinds of problem-solving searches, so far from disparaging the seemingly accidental groping of genes under natural selection pressures, computer scientists may deliberately (now in the conscious sense) seek to imitate a similar process on their unconscious computers. Some sophisticated computer programs use what are called "genetic algorithms" (Holland 1992; 1980; 1975; Davis 1987; Goldberg, 1989; Mühlenbein, Gorges-Schleuter, and Kramer 1988; Whitley, Starkweather, and Bogart 1990; Koza 1992; Forrest 1993; Mitchell 1996).[8] An "algorithm" is a set of instructions or rules that is repeated to solve a problem. In simpler computing programs these algorithms can be precisely and logically specified. But in more complex programs, they cannot, because they are not known. Nor can

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[8] See especially the journal *Evolutionary Computation* (MIT Press), also *Artificial Life* and *Adaptive Behavior* (MIT Press).

there be random searches because all possible solutions to a problem are so numerous that it would take a computer millions of years to check them all.

"Genetic" algorithms involve combining and recombining partial solutions to a problem in order to generate improved solutions. They are "search algorithms based on the mechanics of natural selection and natural genetics" (Goldberg 1989, p. 1). The model for such programs is biological: sexual mating and strings of genes on chromosomes that can be shuffled and selected. The underlying metaphor is natural selection, and the field is sometimes called evolutionary computation. The "genotype" is the bits coding the program, written microscopically on tape and disk; the "phenotype" is what the program does in ordinary life. Scientists may want to program a computer to search for the optimal set of values to solve certain multi-valued problems where the values interact with each other, such as solving certain sets of mathematical equations, or detecting patterns against a background of noise, or predicting the weather, or scheduling the most effective work and meeting times for many dozens of employees in a manufacturing plant, each of whom has different time slots available, a different pay scale, and each of whom contributes different skills to the production process, many of which have to operate together or sequentially.

The computer will generate at random some "bit strings," or "genotypes," analogous to information coded on chromosomes, which are possible values in solution. These sequences are its initial "population." It will then test members of the population for effectiveness at a solution, rank them for what the scientists call their "fitness," and select the fittest. The computer will then generate new possible solutions, stimulating variations, "mutations," on the highest-ranking ones; inhibiting the lower-ranking ones; evaluate the new possibilities for their "fitness", and put them in competition with the previous, partially effective solutions. The computer also "mates" the various solutions, that is, cuts up and splices portions of bit strings that seem to code the most effective values, and then tests these "offspring" for their fitness.

The computer works with coadjusted clusters that probably (but not inevitably) move together during crossover. It may vary the "population size" of the set of solution values that it mates. It will discard solutions with low fitness. If two or more sets of solutions that have little in common (widely separated local optima) begin to appear, the computer will preserve these multiple solution tracks but try an occasional cross-mixing of segments from the different local optima, some of which will result in offspring that have enough fitness to remain in the working population. Such outbreeding prevents getting trapped in local optima that are suboptimal solutions globally.

The computer will continue with lesser probability (which may be varied during the program) occasionally to explore unlikely solutions. Even in large and complicated search spaces, genetic algorithms tend to converge on solutions that are globally optimal or nearly so. Simple bit strings can encode complicated structures, and reiterated transformations of partial solutions have a striking power to improve them. Computer searches for optimal solutions that would take a computer an estimated billion years, if done completely at random, can be accomplished by genetic algorithms in a few hours. Genetic algorithms have been used to find the most effective management of complex cross-country gas pipelines, to engineer better jet engine turbines (analyzing 100 variables, each with a range of values, a search space with over 10^{387} points), and they are being used in the design of the information superhighway. They are more expert than so-called expert systems, just because of the exploratory mutation and mating recombinations.

In these genetic algorithm programs, mimicking the chromosomes, a set of values, coded on the "genes," is being optimized through the concerted interactions of numerous information storage sites. What is being tested is the intensification or inhibition of one part of a solution (one value) coupled with the contributions of many others, all integrated (not just aggregated) in solution. Genetic algorithms only explore software possibilities, but researchers are now also developing software programs that mutate, recombine, regenerate, and test the computer chips themselves, evolving new hardware over many generations, promising the most powerful computing yet (Taubes 1997). And this is more nearly like what genes do, since they revise both morphology and behavior, evolving, so to speak, both new hardware and new software.[9]

[9] A note of caution is in order, worrying about how well computers can simulate natural systems: "Verification and validation of numerical models of natural systems is impossible. This is because natural systems are never closed and because

