Ever Since Darwin

ESD 1. Darwin's Delay

Charles Darwin was still a creationist when he returned to England after his five-year voyage on the *H.M.S. Beagle* in 1837. He quietly "converted" after learning more about the true nature of the Galapagos finches and other animals he encountered on his trip [a tale told in TFS 23], but chose not to go public with his belief until he had established a plausible, scientific mechanism. A year or so later, after reading about Thomas Malthus's famous essay on how animals can reproduce faster than the rate at which the food supply can be increased, he first developed his theory of species formation by natural selection. He clearly recognized the importance of his discovery; yet, he continued to avoid publication. In fact, he did not publish his theory for more than 20 years, and even then only because he was about to be "scooped" by Alfred Russell Wallace. Gould, like others, asks the question "Why the delay?" The usual answer given in biographies is that, since the concept of evolution was controversial, Darwin wanted to gather more supporting evidence before going public. But Gould notes that evolution, in and of itself, was not considered a major heresy at that time. Evolutionary ideas had been floating around for decades in various forms. (Darwin's grandfather, Erasmus, discussed the concept frequently with no ill effects to his career or position.) Intellectual and philosophical compromise certainly seemed possible. Yet, Gould writes, fear unquestionably played a role in Darwin's reluctance to go forward. Fear of what?

Referencing the work *Darwin on Man* by Gruber and Barrett, Gould argues that Darwin's true heresy was not that life might have evolved, but rather that the mechanism of natural selection fell into the category of "philosophical materialism." This is the view that matter is the only "stuff" that exists. Our existence was not planned or designed, but is simply the result of the machinations of an uncaring universe. Other evolutionists spoke in terms of vital forces driving species toward higher and more complex states; Darwin's theory had only statistical variation and chance advantage in local environments. His notebooks clearly show that he understood the materialistic implication of his theory, and that he further understood – unlike Wallace [TPT 4] – that it would have to apply to "the citadel itself," the human mind. Darwin was well aware of the persecution that those who advocated such ideas in England suffered. Gruber and Barrett write:

> In virtually every branch of knowledge, repressive methods were used: lectures were proscribed, publication was hampered, professorships were denied, fierce invective and ridicule appeared in the press. Scholars and scientists learned the lesson and responded to the pressures on them. The ones with unpopular ideas sometimes recanted, published anonymously, presented their ideas in weakened forms, or delayed publications for many years.

The materialistic role of natural selection was such heresy that he sidestepped its role on humans in *Origin of Species* (1859), and even when he confronted it in *The Decent of Man* (1871), did so as gently as possible. [This is consistent with apparent fact that Wallace felt no such fears about publishing the theory – he did not recognize the full implications, or denied them.]

[Throughout most of his writing career, Stephen Jay Gould worked to mitigate and resolve contention between science and religion. He argued that science and religion are non-overlapping Magisteria (areas of teaching authority; see LMC 14, and his 1999 book *Rocks of Ages*) that can and should peacefully coexist. But here, in this early essay, he states the usually-unspoken question: "[I]f the mind has no existence beyond the brain, can God be anything more than an illusion invented by an illusion?" In fact, he goes on to imply that he chose the title "This View of Life" for his monthly column as a tribute to

Darwin's materialistic views, while also acknowledging that Darwin himself was "a gentle revolutionary" who did not want to upset anyone.]

ESD 2. Darwin's Sea Change, or Five Years at the Captain's Table

Gould discusses how Darwin came to join the expedition of the *H.M.S. Beagle* in the 1830's. The common belief is that the expedition needed a naturalist, and that Darwin was selected for this role. In fact, the expedition already had a naturalist; that job belonged to the ship's surgeon, Robert McKormick, until he had a falling out with Captain FitzRoy a few months into the voyage.

The true reason Darwin was aboard the ship on its five-year journey was that FitzRoy needed a companion of his own social class. In the strict British naval tradition, the Captain was not allowed to socialize with any of the crew, not even the officers. There were some other non-military guests aboard, but none were of the right social class. So FitzRoy, who was well aware of his family history of mental illness [see BFB 1], felt the need to find someone of his own class and approximate age in order, he felt – perhaps correctly – to maintain his sanity. The *Beagle's* primary mission was to produce a survey of the waters off the coast of Patagonia and Tierra del Fuego in South America, not to study nature. However, in order to get someone of the right class to give up five years of his life to join him, he had to offer something in return. That "something" was a chance to study the local life and geology, even though the expedition already had a naturalist. Darwin met FitzRoy's needs, and was willing to accept the position. (Gould credits articles by Gruber and Burstyn as the source of the above material.)

The twist, Gould tells us, that Darwin and FitzRoy did not get along very well; for one thing, FitzRoy was a Tory, Darwin a Whig. Another was religion; FitzRoy was zealous, and pontificated at length that God's existence and benevolence can be inferred from the perfection of organic structure. According to the social etiquette of the era, Darwin was not permitted to object or to challenge his host in any way, so for five years he suffered dutifully at the dinner table. Gould speculates that it may have been this experience, perhaps even more than Galapagos finches or Adam Smith's writings on economics, which led Darwin to develop an evolutionary theory with its materialistic implications (see the previous essay). [Gould discusses FitzRoy again in ELP 18.]

ESD 3. Darwin's Dilemma: The Odyssey of Evolution

This is an essay about the definition of term "evolution," and why Darwin did not like it. (Darwin used the phrase "decent with modification" in *Origin of Species*.) The word itself is derived from the Latin *evolvere*, which literally means "to unroll." In Darwin's time, the term was used vernacularly in society to mean an orderly, predictable succession of events, and was still in use by some scientists to discuss the development of an embryo [see "preformationism" in ESD 25 and TFS 25]. It implies a defined path leading from the simple to the complex, or from the primitive to the advanced. In short, the term implies the concept of *progress*; and it was this perspective that Darwin explicitly rejected.

According to Darwin's concept of natural selection, organisms work only toward adaptation to their local environment. As he noted, the simplification of a parasitic organism from an earlier, free-living form is as much an example of evolution as an increase in a mammal's brain size. Darwin carefully avoided using terms such as higher and lower, or primitive and advanced, when discussing organisms.

The man who is most responsible for associating Darwin with the word "evolution" was Herbert Spencer [LSM 17]. Spencer wrote a popular book on the Darwin's theory in 1862, three years after *Origin of Species*, which used the term repeatedly. Spencer was also responsible for the famous phrase, "survival of the fittest." [Gould returns to the etymology and meaning of the word evolution in one of his last essays, IHL 18.]

ESD 4. Darwin's Untimely Burial

Gould begins by referencing an essay entitled "Darwin's Mistake" by Thomas Bethell that appeared in *Harper's Magazine* in 1976, shortly before he wrote this. Bethell's thesis is that the scientific community has quietly abandoned Darwin's theory of evolution, with its emphasis on natural selection as the primary underlying mechanism. He does not argue that natural selection does not exist, nor that it does not play the role of executor of "unfit" individuals; rather, he challenges the view that natural selection is also the main mechanism responsible for the *creation of new species*. [Bethell is not a creationist, and never suggests that the community is questioning the reality of large-scale evolution; only that they are questioning the mechanism driving it.] Gould, as a member of this community, says that this is simply not the case; there are a few members (some of whom he names) that have advocated this position, but they are a small minority. However, this essay is not a simple dismissal of Bethell's charges. Gould argues that he does raise some important, if not original, points that are worthy of discussion, in part for purposes of illumination. [Gould himself will later invoke his own criticisms of natural selection acting on individuals as the primary mechanism of macroevolution – see 2002's *The Structure of Evolutionary Theory* – but in this essay, he defends the Darwinist "party line."]

Importantly, Bethell does not claim that Darwin's mechanism of natural selection is in trouble because of recent discoveries or new scientific evidence, but instead because of an internal, logical flaw – and only recently discovered, he claims. The "flaw" is that Darwin's theory of "survival of the fittest" *equates* survival with being more fit. If this were true, then natural selection can be re-expressed as "survival of those who survive," which is a tautology. Tautologies are inherently true, and therefore not testable, and therefore not scientific. Gould begins by noting that this charge is not "recently discovered" [this was an outright mistake on Bethell's part], and in fact Darwin himself was very aware of it and structured *Origin of Species* to refute it. The first chapter of this book is about pigeons, and the concept of artificial selection. In breeding, favorable characteristics are identified by the breeder and "selected." Darwin argues *by analogy* that nature operates in the same way, but over vastly longer periods of time. It is the legitimacy of this analogy, and in general the approach of arguing from analogy, that Bethell takes issue with. Mindless nature weeding out the unfit is not the same, he argues, as conscious humans allowing individuals with certain desirable features to reproduce – and even if it were, more than a rhetorical claim of analogy would be required to prove it.

The underlying importance of natural selection in the Darwinist paradigm, Bethell notes (and Gould agrees), is that it is responsible for the *creation of new species*. Variation is present and very real in all offspring; in the Darwinist view, the process of "selecting the fittest" by mindless nature gradually but continuously shapes the descendents, over many generations, into different species. But if nature simply selects "those who survive," with no real criteria other than "not weak or sickly," then natural selection cannot be a *creative* force; some other mechanism is required to explain the formation of, say, a whale's tail fluke. Darwinism, he concludes, with its over-reliance on natural selection, is fundamentally flawed. Why were people so taken with Darwin's idea in the first place? Gould writes: "According to Bethell, Darwin's concept of natural selection as a creative force can be no more than an illusion encouraged by the social and political climate of his times. In the throes of Victorian optimism in imperial Britain, change seemed to be inherently progressive; why not equate survival in nature with increasing fitness in the nontautological sense of improved design."

Gould's arguments in defense of Darwinism, he tells us, are neither novel nor profound. He states his belief that Darwin's use of analogy in general is legitimate (although admittedly unattractive), and that the connection between artificial and natural selection is apt. That is: there are external variations that one can point to as "favorable," independent of conscious observation; extra hair on a proto-mammoth really is advantageous when the climate becomes colder. Survival and fitness are not, Darwin and Gould argue, the same thing, and therefore the relationship is not tautological. Further, other models of evolution that did *not* support "survival of the fittest" were very popular at one time, suggesting that this view is not as obvious as it might seem today. The American paleontologist Alpheus Hyatt, for example, advocated the paradigm of racial (that is, "species") life cycles. Species, he argued, like individuals, came into existence, aged, grew senile, and perished of something analogous to old age; Gould's point is that, in this mechanism, "unfit" individuals continued to reproduce for an extended period. Similarly, orthogenesis [ESD 9, HTHT 30] argued that certain evolutionary trends, once begun, continued to proceed past the point of utility into genuine detriment; the Irish elk, for example, was argued to have gone extinct because its antlers continued to increase in size over numerous generations until it could no longer feed or even hold its head up. Not only is "survival of the fittest" not tautological, Gould concludes, it is testable against other models – and it fares well. Therefore, at least in principle, natural selection can act as a creative force (acting on the natural and partially random variation that nature produces via a separate mechanism). Darwin's theory is not ready for burial.

Gould adds that the claim that Darwin's mechanism of natural selection was successful because it represented "progress" to a culture that was eager to see it everywhere is exactly backwards. It is no doubt true (Gould agrees) that much of Darwin's success in convincing the British establishment that evolution occurred was, indeed, due to the Victorian's infatuation with the notion of progress; the term itself implies it [ESD 3, IHL 18]. However, as Gould notes elsewhere [ESD 1], natural selection itself is not at all "progressive" in this sense – and in fact it was not generally accepted as the primary mechanism driving evolution (as Darwin envisioned) until the 1940's, precisely *because* it was materialistic rather than progressive. Darwin himself noted that parasites, usually simplified descendents of more complex free-living ancestors, are just as much a product of natural selection as wings or eyes (or whale flukes).

There is a second, equally important theme throughout this essay. Gould credits Bethell with recognizing that, *in practice*, much of the research in evolutionary theory does simply equate fitness with survival; computer models readily lend themselves to this technique. Gould laments that most of the practitioners do not question, nor even recognize, that this is what they are doing. The young, iconoclastic Gould writes, ". . . I deplore the unwillingness of scientists to explore seriously the logical structure of arguments. Much of what passes for evolutionary theory is as vacuous as Bethell claims. Many great theories are held together by chains of dubious metaphor and analogy. Bethell has correctly identified the hogwash surrounding evolutionary theory."

ESD 5. A Matter of Degree

One of the fundamental debates in western philosophy involves the question, "Is man part of nature, or, because of his mind and/or soul, apart from it?" Gould reduces the focus of this question to the relationship between Man and the great apes, specifically chimpanzees and gorillas. He offers three lines of reasoning to support his belief that the difference between humans and apes is a matter of degree, and not due to the existence of a unique feature or attribute.

