Leonardo’s Mountain of Clams And The Diet of Worms

LM C 1. The Upwardly Mobile Fossils of Leonardo’s Living Earth

One of Stephen Jay Gould’s recurring themes is that it is important to consider a scientist, and all thinkers, within the context of their time. There are two types of pitfalls in viewing earlier generations in modern terms. The first is that we can underestimate the man and his views if we focus only on the fact that his proposals are recognized incorrect today. The second is that we may overestimate, or at least misunderstand, an earlier thinker who proposed something akin to what we believe today. We can only truly understand and appreciate the history of ideas when we make the effort to see the world through the eyes of those who developed them.

In this essay, Gould discusses the so-called Leicester Codex (a private notebook) of the great Leonardo da Vinci (1452 – 1519). In an age before Newton and Galileo, Leonardo filled secret, coded journals with insights that the rest of the world would struggle with for centuries. (Unfortunately, the contents of these journals remained unknown until after most of his findings had been “re”-discovered by others. Thus, Leonardo’s impact on Western civilization was not nearly as great as it might have been.) The Leicester Codex

– named for the 18^{th}-century British Lord who bought it in 1717, about 20 years after it first surfaced in Rome – is filled with astute observations and thoughts regarding the origins of fossil seashells, specifically those found in elevated strata far from the sea. He did believe that these were artifacts of formerly living marine organisms, and that their current location suggested geological upheavals of former sea floors into today's mountains. These are the sorts of insights that lead many scholars to believe that he was a modern man (or at least a Victorian!) living in the 15^{th} century – a "spaceman" (Gould's term) or time-traveler of sorts. Supporters of this view argue that it was his careful observations and clever experiments – signs of a man well ahead of his time – that allowed him to overcome the restrictive, medieval scholasticism of his time. "Not really," Gould warns. Leonardo did make careful observations, and did make an excellent case against two important views of the nature of earth and life; however, he did so from the context of his own medieval paradigm.

Gould introduces the two major paradigms of fossils that Leonardo demolishes. The first is that the great flood of Noah, described in the Bible, is responsible for transporting sea-dwelling creatures hundreds of miles inland. Leonardo pointed out that strata exposed by rivers match up across the divide, which indicates that the sediments that formed them were laid down sequentially, over an extended period. [This discovery is usually credited to Nicholas Steno (1638 – 1686) – see HTHT 5.] Since different layers contain different fossils, he concluded that they could not all have been deposited in a single flood. Further, many bivalves could be found with the shells firmly connected, as in life. He astutely noted that transport after death would quickly have disarticulated them; therefore, they must have died where they lived, and could not have been transported up a mountain. In some bedding planes, distinct traces of worm burrows were visible to the careful observer; this is a further indicator that the sediment was not disturbed before it solidified into stone.

The second paradigm that Leonardo attacks is the Neo-Platonic theory that similar "forms" appear in the animal, plant, and mineral worlds. In this view, fossils are not the remains of formerly-living animals, but mineral-based structures that "grow" inside rocks in a process that is *analogous* to how animals grow on earth, or in the sea. [Gould also credits Steno as the first to recognize the taxonomic distinction between inorganic structures such as crystals and agates, and organic remnants such as shells and bones. At the time, all objects dug out of the ground or found inside rocks were called "fossils."] Again demonstrating the brilliant thinking that justifiably made him the stuff of legend, Leonardo points out that shells are not found in just any type of rock, but only those that show other signs of having been formed underwater via sedimentary processes. Further, while some fossil shells are found beautifully preserved, in other cases they appear as piles or heaps of broken fragments – virtually identical to those found on riverbanks or beaches. Why would Neo-Platonic forms grow in such debris piles, when their animal "counterparts" do not? Third, he identified delicate periodic patterning on some fossil shells that correspond closely with growth lines on living shells. If the shell "grew" inside the rock, he asked rhetorically, what did it eat, and why did it not fracture the matrix that entombed it?

Leonardo's arguments against these two paradigms support the view that he was a modern thinker living in the 15th century. To see the true perspective, Gould writes, we must consider what he was arguing *for* as well as what he was arguing against. The view he supported was that the earth was *literally* a living organism, one that functioned as a macroscopic version of the human body. Both, he believed, were made up of different versions of the same four elements of earth, air, fire, and water. (The Leicester Codex has long been recognized as essentially about water; Gould will make an argument that, he says, will finally "make sense" of the seemingly out-of-place discussions it contains about paleontology.) In Leonardo's view of the four-element human body, bones were analogous to rocks, and blood was analogous to water. The human body maintained itself as a living being by circulating fluid throughout a system of internal channels (arteries and veins); Leonardo was (Gould claims) trying to determine the analogous mechanism by which the earth circulated water. In this, he did not succeed. Gould takes us through a number of tentative solutions Leonardo proposed and then rejected to explain how water might travel internally to mountaintops, whereupon it would return to the sea as streams and rivers. (The answer we recognize today – precipitation – did not satisfy Leonardo, because it was an *external* channel. This mechanism would be like blood raining down on our heads rather than being pumped up from the heart.) It was during these struggles to circulate water, however, that he came up with what he considered to be a satisfactory mechanism for circulating *earth*. He drew on the presence of marine strata (including fossils) on land, often at high elevation, as evidence that earth (the element) did "circulate." [In this argument, he predated James Hutton – see HTHT 6 – by two centuries. This concept also provides the essay's title, as well as the first half of the title of this collection of essays – "Leonardo's Mountain of Clams."]

His mechanism for earth circulation was based on another medieval concept: the paradigm that gravity pulled all matter towards the center *of the universe*, and that objects appeared to fall "down" because the earth was located at that center. If there were no circulatory forces, Leonardo reasoned, our world would be comprised of four concentric spheres about this center; the densest (earth) would be at the bottom, and the lightest (fire) would be at the periphery. Leonardo, an early mechanist, believed that some sort of pump must be in play to create the world we know, including mountains with seashells. The concept he developed – Gould quotes some passages and reprints some figures from the Leicester Codex to support this argument – is based on the view that the geometric center of the earth-element is not perfectly situated on the center of the universe. This is because the earth is not perfectly homogenous, and the less dense part "sticks out." On the other side, water covers the surface, and often erodes great cavities (caverns) that Leonardo believed formed throughout the body of the earth. Eventually, the cavern roof would collapse to the center (or near it), resulting in the remaining section of the earth becoming lighter. Since this side of the earth is now less dense, it will now "rise," forming land (and mountains with seashells) in the process. The other side would, in turn, sink below the waves, and the circulatory process would repeat itself.

The view of earth as a gigantic living body is, of course, not considered valid today; nor are many of the assumptions that Leonardo made regarding gravity and the interior of the earth. The theory of plate tectonics, only developed in the second half of the 20th century

[ESD 20], has finally explained fossils in mountains to the satisfaction of all rational people. However, Gould states, the attempt to prove its validity is what motivated Leonardo to work so hard, and so effectively, to refute what he considered rival theories. He writes:

> Leonardo operated in the context of his time. He used his basically medieval and Renaissance concept of the universe to pose the great questions, and to organize the subjects and phenomena, that would generate his phenomenal originality. If we do not chronicle, *and respect*, the medieval sources and character of Leonardo's thought, we will never understand him or truly appreciate his transforming ideas. All great science, indeed all fruitful thinking, must occur in a social and intellectual context – and contexts are just as likely to promote insight as to constrain thought.