Genetic problem solving, then, does not seem so tinkering,[10] jury-rigged,[11] and blind. To the contrary, it is remarkably like what some of the smartest scientists are doing. "Nature creates highly complex problem-solving entities via evolution," concludes John Koza, surveying the possibilities for the programming of computers by means of natural selection (1992, p. 6). Stephanie Forrest finds that the "use of genetic algorithms suggests a computational view of evolution in which the mechanisms of natural selection, inheritance, and variation serve primarily to transmit and process information" (1993, p. 872). Herbert A. Simon, a cybernetics theorist, compares scientific problem solving with natural selection, to find that, on the cutting edges of science,

> the process ordinarily involves much trial and error. Various paths are tried; some are abandoned, others are pushed further. Before a solution is found, many paths of the maze may be explored. The more difficult and novel the problem, the greater is likely to be the amount of trial and error required to find a solution. At the same time, the trial and error is not completely random or blind; it is, in fact, rather highly selective. . . . Human problem solving, from the most blundering to the most insightful, involves nothing more than varying mixtures of trial and error and selectivity. (1969, pp. 95 and 97)

John Holland, after studying such algorithms for forty years, concludes, "Living organisms are consummate problem solvers. . . . Pragmatic researchers see evolution's remarkable power as something to be emulated. . . . By harnessing the mechanisms of evolution, researchers may be able to 'breed' programs that solve problems even when no person can fully understand their structure" (Holland 1992, p. 66). We will return to this similarity of the genetic search with scientific searching in Chapter 4.

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model results are always non-unique. . . . Confirmation is inherently partial" (Oreskes, Shrader-Frechette, and Belitz 1994, p. 641). "The computational setting is highly simplified compared with the natural world. . . . Necessarily, they have abstracted out much of the richness of biology" (Forrest 1993, pp. 872 and 877). "Explicit fitness evaluation is the most biologically unrealistic aspect of GAs [genetic algorithms]" (Mitchell and Forrest 1994, p. 282). See later, on computer simulations of the emergence of altruism (Chapter 5, Section 2[1]).

[10] Recalling Jacob (1977).

[11] Recalling Gould (1980, pp. 20-21).

6. INTRINSIC AND INCLUSIVE GENETIC VALUES

Using a positive axiological paradigm, genes can be interpreted as loci of intrinsic value, expressed and defended in individuals and also inclusively present and distributed in family, population, and species lines. If one is working from a humanist or psychological view of what "value" can mean, this perspective can seem unfamiliar. On a sentientist and experiential account, when considering all the flora and most of the fauna (microbes, protozoans, insects, nematodes, mollusks, and crustaceans with little central nervous system) – all these organisms, with their genes, are not able to value because they are not able to feel anything. These organisms include over 98 percent of the species of life, or, counted by individuals or cumulative biomass, all but a tiny fraction of living things (Ruppert and Barnes 1994). Nothing "matters" to them because there is "nobody there," no experiential self. There is no valuer evaluating anything, nobody taking an interest in what they are doing. Such organisms, driven by their genes, do not have any options among which they are choosing. A minimally sentient awareness is required for value.

Consider, however, a more biologically based concept of value. Biologists regularly speak of the "selective value" or "adaptive value" of genetic variations (Ayala 1982, p. 88; Tamarin 1996, p. 558). Plant activities, such as dispersing seeds or producing thorns, have "survival value." Bees sting and do their waggle dance. Natural selection picks out whatever traits an organism has that are valuable to it, relative to its survival. Biologically, rather than psychologically, it is difficult to dissociate the idea of value from natural selection. When natural selection has been at work gathering these traits into an organism, coding them into genes, that organism is able to value on the basis of those traits. It is a valuing organism, even if the organism is not a sentient valuer, much less a conscious evaluator. Those traits, though picked out by natural selection, are innate in the organism, that is, stored in its genes. In our terms, these are intrinsic values.

Those who continue to insist on a sentientist or humanist theory of value must argue away all such defense of life under natural selection as not dealing with "real" value at all, but mere function. Those arguments are, in the end, more likely to be stipulations than reasoned arguments. If one stipulates that valuing must be felt valuing, that there must be somebody there, some subject of a life, then all flora and most fauna are not able to value, and that is so by one's definition. But does that definition, faced with the facts of biology, remain plausible? Perhaps the sentientist definition covers correctly but narrowly certain kinds of higher animal valuing, namely, that done by sentient animals, and omits all the rest.

