The Flamingo's Smile

TFS 1. The Flamingo's Smile

This essay presents three examples of animals that have evolved to live "upside down," and discusses the morphological and behavioral changes that natural selection has produced as a result. It also discusses the question – settled in the 19th century – as to which comes first, the new forms and structures, or the new function or mode of living.

The first example is the flamingo. In addition to their bright color, they are noted for being filter feeders; they are the only birds that have evolved this lifestyle, and one of only a handful of vertebrates. Flamingos feed on small crustaceans and other organisms that inhabit hypersaline lakes. They have managed to evolve a whalebone-like filter inside their beaks that strain these creatures from the water, along with a most un-birdlike muscular tongue that acts as a pump. These, however, are not the features that Gould wishes to discuss in this essay. Instead, it is the shape of the beak itself, which has been extensively modified to support the flamingo's almost unique behavior of feeding upside down. Giraffes and camels bend their necks to drink, but keep their heads upright; flamingos actually lean straight over to feed, so that their "upper" bill is nearer the bottom of the salty pond and the "lower" bill is closer to the surface.

In general, upper and lower bills (or jaws, in other vertebrates) differ significantly, in large part for functional reasons. In most vertebrates, the upper jaw is fused to the cranium, while the lower jaw moves. In many birds, both the upper and lower jaws are capable of independent movement, but the upper jaw is invariably larger and more rigid. Life "upside down" has led to a reversal of these roles in the flamingo. The beak is bent differently, and the groove in the fixed bill that accommodates the smaller, mobile bill has switched from the "upper" to the "lower." Gould reproduces a famous illustration of the flamingo by J. J. Audubon, first upside down (with the legs and background erased) and then in the correct orientation. In the first picture, the bird and beak appears slightly odd, but in many ways appears more "conventional" than in the correct perspective; the smaller, thinner bill is now on the bottom. Not only has the bill's structure changed, Gould tells us (referencing the work of P. M. Jenkin from 1957), but the function has changed as well. While preening, flamingos will move either or both of their bills; but while eating, the filter-feeding motion is performed exclusively by the operationally lower beak, which is the anatomically upper beak. This, Gould concludes, is consistent with – and evidence of – Darwin's theory of evolution via natural selection; the bill adapts over time to the new mode of life.

As his second example, Gould discusses a species of Caribbean jellyfish, *Cassiopea xamachana*. In addition to extensively modified tentacle and feeding structure, the bell dome of this jellyfish has a concave dimple on the "top." Most jellyfish have smoothly convex bells, to support the hydrodynamic motion required for their feeding habits. But *Cassiopea* turns upside down in shallow water and uses the concave dimple as a suction cup to attach itself to the sea floor. All jellyfish have a series of circular muscles in their bells; the synchronized contractions of these muscles propel the organism through the water. In this species, the topmost muscle ring – at the edge of the suction cup – controls the adhesion function. (Gould notes that natural selection must make use of the parts available; in this case, a propulsion muscle for anchoring the jellyfish in place! Such contrivances, he notes, are some of the best evidence we have that evolution has actually occurred; he references his essay *The Pandas's Thumb* [TPT 1].)

After presenting these two examples of natural selection changing both form and function of organic structures when a creature changes its lifestyle, Gould poses a question: Which came first, the new form, or the new function? The question was the subject of a great, albeit forgotten, debate between two groups of evolutionists in the early and mid-19th century, and finally settled by Darwin after publication of *Origin of Species* in 1859. On one side were the structuralists, such as Etienne Geoffroy Saint-Hilaire, who argued that the form changed first – and then found a new way to use it. In the case of the flamingo, structuralists argued that changes in the beak *allowed* the animal to exploit a new feeding style and resource. They looked for "laws of form" [see TFS 4] that guided these modifications. On the other side were the functionalists, whose most famous advocate was Jean Baptiste Lamarck. Functionalists argued that the behavior of the creature in question changed first (usually out of dire necessity), at which point key characteristics would evolve via a selective "pressure" in response.

Lamarck got the evolutionary mechanism wrong, arguing for a force generated by the flamingo itself in response to the environment; in his model, the stress would lead to small but inheritable modifications ("the inheritance of acquired characteristics"). But Lamarck's side was determined to be correct in the larger debate, Gould notes, primarily on the theoretical argument of simplicity; in most cases, the function changes before the form. It is much easier to imagine a proto-flamingo with a "normal" bill entering a new and marginal environment and having to adapt to it, rather than an upside-down beak appearing in a population which then proceeds to find saline lakes to feed in [but see ELP 26].

Gould offers a third "inverted life" example to further illustrate the point. There is an African catfish that swims upside down, so that it can feed on algae growing on the bottom of leaves that float on the water's surface. Intriguingly, its coloration pattern has been reversed. Animals that use counter shading as a form of camouflage are dark on top and light on the bottom, to counter the effects of sunlight illumination [see BFB 14]. The catfish in question has reversed this pattern, and is dark on its belly and light on its back. Since no major morphological changes in shape or fin location have occurred (yet), we can conclude that we have caught this change at an early stage; *first* the functional lifestyle changes, and *then* natural selection works to optimize the the result. Gould briefly refers to another proposed inversion by Geoffroy Saint-Hilaire, who notes that an inverted annelid (e.g., earthworm) resembles a simple vertebrate in some key ways. [He will later dedicate an essay to this particular case – see LMC 17.]

[In many of his essays, Gould criticizes the "overreach" of the contemporary adaptationist community, particularly in their claims that natural selection dominates the structural form of existing species in driving evolutionary change. In fact, much of his final 2002 work, *The Structure of Evolutionary Theory,* will argue that there are in fact many cases in which the form is modified "via accident" before a new function is established; also see ELP 26. Gould's later writing shows a great deal of support for Geoffroy Saint-Hilaire in particular. However, in this essay, he focuses on the area where his views coincide with the adaptationists; he sides with them over the structuralists, or formalists. In general, he believes both mechanisms are important.]

TFS 2. Only His Wings Remained

A set of puzzles that continually bothered Darwin was the appearance in nature of features that seemed counterintuitive to natural selection. Two notable examples were the huge, heavy antlers of the extinct Irish Elk [ESD 9], and the attention-grabbing and unwieldy tail plumage of the peacock. The general solution he developed was that these features existed because they assisted the hosts in reproducing in one of two ways: by out-competing other males of the same species for the opportunity to mate (e.g., big antlers), or by directly appealing to the preferences of individual females who could choose among several suitors (e.g., peacock tails). Darwin called this evolutionary mechanism *sexual selection*. Natural selection and sexual selection could work against each other in practice – a larger peacock display might be more appealing to a peahen, but also make the host more vulnerable to a predator. However, both support the same long-term goal: producing more offspring.

Darwin published *The Descent of Man* in 1871. Gould summarizes this book, which is divided into three parts. The first part explores the question of the origin of races within the human species. Dark skin has apparently arisen independently multiple times, always in tropical regions (Gould summarizes), and so is likely an example of adaptation to the local environment via the mechanism of natural selection. However, there are many other features in various groups of humans that make no sense to attribute to preferential survival in a particular environment: the detailed shape of a nose, ear, or leg, or the texture of hair. What could explain the consistency of such functionally arbitrary features among members of each race or tribe? This leads to the second and largest part of the book, which argues for the existence of sexual selection in the animal world. The third part presents the argument that many unique characteristics of each race of humans are due to the mechanism of sexual selection.

(*The Descent of Man* is widely misunderstood, Gould tells us. It is not Darwin's presentation of his views on the evolution of humans from earlier species. The book is about sexual selection, and how this mechanism is capable of producing differing human races from a single common ancestral group. Darwin always avoided speculation; his methodology was to present a plethora of detailed examples in support of smaller but provable points [see HTHT 9]. In 1871, no hominid fossils other than Neanderthals had been discovered. He does, however, note that humans are probably related to apes.)

Many of Gould's early essays present examples of how Darwin's theory can, with the proper interpretation, explain features or behaviors that, on their surface to violate the view that the living world around us is exclusively the result of individuals struggling for their own existence. The example he offers here comes under the heading of "sexual cannibalism." The scientific literature contains anecdotal evidence – usually involving insects, spiders, and their kin – in which the male is eaten by the female after mating. Darwinian theory would appear to favor males that can live to mate again over those who mate and then die. However, Gould references a recent paper by Buskirk, Frohlich, and Ross, which modeled this problem mathematically. The model showed that, if two conditions were met, such behavior could be consistent with Darwin's theory. First, the probability of the male mating again would have to be low; and second, the nourishment that the male's body would provide the female would have to significantly increase the probability that the offspring would be born and survive. Since nature is incredibly diverse, such situations should arise periodically. So the question becomes, in practice, can a combination of natural selection and sexual selection produce a species in which the male "evolves" to be both a sexual partner and a food source for its mate? Can these forces produce a male organism that would give up its life to reproduce?

Gould confesses that, when he started writing this essay, he expected the answer to be "yes." However, Buskirk, Frohlich, and Ross did more than create a mathematical model; they searched for real-world examples, and found very few. Even their best cases, Gould states, are remarkably unconvincing. He notes that it is not sufficient to establish sexual cannibalism as a mode of life if the female simply eats everything in range, and the male merely fails to escape a small percentage of the time; the male must be eaten regularly, if not always, after copulation. Gould discusses the top three examples the paper offers. The first involves a species of praying mantis, in which males try to escape afterwards but are occasionally caught and eaten. (Gould presents an extended 19th century description in which "only his wings remained," producing the essay's title.) The important factor in this case is that the male appears to "try harder" to mate after its head has been eaten off. Such behavior could be indicative, Gould offers, of an adaptation to this mode of life. The authors of the paper found, however, that the male's mating behavior is "hard-wired" via a smaller ganglion in the abdomen; apparently the brain overrides this activity most of the time, when functioning. (Female mantises also exhibit egg-laying motions for a while if decapitated, we are told.) With this mechanism established, the occasional post-mortem mating that may result does not convince Gould that it represents a selected adaptation. He notes in a postscript that further studies indicate sexual cannibalism in a different species of mantis is virtually non-existent.

The second example offered by the paper involves the black widow spider. Females in their webs will attack males (and almost everything else) as they approach, and eat them if they catch them. The males approach very carefully; but if they succeed in mating, they appear far less cautious afterwards, and often remain in the female's web; this suggests self-sacrificial behavior. However, the authors noted, the males insert sperm with small organs called palps, and these palps often break off during mating. On the one hand, this likely prevents the males from mating again, thus meeting one of the requirements of the paper's mathematical model. On the other hand, the male is so small compared to the female – about 2% – that it appears to fail the second requirement. Also, it is possible that the male's apparently careless post-coital behavior could be the result of this injury. Worst of all for this scenario, the male is usually not eaten after coitus, and in fact is often found intact but dead days later, still in the female's web. The third case, involving scorpions, is very weak (Gould says). It is clearly a case of a smaller male occasionally failing to escape from a rapacious female after mating.

Gould acknowledges his confusion. It seemed to him that Darwin's theory ought to provide for at least a few cases of unambiguous sexual cannibalism in nature; but it seems not to. Perhaps, he offers, this perspective is still correct, but – at least at this geologic moment – the constraints of history preclude natural and/or sexual selection from fulfilling their potential in this regard. In the end, however, he is forced to conclude that the actual puzzle may be why such behavior does not seem to exist.

TFS 3. Sex and Size

Gould examines three organisms that change sex as they change size. In most phyla, such organisms usually begin as males, and turn female as they grow; this is called *protandry* ("male first"). In our own phylum of vertebrates, however, *protogyny* ("female first") is more common. Gould puts forth a Darwinian hypothesis: protandry is the default in nature, because in most species, large size is more advantageous to females [see HTHT 1]. However, protogyny can be more common in species with more complex behaviors; these may be examples of sexual selection overriding natural selection. If true, Gould argues, this would be additional evidence that we live in a Darwinian world; one in which the struggle of the individual outweighs what would be best, or most efficient, for the species as a whole. He turns to examples to see if this hypothesis can be supported.

His first example is a limpet, *Crepidula fornicata*, which is a type of snail with a simple, domed shell (looking much like half of a bivalve, but without the other half). These limpets form "stacks"; larger members are on the bottom, and smaller "juvenile" members attaching themselves to the top from time to time. Consistent with the simplicity of the snail's brain, the larger members are consistently female, and the juveniles develop into small adult males. The males grow; when they reach a certain size, they begin their transition to female. More juveniles arrive, and the process continues.

Gould's second example, which involves protogyny, involves a species of tropical marine fish. Here, the male is larger, maintains a "harem" of about eight females, and aggressively struggles with other males to maintain his control – all characteristics of sexual selection. When the male is removed, one of the females changes sex and becomes male. It also develops gaudier colors, longer fin spines, and – importantly – grows larger. This is consistent with Gould's hypothesis, but there are many other possible explanations. Can we find an example, he asks, in which a non-vertebrate species becomes female as it grows larger, and then becomes male again when it grows smaller?

The answer, he states, is "yes," but it does not come from the animal kingdom; animal growth tends to be in one direction only. However, there are plants that change size in both directions, often repeatedly, over their lifetimes. Gould references the work of Policansky, who studied jack-in-the-pulpit plants in the woods around Concord, Massachusetts. The plants of most flowers include both male and female parts, but in the jack-in-the-pulpit, the flowers are either all male or all female. These plants, being perennials, can grow back smaller in years after producing many seeds, or after having been nibbled. Policansky found that there is a median height which, if achieved by the smaller male plant, will start the process of conversion to female. And, to Gould's delight, if a female plant falls below the threshold size, it transitions back to male.

TFS 4. Living with Connections

This is an essay about conjoined twins, and in particular whether "they" are one person or two. Most people today would argue for two, but this has not always been the case. Further, from an embryological and developmental point of view, the answer is in fact not clear-cut. Gould begins with several examples of conjoined twins, including Cheng and Eng, the famous pair from what is now Thailand, which gave us the term "Siamese twins." He also refers to a large 19th century collection of "monstrosities," most of whom died at birth or shortly thereafter, that remain on display in a museum in Paris. Gould came across this collection accidentally, while exploring the museum's voluminous contents. (He discusses the Victorian museum strategy of maximizing the quantity of items on display, which is quite different than our current model of selected examples, careful wording, and good lighting. He discusses the Victorian style in more detail in DIH 18.)

One preserved skeleton demanded more attention, due to its larger size. It was the remains of twins born in 1829, who had lived for several months, and given the names Ritta and Christina (or Ritta-Christina). She/they were well-separated above the waist (two heads, four arms, two spines), but had only one lower body (one pelvis, two legs). Two days later, in a specialty book store, he came across a scientific volume from 1833 that discussed this very case; in fact the author, a major anatomist of his day named Etienne Serres, had dissected the body/bodies after death. Serres was trying to extend a particular theory of biological development to embryology, a field that was then in its infancy. Special cases such as Ritta-Christina offered insight into the natural process (true now as well as then). For Serres, Gould tells us, the crux of the matter could be boiled down to whether the case before him represented one person or two.

Serres' developmental paradigm was a form of romantic biology called *Naturphilosophe* ("Nature Philosophy"), or, as it was called in his native France, transcendental morphology. (It has long since been discredited and almost completely forgotten [but see Oken in TFS 13.]) It was based on the concepts of one of the most influential of all western thinkers, Plato. In Plato's view, organisms were ephemeral and imperfect shadows of eternal and perfect *forms*. To 19th-century Platonists, the goal was to use science to determine the nature of these forms. When considering the development of an organism, the underlying reality that the imperfect world attempted to follow were called *laws of form*, and the goal again was to understand their nature. The puzzle that the transcendental morphologists faced was how two clearly separate form-following beings (above the waist) could fuse so perfectly into a single being, representing a single "perfect form" below the waist. Gould summarizes the three laws of form that Serres advocated, and follows his arguments to his conclusion that Ritta-Christina was, in fact, two people (representing two forms).