He begins with a morphological comparison. He draws on a debate between two great 19th-century anatomists that played out in the press in 1861. In what became known as "the great hippocampus debate" [LMC 6], Richard Owen claimed that he had identified a structure in the brain of humans [the so-called hippocampus minor, a different structure than what we call the hippocampus today] that did not exist in any other animal, including apes. He then extended his argument and claimed that this structure, therefore, houses the features that make us uniquely human, different from all other animals. Thomas Henry Huxley then carefully dissected the brain of a gorilla, and proved that this ape also had the same structure. He won the day, and it was a significant public relations victory for evolution in the years just after the publication of *Origin of Species*. However, it does not unequivocally prove that no such feature exists. Gould then proceeds to quote some recent studies, all of which find no unique structures in humans; the morphological differences between these structures in humans and apes are *all* quantitative.

Another area where people have looked for Man's uniqueness is in the areas of behavior and cognition. Gould discusses the results from contemporary studies, where chimpanzees have been taught a certain amount of sign language. Based on limited "conversations," scientists have concluded that apes do have a sense of themselves. Studies of chimps in the wild also show clear evidence for tool use and advanced planning, behaviors that were once claimed to be unique to humans.

The third area of comparison that Gould explores is genetics. He discusses evidence that human and chimpanzee genomes are more similar than many other so-called sibling species. He recognizes the large physical and behavioral differences between the groups, but argues that this is most likely caused by changes in the regulation of genes, rather than the genes themselves. [He expands on this in ESD 7].

[Gould rests his case here, but it does not end the debate on the relationship of Man with Nature. For example, the Catholic Church had formally stated that evolution is true, but that at some point God injected Man with a soul [LMC 14]. Nonetheless, essentially all professionals now agree that humans are physiologically a species of ape. In fact, the genetic relationship between humans and chimpanzees has since been recognized as even closer than previously thought; chimpanzees are more similar to humans than they are gorillas (DIH 30).]

ESD 6. Bushes and Ladders in Human Evolution

If Gould had to reduce his arsenal of metaphors to a mere four [see DIH 34], one of them would be that the history of life is a bush, not a ladder. The ladder metaphor of evolution is that lines of descent change gradually but continuously over time. Species, in this view, are not "real"; they are analogous to still frames in a movie. Prior to the time that Gould wrote this essay in 1976, he tells us, the "ladder" of human evolution was *Australopithecus africanus* – *Homo habilis* – *Homo erectus* – *Homo sapiens*, with the named species simply representing four moments in time. That is, *A. africanus* and *H. erectus* did not go extinct; rather, their entire populations slowly "morphed" into the next rungs of the ladder. Gould rejects this metaphor; he strongly prefers what he refers to as the "bush" model. In this paradigm, speciation – the formation of new species – occurs by branching off from the ancestral stock, while the ancestors continue on. The details of the process are fuzzy, but proponents argue that it almost always occurs in small, isolated populations (where mutations can spread rapidly through the entire group) in marginal environments (thus increasing the selective pressures). Most such marginal, rapidly evolving groups die off quickly, but those that survive may return to co-inhabit the original range, sometimes replacing the ancestral population. These speciation events occur with a certain regularity, and the resulting diagrams resemble a branch with many offshoots, some of which themselves produce further offshoots: in short, a bush. In this perspective, *A. africanus* and *H. erectus* are, for most of their existence, stable species; and, they eventually become extinct. [Gould does not say so here, but this is an example of punctuated equilibrium; see TPT 17.]

What data does one look for in the fossil record, if one wants to determine whether the ladder or bush metaphor is superior? The branching events of the bush paradigm, being geologically sudden and occurring in small populations, are unlikely to be preserved.

However, the presence of several different species overlapping in time would favor the bush metaphor, while the existence of a single species at each moment would be consistent with the ladder model. [This argument applies to all life; see BFB 11 for its application to horses.] However, Gould was motivated to write this particular essay by the recent discovery (in 1975) of fossil hominid teeth and jaw fragments by the great anthropologist Mary Leakey. To set the stage, he presents a brief summary of some of the most important fossil finds of human ancestors.

Other than Neanderthal fossils, which were discovered and first recognized as non-modern in the 1850's, the first legitimate find of an ancestral hominid was "Java Man" (now classified as *Homo erectus*) in 1891. Another member of this species, "Peking Man," was discovered and described in the early 1920's. Due to their relatively large brain size and upright posture, these were (and still are) classified as members of our own genus, *Homo*, and first appeared around 1.8 million years ago. The next legitimate discovery was the much older *Australopithecus africanus*, first discovered in the 1920's. [For decades, however, this fossil was not considered legitimate, because it differed so significantly from Piltdown Man, described in 1912. It later turned out that Piltdown Man was a fraud; see TPT 10.] *A. africanus* was believed to be older than *H. erectus*, dated at the time as living around 2.0 million years ago. With *A. africanus* recognized, the consensus for the ladder of human evolution ran *A. africanus – H. erectus – H. sapiens*; a ladder. A small issue appeared in the 1930's, with the discovery of another distinct species of *Australopithicus*, named *A. robustus*, which appeared to overlap with *A. africanus*. For the first time, the community had to recognize the apparent existence of a side-branch; but it was not a grave concern, since it was clear that *A. robustus* was not ancestral to modern humans.

The issue became more complex in 1964, when the brilliant and colorful Louis Leakey announced the discovery of a more ancient member of the *Homo* genus, *H. habilis*. Leakey claimed that this new species overlapped in time with *A. africanus*, which would imply that the latter was not ancestral to humans after all – and also presenting a problem for the ladder paradigm. Some argued that Leakey's finds were not really a new species; others argued that it was, but could be squeezed in between *A. africanus* and *H. erectus* in the ladder model. Then, in 1973, Richard Leakey (son of Louis and Mary) made "the discovery of the decade" in Gould's words: he found a partially complete *H. habilis* skull. The importance of this discovery was three-fold. First, it proved that *H. habilis* was real, and that it was clearly different from *H. erectus*. Second, it had a brain that was twice the size of any *A. africanus*. And third, its age was dated between 2 and 3 million years, older than virtually all *Australopithecus* fossils; it clearly coexisted with *A. africanus*, with implications for the latter's role in human evolution, and for the ladder paradigm in general. [Intriguingly, Gould writes: "One can still argue that *Homo* is evolved from an older, as yet undiscovered *Australopithecus*. But no evidence supports such a claim . . . ." In fact, the famous discovery of just such a creature – *A. afarensis*, the famous "Lucy," would be announced just a few years later. See TPT 11.]

What motivated Gould to write this essay was the announcement by Mary Leakey in 1975 of the discovery of even older *H. habilis* fragments, dated between 3.35 and 3.75

million years via bracketing layers of volcanic ash. This, he argues, makes *H. habilis* as ancient as *A. africanus*. Such evidence, he concludes, clearly if not unambiguously, supports the bush model of evolution over the ladder model.

[In 1979, Donald Johanson and Tim White – the discovers of "Lucy" – argued that Mary Leakey's fossils actually belong to *A. afarensis* (that is, the same species as Lucy) and not *H. habilis*. Gould discusses this in TPT 11. This is the nature of the business, he states; but while it delays the origin of *H. habilis*, it does not change any of the bush-versus-ladder arguments presented in this essay. Further, he adds, since the Afar specimens are dated between 2.9 and 3.3 million years, Leakey's fossils are definitely older. Since (as Johanson and White argue) there is virtually no difference in form between the two sets of fossils, this supports the view that the species remained essentially unchanged for hundreds of thousands of years. This is consistent with the other aspect of punctuated equilibrium, "stasis." Gould returns to the bush versus ladder argument in human evolution some 20 years later, with updated data, in LMC 10.]

ESD 7. The Child as Man's Real Father

"Recapitulation" was perhaps the most dominant concept in evolutionary thinking during the late 19th and early 20th centuries [see ESD 27 & 28, TPT 15 & 24, IHL 8, and Gould's technical book from 1977, *Ontogeny and Phylogeny*], prior to the rediscovery of Mendel's genetics. Its catchphrase, "ontogeny recapitulates phylogeny," means that the development of an individual organism from egg to adult – ontogeny – follows the evolutionary history of that organism – phylogeny – from eons ago to today. Recapitulationism was used to explain observations such as the formation of gill slits in all vertebrate embryos, including humans, illustrating their connection with their aquatic ancestors. Today recapitulationism is recognized as fundamentally flawed, but Gould's book argues that many of the supporting observations are both valid and intriguing.

Partially to challenge this model in the 1920's, Dutch anatomist Louis Bolk used his own detailed observations of human development to produce what he referred to as "fetalization theory." In the recapitulationist view, new evolutionary features are added to the end of the parent stock's development. To maintain a reasonable developmental timeframe, this requires that the recapitulation process must take place faster and faster as the eons go by. Bolk's fetalization theory, referred to today as neoteny (literally "holding youth,") argues just the opposite: that humans in particular have evolved by slowing down the rate of fetal and juvenile development relative to other primates.

Bolk's observations on the similarities of human and ape fetuses and juveniles, which diverged as they grew toward adulthood, were both accurate and astute. The cranium of a newborn chimpanzee and human are very similar, but the chimp's grows little after birth while the human's continues at the rapid fetal growth rate. (A rhesus monkey's brain is 65% of its final size at birth, a chimp's is 41%, while a human's is only 23%.) Similarly, the human face retains its baby-like flatness as it grows, while apes produce a pronounced muzzle. Both species have feet with straight toes in utero; but the chimp's toe rotates inward for opposable grasping, while the human's toe stays straight – better for walking upright. The list goes on; Bolk noted some twenty features.

However, Bolk lost credibility when he proposed that the mechanism behind human neoteny was hormonal in nature. The fundamental problem with this view is that not all features are retarded by the same amount, and some – such as the length of our leg bones – are not slowed at all. The idea that a single hormonal change might lead humans to grow more apelike might make a good story (Gould discusses one by Aldous Huxley), but not a convincing scientific argument. Bolk's work, never widely popular, was largely forgotten in the 1930's. However, as Gould notes, primates do live longer than most mammals, and humans longer than most primates; humans spend a greater fraction of their lifetimes as infants and as children; human bones ossify much later; and more. He states his conviction that Bolk's observations, if not his proposed mechanism, do touch on an essential theme in human evolution. He adds that neoteny in general offers a rich source of modifications in descendent species with minimal genetic change. Finally, he closes with some speculation as to the selective advantages of such a process, involving the ability to grow larger brains [next essay] and increased social bonding due to lengthened child rearing.

[Part of Gould's early rise to popular fame can be attributed to the fact that his first book aimed at professional colleagues mentioned above, *Ontogeny and Phylogeny*, was published at about the same time as this collection of essays aimed at a more general audience, *Ever Since Darwin*. This duality was noted in some important reviews at the time.]

ESD 8. Human Babies as Embryos

This essay makes connections between four observations to argue the validity of the title, and goes on to imply that much of Man's behavioral uniqueness may be a result of it. Following the work of the Swiss zoologist Adolf Portmann, Gould explains the difference between altricial and precocial mammals. Altricial mammals have brief gestations and give birth to large litters of relatively poorly developed young; precocial mammals have longer gestations and give birth to smaller numbers of well-developed offspring. Precocial mammals tend to have larger brains, longer life spans, and more complex social behavior.

Gould's first observation, following Portmann, is that primates collectively are highly precocial mammals. His second is that the obvious exception is Man, whose infants are born as helpless as any altricial mammal. Yet we are the most precocial primate species in many ways: in brain size, in the duration of childhood, in the delay of bone ossification, and of longevity. Gould suggests the resolution to this apparent contradiction with a third observation: humans are actually born six to twelve months premature with respect to the development of other primates, based on several referenced studies. (Birth is not an arbitrary demarcation point, he notes; several major transitions in development occur around this time.) Human brains continue to develop at the rapid fetal rate for several months after birth. Most mammal brains are nearly fully formed at birth, while human brains are only one-fourth of their final size.

Gould's fourth observation is really a speculation on why human babies are born "early." One obvious consideration, he notes, is that human heads at birth are about as big as they can be and still pass through the mother's birth canal. He dismisses Portmann's "spiritual" view that early birth is a requirement for our mental development, stating that evolution does not work this way.

ESD 9. The Misnamed, Mistreated, and Misunderstood Irish Elk

The extinct Irish Elk was a huge beast, and possessed the largest antlers of any animal in history; a pair could be up to twelve feet across. Its range was not confined to Ireland, and was actually a deer and not an elk, thus explaining part of the essay's title. This unusual animal was at the center of several debates about the history of life on earth.