Plants, for example, are quite alive. Like all other organisms, they are self-actualizing. Plants are unified entities of the botanical though not of the zoological kind; that is, they are not unitary organisms highly integrated with centered neural control, but they are modular organisms, with a meristem that can repeatedly and indefinitely produce new vegetative modules, additional stem nodes and leaves when there is available space and resources, as well as new reproductive modules, fruits and seeds. Plants repair injuries and move water, nutrients, and photosynthate from cell to cell; they store sugars; they make tannin and other toxins and regulate their levels in defense against grazers; they make nectars and emit pheromones to influence the behavior of pollinating insects and the responses of other plants; they emit allelopathic agents to suppress invaders; they make thorns, trap insects, and so on. They can reject genetically incompatible grafts.

This description of plant activities does not suppose any intentional pursuit of desires. There may be some metaphorical elements in expressions such as "defending life" or "repairing injuries," but we also take this to be a rather literal account, effectively descriptive of what is going on. To say that the genome is a set of "conservation molecules," or that the plant has a "good of-its-own" is not to be dismissed as mere metaphor. That rather seems the plain fact of the matter.

A plant, like any other organism, sentient or not, is a spontaneous, self-maintaining system, sustaining and reproducing itself, executing its program, making a way through the world, checking against performance by means of responsive capacities with which to measure success. Something more than merely physical causes, even when less than sentience, is operating within every organism. In its genetic set, there is *information* superintending the causes; without it the organism would collapse into a sand heap. The information is used to preserve the plant identity. Perhaps in physics and chemistry matter and energy cannot be lost, only transformed, but in biology this information can be and often is lost, and the plant activities promote its vital conservation. Though things do not matter *to* plants, a great deal matters *for* them. We ask, of a failing plant What's the matter *with* that plant? If it is lacking sunshine and soil nutrients, and we arrange for these, we say, The plant is benefiting from them, and "benefit" is – everywhere else we encounter it – a value word. Biologists speak regularly of the beneficial genetic mutations and their phenotypic expressions in morphology and behavior, with their adaptive value. Harmful mutations indicate as well that values are at stake.

We are developing here this more biological, more genetic sense of value. We can approach this thinking of an organism's good-of-its own, its good-of-its-kind. As an heir to its portion of the diversity and complexity generated in evolutionary natural history, any particular organism, with its genes, defends that organism's good inhering in itself, in its "self" – a somatic though not a psychological self - which in reproduction is passed (in part) to an offspring "self," which is also such good defended in kin. Every organism inherits its portion of the past genetic line, by which it is self-constituted, and it must also be self-projecting, pushing itself forward. That is the beauty of life, the means of genesis, not something suspect. Self-development, self-defense, is the essence of biology, the law of the wilderness, though there is more to be said when such individuals are located in families, in populations, in species lines, and in ecosystems.

Why is the organism not valuing what it is making resources of? – even when not consciously so, for we do not want to presume that there is only conscious value or valuing. That should be debated, not assumed. Life is organized vitality, which may or may not have an experiential psychology. A valuer is an entity able to feel value? Yes, psychologically, and only the higher organisms can do so. A valuer is an entity able to defend value? Yes, biologically, and all organisms defend their lives.

Approach this idea with another set of metaphors. Think of a genetic set, with its cybernetic identity and information, as essentially a set of *linguistic* molecules, a *logical* set (Searls 1992). The genetic set is a *propositional* set – to choose a provocative term – recalling how the Latin *propositum* is an assertion, a set task, a theme, a plan, a proposal, a project, as well as a cognitive statement. From this the genetic set is also a motivational set, since these life motifs are set to drive the movement from genotypic potential to phenotypic expression. Given a chance, these molecules seek organic self-expression. They thus proclaim a life way, and with this an organism, unlike an inert rock, claims the environment as source and sink, from which to abstract energy and materials and into which to excrete them. Life thus arises out of Earthen sources (as do rocks), but life turns back on its sources to make resources out of them (unlike rocks). Rocks do not of themselves give rise to other rocks; rivers do not reproduce themselves and make offspring. But oaks make other oaks. An acorn becomes an oak; the oak rises from the ground and stands on its own.

So far this can seem only a description of the logic of life. Value more evidently appears when one recognizes that the genetic set is a *normative set) it* distinguishes between what is and what *ought to be.* The genome is a set of *conservation* molecules (if also, in another sense, a set of developmental molecules). The organism is an axiological, evaluative system. So the oak grows, reproduces, repairs its wounds, and resists death. The physical state that the organism seeks, idealized in its programmatic form, is a valued state. *Value* is present in this achievement. One is not dealing simply with an individual defending its solitary life but with an individual in a species lineage and having situated fitness in an ecosystem. Still, one needs to affirm that the living individual, the "self," taken as a point experience in the web of interconnected life, is per se an intrinsic value.