Today, Gould tells us, we know that embryos are cells that begin dividing from a single ovum after fertilization. Sometimes, in the early stages of dividing, the embryo separates into two separate and genetically identical clumps, each one of which produces a complete fetus; these are identical twins. In very rare cases, the embryo starts to separate, but does not complete the process; the result is conjoined twins. Gould's view is that "one or two?" is the wrong question. Humans readily quantify organisms using integers; but underneath, he argues, nature is really continuous, not discrete. Ritta and Christina fall in the middle; in Gould's view, they are neither "one" nor "two," but somewhere in between.

TFS 5. A Most Ingenious Paradox

The paradox that Gould refers to in the title is really more of a puzzle: in biology, how does one tell the difference between a colony and an organism? The answer would appear obvious, so he introduces some examples that fall in between the two categories. Most of the examples are the siphonophores, a sub-class of the phylum Cnidaria (the "c" is silent). Cnidarians, or "stinging cell animals," include jellyfish (clearly organisms) and coral (clearly colonies; polyps reproduce by budding to form more polyps which remain connected, but each is a complete individual). Siphonophores, such as the famous Portuguese man-of-war, appear to be large jellyfish with distinct organs, but closer examination suggests that they are an aggregation of distinct, individual organisms. However, these "individuals" are not, in general, capable of surviving if separated from the rest of the group; most cannot feed themselves. The title thus reflects the question: is a siphonophore a colony or an organism?

We are introduced to some cnidarian biology at this point. Prototypical cnidarians have a complex life cycle that includes both sexual and asexual reproduction. The polyp is generally cylindrical in shape and invariably fixed to a surface, and uses tentacles fringing the mouth to capture food. It generally reproduces asexually, by budding. But the "bud" is not another polyp, but rather a free-swimming medusa ("jellyfish"). It is this medusa that produces sexual cells, which merge with others and then grow to form new polyps. Some cnidarians, such as the Scyphozoa (true jellyfish) have largely eliminated the polyp stage. Others, such as the Anthoza (true corals), have abandoned the medusa phase and go directly from polyp to polyp by budding. The third major group of cnidarians are the Hydrozoa, which retain both phases; siphonophores are a type of hydrozoan. But unlike even most hydrozoans, siphonophores are not a single medusa, even though they appear so. Each "tentacle" is an individual polyp, and the float is probably a reduced medusa with no tentacles of its own. There are other components as well: sex organs, other float-like bodies that propel the organism/colony, and more. Some of these components have their own nervous systems, but there is another nerve that runs among them and coordinates their movements. Only one component ingests food (through bell-shaped openings that look like siphons, hence the group name); the digested products are distributed throughout the rest of the siphonophores. Is it an organism with multiple organs, as its function suggests? Or is it a colony composed of different types of individuals, as its phylogeny (evolutionary history) seems to imply?

Gould suggests that following its life cycle might provide some additional information. It does, but this also turns out to be ambiguous. Each siphonophore does begin life as a single fertilized egg, suggesting organism. However, as it develops, the various components are generated by budding, and never detach themselves. This is similar to the process that takes place in corals and in plants such as bamboo, which are considered colonial. Further, some of the specialized structures have vestiges of eye spots, mouths, and other components suggesting that they are descended from free-standing individuals; this again suggests the aggregate is a colony. What is the resolution to the paradox? Gould's view is that there isn't one; the question is flawed because it falsely implies that siphonophores must be one or the other. Nature is a continuum, and this is one of the places where we cannot avoid the ambiguity. [While he does not say so here, Gould's interest in this subject is due in part to his interest in the idea that mechanisms analogous to natural selection operate at levels above the individual, such as the group or species. This is an important theme in his 2002 work *The Structure of Evolutionary Theory*. If, he seems to imply, there is no clear delineation between one taxonomic "level" and another, then the view that evolution can select for groups or species becomes more palatable. He elaborates on this in DIH 26.]

The essay notes that Thomas Huxley and Louis Agassiz squared off on this issue, over this very creature, in the 19th century. (Huxley argued for organism, Agassiz for colony. Ernst Haeckel argued for a strange middle ground via an analogy with human civilization. Haeckel, also an excellent artist, drew many of the beautiful but overly-perfect figures that Gould includes in the essay.) Gould also briefly discusses ants, aphids, bamboo, and other species that blur the line between organism and colony [also see ESD 11]. He notes that animals with organs, and multicellular life in general, probably have their origins in some sort of colonial behavior.

TFS 6. Adam's Navel

By the dawn of the 19th century, it was apparent even to believers in a "young earth" that the extensive geologic and paleontological record required an explanation. Some sedimentary strata are miles thick, and many contain evidence of living organisms very different from those alive today. How can these facts be squared with a single act of creation, followed by a mere six thousand years of time? Today's creationists, Gould flatly states, have no real interest in the evidence; at most they associate such strata with Noah's flood, and leave it at that. In the past, however, there were some sincere attempts to reconcile fossils and strata with scripture. Some proposals were fairly simple: they are tests of faith, or evidence that God had a sense of humor. In this essay, Gould discusses one of the more complex attempts, by a man who loved both Christianity and fossils. It failed, even in its own day, but (Gould offers) such failures often provide more insight into the minds of the people of the time than the successes.

Philip Henry Gosse (1810 – 1888) was a dedicated English naturalist, geologist, and member of the Royal Society who spent many years in the field. He published in professional journals, and lectured widely to the public on his areas of expertise, which were several. He was also a devout Christian, and a Biblical literalist. The debate between those who supported a young earth and those who favored "deep time" troubled him greatly, and he labored to come up with a worldview that was consistent with both geological observation and Genesis. He published his book *Omphalos* in 1857, two years before Darwin published *Origin of Species*. Gould quotes several times from it, partly (he acknowledges) to share the incredibly flowery, over-the-top nature of the prose.

The word *Omphalos* means "navel" in Greek, and is a reference to Adam's Navel. This is, in turn, a reference to a puzzle that had been around for a few centuries, namely: Did he have one? Not being born of woman, Adam had no need for an umbilical cord; on the other hand, perhaps God would make him the same form that all future men and women would be. (Gould notes that some paintings of Adam show not only his groin covered by vegetation, but often his central abdomen as well!) Gosse argues Adam was created with a navel. He extends this view of "creation with the appearance of preexistence" to other forms of life. At the end of the book, he extends the argument to the earth itself, arguing for a young earth that *appears* older. Life, he argues, is "circular"; an egg leads to a chicken which leads to another egg, with no changes, forever. However, if Creation were to start from nothing, there would be a moment of abruptness at the transition. To prevent this, Gosse argued, God created life – 6000 years ago – in the middle of a cycle, complete with "evidence" that it had been going on forever. He referred to events that actually occurred as *diachronic*, and those that took place outside of time as *prochronic*. Thus, Adam's navel would be prochronic; his life as described in *Genesis*, diachronic. *Omphalos* goes on to present a colorfully-written virtual tour of the world an hour after the creation, "visiting" various creatures. For example, using his astute knowledge of biology, he argued that the hippo must have been created with teeth that bore the appearance of years of wear, for unworn teeth would not allow the animal to close its mouth. Many other examples follow. Gould notes that, if we were to accept the postulate that evolution cannot occur, this argument is at least self-consistent.

Despite the fact that some 90 per cent of *Omphalos* is about biology, its stated purpose is to argue geology, and for a young earth. In the last section, Gosse argues by analogy that the earth itself is like his biology, with infinitely and perfectly repeating cycles. In this, Gould argues, he stumbles badly. Geological strata do not appear cyclical, and suggest instead a straight-line progression. Worse, what are we to make of the fossil trilobites that Gosse himself loved? Where is the cycle there? Gosse offers a weak analogy: a fossil is to a modern organism as an egg is to an adult, and therefore also implies a cycle.

Gosse hoped that his argument would satisfy both communities. To the devout literalists, he offered a young earth. To the geologists, he offered the promise that, since the strata and fossils also represented God's thoughts, they were still fully worthy of study. Much to his surprise and dismay, his book was either ridiculed or ignored by both camps. (Gould draws on the autobiography of his son, Edmund Gosse, for details. This book, "Father and Son," is considered to be a classic piece of English literature.) Christians would not accept the inevitable implication that, even with good intentions, God had written a lie into the geologic record. The scientific community would not accept the premise that what they were studying was prochronic (that is, "not real"), even with the "concession" that it was important anyway. By today's scientific standards, Gould concludes, the true undoing of *Omphalos* was his claim that the prochronic fossils and strata were completely indistinguishable from what they would have been if they actually had lived and formed over eons. If they are indistinguishable (as they must be, for

Gosse's thesis to hold), then by definition there is no way to test whether his theory is true or false; and therefore, also by definition, it cannot be scientific. The flaw with Gosse's theory is not that it is wrong (how could we tell?); it is that it is useless.

TFS 7. The Freezing of Noah

The Reverend William Buckland (1784-1856) was a creationist his entire life. [He was also the first "official" geologist of Oxford University, ally to Richard Owen (LSM 9), and author of one of the Bridgewater Treatises (HTHT 2).] But unlike today's creationists, Gould writes, Buckland was a legitimate scientist struggling with the issues of the day, and most decidedly not a dogmatist. In this essay, Gould tells the story of how Buckland used geological evidence found in caves and in English soil to argue for the existence of Noah's flood, although most geologists had long since rejected it. Gould stoutly defends Buckland in this essay. He does so because his evidence was real, and his theory testable. When further research argued against his theory, Buckland (and his supporter and fellow Anglican Reverend/Geologist, Adam Sedgewick) acknowledged it, and admitted that the model could not be correct. Buckland went further, and actively supported Louis Agassiz, who correctly identified Buckland's findings as evidence for what we today call the ice age. As Gould tells us, this is science working at its best: testable hypotheses based on empirical evidence, and acceptance when the evidence fails to support it. He closes with one of his recurring themes: religion is not the enemy of science; irrationalism and dogmatism are.

In 1823, Buckland published a book whose English title is "Relics of the Flood: Observations on the Organic Remains Contained in Caves, Fissures, and Diluvial Gravel, and on Other Geological Phenomena Attesting to the Action of a Universal Deluge." While he did believe he had found evidence for a worldwide flood, he did not consider it to be the source of all strata, merely the last in a series. Buckland firmly believed in an ancient earth. Gould quotes a passage written by Buckland in 1836:

> Some have attempted to ascribe the formation of all the stratified rocks to the effects of the Mosaic Deluge; an opinion which is irreconcilable with the enormous thickness and almost infinite subdivisions of these strata, and with the numerous and regular successions which they contain of the remains of animals and vegetables, differing more and more widely from existing species, as the strata in which we find them are older, or placed at greater depths.

(Gould, as an expert witness in the 1982 Arkansas "Creation Science" trial, offered this paragraph as part of his testimony.) Buckland offered three lines of evidence for his conclusion that the earth experienced a universal flood in fairly recent times. The first was in the form of debris found inside of caves, of which he was an avid explorer. From the detailed nature of the fractured bones found there, he correctly concluded that the caves had been hyena dens; hyenas do not live in England today. He also correctly identified many of the bone fragments as having belonged to elephants and rhinoceroses. His conclusion was that the caves were areas that had been sealed with silt during the flood, thus preserving a record of the antediluvian world; these were animals that had not made it to Noah's ark. Since all of these animals live in tropical regions today, he assumed that the flood was also associated with a dramatic cooling of the climate, although he offered no speculations as to why this might have occurred. (Today we recognize them as Pleistocene animals: hairy, cold-weather versions of beasts whose only relatives today live in the tropics.)

The second line of evidence was the distributions of extensive layers of loam and coarse pebbles throughout England and northern Europe, recognizable markers of large-scale flooding. (These in fact turned out to be remnants of the ice sheets, and the resulting smaller-scale flooding that resulted from their periodic melting. He correctly identified the direction of the flooding as coming from the north.) The third line of evidence involved the contours of the hills and valleys of the region, which appeared to be shaped in part by moving water. He also noted the presence of large boulders many miles from their correctly-identified origins far up on mountains. He interpreted these to mean that the floodwaters had risen that high; today we recognize that they were carried down these mountains by now-vanished glaciers.

All of these, Gould tells us, were reasonable interpretations, based on accurate observations. The theory was debated at the Royal Society and elsewhere in the 1830's, with T. H. Huxley and Rupert Murchison leading the opposition. The model fell apart in the 1830's when it became apparent that the ages of the cave deposits were not all the same, as a single universal flood would require. Also, the dates of the gravelly soils in question also differed from the times when the caves were active, and from each other. It also became clear that the southern parts of Europe did not have the same layers of loam and gravel (since the glaciers did not reach there); strong evidence that the event was not, in fact, universal.

TFS 8. False Premise, Good Science

Aristotle believed that the world had existed forever. After the fall of Rome, what few European scholars remained used the Bible to calculate the earth's age; Bishop Ussher [ELP 12], who calculated the year of creation as 4004 B.C., was merely one of the last of these. Given this short amount of geologic time and the scope of earth's mountains, canyons, and other features, it is perhaps not surprising that hundreds of speculative theories of earth's formation – most involving cataclysmic events – were produced. The work of Steno and Hutton [HTHT 5 & 6, respectively] convinced most scientists that the earth was actually far older than this. In 1830, Charles Lyell proposed his theory of uniformity, which stated that processes that we observe today, coupled with vast amounts of "deep time," could account for all geologic features. He argued forcefully that, if geology was to become a science, all speculation – and to him, this included all catastrophic proposals that no human had ever witnessed – must be abandoned [ESD 18]. Darwin, a young protégé of Lyell, agreed completely, and argued that evolution must be similarly continuous, gradual, and slow. Lyell's view of earth's actual age was, if not infinite, then close to it; perhaps 20 billion years. (Today, the earth is recognized as about 4.6 billion years old.) He also believed that, for most of this time, it had been very similar to the world today. [Later he allowed for some cycling of global temperatures, in an analogy to seasons; see TPT 12]. Then, in 1866, the great physicist William Thompson (Lord Kelvin) wrote a paper with the title, *The 'Doctrine of Uniformity' in Geology Briefly Refuted*. Gould quotes the entire paper, excluding the calculation; it is less than a page. He credits it with being the most arrogant title in the history of science.

William Thompson (1824 – 1907) made major contributions to the understanding of electricity and magnetism, and was one of the founding fathers of thermodynamics. [He worked on several important practical problems of the day as well, such as the trans-Atlantic cable, and acquired several patents.] He was also legendary for his intimidating manner. Using the new science of thermodynamics and data from mines and other sources regarding the rate of heat loss through the earth's surface, he estimated the amount of time that had passed since the earth was molten (and thus incapable of forming mountains or strata, or supporting life). The 1866 paper presents the results: between 100 and 500 million years, probably toward the lower end. For most of the next 40 years, he argued that the age of the earth was about 100 million years. This, he believed, was not a sufficient amount of time to support Lyell's uniformity theory as it stood. Also, while not opposed to the concept of evolution, he concluded that the time available was insufficient to support Darwin's theory of natural selection. Darwin himself agreed, and – while he "stuck to his guns" on his theory –considered Thompson's argument to be most troubling. In his last edition of *Origin of Species*, he "conceded" that evolution might have proceeded at a more rapid pace in the distant past than now.