Many well-preserved antlers and several complete skeletons of the Irish Elk had been found in Ireland over the centuries, but no living representatives had ever been seen. By the late 1600's, this led directly to the question of whether the Irish Elk was extinct – and, more fundamentally, whether extinction could occur in nature. Up until this time, it was generally assumed that extinction could not occur, both on empirical grounds, and because it would appear to subvert the goodness and perfection of God's creation. Clearly, the Irish Elk no longer lived in Ireland, but many believed that it could (or even "must") live on elsewhere in the world. But as exploration continued, recognition of its continued absence became unavoidable. This problem was compounded by discoveries of more fossils that could not be attributed to any living species. Finally, the great paleontologist George Cuvier showed the anatomy of the Irish Elk was fundamentally different than animals in existence in 1812, such as the North American moose, and thus effectively established that extinctions do, in fact, occur [see HTHT 7]. Other questions remained. Was there just one period of extinction, which might be attributable to Noah's flood? Or did God create and destroy life multiple times? If the latter were the case, might the earth be older than the 6000 years assumed by the Church? Had the deer lived into historical times, to be wiped out by Celtic hunters? Perhaps the Romans had played a part, as they collected all sorts of beasts for their public games. (Richard Owen, the British naturalist, concluded in 1846 that it had vanished before the arrival of humans.) The Irish Elk played a role in all of these debates, and was involved in another after Darwin published *Origin of Species* in 1859.

Within ten years of its publication, Darwin's book convinced most readers that evolution did occur. However, as is discussed in other essays [e.g., ESD 4], few were convinced that natural selection was the primary mechanism behind it. Opponents used the Irish Elk's antlers as a primary argument against natural selection as a creative mechanism in evolution. It seemed highly improbable, they argued, that these huge, unwieldy structures could offer the deer any sort of selective advantage. Surely the antlers would get caught in brush and trees, and perhaps even prohibit the animal from turning its head for fear of breaking its own neck! Some other mechanism must be responsible, it was argued, and one of the most popular was *orthogenesis*. This mechanism proposed that evolution developed trends that, once begun, acquired an inertia of sorts. The continual increase in size of the antlers, generation after generation, would continue until the animal could no longer function. The large canines of saber-tooth tigers and the seemingly counterproductive coiling of certain oyster shells [HTHT 30; also see ELP 25] were other examples used in support of this argument.

The counterargument made by proponents of Darwin's views on natural selection was that the size of the antlers was firmly tied to the overall size of the animal. Importantly, they claimed, the antlers' size increased at a rate that was greater than the rate of the rest of the deer. Julian Huxley, one of the leaders of this movement, coined the term "allometry" to describe this phenomenon, and it has been presented as the solution to the puzzle in textbooks ever since. [This is a so-called nonadaptive explanation for the antler's size, but argues that this feature is perpetually locked to another feature – in this case, the Elk's overall size – that presumably is adaptive, or selected for. Gould argues that Darwin himself supported such arguments, but other so-called "strict Darwinists" often did so only rarely; see TPT 4.]

Gould came to realize, however, that textbooks copy extensively from one another [see BFB 10], so any errors that creep in may be perpetuated for decades. He discovered that the claim of allometry for the Irish Elk had no published data whatsoever to support it. Therefore, he decided to collect some himself! He measured the size of the antlers and the length of the corresponding skull for about 80 specimens in various collections, and found that the allometric correlation was quite good. He calculated a slope of about 2.5, meaning that the antlers did indeed increase about two and a half times faster than the rest of the deer. (The fact that most of the points lie on or near this line, and not the slope of the line, is the evidence in support of an allometric connection between these two features.)

In spite of this apparent success, Gould remained dissatisfied. Can we really know that the giant antlers offer no selective advantage?, he asks rhetorically. Darwin himself, in *Descent of Man* (1871), speculated that larger antlers might serve a role in sexual selection ("selected" as attractive by the female), rather than as better armament against predators or rivals. Another possibility, Gould suggests, is that they were used against rivals in "ritual combat" rather than literal combat; in ritual combat, males simply compare antler size to decide the winner. He presents some supporting work on modern animals. [However, in LMC 9, he references the work of Tim Clutton-Brock and Andrew Kitchener, which he says convinced him that the Irish Elks did use their antlers for actual combat.] In either case, we cannot dismiss the possibility that the antlers drove the size of the deer, rather than vice versa.

He concludes by posing the question: "If the antlers were not life-threatening to the host in and of themselves, then why did the Irish Elk become extinct?" We do not know, Gould answers. It may have been as simple as climate change; the beast appears to have disappeared from Ireland about the time when the last interstadial (period between glaciations) ended. A feature that is well adapted to one climate may not be helpful in another. [Gould writes about the appearance of Irish Elks in Paleolithic cave paintings in LMC 9. He next discusses *The Descent of Man* and sexual selection in TFS 2.]

ESD 10. Organic Wisdom, or Why Should a Fly Eat Its Mother from Inside

Darwin's theory of evolution states that the most fit individuals will survive and reproduce, passing their genes on to the next generation. With this concept in mind, Gould asks us to consider the cecidomyian gall midge. Under some circumstances, this fly develops through the standard egg-larva-pupa-adult sequence. But under other circumstances, the female larvae do not mature, but instead produce offspring without sex, in a process called parthenogenesis. This technique is not uncommon in nature; in such cases, all of the offspring are female, and all are genetic clones of their mother. What is virtually unique about this species is that, when reproducing via parthenogenesis, the immature parent does not lay eggs; instead, the young hatch within her body, and proceed to eat her alive from the inside out. When the offspring burst out of their mother's empty cuticle, the following generation has already hatched within them and is repeating the process. How can such strange, self-destructive biological behavior be consistent with the theory of natural selection, which supposedly *favors* individuals with selective advantages?

The key to understanding this insect, Gould rhetorically replies, is to understand the nature of its food source: mushrooms. The midge is small and the mushroom is large but very short-lived. When an adult fly arrives, there is a superabundance of food, but for a few days at most. [Gould refers to organisms that live this way as "colonizers" in HTHT 4.] It is during this brief time of plenty that the insect reproduces via parthenogenesis. Once the food supply is gone, the larvae mature in the conventional fashion; they become winged adults and fly away to look for other mushrooms. However, the mushrooms themselves are rare, thus exposing the midge to a brutal boom and bust environment. Many flies must be created in order for a few of them to find the next mushroom. Natural selection nominally works on individuals to hone a species to a state that well adapted to its environment. But when the environment is ephemeral – sometimes abundant, but often absent – there is no single environment to adapt to. Still, it might seem that natural selection would lead the adult midge, when it first discovers a mushroom, to simply lay more eggs. In many species, this is what happens; why the self-destructive behavior here? Gould tells us that this example puzzled scientists for many years.

One way in which this example can be reconciled with Darwin's theory of selecting individuals and not species comes via a field of study called theoretical population ecology. Studies from this field show that organisms can adapt not only their size and form, but also their rates of development and the resources they put into different stages of their lives. (One of the founders of this field, Gould informs us, is E. O. Wilson. Gould concurs with this work, but disagrees with him on other issues, notably in the field of sociobiology, which Wilson also partially founded – see ESD 32 & 33.) If the odds of the midge population surviving are a function of how many flies can be created in a given amount of time, and if natural selection can affect this aspect of its reproductive strategy, then this "adaptation" begins to make sense. It is not whether the individual "survives" that is important, it is whether it reproduces, and whether the offspring will themselves reproduce. As Malthus pointed out, populations can grow exponentially. There are several factors involved, but two are the number of offspring in a generation and the time required between generations. The parthenogenesis approach employed here reduces the time between generations (to a minimum!). This, in turn, allows the population to increase more quickly, if enough generations are allowed, than simply producing more eggs. Aphids have adopted similar, albeit less extreme, versions of this reproductive strategy.

[On the one hand, population ecology shows that the cecidomyian gall midge's life cycle can – at least in principle – be satisfactorily explained by natural selection. On the other hand, it raises the question of natural selection acting on a group or population, rather than on individuals in this case; this is another area of controversy in evolutionary theory, and in Gould's career. This subject is raised explicitly in the next essay.]

ESD 11. Of Bamboos, Cicadas, and the Economy of Adam Smith

Bamboo, like all grasses, continually spreads by producing underground "runners" from which new stalks can grow. It also reproduces sexually, with flowers and seeds, but only on rare occasions. One species does so only once every 120 years. Interestingly, all plants in this species bloom in exactly the same year, even those that have been transplanted to other continents. When this event occurs, the ground around them may be completely blanketed in seeds. Another organism, the cicada, is famous for living underground in larval form for 17 years, then bursting from the soil and molting into and adult for sexual mating, before dying. Again, the timing is both precise and highly correlated; most emerge in the same year, and most of those in the same few weeks. During this time, cicadas are everywhere.

Evolutionary theory must explain how natural selection can produce such behavior. One popular mechanism (unproven, Gould notes, but consistent with observations) is called "predator satiation." Since both bamboo seeds and cicadas are considered to be highly desirable food sources by many animals, producing all offspring at once could be an effective tactic; there would just be too many to eat them all. To prevent the predators from modifying their own life cycles to capitalize on this burst of resources, the prey might develop the ability to go long periods without producing any serviceable food at all.

However, there appears to be a theoretical problem. Darwin's theory, Gould reminds us, states that natural selection works on individuals; those that vary in advantageous ways get to produce more offspring. In both of these cases, it appears that entire groups are working together (by coordinating their reproductive efforts) for the common good of the group or species, not the individual. How can we resolve this apparent paradox? The predator satiation model, it can be shown mathematically, is consistent with Darwin's theory. Once the behavior is initiated, any individual bamboo seed or cicada produced at the wrong time would stand a far greater chance of being eaten, and thus de-selected. As Darwin knew, this is exactly analogous to Adam Smith's theory of the "unseen hand" in economics: that seemingly organized large-scale behavior can appear when each individual member is only acting in his own self-interest. [Gould returns to Adam Smith's influence on Darwin in ELP 9, and to the individual-versus-group-selection puzzle (on which his position evolves considerably) in DIH 26.]

ESD 12. The Problem of Perfection, or How Can a Clam Mount a Fish on Its Rear End?

The freshwater mussel *Lampsilis* has an extension of its inner soft tissue that strongly resembles a small fish. The clam can undulate it in such a way that it appears to swim. This undulating lure attracts real fish. The mussel then squirts its larvae at these fish, some of which attach to their gills; the larvae must reside there for a certain period in order to mature. The lure is a wonderful adaptation, but it raises another thorny problem for Darwin's theory of evolution: How could such a feature evolve via natural selection, when something that looks only a little bit like a fish would presumably have no utility? Would not the lure have to be formed all at once, thus violating the principle of gradual adaptation? There are many similar examples in nature, two of the most famous being wings and eyes.

Gould discusses a possible solution to his problem, called "preadaptation." The concept is that a structure originally developed for one purpose may then act as raw material for another. The term "adaptation," he argues, should be limited to situations in which the organism benefits immediately and directly via natural selection from the variation. [He dislikes this term "preadaptation," and describes his efforts to coin a different one, *exaptation*, in BFB 9. His later essays do not use this term, but seem to use "cooptation" instead.] Gould references a paper that suggests that the initial function of the undulating non-fishlike protrusion may be to aerate newly released larvae, or help to keep them suspended. In support of this scenario, he identifies another species of *Lampsilis* that has a ribbon-like, rather than a fish-like, mantle extension. It also undulates, and also seems to attract fish; however, the mussel apparently ignores them. In this case, the protrusion clearly has a selective function, but it is not the attraction of fish. One can see how such a structure, once formed for one purpose, could be adapted to another. In a later essay [TPT 3], he writes about an anglerfish that has developed a very similar "adaptation."

[This is the first reference in these essays to one of Gould's most important, original, and controversial ideas, presented in the 1979 technical paper with Richard Lewontin, entitled *The Spandrals of San Marco and the Panglossian Paradigm* (available online). The thrust of this paper is that many new and important structures in living organisms had their origins as quasi-random side effects of other structures, and were not formed directly in response to stimulation to the local environment. This differs strongly from the so-called adaptationist argument, which argues that each individual structure serves, or at some point in the past served, a function, honed by natural selection. The crux of this debate is whether natural selection is the only (or at least dominant) force that drives evolution, or if there are others. His next discussions on this topic take place in TPT 4 and HTHT 10.]