A life is defended for what it is in itself, without necessary further contributory reference, although, given the structure of all ecosystems and given the necessity for reproduction, such lives necessarily do have further reference. Organisms have their own standards, fit into their niche though they must. They promote their own realization, at the same time that they track an environment. They have a technique, a know-how. Every organism has a *good-of-its-kind;* it defends its own kind as a *good kind.* As soon as one knows what a giant sequoia tree is, one knows the biological identity that is sought and conserved.

The tree is valuable in the sense that it is able to value itself. If we cannot say this, then we will have to ask, as an open question, Well, the tree has a good of its own, but is there anything of value to it? This tree was injured when the elk rubbed its velvet off its antlers, and the tannin secreted there is killing the invading bacteria. But is this valuable to the tree? Botanists say that the tree is irritable in the biological sense; it responds with the repair of injury. The bee is making use of the nectar in the flower, but is the honey valuable to the bee? Few of us doubt that bees are irritable when they sting. Such capacities can be "vital" now a better word than "biological," and a description with values built into it. These are observations of value in nature with just as much certainty as they are biological facts; that is what they are: facts about value relationships in nature. We are really quite certain that organisms use their resources, and one is overinstructed in philosophy who denies that such resources are of value to organisms instrumentally. But then, why is the tree not defending its own life just as much a fact of the matter as its use of nitrogen and photosynthesis, or honey, to do so?

Bacteria, insects, crustaceans – including also the sentient creatures, the mice and chimpanzees – are projects of their own, each a life-form to be defended for what it is intrinsically. An intrinsic value, from the perspective of biology, is found where there is a constructed, negentropic, cybernetic identity that is defended in such a somatic organismic self with an integrity of its own. Using its genes, the organism is acting "for its own sake," or, more philosophically put, "to protect its intrinsic value." These are "axiological genes."

But the life that the organismic individual has is something passing through the individual as much as something it intrinsically possesses. All such selves have their identity in kinship with others, not on their own. This individual and familial identity is placed in a species line that must be historically maintained in the death and regeneration process, with both information stored at the genotypic level and morphology and behavior expressed at the phenotypic level. A species is another level of biological identity reasserted genetically over time: sequoia-sequoia-sequoia, bee-bee-bee. Identity need not attach solely to the centered or modular organism; it can persist as a discrete pattern over time. The individual is subordinate to the species, not the other way around. The genetic set, in which is coded the *telos,* is as evidently the property of the species as of the individual through which it passes. A consideration of species strains any value theory fixed on individual organisms, much less on sentience or persons. But the result can be biologically more sound.

Reproduction is typically assumed to be a need of individuals, but since any particular individual can flourish somatically without reproducing at all, indeed may be put through duress and risk or spend much energy reproducing, by another logic we can interpret reproduction as the species keeping up its own kind by reenacting itself again and again, individual after individual. It stays in place by its replacements. In this sense a female *grizzly* bear does not bear cubs to be healthy herself, any more than a woman needs children to be healthy. Rather, her cubs are *Ursus arctos*, threatened by nonbeing, recreating itself by continuous performance. A species in reproduction defends its own kind. A female animal does not have mammary glands nor a male animal testicles because the function of these is to preserve its own life; these organs are defending the line of life bigger than the somatic individual. The lineage in which an individual exists dynamically is something dynamically passing through it as much as something it has. The locus of the intrinsic value – the value that is really defended over generations – seems as much in the form of life, the species, as in the individuals, since the individuals are genetically impelled to sacrifice themselves in the interests of reproducing their kind. Value is something dynamic to the specific form of life.

The species line is the *vital* living system, the whole, of which individual organisms are the essential parts. The species too has its integrity, its individuality. Processes of value that we earlier found in an organic individual reappear at the specific level: defending a particular form of life, pursuing a pathway through the world, resisting death (extinction); regeneration maintaining a normative identity over time, creative resilience discovering survival skills. It is as logical to say that the individual is the species' way of propagating itself as to say that the embryo or egg is the individual's way of propagating itself. The value resides in the dynamic form; the individual inherits this, exemplifies it, and passes it on. If, at the specific level, these processes are just as evident, or even more so, what prevents value from existing at that level? The appropriate survival unit is the appropriate location of valuing.