The flaw in Thompson's argument, we now know, is that he did not account for the production of additional heat within the earth via radioactive decay. In fact, the entire earth – other than the crust, which is at most a few tens of miles thick – remains entirely molten. This was scarcely his fault; radioactivity was not discovered until 1903. As the title of this essay suggests, his approach and methodology were valid; it was one of his assumptions ("no additional sources of heat") that was wrong. Thompson was no slouch; he also develolped two other approaches that yielded consistent results, that also shared the same false premise. The first was based on the sun, and how long it could shine based (only) on energy released from gravitational contraction and any possible chemical reactions. The other was based on the nearly spherical shape of the earth. He knew that tidal forces were slowing earth's rotation rate [see TPT 31]. If the earth had solidified billions of years ago, it would have done so at a much faster rotation rate – and this would be apparent in its shape. As discussed above, today we know that the earth never solidified; other than its crust, it is still liquid, and so maintains a shape consistent with its current rotation velocity. Gould references Joe Burchfield's *Lord Kelvin and the Age of the Earth* for these details.

Gould, educated first as a geologist, reports that a false legend has grown up around this saga. All of the above is true; however, the view within the geological community is that Thompson – not a member of their community – stalled progress in his sister field for 40 years with his opposition to uniformitarianism, and nearly drove them back to the bad old days of speculative catastrophism. The moral of this legend, Gould writes, is that "Geologists should have trusted their own intuitions from the start and not bowed before the false lure of physics . . . . [W]e must trust the careful empirical data of a profession and not rely too heavily on theoretical interventions from outside, whatever their apparent credentials."

The real story, he continues, is somewhat different. Most geologists were happy to have an upper limit placed on the age of the earth, as a nearly infinite amount of time present problems of its own. The 100-million-year timeframe was challenging, but most were willing to accept it (until later in Thompson's career, when he reduced his estimate to about 20 million years). It added a "direction" to earth's natural history that was missing from Lyell's vision, and in practice it never threatened to drive geology back into unscientific speculation. Gould also notes that Thompson's attack on Lyell's two different uses of the word "uniformity" – the laws of nature were the same in the past, versus the overall planetary environment and the *rates* of geological processes were the same then as now – was needed [ESD 18]. As to evolutionary biology, Darwin was indeed disturbed, but most members of his community were not. Huxley and Wallace believed that the rate of evolutionary change could be inferred from geology, and both concluded that natural selection therefore simply worked at a faster pace than they had previously thought. (Darwin was more committed to Lyell's specific views on gradualism than most.) This is how science advances, Gould reiterates; not in a straight line, but in a series of twists and turns. In closing, he notes that the discovery of radioactivity not only undid Thompson's arguments, it also became the tool that calculated the true age of the earth, which in turn returned it to the realm of billions of years – geologically ancient.

TFS 9. For Want of a Metaphor

In ESD 25, Gould discusses two obsolete, competing paradigms that attempted to describe how fertilized eggs developed into embryos and then beings: preformationism and epigenesis. Both views date back to the time of Aristotle, but with the invention of the microscope the battle was revisited in the 18th century. This essay is based on a book written by Pierre-Louis Moreau de Maupertuis, a famous French "savant," in 1745. While Maupertuis did not come up with the right answer, he brought to bear arguments that shed light on what the answer could not be. This moved science a small step forward, which, as Gould often notes – with the rarest of exceptions – the only way it moves at all. In the end, he argues that what precluded Maupertuis from having an opportunity to produce a better paradigm was that there was no suitable metaphor in his world to help him bridge the gap. Ways of thinking about things, he argues, are as important as observations to advancing our understanding of nature.

Preformationism postulates that inside the fertilized egg is a preformed, tiny proto-adult called a homunculus. That this homunculus was not visible under the microscopes of the day, supporters argued, was simply because the instruments were not powerful enough. [Better microscopes would eventually lead to the cell-blastula-gastrula-embryo progression that we know today.] Epigenesists, on the other hand, argued that the homunculus did not exist; the embryo appeared to form by differentiating complex parts from simple ones. [Gould discusses the metaphor of differentiation and its association with epigenesis, contrasted with the metaphor of unfolding for preformationism, in IHL

20. He discusses his own position on the “mechanist-vitalist” debate in TFS 25.] Despite the fact that what was seen under the microscope in 1745 appears to be consistent with the latter paradigm, Gould notes that this view is actually the less satisfactory of the two by today’s standards. This was because preformationism proposed a mechanism, albeit an incorrect one, while epigenecism argued for an external “vital force” that interacted with the fertilized egg through non-mechanistic means to form the organism. (The collective term for the views of an external life-force is “vitalism,” which has long since been discredited.)

Maupertuis was in neither of these camps. He considered himself an epigenesist, but was a devout supporter of Newton and his mechanistic view of the universe, and thus rejected vitalist thinking. His 1749 book has the translated title *Physical Love: A Physical Dissertation Inspired by the White Negro*. The first part of the title, we are told, turns out to be a bit of false advertising. While there ae some flowery descriptions about how various animals “do it” (Gould’s choice of words), it is really about embryology as it was understood at the time. Maupertuis’s contribution to the debate was to introduce specific data on how common mutations followed along familial lines. His specific study was how polydactyly (extra fingers) manifested itself in several generations of a German family. Preformationists had always had difficulty with mutations of this sort, due to the problem of *encapsulation*, as follows. If the fertilized egg contains a miniature but complete organism, then each egg (or sperm, if the homunculus was housed by the male – another area of debate) must contain another homunculus. Each of these must also contain them, ad infinitum. In the Christianized version of this paradigm, this implied Eve had all future generations inside her. If this is the case, how does one explain mutations without assuming a bumbling or malicious God?

Maupertuis used the generational polydactyly data of the German family to attack the preformationist paradigm in another way. With regard to the more general problem of the homunculus belonging to either the mother or the father, then why do offspring, on average, resemble both parents? Preformationists argued that the male fluids “influenced” the homunculus inside the female (or vice versa). The data Maupertuis presented was that polydactyly passed with equal probability, and with equal result, through both males and females. But since the homunculus can only reside in one sex or the other, we would expect to see some difference; that we do not is damning. (The preformationist “influence” argument could work for characteristics that varied continuously, such as height, but fails in trying to explain discrete traits.)

The “white Negro” of the book’s subtitle refers specifically to an African albino who was displayed in France and elsewhere during this period. Albinism is another discrete trait, like polydactyly, and again manifests itself in the same way via the maternal or paternal lineages. However, in this case, Maupertuis also played upon the fear and racism of the day. Today, albinism is recognized as a genetic mutation that appears in all races (and many species), and does not alter the host’s race. But at the time, people believed that the “trait” exhibited by this African was that he was, in fact, white. In the preformationist paradigm, this meant that an ancestral African’s eggs included at least some with a white homunculus. If this were so, then it followed that some (white) Europeans might be harboring some eggs with a black homunculus! This, Gould implies, helped render preformationism as socially as well as scientifically unacceptable.

The last section discusses the alternative that Maupertuis proposes. His model was that both the egg and the sperm contained miniature eyes, noses, fingers, kidneys, and so on, and that the mixing associated with fertilization would "assemble" the pre-embryo from these parts. This model thus offered an explanation for extra fingers, as well as the similarity of appearance of offspring to both parents. He tried to propose a mechanism, vaguely analogous to Newton's gravity to bring the parts together correctly (thus explaining why extra fingers always appeared on the hand and never on, say, the forehead); but even he found this to be not very satisfying. His insight was good, Gould concludes, but his problem was that he was still thinking in terms of discrete parts. The metaphor he needed, that of "instructions" (DNA) as opposed to parts, was still some decades away. Music boxes existed, but the automated looms that eventually lead to Hollerith punch cards, programmed instructions, and computers would not come about until the early 19th century.

TFS 10. Of Wasps and WASPs

Alfred C. Kinsey (1894 – 1956) was a Harvard-educated entomologist who studied *Cynips*, a genus of wasp, for most of his career at Indiana University. After being tasked by the University to organize a student-requested course on "marriage" (that is, human sexuality), he reviewed the field, but discovered that there was very little hard data to draw on. He essentially changed fields to focus on the problem. His 1948 report "Sexual Behavior in the Human Male" caused a stir; it discussed his findings on numerous taboo subjects, including not only homosexuality but pedophilia. But his 1953 report "Sexual Behavior in the Human Female" produced a complete uproar. This was in large part due to the findings themselves: women were found to routinely engage in pre-marital and extra-marital sex, for example. As was the case with his report on male sexuality, however, another source of the powerful counter reaction was the report's tone: non-judgmental. At the peak of the McCarthy era, openly discussing the "degeneracy" of American womanhood, and apparently condoning it, was interpreted as near-treasonous; it undermined America's moral character in the face of her enemies. His external funding largely dried up, and he died a few years later.

Most people who even know of Kinsey's career in entomology assume there is little connection between it and his sex studies. Gould tells us that this is not the case. Kinsey's research on both wasps and "WASPs" reflect a common methodology and, more importantly, a common worldview. (WASP, or white Anglo-Saxon Protestant, was a popular acronym at the time the essay was written, and was associated with the "ruling class" in America. Gould notes that, while Kinsey did limit his samples to white Americans, he did not restrict it to only those of British or Protestant descent. Nonetheless, the pun remains.) Kinsey collected hundreds of thousands of wasp specimens in his career. He did not do so simply because he liked collecting; he did so because he drew on a different taxonomic model than most scientists at the time. He believed that variation within species, and even within and between populations, was "primary, copious, and irreducible." He saw species as a *range* of characteristics; this differed from the majority view that assumed the existence of an "essential set" of characteristics, with variation as a nuisance to be averaged out. (This essentialist paradigm dates back to Plato and his perfect or eternal forms; in this view, each species is associated with an ideal, and variations are essentially ways in which individuals fall short of these ideals. This view still held sway in the 1940's, and as a result most entomologists felt it was necessary to collect only a few examples of each species in order to name and describe it.) Kinsey, Gould tells us, was a radical anti-essentialist. He sometimes went too far, naming dozens of species that today are recognized as regional variants, only transient in their existence (since they can still interbreed with other populations.) Nonetheless, his view that variation is what is "real" in species – a view that Darwin depended on – is widely appreciated today. Gould references Ernst Mayr's 1982 book, *The Growth of Biological Thought*.

With this understanding, Gould continues, we can see how Kinsey's work on human sexuality drew on his earlier efforts with wasps, and his view of variation. His sample sizes had to be large, first of all, so that the range of variation in sexual behavior could be determined. This was noticeably in contrast to earlier studies, which focused on determining "normal" and "abnormal." He studied both within-population variations (the range of behaviors of, say, Indiana University students) and between-population variations (old and young, urban and rural, successful and those in prisons, and so on). Secondly, he avoided rigid categories. He famously posited a six-point scale between heterosexual and homosexual, for example, and solicited information to determine where on this "continuum" each subject fell. The third key connection between his two careers is reflected in the absence of judgment on sexual variation. As Gould notes, how could a man like Kinsey condemn the very variation that he felt was so fundamental in nature? Kinsey's critics often stated that absence of judgment on human behavior is, itself, a judgment. On this point, Gould agrees. He adds that he shares Kinsey's "judgment" in this regard; this should come as no surprise, since they are both taxonomists, and both inherently "like" variation. Gould also notes that Kinsey's perspective on variation (not better or worse, just different) makes it more difficult to use science to justify racism.

TFS 11. Opus 100

This essay's title reflects the fact that is the one hundredth Gould has written for his column "This View of Life" in *Natural History* magazine; he states his pride in having never missed an issue or a deadline. As an indulgence, he tells us, he will break one of his unwritten rules and discuss the mainstay of his own research: a genus of land snails called *Cerion*. The origin of this rule, he tells us, was a fear of coming across as a doting parent with endless baby pictures and home movies. He does not wish to bore, and is concerned precisely because he finds these snails so fascinating. He asks for our understanding on this special occasion.

He begins with a discussion of how he came to choose *Cerion* as his primary area of study. First, he notes, iconoclastic as he may be, he always recognized the fundamental importance of becoming an expert in some detailed area of biology, as opposed to simply attempting to be a "big-picture" person. One cannot, he states, become a generalist without first becoming a specialist in something, because it is necessary to have some personal experience and expertise to generalize from. To appreciate the nuances of how nature actually works, one must live for an extended time in the details. He reminds us that Darwin wrote four volumes on barnacles before writing one on the origin of species. He adds that some of the best times of his life have come while exploring and gathering data; field work can be very rewarding, emotionally as well as intellectually.

Why land snails in general, and *Cerion* in particular? Gould tells us that, as a graduate student, he decided to focus on the evolution of form (an organism's physical shape), and how the different forms that an individual organism passes through as it grows may act as sources of evolutionary change. (His first published book, *Ontogeny and Phylogeny* – intended for professionals – discusses this subject.) Land snails are attractive for such purposes because the shell preserves a record of its shape over the host's lifetime. Another advantage is that land snails do not move very far (a few meters) over the course of their lives, so living specimens can be associated with a particular environment. *Cerion* in particular is an optimal choice among land snails, because its form varies so widely; there were some 600 named species when Gould started. [He discusses a south Pacific genus, *Partula*, which varies even more widely in ELP 1.] *Cerion* lives mostly on the islands of the Caribbean, with the most diverse populations living on the Bahamas and Cuba. Gould did most of his field work on the former, and much of this on the islands of Grand Bahama and Abaco.

In an extended aside, Gould tells us that his original plan on his first visit (with geneticist and long-time colleague David Woodruff) was to compare living *Cerions* with fossil shells that could be found in "petrified" sand dunes. (During periods of extensive glaciation, sea levels drop, and many of today's islands become connected. Sand dunes form during periods of high sea levels, which include the present and, in this case, two earlier interstitial ["between glaciations"] periods 120,000 and 200,000 years ago. The grains become cemented together, forming rock.) Unfortunately, Gould discovered upon his arrival on Grand Bahama Island that there were no suitable rocks from which fossil snail shells could be extracted. Woodruff, looking to study a different genus, was put off by swarms of mosquitoes. Both were there for a week, so they teamed up and proceeded to study the intimidating array of local *Cerion* species (some 200 with names on that island alone). What followed changed both of their careers; both science and careers in science advance in unpredictable ways.

Large amounts of diversity often exist within groups that spin off new species easily and often. *Cerion*, it turns out, is unusual in that most of the populations on the islands of the Little Bahama Bank and Great Bahama Bank interbreed where they border each other, forming hybrids. ("Banks" are flat-topped undersea mountains that form extended regions of shallow water; islands are high spots on these banks that actually break the surface. Thus, when the sea level falls, the entire bank may be exposed, joining the small separated islands into a few larger ones. Interestingly, the highest regions are not in the middle of the banks, but along the edges; when sea levels are high, the islands are therefore at the edges of these banks.) If the populations can interbreed with each other, then they are – by modern definition – not separate species. This presents a puzzle; how does this genus establish such diversity while maintaining the ability to interbreed? This puzzle involves genetics as well as morphology; interbreeding populations must be genetically similar, so this implies that it is possible that a small change in the genome can lead to large changes in the organism's form.

With this understanding of *Cerion* and the better part of a week to salvage something productive from their field trip, Gould and Woodruff began exploring the island's snails. What they found was that most of the snails belonged to two groups: what they called "ribby" (having thick shells of uniform color with pronounced, reinforcing bands or ribs) and "mottled" (with thin, smooth shells, and blotchy or mottled coloration). Importantly, the ribby snails were always found along the outer edge of the islands – where the bank fell off quickly into deep water, leading to larger waves and rocky beaches. Similarly, the mottled snails were always found in the middle of the islands and along the coasts that face the interior of the banks, where the beaches were sandy and vegetated, and the water calm. The vast majority of named "species" occurred in the regions where the "bank-edge" and "bank-interior" populations met and overlapped; they were the hybrids. Interestingly, these hybrids did not form a continuous transition between the ribby and mottled populations; both morphologically and genetically, they retained characteristics of each. Part of Gould's technical contribution was to show that, despite the ability to hybridize, the ribby and mottled populations each contained not just a few but many unique features. This implies, he tells us, that ribby snails are not simply mottled snails with thicker shells; they are genuinely different.