LM C 2. The *Great Western* and the Fighting *Temeraire*

Gould loved the arts, and enjoyed the company of artists as much as he did scientists. He defended artist's viewpoints and values to members of his own community, some of whom considered the artist's role in human history to be merely decorative, and of no real significance. However, from time to time, he was confronted with the biases of the artistic community regarding scientists and technologists. One such barb is that the latter are interchangeable cogs in the inevitable progress of science; had Newton never been born, others would eventually come along and make the same discoveries. Artists, on the other hand (so the argument goes), are individuals, "idiosyncratic and necessary creators of their unique masterpieces." This essay is an attempt to defend technological creativity as equally worthy of respect, and is apparently aimed at those in the artistic community who do not share this view.

His approach is to compare two creative 19th century Englishmen, and the mighty ships with which each was associated. The first was the landscape artist J.M.W. Turner (1775 – 1851), who remains famous; the other was the engineer Isambard Kingdom Brunel (1806-1859), who is almost unknown today. Turner painted two masterpieces involving the British Ship-of-the-line *Temeraire*. The first shows Admiral Nelson dying on his flagship in the midst of the famous 1805 Battle of Trafalgar, as seen from the rigging of the *Temeraire*, which played a pivotal role in that battle. The second, painted much later, is entitled *The Fighting* Temeraire*, Tugged to Her Last Berth to Be Broken Up*. It shows a beautiful but aged sailing ship towed by a small steam-powered tugboat belching smoke against a stunning sunset that is clearly metaphorical. Gould presents quotes on the latter painting by writers of different eras who not only mourn for the lost era of sail, but who see the painting as supporting their view of "modern" technology as ugly and soulless.

But this is not at all what Turner was trying to say, Gould continues, referencing art historian Judy Egerton's research. Turner loved to paint steamships, railroads, and the new iron bridges that were appearing all over Britain. Many of these subjects were designed by the other subject of this essay, Brunel, whom Gould identifies as "the greatest practical builder and engineer in British industrial history." Brunel also designed three enormous steamships: the *Great Western*, the *Great Britain*, and the *Great Eastern*. The first of these was launched in 1838, the year the *Temeraire* was broken up for scrap (thus forming the connection that gives the essay its title). It was not the ugly little tugboat that did in the *Temeraire*, Gould writes, it was the coming of steam power and magnificent ships like the *Great Western*. All of these ships, he adds – both sail and steam – are as much the product of creative minds as Turner's paintings. (Gould notes in passing that the marvelous sunset in *The Fighting* Temeraire was made possible by a new, artificially produced pigment called "iodine scarlet" – a triumph of technology that the art world readily adopted.) He also notes that, while Turner did not apparently paint any of these great Brunel ships, he did produce a late masterpiece entitled *Rain, Steam, and Speed – The Great Western Railway* that showed a locomotive in dramatic fashion on one of the many rail lines that Brunel built. Art and technology can and should be mutual admirers, he concludes, not adversaries.

LM C 3. Seeing Eye to Eye, Through a Glass Clearly

The first half of this essay discusses the history of the aquarium. During the 1840's in Great Britain, the development of nearly sealed clear glass cases (allowing the exchange of gases, but minimal loss of water via evaporation) allowed plants to be kept alive indoors with minimal care for extended periods. This technology led not only to the popularity of keeping ferns in the houses of London, it also allowed the English to transport tea and rubber plants (which did not grow well from seeds) on ships over vast distances. Then, when these tanks were filled with water in the 1850's, an aquarium "craze" swept England; every home had to have one. An aquarium, Gould points out, is much more than a fishbowl (which had been around since antiquity); it was a partially self-sustaining ecosystem. It had plants to partially aerate the water and consume fish waste, snails to consume the algae that would foul the tank, and so on. The water would only have to be changed occasionally, as opposed to every day or so.

The aquarium craze faded away after about ten years. However, Gould states, it left behind a subtle but ubiquitous change in how graphic artists depicted aquatic life. Referencing the work of historian of science (and colleague) Martin Rudwick, he notes that prior to this period almost all illustrations of sea life were from the perspective of someone on a ship or a beach. Sea life was either portrayed as swimming near the surface, or as if it were on land, lying on a sketched or implied rock. Within ten or fifteen years of the start of the aquarium fad, however, most images of life in the sea were drawn from the perspective of someone deep underwater, perhaps standing on the sea floor – albeit with good light and clear water. Gould (following Rudwick) argues that this "eye to eye" perspective of aquatic life is the direct result of people growing used to viewing it from this perspective routinely – in their homes – for the first time. His larger point is that the way people interpret the world around them is, as always, a function of the society and culture that they live in.

LM C 4. The Clam Stripped Bare by Her Naturalists, Even

This is a mini-biography of Emmanuel Mendes da Costa (1719 – 1791), a respected if forgotten English naturalist. He was Sephardic Jew living in Britain at a time when very few Jews did, which actually made him fashionably exotic in the upper-class circles he traveled in. He was the first Jew to join the Royal Society, and he restored and reorganized their extensive collections; however, he later spent time in prison for crimes (unspecified in the essay) at this facility. He continued to work as a naturalist after his release. Gould spends several pages chronicling his life and experiences as a Jew in England at this time (most of which were positive), quoting extensively from his letters.

Mendes da Costa produced two major works. The latter, *Elements of Conchology* (about shells) appeared in 1776, and it criticizes the great Linnaeus for naming parts of clams after female anatomy (thus giving the essay its title). This is inappropriate, he claims, not only because it is "licentious" and implicitly hostile to women (who even then worked in this field, albeit rarely for pay), but because it suggests a false connection between different parts of nature. The earlier work, however, is the primary topic of Gould's essay. Published in 1757 and entitled *The Natural History of Fossils*, it stands on the dividing line between what Gould refers to as the baroque age of collecting and displaying curiosities dug out of the earth based on their aesthetic appeal, and the classical age (the Enlightenment) of forming overarching theories to explain the origin and nature of these objects. Mendes da Costa uses the term "fossil" in the old way, referring to all objects dug out of the ground, including rocks and minerals (called "essential fossils") as well as shells and bones (identified at the time as "extraneous fossils"). His book in fact refers only to rocks and earths; Gould presumes that his original vision was to publish a three-volume set, the second on minerals and crystals and the third on what we today recognize as the remains of organisms. He likes this book because it captures a fascinating but soon to be discarded paradigm about order in nature.

Mendes da Costa's approach to classifying soils and rocks was, not coincidentally, the very same one used by Linnaeus to classify animals and plants. This approach is based on the concept of hierarchy, where species are grouped into genera (plural of genus), genera are grouped into families, and so on. Each individual can only belong to one species, one genera, and one family. The hierarchical formatting technique can be applied to many types of systems [for example, armies], but there are many it is not well suited to [for example, flavors of ice cream]. It works for organisms because they are the product of evolution, a process that splits one group into several but does not allow them to rejoin again. As a result, the class of mammals may produce new families and species, but none of these will include a mixture of mammal and, say, a bird; the categories remain separate, and therefore the hierarchical organizing structure remains viable. Rocks, on the other hand, are much more a function of their chemistry than of their history. Quartz crystals forming today may be indistinguishable from those formed a billion years ago. More importantly, while rocks can be categorized in terms of igneous, sedimentary, and metamorphic, below this level they can vary continuously between one type and another. Every "batch" of granite differs slightly based on the exact mix of elements and cooling rate present at the time, and may even vary noticeably over the span of a few meters. Two different types of rock can erode, mix, and then form new rock via heat, pressure, and time. Such conditions render a hierarchical approach not only inappropriate, but useless to science; the inevitable result is endless debate over whether, say, two samples of marble represent a single species or two, with no objective way to resolve the issue.