All such value is deeply embedded in the historical evolutionary ecosystem. The species lineage is woven into a supporting, stimulating, biotic community. The system is a kind of field with characteristics as vital for life as any property contained within particular organisms. The ecosystem is the depth source of individual and species alike; it has systemic value. The molecular configurations of DNA are what they are because they record at the microscopic level the story of a particular form of life in the macroscopic, historical ecosystem. What is generated arises from molecular mutations, but what survives is selected for adaptive fit in an ecosystem. One cannot make sense of biomolecular life without understanding ecosystemic life, the one level as vital as the other.

Values are intrinsic, instrumental, and systemic, and all three are interwoven, no one with final priority over the others in significance, although systemic value is foundational. Each locus of intrinsic value defends its self and kind as a good of its own, and yet each such organism gets folded into instrumental value within the system. There are no intrinsic values, nor instrumental ones either, without the encompassing systemic creativity. Properly understood, the story at the microscopic genetic level reflects the story at the species-ecosystemic level, with the individual a macroscopic midlevel between. The genome is a kind of map coding the species; the individual is an instance incarnating it. The ecosystem is the generative matrix out of which all life comes.

From such an axiological perspective, we can incorporate what theoretical biologists have come to call "inclusive fitness" (Hamilton 1964). ("Inclusive" is an interesting term for such "fitness," partly because of the parallels in social circles, recommending "inclusive" language or "inclusive" politics.) The prevailing account of the behavior of individuals toward family members goes up to the family level at the same time that it goes down to the genetic level. If one takes the gene's-eye view, as one must when the interests at stake are transmitting information and reproducing in families, one has to think of a gene as being present not only in a single cell but in all cells where there are copies of it. Since genes are a kind of information, this is somewhat like asking, Where is the book *War and Peace?* It is wherever there is a copy. So a particular gene is copresent in myriad cells within any one individual. That particular gene may be likewise copresent in relatives, copies within kin in a different skin.

Facing out, the organism finds that it is sometimes facing in, finding a similar self in others. External relations here turn out to be internal relations. Expanding the concept of the self, the survival and reproduction of a relative are partly equivalent in evolutionary effect to one's own survival and reproduction. The individual fitness is held partially in common with kin on all sides, all those "blood relations" in whom there are partial copies of "my genes," of whose genes "my genes" are partial copies. From the "point of view of a gene" (so to speak), or from the point of view of "my self," it does not matter whether the descendants (gene copies) are mine immediately, as a result of my individual fitness, or in my family (inclusive fitness, within two brothers, or eight cousins, and so forth). If I fail entirely to reproduce copies of any of my own individual genes, it is just as well to have copies transmitted over there in my cousins. Narcissism and nepotism are all the same. What I value is found to be present both here and there.

Fitness is now spread across the whole family; some is within me, some in brothers, cousins, parents, children. Some insist on interpreting this from the perspective that the individual acts "selfishly" in his or her own interests (as we will later see in considerable detail), but "selfish" is now being stretched to cover benefits to father, mother, niece, nephew, cousin, children, aunts, uncles, and so on, however far one chooses to look along the indefinitely extended lines of relationship, lines that fan out eventually to all my conspecifics. In this more complete picture of what is going on, the "my" that once was located from the skin in has been so reallocated that it is now an "our." Individuals and their kin need to be distinguished from but related to the populations and species of which they are members. We will return to such a perspective under the theme of genetic identity and organisms in their communities of kin and kind (Chapter 2, Sections 1 and 3).

One must be careful here to set aside any issues of culture or morality and consider this simply biologically, as such genetic dispositions might operate in the nonhuman world. If one gene can locate its interests in a peer gene elsewhere among kin, buried though these genes are in the networked genomes they inhabit, this expands the concept of intrinsic value from something located in any particular self. It distributes value more inclusively. An individual somatic self is helping other selves, but, in turn and in return, their in-common genes also mean that they are helping this first individual self.

Each organism is in pursuit of, that is, values, its own *proper* life (Latin: *proprius*, one's own), which is all that the (nonhuman) individual organism either can or ought to pursue. It turns out, however, that any such "own proper life" is not exclusively individually owned, but is scattered about in the family, and that the individual competently defends its so-called self wherever and to the extent that this is manifested in the whole gene pool. This means that values can be held intrinsically only as they are inclusively distributed, and that places us in a position to reconsider this process by which diversity and complexity are generated.