Gould and Woodruff quickly recognized that they could effectively reduce the 200 or so named species on the islands of the northern Bahamas to only a handful. (*Cerions* that lived on the southern Bahamas and elsewhere in the Caribbean remained separate.) Only with the taxonomic tree simplified in this way, Gould reports, could they detect the pattern of "ribby – bank edge" and "mottled – bank interior," with hybrid-driven diversity at the intersections. Both were ecstatic – a meaningful contribution to science!

But the situation would get stranger. At first they assumed that the ribby and mottled populations would each represent a coherent evolutionary group. But careful analysis of the genome (by Daniel Chung, a student of Woodruff's) and of an indicative part of the soft anatomy (the "penis," by Simon Tillier) showed that populations of the mottled's on different islands were not closely related to each other, nor were the ribby's. That is, it appears that a similar, very complex set of morphological characteristics had arisen independently, multiple times. One might see how the environment would selectively favor some of these features – thick, "ribbed" shells for weathering waves and rocks, versus thin shells for hanging under vegetation, for example – but there were many more that seemed to offer no selective advantage. Evolution, Gould had been taught, was not supposed to work this way. Once species diverged, they continued to diverge; one could always tell the difference between creatures of common ancestry and those that arrived at similar solutions via the process of convergence by examining the details. It was at this time that Gould began to suspect that evolution might follow a series of genetically constrained pathways, rather than being exclusively controlled by natural selection. This has implications for perhaps the thorniest problem in all of evolutionary biology: "How can new and complex forms . . . arise if each requires thousands of separate changes, and if the intermediate stages make little sense as functioning organisms?" [One can see his iconoclastic views against "strict adaptationism" or "strict Darwinism" taking shape. This certainly emphasizes his point at the beginning of the essay that one must study the details of something before one tries to generalize.] He references one of his earlier essays, *Helpful Monsters* [HTHT 15], which discusses the possible role of a hierarchical level of regulating genes on macroevolution. Gould and Woodruff did not solve the mystery of the origin of *Cerion*'s diversity with this work; however, he writes, "we have taken the first step along the only pathway I know."

He adds one more lesson they learned about the diversity of *Cerion* in the Bahamas, drawing on later field trips. Amongst the ribby and mottled populations, they had discovered a few isolated patches of a third, unique group. By examining fossil snail shells from the fossilized sand dunes on several islands, they discovered that this particular species had been abundant 120,000 years ago, during the last glacial interstitial. (No evidence of its existence was found in the earlier, 200,000-year-old dunes.) That is, it appears that the third species is a remnant of a formerly widespread population. [While Gould does not say so here, he apparently noted that this species – as well as fossils of the ribby and mottled groups – were virtually identical to the modern forms. This absence of any apparent "evolution" over more than a hundred thousand years and an ice age likely planted the seed of what would grow into "punctuated equilibrium." Gould returns to the subject of his early field research in DIH 27.]

TFS 12. Human Equality is a Contingent Fact of History

Gould wrote this essay in South Africa in 1984, while lecturing on the history of scientific racism. This piece summarizes the main points of this lecture, and uses the title several times as a "bumper sticker" phrase. He touches on four false models that have argued for the biological inequality of human races in the past. He follows this with three current lines of evolutionary thought that argue that races are, at most, poorly divided subpopulations of humans – meaning that all humans are "equal" in the biological sense. He concludes by explaining his use of the word "contingent" in the title: there is, at this time, only one living species of hominid; but this has not generally been the case, and it is quite possible that the current situation could have been different.

The first of two "genealogical" arguments predates the publication of Darwin's theory. It involves an old but heated debate between the *monogenists* and the *polygenists*; the former believed that Adam and Eve were the ancestors of all mankind, while the latter believed that they were the ancestors of Caucasians only. Either could be used to support racism, although the latter held the edge; it implied that races were different species. Once inequality is introduced, either by separate creation or different degrees of degeneration after expulsion from Eden, the human (or at least Western) desire to "rank" the groups appears. Caucasians invariably end up in first place.

The second genealogical argument is, in some ways, a post-Darwinian modification of the first. It acknowledges a common African ancestor in the distant past, but argues that this creature split into predecessors of our modern races early on. It argues that branches all independently moved convergently toward *Homo sapiens*, but at different rates. Gould references a 1962 book by Carleton Coon entitled *Origin of Races* as this movement's "last gasp." [This model assumes that evolution is a continuous process, and that it tends to move in a specific direction. It still appears in the "multi-regional versus out-of-Africa" debate on Man's origin; see DIH 8 and LMC 10.] Again, it should come as no surprise that all groups independently determined that the Caucasians had the lead in this "race of the races." Gould writes: "We cannot understand much of the history of the late nineteenth – and early twentieth – century anthropology, with its plethora of taxonomic names proposed for nearly every scrap of fossil bone, unless we appreciate its obsession with the identification and ranking of races." [See TFS 18 for how this view is tied to the great chain of being paradigm.] Our modern genealogical understanding, Gould writes, is that *H. sapiens* is one species which came into existence very recently: tens or a few hundreds of thousands of years ago. No one has been able to identify any modern racial characteristics in pre-*sapiens* hominid.

The first of two "geological" arguments is that hominids evolved on the plains of central Asia, on the unsubstantiated argument that this environment was more "challenging" than the tropics of Africa. Raymond Dart's find of an early *Australopithecine* skull in South Africa was ignored, Gould claims, while Piltdown man accepted, in part because of this worldview. As more discoveries made it clear that our lineage did originate in Africa, the fourth argument appeared: some *H. erectus* (Peking Man, Java Man) left Africa, and attained modern form with human consciousness in Asia. Gould again references Coon's book. The current understanding (as of 1984, when he wrote this), was that *H. sapiens* arose from *H. erectus*, but it is not clear whether it was from Asian or African stock that this occurred. [More recent evidence suggests that *H. sapiens* also originated in Africa, and spread to Asia and elsewhere in a separate migration. Some debate remains; see the earlier comment on the "multi-regional versus out-of-Africa" debate.]

The first of Gould's three "positive" arguments for biological human equality comes from taxonomy. The only Linnaean category below species is subspecies. Its use has been largely abandoned by modern taxonomists, Gould writes, because its primary utility has been to describe populations within species, which by definition change; newer techniques are now used [see ESD 29]. Human populations are particularly difficult to map, since they move around so much and interbreed wherever they go. The second argument returns to the recentness of our divergence from a single population of *H. sapiens*, which took place at most a few hundred thousand years ago. The third argument comes from genetics. It has taken a while to develop the appropriate techniques, he continues, but we now know that there is very little genetic difference between races. Most genetic variation is within each race; there have been no genes identified to date that exist in all members of one race but in no others.

By "contingent," Gould means that it did not have to be this way. It could have been that a population of *Homo erectus* or *Australopithicus* survived to the present day. Similarly, had more time passed between the global dispersion of humans and the present, it is possible that some genuine speciation might have occurred. [He elaborates on the argument that the existence of a single living species of hominid is unusual in LMC 10.]

TFS 13. The Rule of Five

In this essay, Gould discusses two pre-Darwinian taxonomic paradigms. Taxonomies, he reiterates, are theoretical models used to classify organisms. It is one of our fundamental drives as humans (and probably as animals) to identify patterns in nature; this drive is so strong that we often find them where they do not exist. [As a trivial example, consider constellations.] One common basis for pattern formation involves numbers; if two or more systems involve the same quantity of something, we often "feel" that this is not a coincidence, but signifies a relationship. Gould discusses two separate models that found false patterns in the living world based on the number five.

The first taxonomic paradigm belongs to Lorenz Oken, one of the best of the early embryologists. He belonged to a school of thought – *Naturphilosophie* – that believed simple laws (like Newton's laws of motion) ruled all of nature, and that great minds could "intuit" these rules. *Naturphilosophie,* as a "romantic" model, believed that nature had an upward, advancing direction from nothingness to the complexity of man and beyond, with each animal a higher or lower link on the great chain of being [TFS 18]. (It is not an evolutionary theory, but instead assumes this ordering was a design criterion during creation.) Oken was looking for a way to fuse the linear directionality of this chain of being with the connections that this school of thought believed existed throughout nature; he believed he had found one between the five senses, with feeling as the "lowest" and sight as the "highest," and what he considered to be the five classes of animal life: invertebrates, fishes, reptiles, birds, and mammals. Gould discusses in some detail Oken's vision of a rolling wheel with five spokes (each representing a sense) that would lay down a taxonomic group wherever a spoke touched the ground. The first revolution produced his five classes of animals, with mammals associated with sight. The second revolution, starting from mammals, produced five more detailed categories: rodents, sloths and marsupials, bats and insectivores, whales and hoofed animals, and carnivores and primates – the last of these again associated with the sense of sight. He continues this rather forced process (Gould's assessment) through the five races of humans: Africans, Australians, (native) Americans, Orientals, and Caucasians.

The second five-based taxonomic paradigm is called the quinary system. One of its champions was William Swainson, who published a version of this model in 1835. Swainson also advocated a five-spoked wheel, with each spoke representing a class of *vertebrate* animal life (but no mention of senses). His choice of the five classes of life differed slightly but significantly from Oken's: he included amphibians, and (by definition) excluded invertebrates. A circle of these five groups, rather than a line, is formed by intermediate "affinities": the fish is connected to the amphibian via the tadpole, while the mammal is connected back to the fish via the whale. This circle is connected via "analogies" to other five-fold circles representing "all" animal life (protozoa, mollusks, echinoderms, worms and arthropods, and vertebrates).

The modern value of these old paradigms, Gould reminds us, is not that they teach us anything about nature (they don't), but that they give us insight into how our ancestors saw the same world we see (differently). It also allows us to see the taxonomic paradigm that replaced both of them, Darwin's theory, in a different perspective. Numerical systems are associated with either simple rules controlling nature (Oken) or a plan-driven creation (Swainson). Either, Gould argues, can be modified to support some version of evolution. Darwin's theory destroyed these paradigms by invoking the contingent (Gould prefers this term to "random") forces of history, from natural selection to major disruptive external events.

TFS 14. Losing the Edge

Gould uses the disappearance of the .400 hitter in baseball to illustrate a larger point about statistics and the nature of trends. He then uses this point to suggest that real trends in natural history – including the overall increase in the complexity of life – may not be what they appear. This essay first appeared in *Vanity Fair*.

Gould, a lifelong Yankees fan, demonstrates that he can be as fanatical about baseball statistics as anyone. He shows, decade by decade, how league-leading batting averages declined over the first half of the 20^{th} century. In particular, he notes that there were several hitters with a season batting average over .400 through the 1920's, but only one after 1930 (Ted Williams, .406, in 1941). If we focus on the extremes – and it seems to be human nature that we do – then a certain type of explanation is required. Many have been offered, Gould tells us, and they fall into two general categories: changes in the players ("the old guard was just plain better"), and changes in the game (relief pitching, night games, the slider.) Gould dismisses the former. He acknowledges the importance of the latter, but uses statistical analysis to show such changes cannot provide the entire explanation; and this takes us to the actual point of the essay.

In any system that exhibits variation – baseball or populations – two different factors must be used to describe it. The first is the mean value or "average" of the distribution. The second is the amount of variation around that average. Gould's analysis shows that changes in the highest batting averages over time are not closely correlated with the "average" batting averages over those same periods. This suggests that a significant part of the change in the extremes is due to changes in the range of variation (lowest to highest) over time. Gould goes on to show that this is the case: the lowest season-long batting averages, minimum 300 at-bats, increased at the same rate and time that the highest batting averages decreased. Not only are .400 hitters extinct, so are successful .200 hitters (other than pitchers) at the major league level. That is, while there have been some changes in the average batting average over time, another important trend is the decrease in variation around that average. Gould attributes this to increased professionalism of all players, corresponding to the game's success in drawing paying crowds, higher player salaries, and as a result, more dedication from more talented youngsters. This is not to say that the introduction of the slider did not have an impact on the highest batting averages; his point is that the improvement in the quality of all players, in all facets of the game, has also played a role. The lesson is that to properly understand the trends of a complex system, we must pay attention to both the median and the variance; and we are asking for trouble if we simply assume that trends in the extremes are equivalent to trends in the median.

Turning to natural history, Gould writes: “We students of life’s history spend most of our time worrying about long-term trends. Has life become more complex through time? Do more species of animals live now than 200 million years ago?” He presents two examples where a focus on the median and variation, as opposed to the extreme, leads to some interesting implications. The first involves the size of mammal brains. It has been well established that primate brains, and hominid brains in particular, have increased regularly and significantly over time [ESD 22, 23]. One could conclude from this that larger brains offer mammals some sort of selective advantage. But this is probably not the case; the most common mammalian brain size has not changed at all since the class was established some 150 million years ago. What we have seen in the past few tens of millions of years, he claims, is a trend toward increased *variation* in mammalian brain size, resulting in some very large brains. Thus, the actual trend that led to our large brains was not a general move in that direction, but probably the opening of new biological niches [after the Cretaceous extinction 65 million years ago], leading to more diversity.

The second example involves the famous Cambrian explosion. Many phyla came into existence during the brief period some 570 million years ago; only a fraction, he states, survived past the end of this period. At the same time, the average number of species included within each phylum appears to have grown tremendously since then. Gould and others consider this decrease in variation at higher taxonomic levels to be a genuine trend, referring to it as “early experimentation and later standardization.” It is presumably due to more optimal designs within the successful lineages, and is thus directly analogous to his argument regarding the extinction of the .400 (and .200) hitter. [Gould elaborates on the early diversity of life at the level of phylum and class in TFS 16, and in his 1989 book *Wonderful Life*. He elaborates on the role of variation in determining trends, including the demise of the .400 hitter, in his 1996 book *Full House*.]

TFS 15. Death and Transfiguration

In 1980, the field of paleontology was rocked by physical evidence that an asteroid had struck the earth 65 million years ago, catastrophically ending the Cretaceous period (including the dinosaurs). For 150 years, consideration of events of this magnitude had been outside of mainstream thought. “Apparent” mass extinctions in the fossil record, followed by the sudden appearance of a host of new species, had long been recognized; they were used to define the transitions between geological periods. However, it was believed that the events were not as abrupt as they appeared, in part (it was assumed) because of particularly poor preservation in the fossil record at those times. The community, Gould tells us, employed two common techniques to justify their belief that these boundaries really represented “more of the same.” The first was to identify “ancestors” of the post-boundary species in the pre-boundary strata. The second was to argue that, while the extinctions were real, they actually took place over an extended period of time. [Dinosaurs, it was argued, were in decline for millions of years before finally succumbing – but see DIH 12.] The discovery of the asteroid impact [HTHT 25], along with recognition that the mass extinction events were genuinely sudden [HTHT 26 & 27], forced the community to view all of natural history in a new light. One of the first major scientific conferences in this field to take place after these discoveries took place in Indianapolis in November 1983, and Gould attended. He wrote this essay in the heady aftermath of several days of new insights and understanding, and summarizes three presentations in particular.