It would be easy to think of Mendes da Costa as foolish for attempting to categorize rocks and minerals in terms of families and species. Certainly, Gould notes, Mendes da Costa was no “Linnaeus” in terms of talent or ability. However, it turns out that Linnaeus himself believed that rocks and minerals could be successfully organized in this way. Linnaeus, Gould reminds us, was not an evolutionist, and worked a century before Darwin; in his view, God “created” both animals and minerals, and the rules by which he did so should apply to both. [Gould elaborates on the success of the Linnaean system in the post-revolutionary world of evolution in IHL 21, *Linnaeus’s Luck?*.] Science does not advance in a straight line, but instead with numerous twists, turns, and dead ends.

LM C 5. Darwin’s American Soulmate: A Bird’s-Eye View

Gould plunges into the alternative worldview of a close contemporary of Darwin’s: the American naturalist James Dwight Dana (1813 – 1895). Not only were Darwin and Dana both members of the same profession and of approximately the same age, there were some other almost uncanny similarities as well. In his youth, Dana spent several years on board an American scientific voyage (the Wilkes expedition, 1831 – 1836, primarily to assess whaling prospects), much as Darwin had traveled on the *Beagle*. Both Darwin’s and Dana’s first published works were on the origin of Coral atolls (and both reached the same conclusions about island subsidence and corresponding coral growth), and both went on to study marine arthropods next. Dana went on to become one of America’s great naturalists, teaching at Yale for decades. Although they never met, they read each other’s works and exchanged many letters over their lifetimes. It is these similarities of profession, experience, and era that makes Dana’s rejection of evolution illuminating.

Dana, like many of his scientific contemporaries, was a Platonist; as such, he believed that each species represented a unique ideal form or type, and that variations were defects from this absolute. In the Christianized version of this worldview, each of these ideal forms represented one of God’s thoughts; a central mission of science, in this paradigm, was to learn more about the mind of God by studying His creations. Dana did believe in an ancient earth and in extinction. His view was that the creation of new species was an ongoing process, fundamentally tied to God’s progressive geological actions. Modern species were superior to ancient ones; but this was not because God’s skills or powers were not as great in the past. Rather, He brought forth the most advanced designs that the earth would allow. Over time, Dana believed, God improved the earth in three ways: he increased the ratio of land to sea (terrestrial life was superior); he “purified” the air (life on dry land was superior to life in swamps); and he cooled the planet (allowing the dominance of warm-blooded mammals). Both geology and the history of life were, in his view, directional and progressive, with the explicit goal of producing a species that could truly appreciate The Maker’s handiwork.

Darwin sent Dana a copy of *Origin of Species* after he published it in 1859. Dana remained unconvinced (although he did not actually read it until sometime later), and offered Darwin three important, if not original, paleontological objections to the transformation of species in general. The first was the apparent absence of transitional forms in the fossil record. The second was that new groups seemed to appear "fully formed," with many complex (and, by implication, "advanced") features. The third was the record of mass extinctions, often followed by the "re-emergence" of different members of previously existing groups. Darwin was familiar with all of these arguments, of course, and had spent a significant fraction of his book addressing them. (His fundamental response to all three arguments, Gould reminds us, was to call on the imperfection of the fossil record. Gould does not discuss punctuated equilibrium here, but he does note that Darwin's responses did not always turn out to be completely correct.)

Darwin, as an evolutionist, believed that the similarities and differences between groups of animals were attributable to genealogy; anatomically similar organisms shared a common ancestor more recently than less similar organisms. Creationism, in and of itself, does not address similarities and differences. For this, Dana drew on one of a number of numerology-based models that were in vogue at the time [see TFS 13 for some other examples]. Humans seek patterns in the world around us, and we often find them where they do not exist. Gould spends several pages discussing Dana's paradigm, which involves a fourfold geometrical structure of vertebrate life: fish (sea dwellers, at the bottom), and then birds, reptiles, and mammals in a triangular pattern (with mammals at the apex) on land. Each group is subdivided into a higher and lower part, with the lower parts of one group pointing towards the higher parts of those below. For example, mammals are divided into placental (the higher group) and "other," including marsupials and monotremes (the lower group). Monotremes include the platypus, which lays eggs, thus suggesting a connection to reptiles. Dana's unique contribution to this paradigm is the concept of "cephalization." His measure of relative superiority in all animal life (not just vertebrates) is not simply brain size, but how far "forward" within the body it lies. This allows man to be placed above whales, which have larger overall brains, but invites no end of difficulties and special pleadings in other species. (Darwin, Gould tells us, recognized that such a measuring stick could only work if one was already certain of how the results.) Dana offers his cephalization argument as "evidence" for placement of mammals above, say, reptiles in his numerological worldview.

Both men had made considerable investments in their respective worldviews by 1860, when a remarkable fossil discovery was made: *Archaeopteryx*. Darwin interpreted it as a wonderfully intermediate form between reptiles and birds, supporting his argument that "descent with modification" occurred and directly refuting Dana's first critique of the truth of evolution (no intermediate forms). Did Dana concede? It should come as no surprise to regular readers of Gould's essays [see ELP 31 in particular] that he did not. Dana was not only able to fit *Archaeopteryx* into his numerological "mind of God" paradigm, he used it to solve a problem he had faced connecting the lower tier of birds to fish – both *Archaeopteryx* and sharks have teeth! (Late in his career, Dana did concede that evolution occurred. However, Gould writes, this was not a true conversion, but rather necessary sacrifice to preserve the larger portion of his cephalization argument.)

There are three familiar observations to make about how Darwin and Dana each viewed this early bird (which also provides part of the essay's title). The first is that, while theories are essential to making and assessing observations, they can constrain us as well. The second is that we should not simply view Dana's worldview in modern terms, but in his own. We learn much more about him, his world, and by perspective our own that way. The third is that taxonomy is not, as some have charged, mere "stamp collecting." The way one orders the structure of relationships between members of a collection matters a great deal in how we think about it, and how we view the world at large. Are there any general rules one can draw from this story regarding when to stand by one's worldview in the face of new evidence, and when to abandon it? Gould cannot come up with any; he offers support for intellectual courage, but notes that most new paradigms are simply wrong.

LM C 6. A Seahorse for All Races

Gould begins this essay with an anecdote: he states with some pride that he recently acquired a book entitled *Memoir on the Gorilla* (written in 1865), by legendary anatomist and naturalist Richard Owen (1804 – 1892). This was not just any copy; it included a hand-written autograph, showing it was a gift to "Charles Dickens, Esq., from his friend the Author" (and from Dickens' personal library). Perhaps surprisingly, gorillas were unknown to European scientists until 1846 (chimpanzees had been known since the late 17th century) [also see TFS 17]. Owen, as chief of natural history at the British Museum, was one of the first Westerners to study the bones, and later preserved animals, in detail; this was the source of his 1865 monograph.

The existence of the gorilla, an ape heavier than man but with a brain about one-third the size, led to a heated battle over the role of man in nature. Are humans "merely" apes, like gorillas, only with bigger brains? Or, are we superficially similar to, but in certain ways fundamentally different than, all other animals? The brain of the gorilla became the battlefield for a proxy war over this question in the 1850's and early 1860's, waged in the press and certain professional meetings, and became known as "the great hippocampus debate." (Interestingly, Gould points out, it began a few years *before* the publication of *Origin of Species* in 1859.) Owen took the side of "fundamental divide," while a young Thomas Henry Huxley (1825 – 1895), another of the greatest naturalists of his day and later "Darwin's bulldog," argued for man as big-brained ape. (Huxley later published his views in *Evidence to Man's Place in Nature*, based on a series of lectures given between 1860 and 1862).