7. DISTRIBUTED AND SHARED GENETIC VALUES

The more neutral word here is "distributed," but now that the individual self has become implicated into an "inclusive" fitness we can introduce, rather provocatively, the word "shared" with which to interpret this genetic "allocating" and "proliferating." "Share" has the Old English and Germanic root *sker*, to cut into parts, surviving in "shears," "plowshare," and "shares" of stock. As used here, to "share" is to distribute in parts the self's genetic information, thereby conserving it. Genes do generate; they reproduce or communicate what survival value they possess; they share (= distribute in portions) their information, literally, although preconsciously and pre-morally. The central feature of genes is that they can be copied and expressed, again and again. They replicate. Their power to send information through to the next generation is what counts. The genetic information gets allocated and reallocated, portioned out, and located in various places. Whatever the process, rather obviously genetic information has been widely distributed, communicated, networked, recycled, and shared throughout natural history.

Take two examples, the first at basic metabolic levels. Some genes code for making cytochrome *c* molecules, and these are found in organisms ranging from yeast to persons: that is, they are extremely widely shared. They are vital in the energy metabolism of all higher plants and animals and go back some 1.5 billion years, to the early history of life. Cytochrome *c* molecules do evolve through various nucleotide substitutions but are comparatively stable molecules. The primary structure is identical in humans and chimpanzees, which diverged about 10 million years ago; there is only one replacement between humans and monkeys, whose most recent common ancestor lived 40 to 50 million years ago. Even between humans and yeast the code is more than half the same, and, where it is different, the differences are often inconsequential in function (Dickerson 1971; Fitch and Margoliash 1967). Similar observations could be made regarding genes that make adenosine triphosphate (ATP), biotin, riboflavin, hematin, thiamine, pyridoxine, vitamins K and B_{12}; or those involved in fatty acid oxidation, glycolysis, and the citric acid cycle; or those that make actin and myosin. These metabolic skills are quite extensively shared by living organisms - or, if you like, quite "inclusively" distributed because their know-how has been transmitted over the millennia on the genes.

As a second example, restricted to primates, consider what *Homo sapiens* holds in common with chimpanzees. Mary-Claire King and Allan Wilson find that the difference in the protein coding sequences of DNA for structural genes in chimpanzees and humans is quite small. "The average human protein is more than 99 percent identical in amino acid sequence to its chimpanzee homolog" (King and Wilson 1975). Jared Diamond gives the figure as 98.4 percent (1992). Differences between the two species lie largely in regulatory genes.[12] E. O. Wilson recognizes this:

> We are literally kin to other organisms. . . . About 99 percent of our genes are identical to the corresponding set in chimpanzees, so that the remaining 1 percent accounts for all the differences between us. . . . Furthermore, the greater distances by which we stand apart from the gorilla, the orangutan, and the remaining species of living apes and monkeys (and beyond them other kinds of animals) are only a matter of degree, measured in small steps as a gradually enlarging magnitude of base-pair differences in DNA. (1984, p. 130; Sibley and Ahlquist 1984)

That means that the vital structural information for making the advanced primate body has been widely shared for millions of years. Similar points could likewise be made with the basic vertebrate body plan, or hearts, livers, kidneys, and so on.

We use the word "share" both as a descriptive term and as a deliberate corrective to the more fashionable word "selfish," frequently applied to such genes. "The selfish gene" is vivid imagery (Dawkins 1989). But imagery needs philosophical analysis, especially

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[12] The similarity can be overemphasized. The regulatory genes, which govern behavior, among other things, are not included here. Many regulatory genes will also be similar in chimpanzees and humans, but many will not. Further, there is much more room for differences than the 99 percent identity in amino acid sequences recognizes. Only about 3 percent of the human genome codes for proteins; 97 percent does not, and this other DNA varies so widely between species, even between organisms of the same species, even between cells of the same organism, that it is difficult to interpret. This has been misinterpreted as "junk DNA," but geneticists increasingly see it as vital to life (Nowak 1994).

imagery that colors worldviews, even more if this seems to have scientific sanction. When scientists speak of ant wars, or queen bees and their slaves, or immunoglobulins as carrying on a battle within" us against invading microbes, they borrow words from one domain of experience and transfer them to another. A careful analyst needs to be cautious about overtones also transferred. A great deal depends on the metaphors one chooses, since these so dramatically color the way we see the natural world. One must be careful not to let negative moral words, borrowed from culture, discolor nature. Something like this happened before in Darwinism when "survival of the fittest" was the paradigm, interpreted as "nature red in tooth and claw" but biologists now prefer to restate this as "adapted fit," a better description, since fitness takes place in various ways, only one of which is combative or aggressive. "Adapted fit" colors events differently than "survival of the fittest."