The first, by Adolf Seilacher, discussed the morphology of the Ediacaran fauna. These soft-bodied macroscopic organisms, named for the locality in Australia where they were first found, lived a few tens of millions of years before the famous Cambrian explosion some 570 million years ago [since re-estimated to about 530 million years ago]. In keeping with the "tradition" of seeking continuity across boundaries, most scientists – Gould included – concluded that these fauna were pre-Cambrian precursors to jellyfish, corals ("sea pens"), segmented worms, and the occasional echinoderm. [Many still do.] Seilacher's presentation argued, using detail that had been available all along, that none of this could be true. Jellyfish fossils, for example, have radial features indicating muscles for swimming outside of radial grooves for feeding; this is reversed in the Ediacaran "jellyfish," and could not possibly work. Likewise, true coral "sea pens" are constructed of branch-like structures that allow water and nutrients to flow through; the associated Ediacaran fauna are thin but solid structures that superficially resemble sea pens, but again could not possibly function in the same way. Instead, Seilacher concludes, the Ediacaran fauna represent a completely different kind of life: thin ribbons and plates to keep their effective surface area sufficiently large without internal organs [see ESD 21]. They did not "evolve" into the Cambrian fauna; they were completely wiped out, in what he concludes to be an early mass extinction.

The second presentation Gould discusses is by Sepkoski and Raup, which is a follow-on to two earlier papers that explores the extinction record in unprecedented chronological detail [HTHT 26 & 27]. These papers demonstrate, quantitatively, that the major extinction events in natural history were in fact much more abrupt than had previously been appreciated. The paper presented here identifies a larger number of smaller but nonetheless sudden extinction events. The authors go further, and suggest a possible periodicity of 26 million years for these events. This led to speculation about a large massive body far from the sun that periodically scatters comets in the direction of earth [see TFS 30].

A third paper, by David Jablonski, suggests that extinctions during catastrophic events have a different character than those of regular times. Some taxonomic groups readily produce new species; he refers to these as "species-rich clades." Others do not, and maintain only a few species over extended periods; these are "species-poor clades." During normal times, with normal extinctions, the former groups continuously increase the number of species they contains, while the latter do not. But during mass extinctions, Jablonski found, species-poor clades fare better, relatively speaking – probably because their few members occupy a larger range of ecosystems. Mass extinctions are not simply "big" regular extinctions. Perhaps, he offers, the existence of catastrophic events explains why species-poor clades have not been completely displaced from the environment.

Gould steps back and generalizes about trends in natural history. Darwin, he reminds us, did not believe in progress at a small scale – natural selection is only about adapting to the local environment. But at large scales, he did expect to see something akin to progress, as his "wedge" metaphor testifies [TFS 30]. To displace an existing organism in a world in which every niche is occupied, he argued, a new species must have a selective advantage; by this reasoning, over extended periods of time, one would expect to see more sophisticated, better-optimized creatures. But we do not; trilobites had very sophisticated eyes, and dinosaurs appear to be as "advanced" as any modern animal [see LSM 9]. Gould writes: "I regard this failure to find a clear 'vector of progress' in life's history as the most puzzling fact of the fossil record." Without catastrophic events, he speculates, perhaps evolution really would grind to a halt. He discusses his hope that punctuated equilibrium (more than ten years old when this essay was written) could help resolve this puzzle. However, he continues, it was intended to address species creation and extinction in normal times. The revolutionary nature of the new mass extinction worldview – with frequent, abrupt, and profound (in terms of species eliminated) events, with different rules for survival, changes everything – including his own catastrophe-friendly perspective. [He returns to the concept of progress and the relative roles of natural selection and catastrophic events in natural history in ELP 21 & 22.]

TFS 16. Reducing Riddles

The Linnaean system of taxonomy identifies the category of species, which are grouped hierarchically into the higher categories of genus, family, order, class, phylum, and kingdom (and, since this essay was written, domain). The category of phylum groups organisms at a high, "body design" level, and includes members such as arthropods, chordates (including vertebrates), and mollusks. Some species have body designs that are so unique that they are assigned to their own phylum; several phyla contain only a few dozen species. In some fossils, not enough information is preserved to uniquely identify the phylum to which they should belong; these are collectively grouped in a "miscellaneous" category called Problematica. This identification is not intended to be permanent; one of the important tasks of paleontology is to determine the correct lineage of each organism. Paleontologists are a conservative lot (Gould tells us), and always prefer to assign each mystery fossil to an existing phylum, rather than creating a new one specifically for it.

Most Problematica are rare; if many specimens are known, the odds of an accurate classification increase. One important exception is the group collectively known as conodonts (literally, "cone teeth"). The fossilized fragments range from microscopic in size to a few millimeters, and resemble sets of sharp teeth. They are amazingly common in sedimentary rocks from the earliest era of multicellular life, the Paleozoic, and lived from the Cambrian into the Mesozoic era's Triassic period before going extinct. They are one of the most useful groups for dating geological strata [HTHT 7], since they are both widespread and change form rapidly. Yet, no one had any idea what kind of organism they came from; they are clearly not complete "shells" or "bones," and no fossils of a conodont-bearing organism had ever been found. Because the conodont fossils themselves were composed of calcium phosphate, like vertebrate bones and teeth but unlike the calcium carbonate shells of most invertebrates, some scientists suspected they might belong to our own phylum.

Then, in 1983, a fossil of a soft-bodied, wormlike object was discovered (in a museum drawer!) that included an organized arrangement of conodonts in the place where one would expect a mouth. (The soft parts of organisms are preserved under only the rarest of circumstances, and there are only a few dozen sites in the world where it occurs at all. This fossil came from one of the smaller of these windows, the so-called shrimp band within the Granton sandstone, located east of Edinburgh, Scotland.) It was this find that motivated Gould to write this essay. The preservation of the conodont animal is fairly poor, but there is enough to show its overall shape and size (40 mm long, about 2 mm in diameter), and to confirm that it was, in fact, a soft-bodied organism with one hard component. The fossil included hints of segmentation and tail structures that could be consistent with our phylum Chordata, but they are not conclusive. As a result, the authors of the paper describing it chose to leave the organism in the category of Problematica. [A few other fossils were discovered in the 1990's and 2000's, but these are also poorly preserved. Nonetheless, as of this writing, the consensus is that at least some of the animals belong in our phylum.]

The essay then expands its scope to consider Problematica generally. One might assume that the number of such species would be relatively constant over geologic time, but this is not the case. There are many Problematica in the Paleozoic era, starting with the Cambrian period. The number of identified Problematica decreases over this era, and by the Mesozoic (which includes the dinosaurs) there are only a few. By the Cenozoic ["the age of mammals"], all are gone. This appears to reflect a genuine trend in the fossil record. This trend is even more apparent at the taxonomic level below phylum, the class. Gould tells us that, in the geologic period after the Cambrian (the Ordovician), there were 16 different classes of echinoderms living simultaneously; today, there are only five: two kinds of starfish, sea urchins, sea cucumbers, and crinoids. Another trend, which at first appears to be contradictory, is that the number species living at any time has simultaneously increased. Detailed work by Sepkoski [HTHT 26 & 27], Valentine, and others show that there are roughly twice as many species in today's oceans as there were in mid-Paleozoic times. During the Cambrian period, the number of species was even lower.

This large diversity at the phylum level but small diversity at the species level shortly after the initiation of multicellular life is consistent with a more general principle that Gould calls "early experimentation and later standardization". This principle can be observed in many aspects of (non-Darwinian) human culture, from batting averages in baseball [see TFS 14] to machines such as cars, typewriters [BFB 4], and personal computers. In this perspective, descendent species of groups with inherently better designs – as determined by natural selection – eventually displace even the most successful members of less successful lineages. Gould finds this viewpoint very attractive; however, he notes that we must also recognize the possibility that another mechanism may play a role in this double-trend. This alternative argument involves the partially "random" mechanism of mass extinction. If, say, half of all living species are randomly wiped out in a catastrophe, the probability that a given group will be completely eliminated is higher for a group that only contains a few species. A group with even a single surviving species can go on to diversify; a group with no survivors is gone forever. Gould argues that both should be considered when examining the fossil record in the future.

Since it appears that no phyla (with one possible exception, the Bryozoans), and very few classes, have come into existence since the Cambrian explosion, an increase in ratio of species to phyla may an indicator of time's direction in the fossil record – like the law of entropy does in physics. Many scientists over the past few centuries had assumed, or at least hoped, that obvious and consistent "evolutionary progress" in the fossil record would act in this way, but it appears that it does not.

[Gould elaborates on these themes in ELP 21 & 22. He will go on to discuss many of the Problematica found in the Burgess Shale in his 1989 book *Wonderful Life*. In this essay, he shows Simon Conway Morris's interpretation of one of the most exotic of these – *Hallucigenia*. This interpretation will later turn out to be incorrect – see ELP 24 – and some (including Conway-Morris himself, interestingly) will use this reversal to challenge Gould's premise that there were many more phyla in the Cambrian then there are today. In his responses, Gould appears to hold his own. His 1996 book *Full House* elaborates on the theme of early experimentation and later standardization.]

TFS 17. To Show an Ape

Edward Tyson (1650 – 1708) was an English physician and anatomist. His most noted work is his 1799 treatise, *The Anatomy of a Pigmie* (a young chimpanzee), *Compared with that of a Monkey, and Ape, and a Man*, which was based on one of the first dissections of a chimpanzee in Europe. (At that time, the term "ape" referred to any large monkey.) When modern scholars refer to him, it is often as a courageous man ahead of his time. This was because he used the relatively new techniques of comparative anatomy to argue that chimpanzees were very similar to humans (a "modern" understanding). This suggests that he saw man as belonging to nature, rather than apart from it, and thus helped set the stage for the acceptance of evolution some 160 years later. This is not so, Gould tells us. These same scholars often express puzzlement that his treatise did not ignite a firestorm of controversy; they also note that he was quite conservative politically. All of this can be understood, Gould continues, by recognizing that Tyson was working well within the mainstream paradigm of the time, the great chain of being. (He reiterates his view that it is important to understand historical figures in the context of their times, not ours. He also urges us to consider the importance of a historical figure's contributions in terms of the additional research they stimulate, rather than the similarity of their views – or our impression of their views – to our own.)

The chain of being is considered to be one of the most influential paradigms in all of Western thought. (Gould references the 1936 classic, *The Great Chain of Being*, by Arthur O. Lovejoy.) This worldview holds that all living things are ranked in a specific order, from the lowest to the highest, with amoebas (or something like them) near the bottom, and humans – made in God's image – near the top (just below angles). The general concept was used by both the Greeks and Romans, and it remained very popular in the middle ages and well into the eighteenth century. There were three major problems that great chain scholars wrestled with over the years. The first was the actual ranking itself; are snails higher than clams, or vice versa? [See LSM 6 for an interesting discussion of Lamarck's struggles with this.] The second was that most of nature does not appear hierarchical, but rather variations on themes; how does one "rank" breeds of dog, or species of snail? The third problem, and the most important one philosophically, had to do with the large gaps between certain groups, such as between plants and animals, or between reptiles and mammals. It was "felt" that the links ought to be more-or-less equally spaced; these apparently larger gaps therefore posed a fundamental problem. It was the gap between monkeys and humans that Tyson was probing. He did not believe, and did not argue, that humans and apes were "related" in any way; the great chain paradigm is firmly based on creation, not evolution. (In Tyson's defense, Gould points out that the desire to find a "missing link" between humans and other primates, which were barely known to Western science at the time, was what drove him to study the chimpanzee in the first place.) That is, Tyson was not a biological "Copernicus," fighting to dethrone Man from the center of the universe. Gould notes that Linnaeus himself proposed the existence of another "species" of human (*Homo troglodytes*) in his 1758 *Systema Naturae*, for the same reason: it "ought" to exist in the chain.

As to the technical quality of Tyson's anatomical work, Gould says that it was meticulous and the descriptions accurate – but it contained two important mistakes that led to his conclusion that chimps are more similar to humans than they actually are. The first was the bias of his worldview – he "wanted" the chimp to be anatomically similar to humans, or at least the "lower races" of humans [see the next essay], to fill in the gap between the two. (Gould again mentions his view that humans must pass all "objective data" through the filter of our minds, with their biases and preconceptions.) For example, Tyson assumed chimpanzees were bipedal. He observed his subject knuckle-walking on "all fours" before it died, but he assumed that this was due to illness. All of the drawings in his treatise show the chimp in a bipedal stance, albeit with a cane or rope for assistance in some cases. The second, more specific mistake is that he assumed that he was dealing with a young adult, when the chimp was actually almost a baby. Gould has written elsewhere [ESD 7 & 8] about neoteny, literally "holding youth"; humans are in some ways like apes that never matured. For example, skull shapes of very young chimpanzees are more similar to humans than either are to adult chimpanzees, and this clearly fooled Tyson. He also mistook the chimpanzee's milk teeth for adult teeth; the former are fairly similar to human adult teeth, although the latter are markedly different.

TFS 18. Bound by the Great Chain

The previous essay discussed the paradigm of the great chain of being, a single unbroken series of links connecting minerals to simple organisms to humans (and then on to God). This essay discusses how this paradigm was applied to human races, which proponents usually argued were different species. Gould focuses on one of the last formal defenses of this worldview, a treatise from 1799 entitled "An account of the regular gradation in man, and in different animals and vegetables" by Charles White. White was a conservative physician and surgeon practicing in Manchester, England, and (Gould tells us) his arguments are representative of the class.

The first part of the book defends the great chain theory generally, concentrating on filling the "gaps" that so bothered its advocates. He included the common arguments for asbestos as the link between minerals and plants, due to its fibrous nature, and the recently-discovered freshwater hydras (relative of coral) to connect plants and animals. He included a few of his own ideas as well, which Gould identifies as a collection of poor analogies, overly general observations, and some flat-out errors.

He then turns to the second part of the book: the ranking of races. As was invariably the case, Caucasians were at the top, Africans at the bottom, and Asians in the middle. What is worth noting, Gould says, is the degree to which White was willing to go to rationalize this preordained conclusion, and how completely he convinced himself of the validity of his arguments. Using the quantitative techniques of comparative anatomy, White compares numerous features of a white man, a black man, and an ape. Gould divides his findings into four categories. The first two involve patterns that go from ape to black to white; some toward "good" such as preferred facial angles [see BFB 15], others toward "bad," such as sweating. White is sincere enough to include the latter group, but always manages to justify how the "bad" features (by conservative, 18th-century British standards) are really "good." The more difficult examples are the cases in which whites fall between blacks and apes (e.g., amount of body hair), with "good" in one direction or the other. Suffice it to say, White rationalizes to his own satisfaction in all cases. He concludes with an argument about the obvious and undeniable beauty of the white race as a whole.

How could otherwise intelligent people – Gould tells us that, as a physician, White was one of the first to insist on absolute cleanliness during deliveries of babies, and was opposed to slavery – convince themselves of such obvious nonsense? The answer, it appears, is that it provides "objective" justification for the gross disparities in living standards between those at the top and those at the bottom, easing the consciences of those like Dr. White, and preaching acceptance of the status quo to the rest. God created the static and eternal chain of being, and every creature must be satisfied with his assigned place – "the serf in his hovel, as well as the lord in his castle" – lest the universe be disrupted.

TFS 19. The Hottentot Venus

This is a story about a native of southern Africa who came to England in 1810, with the goal of making her fortune by displaying herself to audiences as an exotic curiosity.