While the battle could have been waged on a number of different fronts, the actual field of battle was chosen – by Huxley – to be Owen's claim that there were three structures found in the human brain that were not present in the gorilla brain, and that our "humanness" was to be found in one or more of these structures. One of these, which is today known as the calcar avis, was referred to by Owen as the hippocampus minor (a different structure completely than what we today know as the hippocampus). The word "hippocampus" translates into "seahorse," and is thus the source of part of this essay's title. Huxley attacked this argument by organizing his skilled colleagues to do their own dissections of gorilla brains, which had become more common in England, as well as those of other apes. Sure enough, they found that the great Owen was incorrect; all three structures existed in all ape brains, and specifically in gorillas.

While all of this is true, Gould reminds us that history is written by the victors. With the success of Darwin's "team," including Huxley, Owen's true arguments were sometimes neglected or misrepresented. (Gould draws on a recent biography, *Richard Owen: Victorian Naturalist* by N. A. Rupke, for details.) For one thing, Owen was not an opponent of evolutionary thought in general; he did, however, oppose the strict materialism of Darwin's natural selection [see ESD 1]. As to the hippocampus and other structures, Owen (belatedly) admitted their existence, but countered that they are merely *homologous* structures, like the flipper of a dolphin and the wing of a bat. This does not really support Owen's position, but does differ from the uncontested resignation that his opponents imply.

More importantly, however, Gould notes that Huxley's arguments were also "loose with the facts" in certain unpleasant ways, and that Owen correctly challenged him on these arguments at the time. One of Owen's positions was that the factor of three in brain weight between gorillas and humans was important, in and of itself, in setting the two apart. Huxley tried to counter that the range of brain sizes between the smallest ape and gorillas was larger, but this fails on the grounds that there are many ape brain sizes in between, while the gorilla-human gap is unique. Huxley then draws on a profoundly racist (and untrue) argument: that brain size in different races of humans (with Africans at the bottom, as usual) vary by at least this much. If true, it would support Huxley's argument that brain size (and, by implication, intelligence and other unique human traits) varies continuously over the ape spectrum, and thus suggests that humans are simply at one end of a continuum. Owen nails him on this, referencing Friedrich Tiedemann [IHL 27], one of the few truly egalitarian naturalists of the day. Human brain size is remarkably similar across races, Owen notes, as is the ability of all races to support advanced intellectual activity [and providing a pun for the essay's title]. The gap in brain size between humans and other apes (at least in extant species) is real. There is irony in these positions, Gould notes: Huxley was a political liberal of his day, while Owen was a conservative. Gould hopes that Owen's principled stand on race, even on the losing side of a battle about man's place in nature, will be remembered. [Gould writes about Owen's earlier coining of the term "dinosaur," and some of his views on evolution prior to the publication of *Origin of Species*, in LSM 9.]

LM C 7. Mr. Sophia's Pony

Vladimir Kovalevsky (1842-1883) was an important figure in 19^{th}-century paleontology, although he is not widely known today. His wife, on the other hand – Sophia Kovalevsky – is regarded as one of the great female mathematicians; she received many honors in her short lifetime, and went on to become the first female professor at a European university.

Growing up, Gould was both amused and mystified by postal letters addressed to his mother as “Mrs. Leonard Gould”; so in return, he refers to the less-well-known husband and the subject of this essay as “Mr. Sophia.” After sketching the biographies of both Kovalevsky’s, Gould begins his discussion of Vladimir’s work.

After the publication of *Origin of Species* in 1859, most scientists in Europe became convinced that evolution did in fact occur, but few accepted that Darwin’s mechanism of natural selection could be the dominant force behind it. The exception was in Russia, where the pre-revolution intelligentsia (a Russian word) revered Darwin, and fully embraced natural selection. Kovalevsky (that is, Mr. Sophia) worked in Europe from 1869 to 1874 on hoofed animals, exploring museums and excavating his own fossils. He went on to write the first papers on paleontology that explicitly applied evolutionary theory in a detailed way. Specifically, he viewed the anatomical changes through time in terms of adaptations to the changing local environment. In perhaps his best example, he argued that horses evolved from multi-toed creatures with low-crowned teeth into single-toed creatures with high-crowned teeth as an adaptation to the formation of dry grasslands and savannahs. (Multiple toes would be helpful in damp forest ground, but the single toe would be advantageous on the emerging, dry and firm grasslands. Grass, however, is full of silica that wears down teeth; the high crowns of modern horse teeth would directly address this problem.) Along with Thomas Henry Huxley (with whom he corresponded), he was the first to argue that the four genera of Eurasian horse fossils (*Paleotherium*, *Anchitherium*, *Hipparion*, and *Equus*) formed a direct lineage. Huxley’s less detailed but more widely read work (in the West) was a crucial victory for Darwin’s theory.

However, it was wrong in the particulars! Huxley visited the United States in 1876, where he met with O.C. Marsh of Yale. Marsh showed Huxley Yale’s collection of horse fossils, which was sufficient to convince Huxley that the horse had evolved in North America rather than in Europe or Asia. In fact, the four European genera actually reflect four separate migrations from the new world to the old, with each lineage dying off without leaving any descendents. [Gould tells this story in detail in BFB 11.] Thus, while Kovalevsky was the first to apply Darwin’s theory to the paleontological record, and was probably correct in general about the driving force behind modern horse toes and teeth, his conclusion about *Equus* being a direct descendant of *Paleotherium* is technically incorrect. Gould labels this as a fruitful error, in that the techniques and arguments that he applied led to great progress in his field. Rather than be concerned that Kovalevsky’s mistake might give comfort to a creationist enemy, Gould emphasizes the point that scientific arguments, unlike those of creationists, can be refuted with facts.

In an interesting coda, Gould amplifies the theme of the fruitful mistake by showing how Darwin’s “eureka moment” also falls into this category. After his *Beagle* voyage, he was pondering the news from the ornithologist John Gould (no relation) that the two types of rheas (large flightless birds) he had collected in South America, as well as the famous Galapagos finches, all turned out to be separate species [see TFS 23]. Darwin contemplated the implications of geographically separate but neighboring species, and the replacement of one by the other. If species can replace each other in space, Darwin wrote in his journal in 1837, might they not also replace each other in time? The evidence that convinced him that this was in fact true were fossils of *Macrauchenia*, an animal similar to, but clearly distinct from, the modern guanaco (a camel-like creature similar to the llama and alpaca). Eureka! Except, it turns out, that the *Macrauchenia* is not a camel at all, but rather a Litoptern: an order of mammals that became extinct when the Isthmus of Panama formed a few million years ago [see TPT 28]. All of the members of the camel family currently living in South America – including the guanaco – are the descendents of North American immigrants who crossed the isthmus at that time. The similarity in appearance, in this case, turns out to be due to convergence (the term used to explain the external similarity of dolphins and ichthyosaurs to sharks), rather than genealogy. This was perhaps the most fruitful error in the history of biology.

LM C 8. Up Against a Wall

The specific subjects of this essay are the fabulous prehistoric cave paintings found in various parts of Europe. The more general subject is how our personal worldviews, while essential for organizing our observations, can lead us to misinterpret the world around us (a recurring theme in these essays). Paintings on the walls of caves in France, northern Spain, and parts of Italy date from more than 30,000 years ago to as recently as about 12,000 years ago. Most depict the large mammals that lived in the region during the last Ice Age, but some show human figures and abstract symbols. All appear to have been made by Cro-Magnon man, our fully human ancestors; to date, no representative art made by Neanderthals has been discovered. The best of these awe all who view them, professional and layman alike. There are two reasons for this, Gould offers, one good and one bad. The positive reason is that these are true works of art; one expert compares them to the works of Leonardo da Vinci. The negative reason is surprise that they are not more primitive or childlike, which would more readily conform to our views of "cavemen."