In the chapter to follow, under the themes of genetic identity, we pursue this issue in detail; here we can begin to project this more comprehensive scientific and philosophical picture. The genesis of biodiversity and complexity, so striking in natural history, is possible only as information found out by these searching genes is widely distributed, carried on from one generation to the next in such a way that it cumulates; is tested in experience, discarded where it is found to be less fit; selected and conserved where it is found to be more fit. That has happened with cytochrome *c* molecules and with primate protein structures. Genes must find a method of distributing and elaborating, of proliferating what values they contain and conserve. That process makes possible the genesis of life, the accumulation of all those values inherent in biodiversity and complexity.

Along with the word "distribute," en route to the word "share," consider another, relatively neutral word: Genes "divide." They "divide" in order to "multiply." Life must be enclosed in cells; yet cell division is required for cell multiplication, for ongoing life. The cell division requires genetic division. "Dividers" are required to partition out their goods, and this multiplies such goods. Such division and distributing, replicating, recycling, together with adapted fitness, place each gene where it belongs, in a commons in which it participates. The gene is engaged in dispersing vital information, in transmitting its intrinsic values. Communicated information, transmitted when a gene reproduces, has in fact been *re-produced*, produced again. Genes, in their most fundamental character, are bits of valuable information, coding bytes, in a world where vital information, the secret of life, has to be dispersed if life is to continue. Genes are a flow phenomenon.

There is nothing pejorative about either biological conservation or, what is the same thing, biological division. The dividing, reproducing organism is not so much an irremediably selfish self, defending the whole organism that it alone constitutes, and defending slivers of a self in others; rather here are values, instantiated in the self and conserved by distributing them, by defending them wherever they are present as a result of the various cellular and genetic divisions, and thereby replicating and multiplying them. This results in the transgenerational contributing of genetic values, the only kind of values that the organism has.

When used in ethics, "share" has a positive moral tone, and our point in using it biologically here, additionally to describing what is going on, is to neutralize, to unbias, the negative moral tones left by "selfish." "Share" is difficult to interpret selfishly. When genetic information is passed on to a next generation, when that information overleaps death, it would seem as appropriate to say that it has been "shared" (distributed) as that it has been "selfishly" kept. *Genes are no more capable of "sharing" than of being "selfish"– it must at once be said – where "sharing" and "selfish" have their deliberated, moral meanings.* Since genes are not moral agents, they cannot be selfish, and, equally, they cannot be altruistic. But they can transmit information, and, if one is going to stretch a word sometimes employed in the moral world and make it serve in this amoral, though axiological realm, then "share" is as descriptive as "selfish" and without the pejorative overtones. Sometimes one has to lean into the wind to stand up straight. "Dividers" and "multipliers" too find it hard to be selfish. The survival of the fittest turns out to be the survival of the sharers.

We do need to choose our words carefully – "distribute," "disperse," "allocate," "proliferate," "divide," "multiply/' "transmit," "recycle," or "share" in "portions." We want a nonhumanistic, nonanthropocentric account, one unbiased by our morals, either for worse or for better. The distributive account is a much more descriptive paradigm, because there is no good reason to think that genes are selfish; there are no moral agents in wild nature even at the organismic level, much less the genetic one. But there is good reason to think that there are objective, nonanthropocentric values in nature, on which survival and flourishing depend, and that these are defended and distributed by wild creatures in their pursuit of life. Only humans are moral agents, but myriads of living things defend and reproduce their lives.

This is value vocabulary, but the point here is that in the genetic world *value*-based vocabulary is more accurate descriptively than is *morally*-derived vocabulary, for genes essentially are information, and information is of value. A gene is an information fragment, a puzzle piece in a picture of how to make a way through the world, and such a fragmentary piece can be of value to survival. That is not a selfish thing; that is a valuable thing. We are first describing what is the case when we model the phenomena so, and, after that we may also value such value, often prescribing that such value not only *is* present, but *ought* to be conserved in the world. What kindred organisms have is a set of shared values, more or less.

From this point of view one can worry that the "selfish gene" perspective is driving a humanly biased value-laden interpretation of nature, one that has become a kind of paradigm. The jaundiced view is not coming from nature, but from the lens through which the sociobiologist or behavioral ecologist promoting such views is looking. Looked at through the lens of biologically based values, the system contains intrinsic values (such as the somatic lives of individuals, defended for what they are in themselves, transmitted to others); it also contains instrumental values (such as one organism's depending on another, or parenting that contributes to the welfare of offspring, or food chains with organisms eating and being eaten). Every such value is networked interactively into ecological systems, of systemic value. Increasing complexity and diversity require both logically and empirically increasing specialization of parts and roles, which requires increasing coaction, cooperation, and interdependence of these evolving selves. The evolutionary and ecosystemic arrangements require for these values initially to be generated and then regenerated, and subsequently distributed and shared over many millennia. The means to this end is genes.