Saartjie Baartman (the name given to her by the Dutch family that "employed" her in South Africa; her real name is unknown) was a member of the Khoi-San people, which at the time were referred to by the western and more derogatory term of Hottentot or Bushman. She was short – under five feet tall – with several non-Caucasian features, and was presented as barely human, one rung or two above orangutans in the "chain of being" paradigm. To general audiences, she appeared in a cage, and sometimes behaved like a wild animal. Gould takes pains to note that there were many people at the time who objected to the display of humans in this way. However, Saartjie told a judge (in fairly good Dutch) that she was a willing participant, and that she was getting half the profits! After touring England for a few years, she moved on to Paris, where she was also a huge attraction. In addition to performing in front of general audiences, she appeared before the great naturalists of France, including Georges Cuvier [HTHT 7], and posed semi-nude for scientific paintings. However, she died suddenly in 1815, while still in Paris; in this early industrial era, rather than being buried or returned to her homeland, she was dissected – by none other than Cuvier himself. Her skeleton and genitalia (!) remain in the *Musee de l'Homme* (Museum of Man) in Paris, where they were stumbled upon by the essay's author in the early 1980's, prompting this essay.

What made her such a hit in England and Europe? It was not simply the fact that she was a member of an "exotic" race. It was the combination of her perceived bestiality and her striking sexuality. She had two anatomical features that piqued the interest of all men in this pre-internet, pre-TV, pre-movie age. One of these was a huge "tush"; Khoi-San women store more fat on their buttocks than most peoples, and Saartjie was well-endowed even by "Hottentot" standards. As part beast, it was acceptable for her to show her bare rear end in these performances; this was the source of the sensation. The other feature was another largely unique characteristic of the Khoi-San: the so-called *sinus pudoris*, or "curtain of shame." It appeared to be a flap of skin attached to the genitalia that would descend three or four inches, and scientists debated extensively as to whether it was an enlarged part of some existing structure, or something that did not exist in other races. The fact that Saartjie always kept this part of her anatomy covered, even when appearing otherwise nude (even before the scientific community), added greatly to her mystery – and, no doubt, to her marketability. People would pay to see her famous rear end, but no doubt also for the hope to catch a glimpse of a little more. Her death allowed Cuvier his moment of discovery – the *sinus pudoris* is in fact enlarged *labia minora* – and there, in a jar in Paris, is Cuvier's proof. In closing, Gould points out an irony in the perception of her as a lower link than whites in the great chain. By several of the quantitative characteristics that supporters of this approach employed, the Khoi-San people are "farther" from apes than any other race on the planet, including Caucasians.

TFS 20. Carrie Buck's Daughter

One of the negative social impacts that came with the general acceptance of evolution and Mendelian genetics was the eugenics movement [ELP 27]. Popular in the United States between about 1890 and the 1930's, it legitimized xenophobia and racism, and was used to justify immigration laws against many populations [HTHT 22]. But it was used to justify other actions as well; in this essay, Gould discusses how it was used to forcibly sterilize American citizens who were categorized as feeble-minded, criminal, or "ne'er do wells." [The underlying argument was that civilized life allowed the "weak" – there were many ways one could be weak – to survive, when under "natural conditions" they would have been weeded out. In surviving, some reproduce, thus passing their low-quality genes into the population at large, degrading the race. Modern science disproves most of these claims; see the next essay.]

The high-water mark of this movement in the US came in a 1927 Supreme Court decision, which upheld the legality of an 1824 Virginia law that allowed compulsory sterilization. The case, *Buck v. Bell*, paved the way for some 20,000 forced sterilizations by 1935, about half of these in California. The defendant in this case was an 18-year-old white woman named Carrie Buck. She was the "test case," the first person selected for this procedure, in 1924. She was residing at the State Colony for Epileptics and Feeble-Minded, the same institution that housed her mother and her illegitimate daughter. Chief Justice Oliver Wendell Holmes wrote a famous line for the eight-to-one majority: "Three generations of imbeciles are enough." (At this time, the terms idiot, imbecile, and moron were recognized medical categories.) Interestingly, Gould notes, many liberals sided with this view of "progress," especially given that vasectomies for men and fallopian "tube tying" for women, had been developed. It was conservative Christians who brought suit, arguing in part that it was difficult if not impossible to tell whether any individual case of mental deficiency was actually caused by genetics or something in the environment, such as a childhood disease or poor nutrition. The test case was clearly selected because it involved three consecutive generations, enough to "prove" a trend.

Carrie Buck was sterilized, but was later released and lived near Charlottesville, Virginia, until her death in the early 1980's. Gould corresponded with Paul A. Lombardo, a professor at the University of Virginia's School of Law, who followed this case for years and interviewed Ms. Buck. In a letter to Gould, he wrote, "She was not a sophisticated woman . . . but mental health professionals who examined her in later life confirmed my impressions that she was neither mentally ill nor retarded." After she had been born out of wedlock herself, she had been raised by the Dobbs family; and it was, apparently, a relative of Mr. Dobbs who raped young Carrie. Lombardo acquired evidence that Ms. Buck was then committed to the same institution as her mother, not because she was feeble-minded, but to "hide her shame" (and the rapist's identity). As for the child, Emma Buck, she was diagnosed as "feeble-minded" with minimal evidence – while still a baby. This was the "third generation" of imbecile that Justice Holmes referred to. She was adopted and raised by the same Dobbs family, but died at age 8. However, Lombardo was able to recover her report card from the few terms of school she attended, which Gould reproduces in the essays. It is mostly B's and C's, in this pre-grade-inflation era, and she made the honor role in one term. We may conclude, Gould charges, that she was not feeble-minded; she was about average. Most likely her grandmother, Vivian Buck, was as well. Gould takes a sad but principled satisfaction in demonstrating that the most quoted line of the American eugenics movement was based on a complete falsehood.

TFS 21. Singapore's Patrimony (and Matrimony)

Gould wrote this essay a few months after Singapore's Prime Minister, Lee Kwan Yew, publically expressed his concerns about his nation's future talent pool in a 1983 public speech. Lee had combined a number of true and not-so-true facts to come to a misunderstanding that would have fit in very well with the Eugenics movement of America in the 1920's. The true facts were that educated women had fewer children on average, that the program of universal education introduced in Singapore in the 1960's had had a positive effect on the economy, and that educated, working women had become an indispensible part of that economy. One of the not-so-true facts, Gould reports, is that, while the universal education program had produced a bumper crop of talented workers, this had been a one-time event. In Lee's view, all of the talented youngsters had been brought into the middle classes, and their families would now reproduce at a lower rate indefinitely; those who did not do well in school would give birth to more children who would not do well in school, but at a higher rate. Lee's proposed solution was to provide incentives for women with more years of education to have more children.

Gould recognized this argument immediately; it is not new [see ELP 27, as well as the previous essay]. The key assumptions in this false argument are as follows. First, there is such a thing as IQ, a single quantity that can express a person's "intelligence." Second, that this quality is inheritable (more on this in a moment), like height or curly hair. Third, and the main point of this essay, is that the number of years one spends in school is a direct measure of that intelligence. If anything, Gould says, this is exactly backwards: the more time a person spends in school, the "more intelligent" that person tends to appear; that is one of the points of education. Some may do better than others, but almost all improve with increased exposure to quality teaching.

So where would Prime Minister Lee get the idea that children of people with fewer years of education are inherently (and genetically) unintelligent? There are clear indicators, Gould tells us, that it came from an infamous 1969 article by Arthur Jenson stating that intelligence was 80% nature and 20% nurture, and therefore concluding that there was only so much schools could accomplish for the average student [see ESD 31]. The 80/20 data itself was based on the work of Cyril Burt, one of the heroes of the United States' Eugenics movement, who did research on identical twins separated at birth. It turns out, Gould tells us, that Burt flat-out faked his data. What is the true connection between the IQ of parents (accepting its legitimacy for the moment) and their children? Gould writes: "In my reading, the literature on the estimates of heritability for IQ is a confusing mess – with values from 80 percent, still cited by Jenson and others, all the way down to . . . a true heritability of flat zero."

But there is a deeper flaw in this argument as well, he continues. The very term "heritability," when applied to IQ, does not really mean the same thing as it does for, say, blood type. Gould reiterates his argument that intelligence is not a straightforward function of nature, nurture, or some fixed combination of the two; this is an unsupportable simplification. The actual process is a non-deterministic interaction of a genome with the environment from conception to at least adulthood. The true argument, he states, is not nature versus nurture, but biological potential versus biological determinism [ESD 32]. Gould argues that if educated women have fewer children, there will be more slots in the better schools for the best of the remainder, and the educational process itself will produce the next wave of good students – if the educational system itself is sound. [One cannot fail to note that the celebrated Harvard professor who wrote these essays grew up attending public schools in Brooklyn, as the grandson of Jewish immigrants who came through Ellis Island.]

TFS 22. Hannah West's Left Shoulder and the Origin of Natural Selection

As has been noted in these essays, Charles Darwin did not invent or discover the idea of evolution. He is credited with convincing the community (and the world) that evolution occurred, and with proposing natural selection as the primary mechanism driving it. However, it turns out that he was not the first to propose natural selection, either. This essay discusses two of the people who proposed the idea before Darwin, both of whom he acknowledges in later editions of *Origin of Species*. (Both references were obscure, and Darwin was not aware of them; neither influenced him.) Does this mean that Darwin's name should be replaced in the biologist's hall of fame? Not at all, Gould says, along with virtually all other historians of science. It is not enough to have an idea, or to have an important idea first; there will always be examples of these. As others have written, credit should go to the person who *develops* the idea, who shows that parts of nature can be seen in a new and better light as a result of it, and who convinces his peers of its validity and importance. Darwin does, and should, get the credit for natural selection [even though the community at large was not convinced of its role until the 1930's].

Natural selection is associated with three postulates and one derived conclusion: there is variation between individuals, some variations can be transmitted to offspring, and in general, more individuals are born than can survive to adulthood; thus, those that vary in favorable ways are more likely to survive and reproduce than others. A Scottish naturalist named Patrick Matthew (1790 – 1874) published his version of natural selection in 1831, in a work entitled *Naval Timber and Arboriculture*. [Matthew's argument was that always cutting down the best trees to make ships led to a crop of lower-quality trees later.] He was still alive in 1859 when *Origin of Species* appeared, and wrote letters claiming priority. Darwin acknowledged these letters, stated that he was unaware of the work, but offered to mention Matthew (and did) in later editions of his book. Nonetheless, historians note that Matthew did not elaborate on his work after 1831, nor did anyone reference it.

The second example – which predates the first, being published in 1813 – is more involved. The author was physician William Charles Wells (1752 – 1817), who was a member of the Royal Society. Wells had been invited to join after demonstrating that dew was water condensed out of the air, and had received a prestigious award after explaining why we see only one image when we have two eyes. Besides these two major papers, Wells presented a number of lesser ones. One of these was a case study of a Caucasian woman named Hannah West, who had patches of dark, melanic skin on her left shoulder and arm; "As dark as any negro." The main body of the paper was simply a description of the subject and her condition, but he included a seven-page annex that speculated on the origin of human skin colors. He again uses the concepts of natural selection (arguing that darker skin may be correlated with resistance to tropical diseases), but, as noted by Loren Eiseley, his arguments as stated are restricted to changes within species, on the same scale as selective breeding, and not directly extensible to macroevolution. Darwin retains his place of honor.

Gould notes, however, that Wells' argument contains two unusual features. The first is his statement that he does not believe that dark skin, in and of itself, has anything to do with resistance to tropical diseases. Rather, he speculates, it may be an indicator of a larger set of features associated with survival in the tropics. In Gould's terminology, Wells is suggesting that dark skin may be correlated with adaptive features, but is not itself adaptive. This is consistent with some of Gould's views, and in contrast to what are referred to in these essays as "strict Darwinism" [TPT 4]. The second unusual feature involves the taxonomic level at which selection takes place. The standard view is that selection works exclusively on individuals; in this case, those children *within* a population that are born with darker skin would preferentially survive, shifting the average color over many generations. Wells speculated that the locals in this tropical environment were small bands that did not interbreed very much; in his view, it was the *group* with darker skin that would increase its numbers at the expense of the others, emphasizing a struggle between populations rather than between individuals within one or many groups. It is partly based on Wells' incorrect, pre-Mendelian view of inheritance (as was Darwin's), but others – most notably Sewall Wright – made the case for something very similar using the more modern tools of population genetics. Gould is also sympathetic to the role of natural selection, or something closely analogous to it, at the group or species level in addition to the level of the individual.

TFS 23. Darwin at Sea – And the Virtues of Port

This essay challenges the legend that Darwin's conversion to evolution came while at sea on the *HMS Beagle*, as a direct result of his exposure to the fauna of the Galapagos Islands. Drawing on the research of historian of science Frank Sulloway, Gould argues that Darwin was as much a creationist when the Beagle returned home in October 1836 as when it left five years earlier. His conversion came several months later, after he showed his specimens to experts in London, and received the benefit of their professional analyses. The essay's title thus refers to the importance of collaboration in science, rather than to one of Darwin's preferred beverages.

There are three groups of Galapagos fauna that are usually associated with Darwin's breakthrough: mockingbirds, tortoises, and the famous finches. Gould discusses each of these in turn, beginning with the mockingbirds. Darwin quickly realized that he could tell the difference between mockingbirds collected from different islands. As a result, he collected many of each type, identifying which island each came from. Later, while at sea, he wrote a passage in his journal stating that if these birds turned out to be different species, it "would undermine the stability of Species." This sentence convinced several historians that Darwin discovered evolution while at sea. However, Sulloway shows that he dismisses these thoughts, and returned to his earlier conclusion that they were mere variants. (The mainstream creationist view that Darwin held at the time allowed for variations within species, consistent with what dog and pigeon breeders had produced over centuries.) It was not until he returned to England that the prominent ornithologist John Gould (no relation) was able to determine that Darwin had brought back three distince species of mockingbird. As for the tortoises, it turns out that they do comprise a single species, although there are distinct subspecies on several of the islands. However, Darwin did not notice this; he ignored them almost completely, and brought back no specimens. This was because he believed a popular but false story that the tortoises were not native to the Galapagos, but had been brought there from an island in the Indian Ocean by buccaneers just a century or two ago. Thus any apparent differences could not be significant.

The third important fauna that the Galapagos offered are what have since become known as “Darwin’s finches,” after the classic 1947 book of that title by British ornithologist David Lack. Today we recognize that these finches represent a classic example of an adaptive radiation; one species enters a new ecosystem, and rapidly diverges to fill a wide variety of empty ecological niches. The differences among the thirteen species of finch were so great that, this time, Darwin made the opposite mistake: he concluded that they belonged to several different genera, and a few to completely different families. It was again only after returning to England that John Gould showed Darwin that of his finches were closely-related members of a single genus. Darwin’s lack of appreciation for the evolutionary perspective while on the Galapagos is also reflected in his collection methodology. He collected a total of only 31 specimens of finch, in most cases a single male and female of each species, and did not identify the island each came from. S. J. Gould quotes Sulloway: “Contrary to the legend, Darwin’s finches do not appear to have inspired his earliest theoretical views on evolution, even after he became an evolutionist in 1837; rather it was his evolutionary views that allowed him, retrospectively, to understand the complex case of finches.”

Gould touches on two more important points that Darwin learned only after returning to port. The first, also due to the analysis of John Gould, was that all of the other Galapagos bird species that he returned with were distinct from, but closely related to, birds living in the very different environment of South America. This is a puzzle in the creationist paradigm: why were the Galapagos birds created “continent-like” rather than “island-like?” The second point involves some mammalian fossils that he brought back from South America, which were examined by the great vertebrate paleontologist Richard Owen [ELP 4, LMC 6, LSM 9]. Owen concluded that the fossils were different from, but related to, animals that still lived in South America today. The combination of these two points – change in species over distance (Galapagos birds) and over time (South American mammals) – is apparently what finally led to Darwin’s conversion from creationism to evolution. [Interestingly, the fossils would later turn out to be a completely different order of mammal from the current fauna, with the resemblance due to convergence; see LMC 7 for Gould’s discussion of this “fruitful error.”]