ESD 13. The Pentagon of Life

As far back as Linnaeus in the mid-18th century, life on earth had been organized into two kingdoms: Plantae and Animalia. This taxonomic structure presents problems when dealing with single-celled organisms, however. For example, there are many mobile unicellular organisms that photosynthesize; plant or animal? Most do not appear to fit easily into either category. A revised taxonomy, developed in the late 1960's and 1970's by R. A. Whittaker and Lynn Margulis, replaced the two kingdoms with five. Two of these new kingdoms belong exclusively to single-celled organisms. The first kingdom is the Monera, or prokaryotes, which include bacteria and blue-green algae. Prokaryotes are small, even by unicellular standards; as their name implies, they do not have a nucleus or any other organelles such as mitochondria or chloroplasts. The second unicellular kingdom is the Protista, or eukaryotes, which are much larger and do have organelles, including a well-defined nucleus that contains most of the organism's DNA. At the multicellular level, plants and animals remain – but fungi are broken out from plants and given their own kingdom. All plants photosynthesize; no fungi do. Instead, they secrete enzymes that externally digest their food sources, and then absorb the nutrients. There are many other important differences as well. For example, some fungi form large clumps of protoplasm that contain many nuclei, but which are not divided up into cells; no plants do this.

Gould emphasizes that this change in taxonomic structure does matter; a good taxonomy can aid in the understanding life, while a bad one can impede it. The older structure implied that the major division of life on earth is between plants and animals. The revised taxonomy illustrates that the two major divisions of life are between prokaryotes and eukaryotes, and between eukaryotes and multicellular life. In other words, the differences between plants, animals, and fungi are less important than these more fundamental divisions. Not only does the new taxonomy reflect basic differences in structure, he tells us, it also reflects the most important events in the history of life on earth. Evidence for prokaryotic cells goes back to the oldest known rocks, which formed between three and four billion years ago. For most of earth's history, prokaryotes were the only form of life on the planet. Gould states that current evidence (as of the mid-1970's) indicates that the first eukaryotes may have appeared around 1 billion years ago, most likely as colonies of prokaryotes. Not only are eukaryotes much larger than prokaryotes, some of them can reproduce sexually by exchanging DNA. This allows for a drastic increase in genetic diversity, which in turn leads to a much more rapid pace of evolution. The earliest evidence of multicellular life, which is composed entirely of eukaryotic cells, also appears around one billion years ago. (Some of these estimates have changed since this essay was written, although debate remains.)

Gould adds a fascinating point about the origins of multicellularity. According to Whittaker, what we call "plants" evolved four separate times from eukaryotic ancestors, fungi five times, and animals three times (the so-called “peculiar metazoans,” sponges, and everything else, including us). But despite the fact that at each of these transitions the complexity of the new forms increased, he cautions, these results should not be interpreted as evidence for progress toward complexity in general in the history of life. [This is one of the principle themes of Gould’s 1996 book *Full House*.] Modern prokaryotes do not appear to be any more complex than those of three billion years ago. It also appears that, after the initial bursts, the resulting eukaryotic and multicellular forms have remained remarkably stable; see his essays on the Cambrian Explosion, beginning with the next two essays.

[Since Gould wrote this essay, the taxonomic picture has been revised again. New genetic evidence, based on the work of Woese and Fox [see TPT 21], showed that the prokaryotic kingdom of Monera itself seems to be two separate groups: the Bacteria and the Archaea. A revised taxonomic structure creates a level above kingdom, called *domain*, with the Bacteria, Archaea, and Eukarya as the three domains. Within the domain Eukarya would be the familiar kingdoms of Protista, Animalia, Plantae, and Fungi. While this change would add another chapter to the story of life as Gould described it here, the underlying point remains: taxonomies are highly relevant to a proper understanding of nature.]

ESD 14. An Unsung Single-Celled Hero

About 530 million years ago, near the beginning of the Cambrian period, all or nearly all modern phyla of multicellular animal life came into existence. None arose before and, with a few possible exceptions, none arose afterwards. This unique period, some five or ten million years in duration, is known as the Cambrian explosion. One of the major problems that evolutionary biology must explain is the relative abruptness with which this event occurred. It must also, at the same time, explain why this event did not occur at any prior time during the 3 billion or so years in which life existed. Darwin considered it a major problem in *Origin of Species*, and many creationist-scientists (not an oxymoron at the time) interpreted it as the period in which God first populated the world.

Dozens of explanations for the Cambrian explosion have been proposed over the years, and Gould organizes these into three categories. The first group argues that the explosion is not real, but only appears that way due to an incomplete fossil record. Darwin himself was in this group. This view argues that the formation of modern phyla occurred gradually, over a much longer period. However, as more high-quality data was obtained over the decades, this position ceased to be viable [see DIH 8 and 9]. The second group of explanations involves changes in the external, physical environment at that time. One of the most popular themes involved a postulated increase in atmospheric oxygen; other possibilities, mentioned in the next essay, include changes in ocean chemistry and temperature. Gould does not dismiss these arguments, although he notes that there is no clear-cut evidence that such changes actually occurred at this time. Instead, he criticizes the view that once a physical barrier is removed that biology inevitably and immediately follows. Removal of a physical barrier or limitation might be necessary for the Cambrian explosion, he argues, but it is not sufficient.

The third category of possible explanations involves changes within the living world itself. Gould references a 1973 paper by S. M. Stanley on the “cropping principle,” which he finds attractive. Stanley approaches the problem mathematically, from the perspective of a sub-field called theoretical ecology, rather than empirically from fossil evidence. In the absence of predators, he states, the environment tends to be dominated by a small number of species. This has been observed in nature, and seems to be consistent with the multi-billion-year period in which prokaryotes were the sole kingdom of life. If a predator were to be introduced into such an ecosystem that feeds on the most abundant organism, mathematical models (and some limited data) suggest that the result is a decrease in the population of that organism, but an increase in overall diversity. The creation of a single-celled eukaryotic predator, or “cropper,” of prokaryotic bacteria and blue-green algae could (he argues) be the trigger for the Cambrian explosion. Stanley acknowledges there is no direct evidence for this model, but that it is simple and consistent with known events. Gould makes the point that science often progresses by bringing new perspectives and approaches to thorny problems. He continues this discussion in the next essay.

ESD 15. Is the Cambrian Explosion a Sigmoid Fraud?

As discussed in the previous essay, the Cambrian explosion poses several important challenges to “gradual and continuous” aspects of Darwin’s theory of evolution. In the centuries since the geologically abrupt transition in the fossil record was discovered, scientists have struggled without success to explain both its suddenness and its timing. In this essay, Gould argues that contemporary work (in the 1970’s) may have reformulated the problem, if not truly solved it.

He begins by crediting scientists in the Soviet Union for their recent and meticulous analysis of the appearance and disappearance of fossils in very fine Cambrian strata. This data shows that creatures appeared in the fossil record in a staggered fashion, rather than all at once. He then references the work of his colleague, J. J. Sepkoski, who has plotted the diversity of early Cambrian fauna against time. What he has found, we are told, is a classic sigmoidal (S-shaped) pattern of growth. This profile is commonly associated with the growth of a single species, such as a bacterium in a culture dish, under “open” conditions. (Open or unconstrained conditions are those in which there are plenty of nutrients, no toxins, and no biological competitors for the resources.) In such conditions, the population will grow exponentially at first, then level off as all space is occupied, and as the accumulating waste products begin to have an effect on the environment. Gould argues by analogy that the same pattern should appear, over a longer period, in species diversification rather than population growth – if the stage were set in terms of nutrients and an early absence of competition. If this were the case, then the mystery of the Cambrian explosion would be shifted away from something unusual about that particular time (e.g., ocean chemistry, atmospheric oxygen), and instead toward a triggering event in the late Precambrian. This event might have been the evolution of a predatory eukaryotic “cropper” (see the previous essay), or perhaps the development of an early multi-cellular organism with entirely new feeding and reproductive strategies.

While noting that such an evolutionary event could produce and thus "explain" the Cambrian explosion, he acknowledges that the reason for the event at this particular time remains a mystery.

He closes by describing some of his own work, with several colleagues, in this field. Using the Soviet data and other relevant sources, he spent a year creating "spindle diagrams" of Cambrian fauna. A spindle diagram is a timeline of variable width: narrow where each family or other group contains only a few species, and wide where the diversity is larger. Most spindle diagrams are symmetric along their time axis. That is, the time of maximum group diversity is roughly in the midpoint of the time between first and last appearance in the fossil record. Computer modeling suggests that spindles that form in an open environments are not symmetric; rather, the maximum width (diversity) is closer to the beginning than the end of the family's existence. Gould's work indicates that the spindle diagrams of groups early in the Cambrian period are asymmetric in just this way, while those that appear later are more symmetric. This, he offers, is more circumstantial evidence for a sigmoidal growth period at this time.

[This essay, and the ones that immediately precede and follow, are more speculative than most of Gould's writings. He will later conclude that he had grossly underappreciated the significance of the Cambrian explosion, primarily as a result the reinterpretation of the Burgess Shale fossils by Harry Whittington in the 1970's and 80's. This is discussed in ELP 15, and is the subject of his best-selling 1989 book, *Wonderful Life*.]

ESD 16. The Great Dying

The mass extinction that occurred at the end of the Permian period, about 251 million years ago, is the largest such event in earth's history; the extinction of the dinosaurs and many other orders at the end of the Cretaceous period is a distant second. The reason for the Permian extinction has been a mystery since it was discovered in the fossil record, and dozens of explanations have been proposed. In this essay, Gould argues that the mystery may have been solved, but in a way that has been so subtle that even the professionals have not noticed. The possible answer, he argues, is the great shortage of shallow seas that occurred during this time. ("Shallow" seas are those in which enough sunlight to support photosynthesis reaches the ocean floor. The vast majority of ocean life exists in such areas.)

A key piece of this possible mechanism is the recent acceptance of continental drift, a theory that had been around for decades but seemed implausible until plate tectonics were discovered (see ESD 20). Once it became clear that continents moved, the evidence quickly showed that, at one time, all of the large landmasses had coalesced into the super-continent of Pangaea – and that this occurred at the end of the Permian. Most shallow seas occur on the continental shelves, which are the submerged margins of these landmasses. If all of the continents are merged, the amount of "edge" is greatly reduced. Gould also argues that the grouped continents would prevent the sea floor from spreading at the mid-oceanic ridges. These ridges, when active, rise high off the sea floor and displace lots of ocean water, raising sea levels. When locked up, the reasoning goes, the ridges and the sea levels fall, which uncovers large parts of the continental shelves, reducing the habitable space further.

The other part of the proposed solution to the mystery, he continues, comes again from studies in theoretical ecology. These studies, which he references, indicate that the number of species that an area can support is proportional to the size of that area. Thus, reducing the available shelf space not only wipes out individuals, it tends to condense the ecosystem down to a smaller number at all taxonomic levels.

ESD 17. The Reverend Thomas' Dirty Little Planet

An important and recurring theme in Gould's writings is that religion is not the enemy of science – historically, religion has often supported science – but that dogmatism and irrationality are the enemy of both. [His penultimate essay in this category is LMC 14.] He uses the term "irrational" in the literal sense, referring to those who claim knowledge by revelation or the unquestioning reference of authoritative sources, rather than the analytical, reasoning techniques commonly associated with the scientific method. Many of these "irrational" people are intolerant of other views. (He notes that scientists can and often do fall into this mode as well.) Within this context, he discusses a famous book from the late 17th century, *The Sacred Theory of the Earth* by Thomas Burnet.

Burnet was an ordained minister in the Church of England, and his book was an attempt to reconcile the events of the Bible with Newton's recently-developed laws of motion and gravity. Today, Gould states, most students of this work assume it represents a rear-guard action by the Church to slow the inevitable advance of science. This is not the case; Burnet was a rationalist of his time, and in fact came under fire from the more dogmatic Church administration. Burnet did take the events described in the Bible, and in particular, the story of Noah's flood, as literally true; he also accepted as fact that the flood was global, and not simply the perspective of a local population who never traveled far. However, in the spirit of Newton (who was also devoutly religious), he conceived of God as The Great Watchmaker, who worked via natural law rather than by fiat or periodic miracles. Burnet recognized that there was not enough water in the oceans to cover Earth's mountains, and he would not accept that God had created extra water (miraculously) for that purpose. Within these constraints, he invented a model of what might have happened, his "sacred theory."