Gould turns to the work of two of the most famous investigators of European Paleolithic cave art, both of whom spent their careers trying to interpret their meaning. Gould focuses on the fact that both fell into the mental trap of finding a correlation between "sophistication" and "recentness" that turned out not to exist. The first researcher is Abbé Henri Breuil, a professional artist who studied the paintings extensively over the first half of the 20th century. The second, André Leroi-Gourhan, came a generation later; he was an anthropologist and philosopher by profession. Both men discussed not only their views on the significance of the subjects to the artists, but also offered "stories" (in the professional sense) on the rise, development, and eventual dissipation of the culture that produced them, inferred from the artwork itself. While these stories differed significantly, Gould notes, the chronology each proposed for the order in which the works were created was very similar. Both believed that the paintings composed of simple, monochrome outlines came first, and that shaded, multicolored, and "lifelike" forms came later – consistent with the notion of advancement and progress.

Gould offers two lines of reasoning for rejecting this view: one theoretical, and the other empirical. The first, which he calls *theoretical dubiety*, is that the time scales are wrong.

The amount of time between the most ancient and the most recent cave paintings is about 20,000 years. If one is to compare this time with *biological* evolution, the problem is that this amount of time is too short: *Homo sapiens* (Cro-Magnon man) first appeared some 200,000 years ago, and appear to have entered Europe at least 90,000 years ago (coexisting with Neanderthals). Thus, even if one assumes continuous evolution, the range of cave paintings only covers a fraction of this period. As such, it should only show a small portion of the observed artistic "progress." If, on the other hand, one wishes to compare the range of ages of cave paintings to *cultural* evolution, then the amount of time is too long. The time difference between early Mesopotamian art and Greek art is a few thousand years, similar to the amount of time between Greek art and, say, Picasso. What principles does one use to compare art across spans of time several times as long? Further, the physical locations of these cave paintings are hundreds, and sometimes thousands, of miles apart. One cannot determine the relative ages of fifth-century Byzantine art and fifteenth-century Japanese art merely by comparing style.

The second line of reasoning comes from empirical carbon-14 dating of the pigments used in the drawings themselves – a method that neither Breuil nor Leroi-Gourhan had access to. In fact, we now know that there is virtually no correlation between artistic sophistication and relative age. In particular, some of the most spectacular artwork – that found in Chauvet cave, discovered in 1994 – is in fact some of the very oldest, dating back to more than 30,000 years before present. Both men, most scholars now conclude, were projecting their personal worldviews onto a limited set of data to draw invalid conclusions – an all-too-common human failing. Gould discusses the significance of the cave paintings themselves, as a window into the world of Ice Age Man, in the next essay.

LM C 9. A Lesson from the Old Masters

One of Gould's earliest essays discusses the Irish Elk (*Megaloceros giganeus*), an animal that roamed much of Europe and Asia from about 400,000 years ago until about 11,000 years ago [ESD 9]. The animal was actually a giant deer rather than an elk, he reminds us; it lived all over Europe and Asia, but most of the best-preserved specimens are from the peat bogs of Ireland. It is most famous for its enormous palmate (plate-like) antlers; at up to 100 pounds per pair, they are the largest known antlers in the animal kingdom [and the subject of his earlier essay].

The Irish Elk has played a central role in two important debates in natural history. The first took place over the course of the 17^{th} century, and was on the subject of extinction; specifically, did it occur? If so, did it leave a hole in God's design? If not, were Irish Elks (a common example) still alive today, perhaps in still-largely-unexplored Canada? Cuvier is credited with "proving" that extinction does occur in his 1812 publication, *Recherches sur les ossemens fossiles* (*Studies on fossil bones*). [Gould tells this story in HTHT 7.]

The second question appeared much later, after the discovery of Neanderthal and Cro-Magnon man in the mid-19^{th} century, and after the discovery of Paleolithic cave paintings starting [the first of which was Altamira in northern Spain, discovered around 1880].

That question was: did our ancestors ever see or interact with Irish Elk? No butchered bones appear in known Cro-Magnon sights, but these animals were known to be relatively rare. Researchers turned to cave art; were these animals depicted in paintings? The first unambiguous finding occurred relatively late, from the Cougnoc cave in France discovered in 1952. As of 1996, when this essay was written, Irish Elks were only known from four of the over 300 known cave painting sites, the most recent discovery being Chauvet site [discussed in the previous essay].

In addition to the emotionally charged recognition that our ancestors saw these long-extinct animals with their own eyes, the drawings provide some additional priceless nuggets of information. First, the nose was thin like a deer rather than fleshy like a moose, the way they had usually been portrayed by artists due to their moose-like size. Second, despite the weight of their antlers, these animals carried their heads "out front," parallel to their bodies, rather than erect (that is, parallel to and directly above the front legs). Gould reproduces a drawing by the great naturalist Richard Owen [LMC 6 and elsewhere] posing the Irish Elk in this un-lifelike fashion. Third, the drawings clearly show a pronounced "hump" over the shoulder vertebrae, like a camel but quite unlike the broad raised area of moose. Further, this hump was distinctively darker shade than the rest of the animal, and thus a visually striking feature. This distinctive coloration almost certainly served some purpose, perhaps sexual attraction or a sign of dominance (although Gould notes that it appears on both male and female animals). He offers this as an example of co-optation [BFB 9], where a feature developed ("selected") for one purpose is pressed into service for a different one. [He refers to this as the "tires to sandals principle" in ELP 22, and as a "spandrel" in one of his most famous professional papers.]

Non-bony structures (such as the nose and hump) almost never fossilize, nor does coloration or behaviors such as posture. Gould expresses his joy in the fact that this information was not lost to time as, by all rights, it should have been. He expresses gratitude to the ancient humans who preserved this data in a way that had never been possible before in natural history.

LM C 10. Our Unusual Unity

Gould begins this convoluted essay with a cautionary tale about the pitfalls of elevating our personal or cultural biases (and we all have them, he acknowledges) to "universal status." He writes, "[T]he assumption that human history should progress in a linear sequence of improvement (with Africans behind the Europeans) . . . may be the most harmful and widespread of all culturally embedded errors falsely promoted to universal truth."

As an example, he describes how a form of this impediment significantly delayed the time it took to decipher the written Mayan language. (Gould had recently returned from a trip to Yucatan and Guatemala, and references the book *Breaking the Maya Code* by Michael D. Coe.) The problem arose not from the fact that the language was so complex (although it was), or that the Conquistadors destroyed the vast majority of the documents that survived the collapse of this civilization around 900 A.D. (which they did). Rather, it was because several key anthropologists *assumed* that the Mayan symbols could not be phonetic, and the written language could not contain grammar, both of which proved to be incorrect. These assumptions were made, in turn, because they deemed the overall level of the vanished culture as not sufficiently advanced – assuming a linear correlation between language and various European advancements – to have produced such progressive linguistic characteristics. Specifically, linguists were laboring under the assumption that all languages had to pass (linearly) through certain stages: pictographs, then ideographic (like Chinese), and finally to phonetic; today, the Mayan language is recognized as partially phonetic, like Egyptian hieroglyphics. Referencing Coe, Gould writes that "the old error of construing human history as linear progress also played a major role. Since the Mayans peaked so long ago (while Europe remained a backwater), and belonged to an ethnic group judged inferior by many scholars of European extraction, several leading experts on Mayan culture simply refused to believe that these inscriptions could represent a complete written language."