S. J. Gould adds a final point. While both John Gould and Richard Owen saw the same data as Darwin – in many ways more clearly – neither made the leap that the source of the difference was "descent with modification." For this, it took an *amateur* – S. J. Gould refers to Darwin this way twice in this essay. Gould's primary message is that science is a collective endeavor. Not even Darwin could create a scientific revolution on his own.

TFS 24. A Short Way to Corn

While wheat, rice, and most other domesticated cereal grains have wild analogs, corn – or, more specifically, maize – does not. Its closest relative is a Central American grass called teosinte, which differs greatly in form. Among other things, its ears are composed of exactly two short rows of triangular, interlaced seeds; there is no "cob." Further, the seeds themselves have a stony coating that makes them essentially inedible to humans. There are a number of other significant morphological differences between the two grasses. Nonetheless, the traditional view is that teosinte evolved, gradually and continuously, into maize; the two-rowed ears became multi-rowed cobs by adding kernels over time. However, the anthropological record shows that maize appears abruptly (albeit with smaller cobs) around seven thousand years ago; no intermediate forms have been found. In this essay, Gould reports on another model for the origin of corn, one put forward by Hugh Iltus of the University of Wisconsin at Madison and presented in the journal *Science*. The model argues that the change in a single regulatory gene could lead, through a cascading process, to all of the major morphological changes; after that, selective breeding "fine tunes" the ear into its modern form. Gould does not claim to know enough corn biology to pass judgment on this model, but he likes it. If it proves to be true, he states, it would make an excellent example of a macroevolutionary "leap," rather than a gradual series of microevolutionary steps; that is, it would represent a "hopeful monster" [TPT 18, HTHT 15].

The group of flowering plants that include corn and teosinte are fairly unusual, in that the male parts of the flower are physically separated from the female parts. Teosinte also possesses the uncommon feature, for a grass, of sending out sturdy lateral branches from its main stalk at each vertical segment. These branches, along with a leaf, alternate from side to side up the stem. At the ends of both the main stalk and the branches are the male "tassels" that produce pollen. Near the base of each branch (but not the main stalk) are the female components that become the teosinte ear when fertilized. Iltus notes that there is a smooth gradient of hormones from the (female) base to the (male) tip of each branch. Maize, on the other hand, has few branches, and those it does have are very short – and terminate in the ear, which "appears" to be attached directly to the stalk. The placement of the ear at the *end* of the branch, rather than along the sides near the base as in teosinte, is suspicious. The corn ear is also surrounded by many leaves, which form the husk. Iltus' proposal is that a single genetic change produces lateral branches that are very short [hence the essay title's play on words], which results in the presence of female hormones in the region of the male tassel, as well as the juxtaposition of many leaves to form the husk. The presence of the female hormones, he argues, changes the tassel into a cob-based ear. (Gould references HTHT 11, which presents an example from the animal kingdom – the spotted hyena – where a simple change in sex hormones during development leads to major changes in the adult.) This implies, Iltus argues, that the corn ear is *not* a homolog of the (female) teosinte ear; rather, it is the homolog of the (male) tassel. The "new" ear, which develops sequentially from the outer tip to the base, would presumably consume all of the necessary resources that the female ears would need to develop, thus explaining why they do not form at all in maize.

This single genetic change could have happened many times, Iltus speculates. But the presence of the husk would prevent the seeds from scattering, limiting the viability of the next generation; that is, until humans came along, appreciated the edibility of this mutation, and deliberately separated and planted the seeds. Corn would not survive without humans.

When Gould wrote this essay, the genomes of the two plants were still largely unknown. However, he notes, teosinte and corn hybridize so easily that botanists group them into the same species. This is an indication their genetic similarity, and if nothing else shows empirically that small changes in the genome can, under some circumstances, produce a major change in the form of the resulting organism. He then adds his support for the early, moderate version of Richard Goldschmidt's "hopeful monster" view of macroevolution as an evolutionary mechanism *in addition to* continuous, gradual change. (He adds that the "leap" only gets to proto-maize, not modern corn; the conventional process, in this case with human assistance, then plays its usual role.) He emphasizes that the hopeful monster process does produce major changes in any old direction – pigs will not sprout wings under this paradigm – but rather, only along the guided and restricted paths of the organism's development [HTHT 14, ESD 7].

TFS 25. Just in the Middle

What is life? The subject of this essay is a discussion of what Gould argues is a false choice between those who believe that life can be explained entirely in terms of the physics of atoms and the chemistry of molecules, and those who believe that life is associated with other forces that are not subject to natural law. The former are often referred to as "mechanists" or "reductionists"; the latter as "vitalists." Gould notes that there have been no professional vitalists in the field of biology since the nineteenth century, but he does know a few mechanists. However, he states, there is a middle position; one that not only represents his views, but (he claims) those of most biologists. This view, which Gould refers to as "organizational" or "holistic," argues that there are principles *in addition to* those of physics and chemistry that appear at each level of increased complexity: atom, molecule, gene, cell, tissue, organism, and population. He writes: ". . . new properties arise as results of interactions and interconnections emerging at each new level. A higher level cannot be fully explained by taking it apart into component elements and rendering their properties in the absence of these interactions." A dead cell may be chemically identical to a living cell (for a while), but they are not biologically identical; they behave differently, in ways that chemistry and physics do not and cannot adequately describe.

[Gould argues that this is literally true. That is, it is not just that our current knowledge of physics is not yet capable of modeling an organism the way that it can model a solar system; rather, it will not, *in principle*, ever be able to do so. The laws of physics and chemistry hold in all cases, he agrees, but additional laws are required. These additional rules do not represent "spiritual" or mystical forces; they are laws of nature, and can be studied using the techniques and methodology of science. However, they can only be successfully investigated at the higher level of organization; merely studying the components is not sufficient. This view of biology permeates Gould's thinking at many levels. It is clearly behind his view that something as complex as human behavior cannot be determined from something as "simple" as the human genome (ESD 30, LSM 18).]

One of the early and forceful proponents of this holistic view of life was a brilliant American embryologist named Ernest Everett Just (1883 – 1941), who worked in the 1920's at the Marine Biological Laboratory at Wood's Hole, and in the 1930's in Europe. (Gould wrote this essay in 1983, to celebrate the one hundredth anniversary of his birth.) E. E. Just worked on the phenomenon of fertilization, primarily on eggs of marine invertebrates. He was a meticulous experimentalist, and was able to design and execute experiments that resolved several complex issues. In his first paper, for example, he was able to show two things: first, that the sperm cell could enter the egg cell anywhere on the surface, and second, that the plane along which the fertilized cell first divides intersects the point where the sperm entered. This was no trivial detail: it settled part of a long-standing argument between preformationists, who argued that all adult structures were present in the egg at fertilization, and the epigenesists, who argued that the cell contained no preformed parts, but would differentiate into them as the embryo developed [see ESD 25 and TFS 9]. Just's paper effectively demolished the preformationist model.

There are two parts of his experimental work that led to the development of his holistic viewpoint, Gould argues. First, Just had an uncanny ability to keep individual cells alive and functional in the laboratory environment. From this, he came to appreciate that living and healthy cells behaved differently than dead or abnormal cells, and that these differences had to be taken into account. Second, he focused not on the nucleus of these cells, but on the membrane. Others at the time usually considered the cell membrane to be a passive, inert barrier against the outside world. Just was able to show that it behaved in a highly organized, coherent way; it was "alive," and had to be studied in that way. During fertilization, the membrane will allow one sperm cell to become implanted, but after that it "thickens" to prevent any other sperm cells from being able to do so. He was able to observe this process, and gives a description of the membrane becoming opaque over a period of some 20 seconds after fertilization, and then rapidly clearing again. This is strong evidence that the cell membrane behaves in a coordinated fashion, and not – as mechanists proposed – simply a layer of molecules that can be moved aside due to a chemical reaction with the sperm cell. He was able to show that much of the published literature on cell biology was incorrect, the results due instead to the poor condition of the cells.

Gould quotes several passages from Just's papers and books that illustrate his holistic worldview. For example, from a 1933 article: "We have often striven to prove life as wholly mechanistic, starting with the hypothesis than organisms are machines! Thus we overlook the organ-dynamics of protoplasm – its power to organize itself. Living substance is such because it possesses this organization – something more than the sum of its minutest parts. . . . It is . . . the organization of protoplasm, which is its predominant characteristic and which places biology in a category quite apart from physics and chemistry . . . . Nor is it barren vitalism to say that there is something remaining in the behavior of protoplasm which our physic-chemical studies leave unexplained. This 'something' is the peculiar organization of protoplasm."

[Gould does recognize that holism can be taken too far. The other extreme of this paradigm, expressed well by Cuvier along with many others, is that organisms are so well integrated that evolution cannot occur. This is because, the argument goes, if one part "transmutes," several other parts would have to change correspondingly in order for the creature to continue functioning, and the probability of this is infinitesimally small. Gould does recognize – as he explains in ELP 17 – that organisms can, to an extent, be "dissociated" into component parts, which natural selection can operate on relatively independently. Gould's position thus somewhere in the middle of this spectrum.]

Just is not as well-known today as he should be, Gould argues. In part, this was because he worked just before the invention of the electron microscope. This instrument revolutionized his field, and rendered most of his studies obsolete (although most of his conclusions were validated). However, Gould notes, there was another factor as well: Just was black. Although he received degrees with high honors from Dartmouth and the University of Chicago, and although his work was clearly masterful, there were no opportunities for blacks to become professors at research universities at this time. Just took a position at Howard University, a fine institution but one that required a heavy teaching load; this left little time and few resources for research. (He was able to spend summers at Wood's Hole.) Even those who did sponsor his work, Gould says, tended toward paternalism. That he was able to accomplish as much as he did under such circumstances makes him all the more remarkable, although he had his flaws as well. Gould references the contemporary 1983 biography, Kenneth R. Manning's *Black Apollo of Science: The Life of Ernest Everett Just*.

TFS 26. Mind and Supermind

Gould uses his knowledge of the history of science to attack the "anthropic principle," a view that postulates that the laws of nature and the structure of the universe were specifically designed for the purpose of producing humans and/or other intelligent life. He was motivated to write this after reading an essay by physicist Freeman Dyson, which advocates such a view. Dyson's idea, Gould reports, is not new. He presents a summary of a similar argument made by Alfred Russel Wallace, co-discoverer of natural selection. After comparing and contrasting the two arguments, Gould identifies the common flaws in each, and then uses the juxtaposition of the two to show that both authors are really basing their arguments on hope, rather than rationality.

Freeman Dyson – a brilliant physicist and one of the key developers of quantum electrodynamics – published his autobiography, *Disturbing the Universe*, in 1979. It includes an essay entitled "The Argument from Design," in which he notes several properties of the universe that, were they different, would preclude intelligent life. In one of several examples, Dyson argues that if the so-called "strong force" in physics, responsible for holding neutrons and protons together in the nucleus, were a little weaker or a little stronger, then life as we know it – in fact, stars as we know them – could not exist. This is probably true; but the critical part of Dyson's argument, from Gould's perspective, is what comes next. Dyson concludes that the fact that the universe works the way it "must" in order for people to exist is, itself, evidence for design, and for an intelligent designer. This is the anthropic principle.

Alfred Russel Wallace (1823 – 1913) saw the universe in a different way, but came to many of the same conclusions. Wallace favored many theories that were considered somewhat odd even in his day [see LSM 10]. In his book *Man's Place in the Universe*, published in 1903, he argued that "mind" pervades the cosmos, but earth is the only place where this cosmic supermind has fused to physical objects (that is, *Homo sapiens*). [He did not believe that the human mind could be a product of natural selection; see TPT 4.] Working with a view of the universe that recognized stars as other suns, but that had yet to discover the nuclear energy sources that powered them, he followed the analyses of great thinkers like Lord Kelvin [TFS 8] and developed his own model. Wallace recognized that our sun would have to burn for hundreds of millions of years at least, in order for life to evolve. The only known way (at that time) for a sun to produce energy for that long was for matter to continually fall into it, which would then release energy via gravitational contraction. Where would this matter come from? Wallace believed that the center of this universe contained a cluster of stars, and that our sun had to be on the edge of this cluster. Outside of this central cluster were two rings of stars, separated from each other and the central core by largely empty gaps. From the outer ring – the "Milky Way" – matter fell toward the center. (Life could not exist in this outer ring, he believed, because the stars were too close together, the inevitable result being collisions and catastrophic near-misses.) But so much matter would "fall" that it would destroy any life in the middle ring. But the middle ring's "filtering" action would allow just enough matter to fall to the outer edge of the inner core to maintain the sun's continuous burning. This edge would absorb most of the incoming material, preventing those stars inside the core from collecting enough to live very long. Thus, Wallace argued, life can only exist in the region where conditions are "just right," which happens to be where we are, which in turn allows the cosmic mind some sufficiently evolved creatures to merge with. The odds of all these things happening on their own are remote, and therefore indicative of design. It also reflects what Dyson would recognize as the anthropic principle.

Gould discusses the flaws with the reasoning of both Dyson and Wallace. He does not challenge the first part of their argument – that if the universe were sufficiently different, we would not be here to reflect on it. Rather, he focuses on the steps that follow. His counterargument is to note that the odds of any one way that the universe could have been are infinitesimal, but one of them had to happen. If it had happened another way, and we were not here to reflect on it – then so what? What makes us think that an intelligent designer, if one exists, is more interested in us than in (say) a universe of nothing but hydrogen atoms, or feels a need to merge the cosmic mind with matter somewhere? Perhaps these things are true – but there is nothing in any study that backs up such a claim. It is speculation, not science.

Gould then makes the case that what motivated both Dyson and Wallace is hope, not rationality; specifically, the hope that "we are meant to be here." He does this by comparing the differences, as well as the similarities, of the two universe models. Dyson's universe is the one we know today: a "big bang," stable stars, and trillions of galaxies. Wallace's universe was very different: a much smaller expanse, stars burning via the influx of new matter, and no nuclear fusion. Yet both concluded that the universe had to be very close to exactly the way they each believed it to be. Does this not suggest something more about the creators of anthropocentric arguments than it does about cosmic design and the existence of an intelligent designer?

In a postscript, Gould notes that Mark Twain himself wrote a series of essays challenging Wallace's view of man's place in the universe. Even with timescales of limited accuracy, he notes that humans have been around for only a very short fraction of Earth's existence. Twain pokes fun at the idea that the entirety of natural history is nothing but a prelude for the final, eventual coming of man.

TFS 27. SETI and the Wisdom of Casey Stengel

This essay was published in *Discover Magazine* in 1983, and Gould used it to offer his support, as an evolutionary biologist, for SETI (Search for Extraterrestrial Intelligence). The program was just being proposed at this time, and was seeking government support via NASA. The program proposed to examine microwave emissions from stars that might have planets, with the goal of finding radio signals that are not consistent with natural phenomena. The detection of such signals would imply the presence of a species capable of constructing a signal transmitting device, perhaps for "domestic" purposes such as our radio and television.

One of the most vocal opponents of the SETI program at the time was a physicist named Frank J. Tipler (1947 –) of Tulane University. Tipler argued that funding such a program would be a waste of resources, on the grounds that it was doomed to failure; he was certain that no extraterrestrial intelligences existed. He stated two principle reasons for this belief. The first was that, if such races existed, they would have already discovered us. [A more passive view of this argument actually dates back to Enrico Fermi in the 1950's, and his so-called "Fermi Paradox."] His second reason is that virtually all evolutionary biologists agree that the probability of a single-celled organism evolving into an intelligent species is so remote that the odds of it happening twice are virtually nil. Gould does not have the qualifications to comment on Tipler's first argument, he tells us, but feels comfortable commenting on the second.