Burnet proposed that the Earth condensed out from the void, with the heavy core materials sinking to the center. A world-wide ocean covered this core, and on top of this was a thin, flat, uniform layer of earth and rock that formed the crust. This smooth crust held the Garden of Eden and early humans; there were no seasons, for earth's rotational axis pointed straight up at this time. Due to a "pressure cooker" event, however, the ocean ruptured through the land surface, flooding it. The explosion was so great that it not only altered the axis of rotation, it smashed the land into its current collection of mountain ranges, leaving vast open areas of ocean behind. Earth became a "dirty little planet" that shortened the lifetimes of its human inhabitants from the 900 years commonly stated in Genesis to those we experience today.

Burnet was no scientist, Gould notes; he did no experiments and made no first-hand observations. But he did argue for physically conceivable causes for Noah's flood and the current configuration of the planet, as opposed to those who argued that such arguments were unnecessary, and possibly heretical. Burnet later got in even more trouble for suggesting that the six days of creation might be allegorical rather than literal. [Gould writes more about the history of geology, and specifically the efforts of Thomas Burnet, Thomas Hutton (HTHT 6), and Charles Lyell (next essay), in his 1988 book *Time's Arrow, Time's Cycle*. Burnet becomes the first of a group that some, including Gould, call "world makers"; see the next essay and BFB 25.]

ESD 18. Uniformity and Catastrophe

Charles Lyell (1797-1875) is generally considered the father of modern geology; Gould wrote this essay in 1975, the centennial of his death. Lyell's first volume of *Principles of Geology*, published in 1830, is usually credited with driving speculative and often supernatural claims out of the field, and replacing them with natural, measurable processes that have been observed in historical times. Supernatural events, or at the very least an earth that was far more active in the past than today, are almost required to explain mountains and canyons – *if* the planet were only 6000 years old, as most people at that time believed. Lyell drew on the recent discovery of "deep time" – a truly ancient earth – to produce a completely different worldview. [Thomas Hutton's *Theory of the Earth*, which is credited with formally introducing this concept, was published in 1795; see HTHT 6.] Lyell argued that geology could never become a science if the community accepted the notion of a very different earth, with different rules, in the past. If instead, however, billions of years of time were available for the ordinary processes we observe today, then earth's surface could be explained using *only* measurable processes and testable concepts; this view came to be known as *uniformity* or *uniformitarianism*. [Lyell actually allowed *too much* time; this is discussed in TFS 8.]

As legend has it (Gould tells us, quoting from some contemporary texts), Lyell's opponents were the *catastrophists*, religious fundamentalists of the day who tried to hold back the march of science by clinging to a young earth and speculative, spectacular events. Lyell's book led to their defeat, at least within professional and educated circles. This is a good story, Gould continues, but it is not really true. In 1830 there were several important members of the catastrophic school, including Cuvier [HTHT 7], Agassiz [TFS 7, ELP 29], Sedgwick, and Murchison; but all of these scientists did believe in an ancient earth. Further, they admired Lyell's *Principles of Geology*; Gould tells us that came across Agassiz's personal copy of this book in Harvard's library, with hand-written notes by the owner in the margin, reflecting broad approval. What, Gould asks, was really going on?

There was a real battle between the uniformists (also called "gradualists") and the catastrophists, Gould tells us, but it was a bit different than the canonical story. The so-called catastrophist view within the scientific community was that – even with an ancient earth – there were probably major events in the distant past that are unlike anything man has ever observed. Lyell and his faction argued that no such processes should even be considered while the basics of the science were being established (for a generation at least), although it is clear that he did not believe any such processes would ever be found. [In LSM 7, Gould suggests that Lyell's perspective was based at least in part on the fear that, if the earth had been shaped by "catastrophes," it would be impossible to decipher its past. As a result of this view, Gould mentions in this essay, Lyell did not even accept Agassiz's evidence for ice ages until much later in life.]

Lyell played to win, and used his earlier experience as a lawyer to "make the case" for his view; *Principles of Geology* was, Gould claims, a legal brief (to convince) as much as a textbook (to illuminate). In this mode, he pulled two "fast ones" (Gould's term). The first was to subtly mix the views of his professional catastrophic colleagues in with those of society at large, where a young earth and supernatural processes remained popular. The second was a similar mixing of four *distinct* concepts of uniformity into a single term. [In LSM 7, Gould mentions that this analysis led to his first professional paper, published in 1965.] The first is uniformity of physical law across space and time; this is a postulate, rather than a conclusion, as it must be *assumed* if the scientific method is to be effective. The second is the uniformity of geologic processes through time, meaning that erosion and volcanoes (for example) behaved in the past the same way they do today. Lyell's catastrophic opponents concurred with both of these, and approved of the way in which these arguments were presented in *Principles of Geology*. (The professional catastrophists believed that Lyell's uniform processes were *necessary* to explain the earth today, but they were probably not *sufficient* – this was the true disagreement.) The third is "uniformity of rate"; this is the key point of Lyell's model, and he "slips in" this unproven – but ultimately testable – hypothesis that geologic processes have always occurred at about the same rate we observe them today. Through this tactic, Lyell leads the reader to infer that if he does not accept number three, then he must also reject numbers one and two – and thus, the scientific method altogether. This argument, Gould claims, has held up remarkably well in the century since Lyell's passing. But Agassiz, Cuvier, and the scientific catastrophists were actually being more empirical than Lyell was; they pointed to abrupt discontinuities in strata and apparent "mass extinctions" in the fossil record as evidence that catastrophes had, apparently, occurred. Lyell's counter to this was to call on the sparseness of these records, arguing that – despite appearances – these did not represent "real" events. [Gould elaborates on this aspect of the debate in LSM 7.]

The fourth component of Lyell's vision is uniformity of configuration. It has been politely forgotten today, but Lyell considered it to be the most important of the four for most of his career. Lyell not only believed in a truly ancient earth [perhaps 20 billion years, according to TFS 8], he also believed that earth's history was cyclical rather than linear, slowly changing from colder climates to warmer and back again. One implication, abandoned only late in life, was that mammal fossils (or something very similar) would be found in the oldest geologic strata, corresponding to the last eon in which the earth was as cool as it is today. [In fairness to Lyell, LSM 7 also notes that the catastrophists did, in general, believe that major geologic events – volcanoes, floods, earthquakes, mountain formation, and so on – were both more frequent and more intense in the past.

This was consistent with their commonly-held view that the earth originated as a molten sphere, probably ejected from the sun, and then cooled – rapidly at first, and then more slowly. Lyell's younger friend and colleague, Charles Darwin, accepted his gradualism, but not his cyclical view of natural history. The metaphors of linear and cyclical time are discussed again in DIH 3, and in Gould's 1987 book *Time's Arrow, Time's Cycle*.]

[It is interesting that Gould wrote this essay, essentially advocating a better balance between the uniformist and catastrophic views expressed here, about five years *before* the discovery of a comet or asteroid impact that "catastrophically" ended the age of dinosaurs – see HTHT 25. His perspective, he acknowledges, was not due to better insight, but was developed in defense of his model of punctuated equilibrium, co-developed with Niles Eldredge (TPT 17), which they had introduced several years earlier. This view argues that the abrupt transitions in the fossil record are, at least sometimes, real after all. At least part of the early resistance that their model faced, Gould claimed, was due to the continuing sway of Lyell's uniformitarian argument.]

ESD 19. Velikovsky in Collision

Immanuel Velikovsky (1895-1979) was born in what is now Belarus, and educated at the prestigious University of Moscow. There he studied medicine and psychoanalysis under a student of Freud's, receiving a medical degree in 1921. He worked primarily in what is now Israel, corresponded with Einstein, and helped found the Hebrew University of Jerusalem. He moved to New York just before the Second World War. Gould does not discuss these details here; he simply notes that Velikovsky is no crank and no charlatan. Inspired in part by Freud's book *Moses and Monotheism* [see IHL 8 for more on Freud's views of evolution and human history], Velikovsky became enamored with a very small field that he called "comparative mythology" [also see IHL 7]. His perspective was that many of the apocalyptic stories in the Bible and other contemporary legends were based on real events; the sun did stand still in the sky, and the rivers did run red. Starting from this premise, he then developed a series of physical "explanations" for these catastrophes. These involved events in which planets, usually Venus and Mars, changed their orbits and made close passes with the Earth. These near-collisions would temporarily stop Earth's rotation and/or cause it to flip over, resulting in no end of earthquakes, volcanic eruptions, and flooding. Velikovsky recognized that the force of gravity alone would not permit these sorts of events, so he proposed that there must have been other forces at work. That is, in the presence of discrepancies between historical myths and physical theory, he argued that the myths were more reliable; this is certainly opposite of the way most scientists work. (Velikovsky argued that the result of these traumas to the collective human psyche, which as a psychoanalyst he was primarily interested in, was terror so great that humans acquired a collective amnesia. These repressed memories manifest themselves as fear, neuroses, and aggressive behavior, including war.)

No peer-reviewed scientific journals would publish these writings, so he rewrote them in book form for a lay audience. *Worlds in Collision* was published in 1950, and sold very well (due in part to favorable quasi-creationist reviews in *Reader's Digest* and *Harper's Magazine*). Once he had established his revised physics, he looked for more evidence of catastrophic events in Earth's history, and found plenty. Of particular interest were discoveries such as coal in Antarctica and evidence of ancient glaciers in South America, which he interpreted as evidence that the poles and equator had switched places. In 1955, he published another book called *Earth in Upheaval*. This work is truly the antithesis of Lyell's uniformitarianism [see the previous essay], and claims that catastrophes are behind virtually all major geologic features. In fact, it is very much in the spirit of the earlier "world-makers" [also see BFB 25] that Lyell was so opposed to.

Gould reminds us that he is not a physicist or astronomer, and thus will not comment on Velikovsky's planetary mechanisms. However, he is a geologist (among other things), and therefore feels qualified to comment on *Earth in Upheaval*. In a calm but firm tone, he lists five different classes of problems with the book. Some are structural in nature. Velikovsky explicitly assumes that large effects must imply sudden, catastrophic events; for example, the creation of glacial ice sheets requires that the sea actually boil at some point. He also assumes that all catastrophes affect the entire world and not simply the local area. Others problems are smaller, but work against a sense of confidence: most of his references are decades old (some more than a century), and the text itself contains many factual errors and half-truths. In the end, however, all of these issues are dwarfed by the discovery of plate tectonics in the 1960's (next essay). Velikovsky did not know, and could not have known, that the continents rest on plates that move and collide, and thus bears no blame for his ignorance. Nonetheless, this modern geologic theory explains not only mountains and earthquakes, but the vastly different climate history of continents in the past. Thus, the Great Rift Valley in Africa is not a crack caused by a planetary near-miss, but the result of two plates sliding apart. Further, it explains all these things without introducing new laws of physics. Worse for Velikovsky, the catastrophic effects of mountain building, volcanoes, and continental drift are, in this model, the result of steady plate movement of a few centimeters per year, and thus fits neatly into Lyell's uniformitarian perspective.

[When Gould wrote this essay, he was wading in to a controversy that was still raging; Velikovsky was still alive in 1975, and his books were selling quite well. Adding to Velikovsky's mystique was the fact that several prominent scientists, led by the famous Harvard astronomer Harlow Shapley, had tried earlier to prevent a prominent publishing house from printing *Worlds in Collision*. Velikovsky played up this "snubbing" by mainstream academia, arguing that he was being persecuted like Bruno or Galileo. The episode came to be known as "the Velikovsky affair" by his supporters.]

Gould closes with a few thoughts on the role of nonprofessionals in science. He acknowledges that many of the great breakthroughs in scientific thought have their origins as speculative heresies from outsiders, and that the professional community often did not respond very warmly [see the next essay, and also HTHT 25]. He notes that he himself has proposed a few heresies, including some on the subject of catastrophism. However, he adds, for every victorious heretic, there are a hundred who were just plain wrong. Gould does not think that Velikovsky will be one of the lucky few that beat the odds.

ESD 20. The Validation of Continental Drift

In the first half of the 20th century, Alfred Wegener (1880-1930) argued that continents drift over the surface of the earth. He based this argument on geography (e.g., the east coast of South America appears to match up with the west coast of Africa), geology (similar types of rocks and formations in different continents), and paleontology (similar fossils). This evidence convinced few that continental drift occurred. This was not because the data was suspect, or because there were other, simpler explanations for them; it was because no one could envision a mechanism by which continents could plow their way through earth's crust.

One important example of Wegener's evidence is the existence of glaciers on both South America and Africa during the late Paleozoic period, with the striations suggesting these glaciers originated in (what is now) a tropical ocean. Meanwhile, there were no glaciers at this time in North America. This can be explained if South America and Africa were joined at the time and located at the South Pole, as is now believed, but very difficult otherwise. One alternative model, supported by many scientists, was that a series of narrow land bridges existed between the continents. These land bridges, for which there was never any direct evidence, separated the northern ocean (which did not freeze) from the southern one (that did). Many in the scientific community readily accepted this speculation as theory, because the need to rationalize difficult data was so strong and the alternative so unappealing. He sites some other examples as well. He adds that Wegener himself fell into a similar trap; he and his supporters proposed a number of highly implausible mechanisms to drive continents through the crust.