Gould then turns to the heart of the essay, which involves the biological rather than the cultural evolution of humans (but whose *study* can suffer from the same error of assuming linear progress). The study of natural history often seeks to identify *trends*, and certainly one of the most interesting is the apparent trend of increasing brain size in the evolution of hominids since their split from the ancestor of chimpanzees some 6 or 7 million years ago. He harbors no doubts that the degree of consciousness exhibited by *Homo sapiens* is a direct function of our large brain. What he challenges is the assumption that the growth in brain size through the australopithecine and hominid lineages must involve a linear, progressive trend. There is an alternative to this "ladder of progress" model, he states: it is his familiar model of the bush that branches often, and is later pruned to almost the same degree. He offers the hypothetical example of a moderately brainy species of ape that speciates, or "branches," into other species of various brain sizes. The brain size of each species remains constant for the duration of its existence. [He is drawing on the concept of "stasis" here, although he does not explicitly mention punctuated equilibrium in this essay.] If, over time, all of these species become extinct ("pruned") except for the one with the largest brain, then the model of steady, continuous, "progressive" brain size increase would be invalid. [He avoids any discussion of whether the survival of the biggest-brained species is due to a selective advantage that it provides, although he implies that we should not assume so. He discusses a similar apparent trend in natural history, that of the horse, in BFB 11 and LMC 8.]

The difference between the apparent trend toward increasing brain size via the ladder model [elsewhere referred to as phyletic gradualism or anagenesis] and the bush model [closely correlated with punctuated equilibrium] directly manifests itself in one of the ongoing debates on human origins: the battle between the so-called "multiregionalism" and the "out of Africa" models [see TFS 12]. Proponents of both models agree that one of our ancestors – probably *Homo erectus* – moved into Europe and Asia over one million years ago. In the multiregionalism paradigm, this ancestor split into a few major populations, each of which evolved (largely independently) into bigger-brained *Homo* *sapiens*, which in turn lead to the major ethnic groups we see today. This paradigm is fundamentally dependent on the assumption that evolution proceeds linearly toward increasing brain size – blacks, whites, and Orientals all have brains that are the same size, but each got there via at least partially independent paths. In the Out-of-Africa paradigm, *H. sapiens* evolved only once – probably again in Africa, and probably from one of the *H. erectus* populations that remained there – and then moved into Europe and Asia about 200,000 years ago in a second, separate hominid diaspora. Today they are the sole survivors of the hominid bush.

Is there any way we can use the fossil record to determine which of these paradigms is superior? There is, Gould argues. If the multiregional model were correct, we would expect to see one species gradually transition into the other over time. If, on the other hand, the out-of-Africa paradigm is valid, we might expect to find different species overlapping each other for extended periods, along with evidence that each species remains essentially unchanged for the duration of their existence. [To find overlapping species would also require that coexistence is possible; that the presence of one group does not rapidly lead to the extinction of the other.] He next proceeds to list five sets of data (in order of historical discovery) that, in his view, support the bush over the ladder model of human evolution. The last of these discoveries was contemporary news, and was the stimulus for this essay.

It had been recognized since the 1920s that there were two coexisting species of Australopithecines, a genus closely related to Homo, living concurrently between 2.5 and 1 million years ago. These were the "gracile" *Australopithicus africanus* and the "robust" *Australopithicus robustus*. Gould's first set of discoveries took place in 1959, when Mary Leakey found evidence of a third contemporary species. (She called it *Zinjanthropus*, but today it is known as *Australopithicus boisei*.) These were all much older than the earliest Homo fossils known by this time, the famous Java Man (from Indonesia) and Peking Man (from China), later also found in Africa and recognized today as *Homo erectus*. The second discovery was made by Mary Leakey's son Richard, and took place in the mid-1970's. This was the recovery of an *A. boisei* specimen in the same strata as African *H. erectus*, implying that two different genera of the hominid family apparently coexisted. Proponents of multiregionalism argued that, while there might have been a few "dead end" side branches, once *Homo* came into existence, it evolved in a ladder-like fashion. This view suffers at the hands Gould's third case, a broad collection of African discoveries about multiple coexisting species of both Homo and Australopithicus during the period of 1.5 to 3.0 million years ago. (Human species during this period include *H. habilis*, *H. rudolfensis*, and *H. ergaster*, the last of which may be identical to *H. erectus*. Gould notes that there is only one known species of hominid, *A. afarensis* – including the famous "Lucy" – from 3 to more than 4 million years ago.)

Whatever may have happened in Africa, proponents of multiregionalism continued to advocate that once our ancestors reached Eurasia they evolved via the ladder model. Gould's fourth argument does not involve a specific discovery, but rather the debate between interpretations of Neanderthal man (living only in Europe and parts of Asia, not Africa). Is Neanderthal man a separate branch of *Homo*, or an transitional step between

H. erectus and *H. sapiens*? That is, does Europe at this time contain a small bush of *Homo* species or a sequential ladder?

The fifth argument derives from a contemporary update to an older discovery made in Asia. At the time, the youngest positively dated *H. erectus* fossil – the famous "Java man" remains, found in 1890 – were known to be about 300,000 years old. Some additional skull caps had been discovered in a nearby cave in the 1930's, near the Solo river (and hence called "Solo man"), but these could not be positively dated without seriously damaging them. (The consensus today, Gould writes, is that Solo man is also *H. erectus*, like Java man.) Meanwhile, the oldest *H. sapiens* remains found in the region did not exceed 40,000 years. This gap in the fossil record precluded a determination between the ladder and bush models. Then, in 1996, using new minimally destructive methods, the Solo man skulls were found to be between 27,000 and 53,000 years old; this strongly suggests an overlap with *H. sapiens*. It thus appears that at least three species of *Homo* (counting Neanderthal) were coexisting as recently as 40,000 years ago, in support of the bush model. The essay's title expresses a corollary of this viewpoint: that the current existence of only one member of the hominid family is the exception, not the rule. He returns to his opening argument, stating that we must be careful about the tendency to extrapolate from the specific to the general.

LM C 11. A *Cerion* for Christopher

Gould wrote this essay after a visit to San Salvador in the Bahamas, believed by most experts to be the island where Christopher Columbus made landfall in the new world some five hundred years earlier. Because there are several hundred islands in the Bahamas, and because the artifacts are few and records sketchy, there remains some doubt as to the exact island and location. Gould makes the case that if Columbus had picked up and kept a single snail shell (genus *Cerion*, his primary area of professional expertise) on his visit then today we would be able so say for certain where he landed. This is because each island has its own distinct *Cerion* variations, one of the key features that make land snails so interesting to study from an evolutionary standpoint. Gould spends a few pages discussing the snail variations he observed there, while on breaks from a conference he was attending. [See TFS 11 for more on these snails.]

The discussion of *Cerion* fulfills the essay's "natural history" obligation. Most of the essay discusses Columbus's activities after his time on San Salvador on the local Tiano peoples, and of the conquistadors that followed. Gould turns to Columbus's log (from a copy of a copy, all that survives) and other resources to track his actions and assess his motivations. It is abundantly clear that he had little if any interest in exploration or discovery; he was after gold. Despite the warm reception by the Tiano, his writings show that his only long-term interest in them was the ease with they could be enslaved to dig for gold found in Hispaniola. This is exactly what came to pass; drawing on C. O. Sauer's classic book *The Early Spanish Main*, he reports that the entire indigenous population of the Bahamas – estimated at about 40,000 – was wiped out in less than 20 years. The conquerors sailed further and further for captives – it was really more slaves, not cities of gold, that Ponce de León was searching for in Florida – and it was not long before they brought in the African population whose descendants populate the islands today. One of the ironies is that, had the Tiano populace and culture not been so completely exterminated, their descendants would no doubt be able to tell us exactly where Columbus landed. In fact, Columbus recorded the Tiano name for the island in his log: *Guanahani*. Nothing survives to tell us where this place was. In the next essay, Gould mentions that only surviving artifact of their entire culture is a single word: "hammock."