8. STORIED NATURAL HISTORY

Earth is the planet with genetic natural history, several billion years worth, and that genesis is stored in genes. There are no genes on the moon, nor Jupiter, nor Venus. Physics and chemistry are, scientists think, true all over the universe; so astronomers and cosmologists confidently spin their theories extrapolating across the vast reaches of space and backward and forward in time. Elsewhere in space, where conditions permit, one expects to find the mineral classes and rock types that have been discovered on Earth. One expects chemical reactions to conform to the atomic table. But biology is Earth-bound. Even if there is life elsewhere (as we may hope, but for which we have only modest evidence), we do not expect to find trilobites, or dinosaurs, or tigers, or Neanderthals. Physics, chemistry, mineralogy, geology are nomothetic sciences, but biological history is idiographic to Earth. We do not expect elsewhere these historically derived genes and their Earthly generated products. They are more particular than universal, more story than law.

Max Delbrück, trained first in physics and turning to biology, reflected:

> A mature physicist, acquainting himself for the first time with the problems of biology, is puzzled by the circumstance that there are no "absolute phenomena" in biology. Everything is time bound and space bound. The animal or plant or microorganism he is working with is but a link in an evolutionary chain of changing forms, none of which has any permanent validity. Even the molecular species and the chemical reactions which he encounters are the fashions of today to be replaced as evolution goes on. . . . Every biological phenomenon is essentially an historical one, one unique situation in the infinite total complex of life. (1966, pp. 9-10)

And yet, he continues, it is in just this historical character that the most impressive genesis occurs, this enormous complexity in life. He marvels at what seems almost "magic":

> how the same matter, which in physics and chemistry displays orderly and reproducible and relatively simple properties, arranges itself in the most astounding fashions as soon as it is drawn into the orbit of the living organism. The closer one looks at these performances of matter in living organisms the more impressive the show becomes. . . . Any living cell carries with it the experiences of a billion years of experimentation by its ancestors. (1966, pp. 10-11)

This Earth story is not simply coded in genes; and we shall, in due course, give ample space to cultural history with its novelties. Even the genes, as they spin a natural history that they also record, are placed in larger events of climate, geomorphology, or marine hydrology. The story takes place at multiple levels, of which the microscopic genes are only one, the level of smallest scale. There are, on smaller scales still, atoms, electrons, quarks, on which the story motifs are superimposed, but we do not know of any cybernetically transmitted, accumulating historical coding that is registered in structures and processes at these lower levels. There are, on larger scales, the native range events with which the phenotype must reckon, the blooming, buzzing confusion of life on land and in the sea.

Once upon a time on Earth, there was no biology, only geophysics and geochemistry, and these materials organized themselves into biological molecules, into organisms. So the creativity does not begin in biology; it is already latent in the precursor materials. We are dealing with self-organizing in nature (autopoiesis), a spontaneous nature that on Earth organizes selves, but whose processes transcend those selves to increase their diversity and complexity. In a world that coheres through connections, one must put into place the assertive individualism epitomized in the selfish gene theory, find the appropriate place for the gene in a world where what is of value is widely shared, distributed, reproduced.

The story becomes memorable – able to employ a memory – only with genes (or comparable predecessor molecules). That means that the story can become cumulative and transmissible, that is, historic. Acetylcholine molecules and their transmembrane receptor channels are distinctively Earth-bound and historically derived; they are not intrinsic to physics and chemistry, not universal laws that one can expect to find repeatedly expressed when we explore outer space. If there is life elsewhere, one can expect levels of coding and coping, mutating and mating, and perhaps there too the best adapted survive. Wherever there is life, it will have to be defended somehow. But no biologist will predict ribosomes and Golgi apparatus in the Andromeda galaxy. This memory is loaded into the Earthen genes; these are events peculiar to Earthen biological genesis.

The production and defense of natural kinds are what is ultimately involved in the alleged "selfishness" of these genes. The historical evolution and reenactment of individuals instantiating the diverse natural kinds cannot be evil. After all – anticipating a monotheist view of the matter (Chapter 6) – God created Earth as the home (the ecosystem) that could produce all those myriad kinds. "Let the earth bring forth living creatures according to their kinds" (Genesis 1.24). There is nothing ungodly about a world in which every living thing defends its intrinsic value, those brought forth from its own perspective, at the same time that it shares, or distributes, these to offspring, to others, in the ongoing evolutionary narrative. There might be something godly about a human kind that, made in the image of God, could oversee this panorama of natural history, find (again) that it is "very good," and rejoice in it.