In the 1960's, a new type of data became available: high-resolution mapping of the deep sea floor. What became apparent was that earth's crust, on which the continents floated, was comprised of a series of large plates. Further, these plates moved constantly with respect to each other. Where they spread apart, there were high ridges where the molten interior rose up to make new crust to fill in the gaps. Where they came together, at deep-sea trenches, one plate would dive below the other and re-melt. In this new model, the continents did not "plow through" earth's crust; they were locked into it. It was the crust itself that moved, as part of a mantle convection process. The theory of continental drift was thus subsumed into the larger theory of plate tectonics. With the acceptance of plate tectonics, all of Wegener's evidence for continental drift was "rehabilitated" and offered as evidence for plate tectonics. [Gould discusses another example of where a geologic mechanism was required before "obvious" data could be properly interpreted in TPT 19.]

The real theme of this essay is how the scientific community deals with a major paradigm shift, as this surely was. Referencing a quote from von Baer on natural selection, Gould states that successful new paradigms go through three phases. The first is quick dismissal as nonsense; the second is active resistance to what has become heresy; and the third is acceptance as the new dogma, with many converts claiming that they had always known it to be true. Gould describes his own seat in watching this process, as an undergraduate geology major at Antioch College (where he showed up in the second phase) through graduate school at Columbia. The way such stories are usually told, he says, is that science grows by accumulation of new facts. In this case, the new facts were the observations of active deep-sea ridges and trenches, which provided the mechanism for drift that had been missing. Far more interesting, Gould offers, is that Wegener's observations played no role at all in the acceptance of the theory; it was merely used afterwards as supporting evidence.

The lesson here, Gould states, is not to judge scientists harshly simply because they are as human as the rest of us. Science tends to work this way, for a good reason. Contrary to popular belief, the observed scientific facts do not speak for themselves; they *must* be read in the light of theory [see ESD 25]. Science is as much a creative human endeavor as art, and thinking creatively – even speculatively – is part of the process. New data obtained under the umbrella of existing theory is unlikely to overthrow that theory. The lesson, he states, is that existing theory can only be overthrown by new theory, which itself will likely go through periods of both speculation and zeal. In a closing paragraph that illustrates how new the theory was when he wrote this, Gould states that he is not terribly bothered by the fervor *for* plate tectonics, for two reasons: he suspects that it is correct, and in any case, it is definitely exciting.

ESD 21. Size and Shape

This essay addresses the physical fact that as objects grow larger, their volumes increase faster than their surface areas (by the cube and square of the body's linear dimension, respectively). Since living creatures are physical objects, this has repercussions on their design. Larger organisms must have highly convoluted features such as alveoli in lungs or villi in the small intestine, because the absorption of oxygen and nutrients takes place through a two-dimensional surface. Insects, being small, can effectively use simple holes in their exoskeletons to bring air into their bodies. Since the surface where the holes are does not increase as rapidly with increasing size as the volume that needs to be aerated, this design feature places an upper limit on the size of insects.

Gould notes that buildings with stone columns experience the same issue as large animals with bones as they grow larger; the column/bone must grow relatively "thicker" as the length increases to support the increased mass of the new volume. He also notes the relative effect of gravitational versus surface (electrostatic) forces on the size of animals. If humans were the size of flies, he argues, it would be much easier for us to climb walls with our bare hands and feet. Similarly, an insect would have to increase its wing size more rapidly than its length if it is to maintain its ability to fly.

ESD 22. Sizing Up Human Intelligence

Several physical characteristics help define us as human. These include bipedal posture, opposable thumbs, and a larynx complex enough to support speech. The feature referenced most often, of course, is our large brain. Gould begins this essay by discussing the underappreciated importance of our large physical size, which is required to support this brain. Contrary to common perception, we are larger than 99% of all animal species on this planet, including primates. Human brains average about 1300 cubic centimeters in size. Although the observed range around this mean is large, and seems to have no impact on intelligence, nonetheless there is presumably a minimum number of neurons required to support what we call human consciousness; this in turn requires a minimum physical body size to support it. He continues in a speculative vein that if we were the size of ants, even if we could find a way to maintain our intelligence, we could not live "human" lives. Static forces would allow us to climb walls, but not take off clothing; fire would be impossible to manage.

Nonetheless, brains do more than allow us to think; they control many aspects of the body. Thus, elephants and whales have larger brains than humans do, but this is due in part to their larger bodies. Gould introduces the "mouse to elephant curve," a best-fit line through a series of points that plot adult mammalian body weight along the x-axis and the corresponding brain weight along the y-axis. The curve is linear, but its slope is significantly less than one; it is about 2/3. That is, if one mammal has a body mass three times than of another, on average its brain weight would only be twice as great. Gould notes that the great apes all fall significantly above this line, indicating a larger-than-average brain-to-body weight ratio. Humans fall the farthest above this line. Gould then presents data showing that the hominid lineage, from australopithecines to modern humans, shows a consistently increasing distance from the median line. The data presented represent work that Gould and colleagues published in the journal *Science*, giving us some insight into his "day job." [Gould discusses how lifetime scales with size, and how again humans fall well above this line, in TPT 29.]

ESD 23. History of the Vertebrate Brain

This essay reviews the thesis of a contemporary book: *The Evolution of the Brain and Intelligence* by Harry J. Jerison, 1973. Jerison uses the brain weight to body weight chart discussed in Gould's previous essay to confront what he considers to be the false ladder of vertebrates: fish, amphibians, reptiles, birds, and then mammals. His studies, Gould reports, indicate that there is really only one division by this category: the warm-blooded vertebrates on the one hand, and the cold-blooded on the other. This he attributes to physiology, not intelligence. Jerison speculates that mammals evolved their relatively large brains during the age of dinosaurs not for intelligence, but for processing of sound and smell patterns into spatial awareness. This was necessary, he speculates, because these creatures were probably nocturnal, living well down on the food chain. Gould goes on to note that Archaeopteryx has a relative brain weight in between the two.

For the most part, Jerison reports no increase in the average brain-to-body ratio over time within each vertebrate group. One important exception, however, involves the mammals that evolved after the Cretaceous extinction about 65 million years ago. These tertiary mammals are binned as early, middle, and late. The brain weight to body weight ratio increases at each stage, in each case with carnivores above herbivores. In closing, he observes that primate brains have always been above average even for mammals. Since original primates were similar to tree-dwelling shrews in appearance, it is not obvious why this should be the case. Gould acknowledges that this remains a mystery.

ESD 24. Planetary Sizes and Surfaces

This essay begins with a recapitulation of Charles Lyell's principle of uniformitarianism in geology [ESD 18]. Referencing the work of some colleagues, Gould describes the two heat engines that drive the gradual, continuous processes of Lyell's theory. The first is the sun-driven engine behind atmospheric and oceanic processes, which encompass all erosion effects. The second, discovered only a decade earlier, is the mantle convection process that moves the earth's tectonic plates around [ESD 20]. This convection is powered by radioactive decay at earth's core, and is responsible for most earthquakes and volcanic eruptions. Notably absent from this list of significant geological effects are meteor impacts. Few are visible on earth today, due to the uniform processes just described, but they are the most characteristic surface feature on other heavenly bodies such as the moon and Mercury. These bodies have no atmosphere or oceans, and the crust is too thick in both cases to allow tectonic activity. If Lyell were to have found a way to grow up on either of these worlds, Gould states, he would not have proposed a gradualistic geology.

Gould wrote this essay in 1977, shortly after the Viking probes landed on Mars, but before the Pioneer and Voyager fly-bys of the outer planets. This was also written at a time when he was exploring the concept of size and scaling on various systems in his professional career (see the previous three essays). He speculates that planetary size alone is primarily responsible for the geologic differences between the earth and the moon. The moon and Mercury have no atmospheres, because their gravitational mass is not sufficient to hold them. It may also be that the large surface-area-to-volume ratio of the smaller bodies that is responsible for their thicker and thus rigid crusts, since smaller objects lose a larger fraction of their heat through their surfaces. Without either heat engine, all that is left to shape the surface of these worlds are meteor impacts – which then remain largely unchanged over time, as there is nothing to erode them. He suggests that if his hypothesis were valid, an intermediate-sized body would show intermediate effects. He offers Mars, only recently photographed at high resolution by the Viking orbiters, in support of his argument. Mars does have a thin atmosphere and some very large volcanoes, but no oceans and no plate tectonics. Its surface is roughly half cratered (catastrophic events) and half covered by other structures, including volcanoes and dune fields (gradualistic effects).

[Gould will reference this essay in the 1980's, after the Pioneer and Voyager missions show amazing details of the moons of Jupiter, Saturn, Uranus, and Neptune. His model does not hold up well, he acknowledges – see BFB 34 & 35. Radar mapping of Venus by the Magellan spacecraft also shows that this planet is not consistent with his simple model. The lesson is not that scientists can be wrong; that has always been known. It is that scientists make predictions, and when nature invalidates those predictions, the good scientist accepts nature's verdict.]

ESD 25. On Heroes and Fools in Science

In addition to being a geologist and paleontologist, Gould was also a historian of science; he published original research in their professional journals. Two of the themes that recur regularly in his writings appear in this essay. The first is that science does not, contrary to popular opinion (even within the scientific community), move in a straight line from ignorance to truth via the collection of objective facts. Science is a creative human endeavor, and tends to move in fits and starts. Facts do not speak for themselves, but are always seen in the light of some model or theory [see DIH 12 for a further discussion]. The second recurring theme is the importance of not judging historical figures and their ideas in terms of today's theories. In order to properly understand the history of science, it is important to understand what these people knew, thought they knew, and did not know at that time. It is all too common, Gould writes, to think of those historical figures whose ideas are most similar to ours as the good guys, and their opponents to be fuzzy-thinking dogmatists, villains, or fools. It is this second theme that gives the essay its title.

Gould presents the example of two competing 17^{th} century views within the budding science of embryology to illustrate the difficulty associated with considering historical scientific controversies in modern terms. The first model of how embryos develop is called *preformationism*, and argues that each egg (or sperm) contains all of the structures of an adult in miniaturized form, albeit with greatly different proportions. Inside the tiny eggs of this *homunculus*, or "little person," is a yet tinier homunculus, and so on. [Gould states in IHL 20 that "No serious scientific preformationist held such a view" regarding the literal reality of a homunculus.] The second view is known as *epigenecism*. This paradigm argues that the original fertilized egg has no internal structure at all to begin with, and that the complexity of the embryo grows from the uniform simplicity of the egg. In the storybook version of this intellectual struggle, by the mid-19^{th} century the epigeneticists had won out because their observations were more accurate. This is an oversimplification, Gould argues, and because of it we miss an insight into the models, and in general how science proceeds.

He begins by noting that most of the preformationists did recognize, through their own accurate and detailed observations, that embryos did appear to begin as simpler structures. But if matter was being transformed from the simple to the complex, then what was the force that was doing the transforming? In the era before there was any inkling of DNA or even cells, the observations taken at face value appeared to be supernatural "vitalism," untestable in any way and thus unscientific. Therefore, Gould argues, it was actually the preformationists who were trying to incorporate a degree of rationality upon the proto-science of embryology. The epigeneticists, commonly credited as the heroes of this debate by simply reporting what they actually observed, in many cases had no such qualms about invoking supernatural forces.

What about the problem of an infinite series of homunculi nested within one another? Surely this points out the absurdity of the preformationist position. But at the time, Gould argues, the lifetime of the earth (past and future) was believed to be only a few thousand years, so that an infinite number of homunculi nested inside each other would not be required. Further, no lower limit on the size of organelles within cells was recognized at that time (the 1760's), due largely to the limited quality of the microscopes of that era. In short, preformationism – clearly wrong, as there are no preformed parts inside a fertilized egg – not only made some of sense at the time, but struggled against what was, at least in part, a non-rational alternative.

[Today, both theories are recognized as incorrect; the truth is that the fertilized egg contains a set of coded instructions, in the form of DNA. The epigeneticists appear "closer" to this model only in hindsight; they would have been as surprised the modern view as the preformationists. Gould explores the concept that neither group had the appropriate metaphor – "programmed instruction" – in TFS 9. He returns to the metaphors that each faction did have to work with in IHL 20. He briefly discusses the downfall of preformationism in TFS 25.]