LM C 12. The Dodo in the Caucus Race

Gould begins with a personal anecdote about the joy of finding relics of an era whose time has passed – in this case, remnants of the once-vibrant Yiddish culture of his parent's and grandparent's generation in New York. He generalizes this to the preservation of fragments of extinct creatures and peoples. This is both a noble and a depressing calling, he tells us.

The dodo is one of the most famous examples of human-induced extinction. Dodos were large flightless pigeons, sometimes exceeding 50 pounds, and lived on the human- and predator-free island of Mauritius (east of Madagascar) until the Portuguese first arrived in the early 1500's. By 1690 the dodo was extinct, in part due to sailors capturing them for food, and in part due to the introduction of pigs and monkeys to the island, which ate their unprotected eggs. To compound the loss, only a few anatomical fragments of dodos exist today; there are no complete specimens, only a few heads, feet, and a handful of drawings and descriptions made from life. Gould approaches the topic of the dodo and two other examples of human-induced extinction from the perspective of a museum curator, one of his job titles. The other examples are the blauuwbock (the blue antelope, discussed in DIH 21), and the pre- and very slightly post-Columbian human population of the Bahamas, the Tiano (discussed in the previous essay). He identifies a recurring irony: most of his brethren in this lonesome field express anguish for the loss of the very populations that make collecting their remnants so valuable, while simultaneously "blaming the victim" for their fate!

The dodo in particular comes under fire from such luminaries as Linnaeus, Buffon, Lyell, Owen, and Lamarck for being too fat, slow, and stupid to survive for long in the modern world. Many of these criticisms go beyond this and blame the dodo's "character" as lazy and slothful. Owen in particular blames the "degeneration" of the species due to the absence of predators, in a rebuttal to contemporary H. E. Strickland's 1848 (pre-Darwinian) claim that the bird was well-adapted to its environment. Those who preserved and described the few bone fragments and artifacts of the Tiano people express a similar duality. W. K. Brooks explicitly lamented, in 1889, the dark side of the upcoming 400th anniversary of Columbus's landfall; yet in the same document, he writes that his analysis of four existing Tiano skulls showed them to be "primitive," and thus more susceptible to extermination.

Gould suggests that the source of this interpretive duality is our widespread cultural view that extinction is associated with failure; the survivors have "won," the others have "lost," and in a fair and just world, the losers must be inferior. He has noted in other essays that, by this criterion, all species are losers, since extinction is the ultimate fate of all. As an alternative, he turns to the character of the dodo in *Alice in Wonderland*. After all parties in the story have become soaking wet, the dodo suggests that the best way to get dry is to have a race; not from one point to another, but rather in a circular track. The characters are all allowed to start and stop running whenever they want to, and after a half hour all are dry and the race is declared over. The question of who has won is raised, to which the dodo replies, "everyone." Gould argues that this is a better way to view the once-in-natural-history existence of any species. He adds, however, that the three examples presented here should not be seen as inevitable, but as tragedies whose reoccurrence we can and should work to prevent.

LM C 13. The Diet of Worms and the Defenestration of Prague

As a professional wordsmith, Gould reflects on two of his favorite humorous or eponymous phrases from elementary school history classes – presented in the title of this essay. [The first is also the source of the second half of the title of this collection of essays.] He adds that he was motivated to write this essay after visiting the locations where the corresponding events occurred. He then turns to the stories behind them, each of which led to dramatic – and, generally, horrible – events in European history. He begins with the Diet of Worms.

After the Pope excommunicated Martin Luther in 1521, he was called before the newly elected Holy Roman Emperor, and asked to either defend or recant his positions. He met before the governing body – the Diet – in the town of Worms, near Heidelberg. The story goes that he defended himself bravely, and even though he was "convicted," he was allowed to escape and live in safety elsewhere. This story has several great themes: personal courage, defiance of ossified authority, commitment to a true belief; and it is all essentially true. However, Gould continues, it is not the complete story. First, religious doctrine and corruption in the Church were only the tip of the iceberg in what was really an enormous power struggle on several levels. Gould writes: "Scratch the surface of soaring notions like 'justification by faith,' and you encounter a world where any major idea becomes a political instrument in a quest for social order, or a tool in the struggle between distant popes and local princes." Secondly, he discusses the extreme totality with which such struggles were fought. It was not enough to simply condemn Luther and reject his doctrine; the resulting Edict of Worms calls for the complete destruction of all copies of his writings and, if necessary, the execution of every one of his followers. As an academic, Gould finds the call for destruction of an entire school of thought or belief to be particularly repulsive. Third, he notes that Luther himself was little better in this regard. He, too, called for the complete destruction of certain groups as a means toward destroying their ideas and culture, from rebellious German citizens to Jews.

In Latin, *fenestra* means window, and so defenestration means to throw something (or someone) out of a window. Gould takes us through the surprisingly long history of defenestrations in the city of Prague; however, the one with the capital "D" took place in

1618. In this event, three Catholic councilors (government workers) were thrown out of a castle window by a proto-Protestant group angered by the reneging of their religious freedoms by the Catholic king. Remarkably, considering the height of the fall, the victims were not seriously injured; however, this date is traditionally identified as the start of the appallingly horrific Thirty Years War. Gould describes some of the carnage, both between Christian factions and against Jews and other non-Christians.

After describing these dramatic events in human history, he relates them to natural history by posing the general question, what makes humans behave so badly? He asks this in the context of evolutionary psychology [criticized in ESD 32], an area of both professional study and popular writing. The proponents argue that it can be used to explain many types of human behavior, from male infidelity to genocide. Gould concedes that there is likely something in our genes that gives us the capability to be aggressive and cruel, as well as kind and nurturing. However, he objects to the legitimacy of the field for three reasons. The first is practical: the field, at least so far, does not tell us anything we do not already know. Humans can be good, humans can be bad, and evolutionary psychology does not allow us to make any new predictions about when we are likely to behave in either way. His second objection is moral: he argues that faith in such a paradigm would allow us to duck our responsibilities to stand against atrocities; "we can't help it, it's in our genes." The third objection is purely technical. Individual and group behavior, he argues, is far more a product of culture than of genetics. Cultural evolution follows the laws of Lamarckism, in that experiences and lessons can be passed on to others in ways other than reproduction. This makes it fundamentally different from Mendelian genetics and natural selection, the underlying mechanisms of evolutionary psychology.

LM C 14. Non-Overlapping Magisteria

Gould pulls several of his recurring themes together in this essay to produce an intellectual construct that he hopes will help science and religion to peacefully, and even fruitfully, coexist. He begins by noting that many people believe that a state of war currently exists between these two artifices. He refers to a discussion he once had with a devout and troubled student in one of his classes at Harvard, who asked him if science – and, in particular, evolution – and Christianity were fundamentally incompatible. Gould writes: "Again, I gulped hard, did my intellectual duty, and reassured him that evolution was both true and entirely compatible with Christian belief – a position that I hold sincerely, but still an odd situation for a Jewish agnostic."