He begins by noting that the second claim is factually incorrect; he names several scientists, including Carl Sagan, who do not believe the probability is infinitesimal.

[Sagan, a fellow native New Yorker and friend of Gould's, was one of the people championing the SETI program. When he died in 1996, Gould wrote one of his obituaries; this is reprinted in this series as LSM 14.] But Gould's main thrust is to note that Tipler is mistaken in his understanding of what those evolutionary biologists were actually stating. The actual view is that humans, or humanoids (or, for that matter, any specific species at all) had a miniscule chance of evolving twice. This is because evolutionary biology is not a "deterministic" field, where the same initial conditions produce the same results; it is a "historical" field, where events such as mass extinctions and the myriad flukes of evolution produce unique results. Yes, Gould agrees, the probability of *Homo sapiens* evolving on another world is negligible; but the probability of an intelligent species of some other form – the more general case – is not ruled out. Gould uses a story about Casey Stengel, famous baseball personality and first manager of the expansion New York Mets, to illustrate the difference between the specific and the general. When pressed to explain why he used his first draft pick to acquire a catcher of "modest abilities," Stengel famously replied: "You have to have a catcher, because if you don't, you're likely to have a lot of passed balls." Stengel was no fool, Gould says, and was deliberately confusing the *class* of catchers with one *individual* catcher to deflect criticism via humor; but the point applies to Tipler's argument. Gould's professional opinion is that evolutionary biology has established no firm consensus on the probability of extraterrestrial intelligence; and he, for one, supports the idea of taking a look.

[Frank Tipler would go on to make a name for himself on the fringes of mainstream physics. He co-authored a book in 1986 entitled *The Anthropic Cosmological Principle* (see previous essay), and went on to greater fame with *The Physics of Immortality* (1994) and *The Physics of Christianity* (2007). Meanwhile, SETI has continued to operate – on minimal budgets, largely from private donations – with some access to major radio telescope facilities. To date, the program has detected no convincing evidence of artificial signals. Gould notes in other essays – notably LMC 18 – that people easily confuse the probability of the evolution of microbes on another planet with the probability of intelligent life. The former, he states emphatically, does not inevitably lead to the latter.]

TFS 28. Sex, Drugs, Disasters, and the Extinction of Dinosaurs

This piece, like the one before it, first appeared in the more general forum of *Discover Magazine*. Gould discusses three theories that have been proposed to explain the extinction of the dinosaurs at the end of the Cretaceous period. Each of these models draws on a "sellable" theme: sex, drugs, and violence, respectively (hence the essay's title). As a result, he writes, all have been presented in the "popular science" press as having approximately equal validity (circa 1984). However, he continues, two of these "theories" are really empty speculation, while the third is good science. The essay tries to serve two purposes. The first is to explain the difference in scientific quality of the three models. The second is to gently encourage the writers of popular science (including, presumably, those at *Discover*) to do a better job of explaining these differences to their readership. The problem with speculation, he concludes, is not that it is wrong; it is that they cannot be tested, and therefore leads nowhere, even if true. He writes: "Science, in its most fundamental definition, is a fruitful mode of inquiry, not a list of enticing conclusions. The conclusions are the consequence, not the essence." He later adds: "Science works with testable proposals."

The first offering that Gould presents is that warmer temperatures rendered male dinosaurs sterile (this is the "sex" of the essay's title). It is well-known that testes only function in a narrow range of temperatures, which is "why" warm-blooded mammals carry them in an external scrotum. The proponents that Gould references did legitimate work on how rapidly cold-blooded reptiles (specifically, alligators) gain or lose heat as a function of body mass; body temperature changes more slowly in larger animals [see ESD 21]. Extrapolating this curve to large dinosaurs, they conclude that a "heat wave" could have exterminated the dinosaurs by sterilizing them, if they could not shed excessive body heat. The second offering argues that dinosaurs may have "overdosed" on alkaloid drugs produced by the recently-evolved flowering plants. (These plants arose about ten million years before the dinosaurs became extinct.) Many animals consume alcohol or other drugs if given the opportunity; however, mammals today avoid the most notorious (and toxic) mind-altering drugs because of their bitter taste. But should a mammal consume a limited amount, it can be removed from the bloodstream by the liver. The referenced authors suggest that the dinosaurs may not have been able to taste the bitterness of these chemicals, and/or that their livers were not as effective as removing them from their bodies.

In critiquing these models, Gould begins by noting that the dinosaurs were only one of a large number of organisms, on land and in the oceans, that became extinct at the end of the cretaceous period. Thus, any model that only "works" for dinosaurs is almost certainly incorrect. A heat-wave could possibly affect life in the oceans as well as on land; but sea life, especially the photosynthetic, single-celled plankton that were devastated in this mass extinction, could not reasonably be wiped out by poison plants on land. His second and larger criticism is that neither of these models can be tested. We know nothing about the range of temperatures required to sterilize a dinosaur, nor what other options – cooling off in caves, for example – were available. Further, the geological and paleontological records do not provide sufficient information to determine the existence of a heat wave lasting days, years, or even centuries. As for the "drugs" model, there is even less chance of gathering supporting or conflicting evidence. Neither taste buds nor livers fossilize, and there is little hope of determining what specific alkaloids were present in Cretaceous flowers. Neither hypothesis is testable; as a result, even if they were "true" (which is unlikely), they are useless to science. And in fact, virtually nothing has come of either of these ideas since they were originally presented.

The third example of a dinosaur extinction theory is that of a large comet or asteroid impact. In addition to local devastation, such an event could inject enough dust into the atmosphere to preclude photosynthesis for weeks, months, or even years; this, in turn would lead to a collapse of the food chain. Such models have been proposed many times in the past, and have generally been as speculative as the previous two examples. However, this time something is different; a few years prior, Alvarez et al. discovered a huge increase in the background level of the element iridium precisely at the geologic boundary between the Cretaceous and Tertiary [see HTHT 25]. Dispersed iridium of this type is known to be mostly extraterrestrial in origin; the fact that the distribution is both world-wide and coincides very closely with dinosaur extinction puts this model into the category of hypothesis. It is testable; scientists can look for evidence of iridium and other signatures of a large impact in other strata. It has also been fruitful, presenting hundreds of scientists with problems to work on: studying the nature of plankton and marine extinctions in view of a worldwide dust cloud, researching the actual abruptness of the dinosaur extinction [DIH 12], and searching the globe for a crater of the right age and size, to name three. Speculation is not the same thing as a scientific hypothesis, and should not be treated as such.

TFS 29. Continuity

Gould wrote this essay while in Rome on business. He and nineteen other scientists, in several fields and from eight countries, were there at the invitation of the Vatican's Pontifical Academy of Science. This group was asked to draft a statement for Pope John Paul II, on the threat of "nuclear winter." Their statement, representing the secular community, would offer one side of a new, dual-edged argument against nuclear war; the other side of that argument, based on morality, would be provided by the Pope himself. Gould's friend and colleague Carl Sagan was another prominent co-signer.

The nuclear winter scenario appeared a few years after the breaking of the hottest (and most popular) scientific story of the decade: that the cretaceous extinction that wiped out the dinosaurs, along with many other groups, was probably due to the impact of a large comet or asteroid [HTHT 25]. The lethality mechanism, outside of the immediate area, was probably due indirectly to the injection of a large quantity of dust and soot into the upper atmosphere. This fine material would likely have shut down photosynthesis for an extended period, and probably also resulted in a significant and global drop in temperature. [The authors of the impact paper noted that global temperatures dipped significantly after the largest volcanic eruption in modern history, Krakatau, in 1883.] In December 1983, the famous TTAPS study appeared in the journal *Science*; the name is a pun, being based on an acronym of the author's last names – the "S" was for Sagan. The TTAPS study used early computer-based climate modeling techniques, and suggested that the dust and smoke produced by a nuclear war would be sufficient to reenact at least parts of this scenario. (The global cooling aspect led to the signature name of nuclear winter.) An important implication of this scenario is that people living in the southern hemisphere and in remote locations could all succumb to these sunlight-related effects of a nuclear war, even if no weapons explode anywhere near them.

In this essay, Gould reflects on what the new threat means to him. Nuclear war would be a tragedy for all, he states, but previously most people had assumed that humanity itself would survive. The nuclear winter scenario suggests that this may not be the case. He discusses continuity: life on earth is at least 3.5 billion years old, and humans (along with all other living species) are mere twigs on the tree of life, but each represent a direct, unbroken link to that original organism. Extinction is the fate of all species, including our own; it is the nature of life. But the self-extermination of human consciousness would be a unique tragedy. He writes: "If we extirpate this twig directly by nuclear winter, or lose so many other twigs that our own eventually withers away, then we have canceled forever the most peculiar and different, unplanned experiment ever generated among the billions of branches – the origin, via consciousness, of a twig that could discover its own history and appreciate its continuity." This kind of self-awareness, he adds, is unlikely to ever arise on earth again in the time that remains before the sun exhausts its fuel. He includes the final text of the official Vatican statement in a postscript. [He returns to the theme of the continuity of life over billions of years in the very last essay he wrote for his column in Natural *History* magazine: IHL 1, "I Have Landed."]

TFS 30. The Cosmic Dance of Siva

At its core, this essay is about nothing less than the nature of life's history, and discusses a profound change in the way scientists may have to think about this nature. Ever since Darwin, the dominant view has been that competition among species drives the continuous evolutionary changes that we observe in the fossil record. While microevolution only works to optimize populations to their local environment, and while macroevolution is understood in these terms to be nothing more than microevolution plus vast amounts of time, even Darwin believed that some sort of global progress would take place over geologic timescales. He expresses this view in the "metaphor of the wedge," referring to the woodsman's tool used to split logs. In this metaphor, the ecosystem is a log, and the species that fill the ecological niches are wedges. The surface of the log is completely covered with wedges that bite into its surface, suggestive of a system in which all the niches are filled. For a new species, represented by a new wedge, to establish itself, it has to reach the surface of the wood; this, in turn, involves displacing some other wedge. Natural selection is represented by hammer blows striking continuously all over the surface, pounding some new wedges in while others are driven out. Eventually, better wedges would replace weaker ones; this, Darwin wrote, can be thought of as evolutionary progress. Gould writes: "Even if environments were perfectly constant, evolution would continue as organisms struggle (literally or figuratively) with others in the race for life. You don't necessarily get anywhere (measured by triumph over others) because everyone else is struggling too, but the net result is a kind of upward relay preserving balances among competitors as all struggle for temporary advantages. Paleontologist Leigh Van Valen has codified this model for life's history as the "Red Queen" hypothesis in honor of Alice's compatriot (in *Through the Looking Glass*), who had to keep running all the time just to stay in the same place."

There is an alternative view, held by a minority, that views evolution differently. This minority postulates that species do not primarily compete against each other, but rather against the environment [see BFB 22]. In the extreme version of this view, once a species has evolved to the point where it successfully occupies an ecological niche, it is almost impossible to displace via the process of natural selection acting on local would-be competitors. (An invasive species that appears more-or-less fully formed in the ecosystem is a different matter.) In such a perspective, if the global environment never changed, evolution might very well grind to a complete halt. The major changes in the history of life therefore reflect external events that open niches via extinction, from climate changes to natural disasters, rather than forces internal to life itself. Only in the presence of an unoccupied niche can natural selection shape new species to conquer that niche.

Gould states that he does not believe in the extreme version of this second view, but he has become intrigued by a more limited version of it. He discusses a professional paper that he co-authored with C. B. Calloway in 1980, entitled "Clams and brachiopods – ships that pass in the night." Clams, a member of the mollusk phylum, superficially resemble brachiopods: both have two shells that can open along a hinge. They also share a similar lifestyle, filtering food from the water and either attaching to the seafloor or burrowing in marine sediments. In the Paleozoic period, brachiopods dominated many marine ecosystems, while clams were relatively rare; today, that situation is essentially reversed. The "standard" evolutionary story is that clams possess a superior biology, and slowly but steadily over the eons out-competed and displaced the brachiopods. This is apparently not the case, according to the research of Gould and Calloway. Detailed examination of the fossil record shows that clams and brachiopods diversified together during certain periods, and suffered similarly during others. Clams do increase in quantity during each period of time examined, but brachiopods hold their own; the two groups appear, Gould reports, to have been oblivious of each other. The one exception is the great Permian extinction some 251 million years ago, which devastated the brachiopods but left the clams almost unscathed. The brachiopods never really recovered; it was this mass extinction event, Gould argues, that is the dominant factor in their reversal of fortune, rather than interspecies (or inter-phyla) "wedging."

In a paradigm in which global catastrophes are nonexistent – Lyell's uniformitarian perspective [ESD 18] – and in which mass extinction events are both rare and more gradual than the geological record seems to indicate, the second view of evolution makes no sense. However, the 1980's produced convincing evidence that at least one extinction event – the one that eliminated the dinosaurs, as well as many other groups – was correlated with the impact of a large asteroid or comet [HTHT 25, and the previous two essays]. Further, detailed studies of extinction rates versus time by Raup and Sepkoski showed that mass extinctions were both deeper, in terms of groups eliminated, and more abrupt, than had been previously appreciated [HTHT 26 & 27]. Perhaps, Gould writes, the role of relatively sudden external events play a large, even a dominant, role in the macroevolutionary history of life on earth. [He presents a more thorough discussion of these thoughts in ELP 21 & 22.]

The work of Raup and Sepkoski also indicate that mass extinctions are more common than had been believed; the fine resolution of their data identified a number of smaller events which had previously gone undetected. In another paper [referenced in TFS 15], this team suggests that the events might be periodic, with a period of about 26 million years. Another group studying the dates of twenty or so large craters on earth also identified what could be a periodic relationship, on the order of 28.4 million years – close enough to suggest that the two might be related. Perhaps large impacts produced *all* mass extinctions, not just one. What could produce a regular pattern of major impacts? Two groups independently suggested the existence of a dark, massive body orbiting the sun beyond Neptune in a highly elliptic, 26-million year orbit. At closest approach it could pass through the Oort cloud, a region that is believed to be the source of all the comets in our solar system. This hypothetical body, which the two groups named “Nemesis,” might gravitationally scatter a large number of comets during this period of closest approach, and one or two of these might hit the earth. Gould reserves judgment on this theory, noting that scientific predictions based on what theory says “ought” to be there have had a poor history [see, for example, TPT 23]. But he likes the idea, and especially appreciates the way it allows us to consider natural history in a different light. He adds that the hypothesis meets the definition of good science, in that it is testable.

[The Nemesis hypothesis always had flaws and was never generally adopted. The major problems involved whether either “cycle” was really periodic, the absence of iridium or shocked quartz fingerprints at the time of the other extinctions, questions about the orbital stability of an object so distant from the sun, and the absence of any firm evidence of its existence in the years since it was proposed, despite a number of space-based infrared sky surveys. Nevertheless, it retains some support.]

In closing, Gould suggests that if the object does exist, its name should be changed to Siva. In mythology, he tells us, Nemesis is the god of righteous anger, who considers it her mission to punish the vain and powerful. On the other hand, Siva is one part of the Hindu triad of gods: Brahma the creator, Vishnu the preserver, and Siva the destroyer. All three are faces of the same phenomenon; one thing must be destroyed for another to be created. Gould argues that this far more closely represents the view of natural history from the extinction-driven perspective. He reiterates that, without the extinction of the dinosaurs, large mammals – including us – would likely never have evolved.