ESD 26. Posture Maketh the Man

With the acceptance of evolution in the last third of the 19th century, people began to speculate about human ancestors. (A few wrote even earlier; Gould references von Baer from 1828.) The three primary differences between man and other apes were usually categorized as follows. First, there is upright posture, with the associated attribute of free hands. The second is speech, which is tied to a more complex larynx. The third is the relatively large brain for the given body weight, and a presumed correlation with more complex and abstract behavior. However, no fossils of modern man's ancestors were found until the 1920's and 30's, when Java Man and Peking Man (now both recognized as *Homo erectus*) were discovered. [However, see TPT 10 for a discussion of the "Piltdown Man" fraud, and the resulting false consensus on human evolution that it led to. The Piltdown fraud also led scientists to not appreciate the importance of the more ancient Australopithecus fossils, also first found in the 1920's.] This temporal gap left ample time for scientists and nonprofessionals to speculate about what these intermediate creatures might have looked like. It is these speculations, forged in the absence of data, which are the subject of this essay.

There were two primary schools of thought. The more popular by far was that the human brain started to grow first, with the posture following along from knuckle-walking ape through several degrees of stoop-shouldered cavemen to fully-erect moderns. (This sequence is still seen on book-cover illustrations, political cartoons, and tee shirts, and was one of Gould's pet peeves.) This makes sense, its proponents argued, because we control so much of the world by our uniquely human inventions. The second school, a distinct minority, argued that our ancestors became fully bipedal first, and only then grew larger brains. This would be consistent, they argued, with a species of ape leaving the rain forests for the savannahs, where bipedalism would presumably provide the advantage of long-distance viewing. After this, increasingly larger brains would harness the tool-making power of the hand. In retrospect, the upright-posture-first group (which included Darwin's biggest supporter in Germany, Ernst Haeckel and, interestingly, Sigmund Freud) has been largely vindicated.

Why, Gould asks, in the absence of data either way, did most scientists (and Westerners in general) opt for the big-brain-first perspective? Gould proposes that the answer can be found in the biases of Western man, as explained in an 1876 essay by none other than Friedrich Engels. Engels, one of the fathers of communist theory in the 19th century, argued a developmental theory very similar to Haeckel's in his *The Part Played by Labor in the Transition from Ape to Man*. This essay had no impact at all on the scientific community, but it offers some interesting speculation on why so many people were surprised later. According to Engles, as the brain developed in capability, at first it made "Labor" (in the Marxist sense) more powerful via agriculture, architecture, and so on. But eventually the brain developed to the point where it could support the concept of religion. After this, a small band of power-seekers used that capability to control the rest of the group. Whether true or not, Gould notes, westerners do tend to rank intellectual activities as superior to manual work. Whatever the origin of this bias in our culture, he concludes that it may be responsible for the general degree of surprise when our ancestors were found to be fully bipedal but with brains only slightly larger than apes. Biases, Gould concludes, must be recognized before they can be confronted.

ESD 27. Racism and Recapitulation

Gould discusses two biological theories of the late 19th and early 20th centuries that relate the development of an organism to its evolutionary history. Both were applied to human evolution generally, and specifically to evolutionary differences between races. The thrust of this essay is not so much the theories themselves, but rather on the fact that these theories – which argue opposite views in terms of evolutionary progress – were *both* used to justify identical racist and colonialist policies. [In IHL 27, Gould defines racism as "the claim for intrinsically biological and therefore ineradicable differences in intellectual or moral status among peoples."]

The first theory, recapitulation [briefly discussed in ESD 7, and more extensively in TPT 24], argues that "ontogeny recapitulates phylogeny," or that the development of an individual from egg to adult "reenacts" the evolutionary history of that species. Mammal embryos thus pass through a fish-stage (with gill slits), and then "amphibian" stage (with a tail), and then a "reptile" stage (a three-chambered heart). Implied in this biologically directional and progressive model is that embryos and infants must develop faster and faster over geologic time, since there will always be more steps to pass through. The second theory, neoteny (also in ESD 7), notes that in some cases evolution proceeds by slowing down early development. Humans in particular retain many features that are lost after the juvenile stage in other primates. Both theories fell into disfavor within a few decades of the rediscovery of Mendel's genetics in 1900. The theory of genetics shows that different developmental processes can be speeded up or slowed down independently, as they are affected by regulatory genes. It also shows that the effects can take place anywhere in the developmental process, not just at the end – although modifications that occur very early are usually fatal.

The primary developer of recapitulation theory, Ernst Haeckel, had no qualms about applying a biological theory to sociological issues within human culture. He was a liberal of his day, and tried to use his model to attack the hierarchical social structures of his native Germany. However, his model was usurped by the power elites in both Germany and England to justify racist and imperial policies. There are all sorts of minor differences in the development of different populations and races, and easy to find examples where Europeans developed faster or farther than others. These technical details were sited as evidence that Europeans were biologically superior to other races; further, that the adults of these other races were much like European children [see TPT 15 and IHL 8, as well as his 1977 book *Ontogeny and Phylogeny*], and thus in need of "adult supervision." Later, when key aspects of neoteny were recognized, the community delved back into the data to find examples of where Europeans developed more slowly or less completely than other races; these examples were then also presented as evolutionary evidence of white superiority. At no time, Gould states, did anyone inside or outside of the scientific community call attention to the fact that the evidence supporting racial superiority via neoteny directly refuted the evidence supporting racial superiority via recapitulation, or vice versa. [Gould attempts to remedy this and similar abuses of science for racist purposes with the publication of his 1981 book, *The Mismeasure of Man*.] This is not simply a matter of history, Gould warns; similar arguments arise continuously relating race to intelligence. He expands on this theme in the next several essays.

[Recapitulation concepts Haeckel; his work reflects the culmination of a line of thinking that developed almost from the beginning of the field of embryology. Gould discusses this story in detail in *Ontogeny and Phylogeny*. In IHL 27, in reference to the German physiologist Friedrich Tiedemann (1781 – 1861), he writes:

> As a central question in pre-Darwinian biology, scientists of Tiedemann's generation yearned to know whether all developmental processes followed a single general law, or if each pursued an independent path. Two processes stood out for the evident study: the growth of organs in the embryology of "higher" animals, and the sequence of structural advance (in created order, not by evolutionary descent) in a classification of animals from "lowest" to "highest" along the chain of being.
>
> In rough terms, both sequences seemed to move from small, simple, and homogeneous beginnings to larger, more-complex, and more-differentiated endpoints. How similar might these two sequences be? Could adults of lower animals really be compared with transitory states in the embryology of higher creatures? If so, then a single law of development might pervade nature to reveal the order and intent of the universe and its creator. This heady prospect drove a substantial amount of biological research during the late eighteenth and early nineteenth centuries.]

ESD 28. The Criminal as Nature's Mistake, or the Ape in Some of Us

Gould recognizes the centennial of a late 19th-century theory and social movement called "criminal anthropology" in this essay. This movement is assumes that "born criminals" exist, and can be explained as *atavisms* (literally, throwbacks to earlier evolutionary stage), via incomplete recapitulation – see the previous essay. This implies that what we call criminal behavior today was normal and even necessary behavior for these ancestors. Italian physician Cesare Lombroso started the movement in 1876, with the publication of his book *L'uomo delinquente* (*Criminal Man*).

Gould makes three points. The first is that scientists have an obligation to be aware that their theories can be leveraged for social ends; technical ideas can have political consequences. The second is that, even when the scientist himself argues for his theory to be applied to society in one way, others may employ it for their own ends. In this case, Lombroso tried to use his theory in part to bring enlightenment to the treatment of criminals. Instead, he gave the European ruling classes another line of reasoning to maintain the hierarchical class structure domestically, and to engage in imperialism abroad. If the evidence is there, Gould states, we must support the model even if we find it distasteful; but the scientific community has an extra responsibility to refrain from speculating on subjects that involve human behavior. His third point is that, while this particular theory is long and deservedly dead (Lombroso's science was terrible even by 19th century standards), similar theories continue to pop up. In particular, he discusses the XYY-chromosome issue, popular in 1976 when this essay was written because of the Richard Speck case. (It turns out that Speck did not have this particular abnormality, and the genetic data gathered on violent prisoners that followed was highly ambiguous.) We must remain vigilant, so as not to repeat past mistakes. [Gould discusses biological atavisms in HTHT 14, and to the role of recapitulation in other realms – in particular, Freud's psychoanalysis – in IHL 8.]

ESD 29. Why We Should Not Name Human Races: A Biological View

Taxonomy is the science of organizing and categorizing complex systems. In several of his essays, Gould writes that he considers himself a professional taxonomist, specializing in a particularly diverse genus of land snail, *Cerion* [TFS 11]. In this essay, he applies his expertise in this field to the problem of categorizing variations – or more specifically, races – in humans.

In biology, we classify all living and extinct organisms by the hierarchical taxonomic structure initially developed by Linnaeus in the 18th century. All organisms are assigned to a species, and then closely related species are grouped into a genus. The name *Canis familiaras* is the "binomial nomenclature" terminology for the dog: *Canis* (capitalized) is the genus, while *familiaras* (not capitalized) is the species, differentiating it from *Canis lupus* (wolf). The rigorously hierarchal taxonomic structure continues: above the level of genus are the levels of family (canids in the case of dogs, which includes foxes and coyotes), order (carnivore), class (mammal), phylum (vertebrate or chordate), kingdom (animal), and, since Gould wrote this, domain (eukaryotes). Today, this structure is interpreted as indicating lines of common descent (dogs and wolves share a common ancestor), but this was not always the case [see IHL 21]. Of all these categories, only the species is considered "real," in that it has a measurable attribute: the ability or potential to interbreed with other members of that species. Above this level, it is more a matter of definition, and there are debates about whether a particular group should (for example) be considered a family or an order. If two species are in the same genus, the taxonomic rules dictate that they are also in the same family, and share all higher levels. While all organisms must be assigned to each of these categories, they may or may not also be assigned to a number of intermediate divisions, such as "subphylum" and "superfamily."

There is one recognized (and optional) level below the level of species in this taxonomy, called subspecies. Gould quotes Ernst Mayr's 1924 definition: "The subspecies, or geographic race, is a geographically localized subdivision of the species, which differs genetically and taxonomically from other subdivisions of the species." In species that exhibit a wide degree of geographic variation, such as land snails, it has been common in the past to describe each of these in the same detail as the species as a whole. On the one hand, this appears to be a valid responsibility of the biologist. However, this approach has a number of drawbacks, including the "burying" of species-level information in a plethora of only quasi-meaningful subspecies data. The biggest disadvantage, however, is that the taxonomy and distribution of these subspecies are not static, since by definition individuals of different subspecies can and do interbreed. Gould presents the example of large-scale variation of European house sparrows, introduced to North America in the 1850's. A little more than a century later, these birds exhibit a large degree of geographic variation. In this example, the use of the "static" subspecies characterization is inappropriate because the sub-populations are varying in "real time."

Until the 1970's, there were no practical alternatives to describing individual subspecies (at that moment in time) other than to ignore them. This changed with the availability of affordable computer power. This enabled the practical application of a statistical technique called multivariate analysis, which allows the simultaneous comparison of many different morphological features. This, at least in principle, allows the naturalist for the first time to separate out those variations that are actually due to internal genetic differences from those that are made in response to the immediate local environment, such as soil type, rainfall, and elevation. Scientists that employ multivariate analysis, Gould states, usually decline to use the optional (and static) taxonomic category of subspecies. The products of multivariate analysis offer a better way of describing geographic variation within species than the use of subspecies. [In DIH 27, many years later, Gould recalls his own application of this technique to his early research on *Cerion*. There, he notes that even this technique has its limitations.]

This finally brings us to the subject of human races. Other academic groups (referenced by Gould) have argued against the use of race in analyzing humans, for a variety of reasons. Their success in convincing their colleagues had been very limited, due to what many have referred to as the "obvious" and "self-evident" existence of race. Gould takes a different approach. All humans are recognized as belonging to a single species, *Homo sapiens*, since all can interbreed, so the vernacular term "race" is therefore associated in the binomial taxonomic structure as "subspecies." Therefore, he continues, what is "obvious" in humans is not race, but rather geographic variability. Since this variability is not static, due to the human practice of relocation and intermarrying, the use of subspecies – that is, "race" – is not a very good way to describe the differences within our species, from a purely biological viewpoint. [Gould extends the arguments of this essay in TFS 12.]

ESD 30. The Nonscience of Human Nature

This is the first of several essays in which Gould opposes what he refers to as "biological determinism." It is related to the classic nature-versus-nurture debate, and has been an area of controversy both in the scientific and popular press, and for him personally. The first tenant of this viewpoint, Gould states, is that human behavior is directly controlled by genetics. In this view, there are genes that code for, or at least are highly correlated with, behaviors such as aggression, xenophobia, and even marital infidelity and homosexuality. The second tenant is that these the features controlled by these genes, like others, have been shaped by natural selection. Since we were hunter-gatherers for most of our natural history as a species, our behavior has until very recently, the theory goes, been optimized for these environments. Culture, education, and free will can channel these behaviors, but cannot overcome them.

Gould opposes this model for two reasons. The first is technical: we have no idea how to tell from a genome what something as quantitative as the hair color of the owner is; to map behavior to a genome is far more difficult still. Further, controlled experiments are very difficult to perform. Experiments on humans are unethical, and experiments on animals cannot give us the kind of insight into human behavior that we would require. Therefore, the field is nowhere near being a science, and can only be an area for speculation. The second reason for Gould's opposition is political: he notes that these models are often adopted by those in power to justify their status or rationalize their behavior. If the theory is true, we must recognize it even if we find it distasteful, Gould states [in ESD 32]; but if it is just speculation, then scientists should be aware of the social and political impacts these ideas can have.

There are two main applications of deterministic behavioral arguments, he continues. The first involves human nature generally, and is the subject of this essay. The second is the differences in human nature within the species, usually broken down along lines of race or gender. That is the subject of the next essay.

When discussing the role of genes in human behavior, Gould claims, proponents draw on two lines of reasoning. The first compares human behavior with animal behavior. Yes, he agrees, chimpanzees are territorial, but we cannot extrapolate from this behavior that war in humans is genetically dictated. At the very least, the two behaviors could be analogous instead of homologous; they could represent behaviors that appear similar in some ways, but do not share a common evolutionary-based genetic origin. It is difficult to tell analogous from homologous relationships in physical structures such as muscles and bones; to do so in behavior is a step beyond. It might be true, Gould states, but it might not; this is speculation, not science. The second line of reasoning comes from interpretations of hominid fossils; the same family and genus as us, at least, but the evidence is much scrappier. Some of the works of this period – most notably the best sellers of the time *African Genesis* by Robert Ardrey and *The Naked Ape* by Desmond

Morris – depict our ancestors as cruel and brutish killers, and ourselves as basically the same (via genetics) under a thin veneer of civilization. Trying to discern animal behavior from fossils is always challenging, and with our ancestors, this issue is compounded by the fragmentary nature of the record. We can often tell whether the creature in question was herbivorous or carnivorous, however. Both of the referenced authors argue that our ancestor species were carnivorous based on their teeth, which were smaller than a contemporary herbivorous species of Australopithecus that later went extinct. Both argue that our ancestor actively wiped out this related species. While this is again possible, Gould notes that our ancestor species is now recognized as primarily herbivorous. [In addition, the species of Australopithecus in question is no longer considered a direct ancestor.] Thus, the evidentiary argument – such as it was – falls apart, and once again, we are left with speculation, not science. [BFB 22 offers a view of our underlying, "animalistic" nature that is far more positive. He returns to the theme of genes controlling behavior in LSM 18.]

ESD 31. Racist Arguments and IQ

This essay continues the case against the recognition of what Gould calls "biological determinism" as a science. Here, he focuses on cases that imply that one particular characteristic, "intelligence," is not only genetically based but differs significantly between racial groups. The specific topic is the argument that blacks are not as intelligent as whites (as defined by IQ scores on tests), with the implication that there is nothing that can be done about it since the source of IQ is genetic. Gould wrote this essay in the mid-1970's, in response to the widespread attention that followed an article published in the *Harvard Educational Review* in 1969. The article, by Arthur Jenson, was entitled "How Much Can We Boost IQ and Scholastic Achievement?" In the context of American history, this argument came at the end of a decade on progress on civil rights issues and a hope that good schools would produce good students regardless of the origins of the students. Academic results on this front improved much more slowly than political liberals (including Gould) had hoped, and many (such as Jenson) argued that the reason was because that intelligence – that is, IQ – is not so much cultural as genetic in origin. In these studies, blacks scored about 15 points below whites on IQ tests. Gould critiques the evidence behind Jenson's position in pieces. First, he notes that "intelligence" is hard to define, let alone measure, and that IQ tests themselves cannot distinguish between biological and social factors. Next, he notes that the data supporting the argument of a genetic role for IQ (primarily studies of identical twins separated at birth collected by Cyril Burt, concluding that IQ is about 80% inherited) collected before Jenson's paper have proven to be misleading, inaccurate, and perhaps fraudulent. [Fraud by Burt was later established; Gould references this in TFS 21.] Finally, Gould notes that Jenson presents no evidence that the differences in IQ scores are due to an inherited component as opposed to a non-inherited component; he simply assumes it.

It is worth noting that Gould does not make the more sweeping claim that there is no connection between genetics and intelligence. His point is much more specific: he simply states his conviction that Jenson's arguments are not valid. He adds, however, that the social consequences of this "bad science" are used by those groups who score higher on IQ tests as justification to reduce both funding and expectations for those groups who score lower.

ESD 32. Biological Potentiality vs. Biological Determinism

Gould continues his argument against biological determinism. His position, in his own words, is: “[T]he statement that humans are animals does not imply that our specific patterns of behavior and social arrangements are in any way directly determined by our genes. *Potentiality* and *determination* are different concepts.” Gould acknowledges that “violence, sexism, and general nastiness are biological . . . . But peacefulness, equality, and kindness are just as biological.” He offers an alternative to the model that specific genes correspond to specific behavioral traits, which he calls “biological potentiality.” His view is that the complexity of the human brain allows for all of our observed behaviors, but none are biologically required or even preferred. He agrees that human social behavior is highly adaptive, but argues that these adaptations are more likely learned than inherited. [Without using the term, he is suggesting that human behavior is Lamarckian – “inheritance of acquired characteristics” – rather than Darwinian, which is based on natural selection. He alludes to this again in later essays.] His argumentative tactic is to introduce a plausible alternative to biological determinism, and thus introduce what the law profession would call reasonable doubt. That is, we simply do not know enough about the relationship of genes to human behavior to consider it a science, with the implied authority that the term carries. He reiterates his concern that models put forth by scientists can and are used for unintended social and political purposes, and thus this is no idle matter. While conceding that his potentiality model is just as speculative as what he claims about biological determinism, it is clear that he thinks it likely to be true.

What triggered Gould to write this essay in about 1975 was the recent publication of *Sociobiology* by another great Harvard scientist and author, Edward O. Wilson. Gould praises the first 26 (of 27) chapters, which discuss the social behavior of all groups of animals in terms of evolutionary principles, based on meticulous research. However, it was the final chapter got the vast majority of the media attention. This chapter is entitled “From Sociobiology to Sociology,” and Gould describes it as an “extended speculation into the genetic basis of supposedly universal patterns in human behavior.” Gould acknowledges that Wilson cedes a large and possibly dominant role of non-genetic learning in human behavior, so the argument appears to be one of degree. However, Wilson goes too far (Gould states) when he argues for the creation of a new discipline called anthropological genetics, for the reasons given above. He presents a summary of what he believes are Wilson’s theses, including the nature of altruistic behavior (see the next essay), and offers his critiques. [He demonstrates that his views on this topic remained unchanged 20 years later in LMC 13 and LSM 18.]

ESD 33. So Cleverly Kind an Animal

Here, Gould addresses one of the classic problems in evolutionary theory: how can altruistic behavior be reconciled with Darwin’s theory of evolution? Darwin’s mechanism of natural selection implies that individuals work in their own self-interest, and that any order or organizational structure that appears in nature is merely a side effect. That is, there are no larger principles at work in nature at higher levels; there are no forces that work "for the good of the species" (or community or even family) that override natural selection at the level of the individual. How can altruism arise when the selfishness in the face of limited resources is what is rewarded? As with virtually everything in evolutionary theory, Gould reminds us, there are political implications that must be considered. If altruism is not consistent with Darwinism, then it could be argued that our animal nature is to be "brutish" [ESD 30], and that "civilized behavior" is nothing but a veneer of learned behavior. (The fact that altruistic and other cooperative behaviors are found throughout the animal kingdom undercuts this argument logically, but not always politically.)

The solution Gould presents to the apparent paradox of altruism, where individuals do appear to sacrifice their own interests for those of another, is called "kin selection." It was first proposed by the great evolutionary theorist J.B.S. Haldane [discussed in another context in LSM 20], and modeled with more mathematical rigor by W. D. Hamilton in the 1960's. While he disagrees with certain themes in E.O. Wilson's *Sociobiology* [see previous essay], here Gould supports his extensive use of kin selection. This model argues that it is to the individual's *selective* advantage to sacrifice one's own life for two brothers (or eight cousins), in the sense that such a sacrifice would allow more of one's genes to pass to the next generation. This is, obviously, a mathematical argument, not a behavioral one. It does not mean that individuals perform calculations before deciding whether to behave altruistically; only that altruistic behavior can, theoretically, be consistent with natural selection's "survival of the fittest" criterion that the individual organism benefit. [As discussed ESD 11, what really matters in Darwin's theory is reproductive success.] Once it is determined that self-sacrifice can be consistent with self-interest, at least theoretically, then one can extend the argument to "allow" other forms of altruistic behavior within Darwinism generally.

An important and specific line of support within the animal kingdom for genetically-driven kin selection comes from insects that form large colonies, particularly ants, bees, and wasps. (E. O. Wilson is, first and foremost, an expert on ants.) Most animals are diploid, meaning that they have two copies of each chromosome – one from each parent. Some individuals within some species, mostly insects, are haploid; they have only one copy, and are produced without fertilization. There are a number of species in which the females are diploid and the males are haploid; this is called haplodiploidy. All of the social insects – ants, bees, and in fact the entire order of Hymenoptera – are all haplodiploid. (Gould notes that termites, which also live in large colonies, are diploid.) Another factor that characterizes the social insects is the existence of a large "worker caste" of sterile females within the colony. This re-introduces the "altruistic problem": since evolution is supposed to work on individuals, why do individual workers put effort in to helping another – the queen – reproduce? Further, why are the workers in such colonies always entirely female? The answer offered is that female workers in haplodiploid species share 75% of their genes with their sisters (including those in eggs just laid by the queen), which is more than the 50% that fertile females in diploid species leave in their offspring. The 75% figure is due to the fact that the daughters receive all, rather than half, of the father's genes, since he is haploid; this increases the genetic similarity between sisters. Males, on the other hand, share only 25% of their genes with their sisters, in part because they simply have less genetic material. If one views natural selection in terms of leaving more copies of one's genetic material to future generations, as opposed to directly producing offspring, then one can argue that the apparently altruistic behavior of the worker class of insects is consistent with Darwin's theory. This approach also provides an explanation for why the workers are all female. (It does not explain social behavior in termites, but Gould points out that the workers in those species are both male and female.) He briefly discusses some more recent publications that are also consistent with this viewpoint.

Even if true, do these conclusions about social behavior in certain insect groups bear any relationship to altruistic behavior in humans? In a very general way, they do, he argues; it suggests that human kindness may be as much part of our "animal nature" as cruelty, rather than the result of an overlay of civilization that we chafe against. However, he remains strongly opposed to associating any specific human behaviors to genetic control. He reiterates his view on biological potential versus determinism from the previous essay: we cannot say that humans are kind for the same reason that worker bees are female, only that kindness as well as cruelty is within the range of behaviors allowed by Darwinian principles.

[The issue addressed here introduces another problem: whether natural selection can work at levels above (groups or species) or below (genes) the level of individual. This was and continues to be a highly contentious issue within the professional community, and it has some far-ranging implications. Gould seems to begin as a conventional believer that all biological behavior could be explained in terms of selective advantages to the individual – see ESD 10 and 11 – but his views changed over time. In TPT 8, he specifically challenges Richard Dawkins' "Selfish Gene" model, which argues that selection works exclusively at the level of the gene and not the individual. In HTHT 13, he discusses a different argument by Francis Crick, who argues that DNA can, under some circumstances, also be "selected," and expresses support for the idea. In BFB 22, he discusses how the almost-forgotten work of Kropotkin, who focused on competition with the environment for survival rather than other individuals; in such environments, altruism and Darwin's theory are much less incompatible. By ELP 22 and 28, he appears to have accepted species sorting – he dislikes the phrase "species selection" – as a process that is analogous to natural selection, and directly tied to his evolved views on punctuated equilibrium. This final perspective makes it into his last work, *The Structure of Evolutionary Theory* (2002).]