Gould then argues, as he does in other essays, that there is that there is no war between science and religion today, since (he states) there is no actual overlap of the two. He explains: the empirical universe – what it is made of, and the rules for how it operates – fall under the jurisdiction, or *magisteria* (area of teaching) of science, and not of religion. Likewise, science has nothing to say about how we should behave towards each other, definitions of "right and wrong" (in the general sense), what behaviors are morally inappropriate, and what happens to our souls when we die. Science gets into trouble, for example, when it attempts to define morality by drawing on examples from nature (a familiar theme in his writings), or when it tries to justify racist, sexist, or other exploitive behaviors in culture in biological terms (another popular theme). Likewise, religion gets into trouble when it attempts to weigh in on the orbital motion of the earth-sun system, or the amount of time that has transpired since each was formed. Science and religion really have nothing to fight about, he states, unless either crosses the line; and both can enrich our lives. Gould has given a name to this view: non-overlapping magisteria (NOMA). He argues that science and religion are, or should be, natural allies. He writes openly of his own agnosticism, but emphasizes that his beliefs in this matter are *not based on science*. He also recognizes that faith in the immortality of the soul (as an example) is comforting to many people, and therefore has value even to him. [He elaborates on the concept of non-overlapping magisteria in his 1999 book, *Rocks of Ages*.]

(Gould acknowledges the skepticism of many members of the scientific community regarding the NOMA concept, and professes dismay at this. He states that the views he expresses about the role of science and the soul are sincerely held, and not just a "sop" to a broad fraction of American society whose support science requires in order to survive and flourish. Over the years, Gould made extensive efforts to be an agent of peace between the two communities; he was always careful to point out that his attacks on creationism were not attacks on religion, but rather on a group of people who would use people's fears for political ends [for example, HTHT 20].)

The specific event that triggered the writing of this essay was the release of a document on evolution by Pope John Paul II on October 22, 1996. The document, entitled "Truth Cannot Contradict Truth," defends both the evidence for evolution and its consistency with Catholic religious doctrine. As such, Gould did not consider this news – the Catholic Church has often stated its support for the NOMA principle. However, the *New York Times* reported on its front page, "Pope Bolsters Church's Support for Scientific View of Evolution"; perhaps, he wondered, even the *Times* bought into the idea of a war between science and religion? Gould knew there was no such war; he was familiar with an encyclical released by Pope Pius XII decades ago, in 1950, entitled *Humani Generis*. This document famously states that Catholics should believe whatever science determines about the origin of man, but must also accept that at some point God infused the creature with a soul. (Gould states that he has no objection to this caveat; he does not personally believe it, but notes that such questions are outside of his magisteria.) Yet the story received a huge amount of publicity, in Europe as well as in America, and the Vatican itself had deliberately drawn attention to it. He remained puzzled, so he turned to the classic (and yet, he notes, the disappointingly rare) strategy of reading the source documents.

Humani Generis, he discovered, was not primarily about evolution. In the years of disillusion after the Second World War and the Holocaust, Pope Pius was trying to reassert Church authority over doctrine – what one *had* to believe in order to be a good Catholic. While tolerance was important, he wrote, doctrinal relativism was not acceptable; for example, belief in the Church's view of Transubstantiation was not optional. One of the threats to the Church's magisteria – this is where Gould acquired the term – came from communism, which argued that there was no requirement for God.

Communism (along with various other “isms,” such as existentialism and pan-theism) argued that Darwin’s theory of evolution could explain man’s origins without any divine assistance. Pius acknowledged the NOMA concept, Gould states, when he wrote the following words:

> The Teaching Authority of the Church does not forbid that, in conformity with the present state of human sciences and sacred theology, research and discussions, on the part of men experienced in both fields, take place with regard to the doctrine of evolution, in as far as it inquires into the origin of the human body as coming from pre-existent and living matter – for the Catholic faith obliges us to hold that souls are immediately created by God.

So far, so good, Gould writes; but then he reads on to find another paragraph that he has not seen before. On the study of evolution itself, Pius continues:

> However, this must be done in such a way that the reasons for both opinions, that is, those favorable and those unfavorable to evolution, be weighted and judged with the necessary seriousness, moderation and measure . . . Some however, rashly transgress this liberty of discussion, when they act as if the origin of the human body from pre-existing and living matter were already completely certain and proved by the facts which have been discovered up to now and by reasoning on those facts, and as if there were nothing in the sources of divine revelation which demands the greatest moderation and caution in this question.

That is, Gould summarizes, the Pope has some words of warning for scientists: “[T]he idea is not yet proven, and you all need to be especially cautious because evolution raises many troubling issues right on the border of my magisterium.” It was to this paragraph that John Paul was responding. From the 1996 document, “Truth Cannot Contradict Truth”:

> Pius XII added . . . that this opinion [evolution] should not be adopted as though it were a certain, proven doctrine . . . Today, almost half a century after the publication of the encyclical, new knowledge has led to the recognition of the theory of evolution as more than a hypothesis. It is indeed remarkable that this theory has been progressively accepted by researchers, following a series of discoveries in various fields of knowledge. The convergence, neither sought nor fabricated, of the results of work that was conducted independently is in itself a significant argument in favor of the theory.

Gould now appreciates the significance of the announcement, and is delighted. He does not gloat, however; instead, he writes: “NOMA represents a principled position on moral and intellectual grounds, not merely a diplomatic solution. NOMA also cuts both ways. If religion can no longer dictate the nature of factual conclusions residing properly within the magisterium of science, then scientists cannot claim higher insight into moral truth from any superior knowledge of the world’s empirical constitution. This mutual humility leads to important practical consequences in a world of such diverse passions.”

LM C 15. Boyle's Law and Darwin's Details

This essay appeared in *Natural History magazine* the month after his essay *Can We Complete Darwin's Revolution?* [DIH 25], and is essentially a continuation of it. It begins by recapitulating Sigmund Freud's assessment that scientific revolutions are not completed until society accepts not only the revised view of the universe, but the demotion of man's *status* in the new worldview as well. Gould refers to the acceptance of these implications as "pedestal smashing," and to resistance as "spin doctoring." Freud emphasizes two such events: the famous Copernican/Galilean revolution that removes Earth from the center of the universe, and Darwin's revolution on the origin of man. Galileo's revolution is complete; almost everyone accepts that the earth-sun system is a speck (albeit a nice one) in the context of the galaxy and the universe. In his earlier essay, Gould offered evidence to support his claim that Darwin's revolution is not complete; many of those who accept the concept of evolution by natural selection do not fully accept the implication that man is just another species. He writes that ". . . we spin-doctor the results of evolution to preserve our pedestal of arrogance by misreading the process as a predictable accumulation of improvements, leading sensibly to the late appearance of human intelligence as a culmination." In this essay, he explores the long-completed Galilean revolution, through the writings of a key player who lived through it.

Gould first probes the question of whether Darwin's revolution has simply not had sufficient time to reach completion. He concludes that this is not the case, referencing the work of the great English scientist Robert Boyle (1627-1691). Galileo got in trouble with the Pope when he published *Dialogue on the Two Chief World Systems* in 1633, which argued for a sun-centered solar system. In 1688, only 55 years later, Boyle published a treatise that left little doubt that the situation had changed completely. He was a member of the establishment – he helped found the Royal Society – and yet he wrote without apparent concern for his status, much less his safety, that earth was not at the center of the universe. He went so far as to ridicule the idea that God created the sun and the heavens purely for human benefit. As of 1995 (when this essay first appeared), more than 135 years had passed since Darwin published *Origin of Species*; this is more than twice the time required to complete Galileo's revolution, so time itself is probably not the constraint.

In reading Boyle, however – especially his 1688 treatise *Disquisition About the Final Causes of Natural Things* – Gould finds something else: the origins of natural theology [see ELP 9]. This doctrine, which also reflected the views of Newton, saw God not as a constant maker of miracles (although He could perform them when needed), but instead as a "great watchmaker" who created the rules of the universe – including Newton's gravity – and then stepped back and let it run. Natural theology argues that both God's existence *and His benevolence* can be inferred from the Creation itself – a line of reasoning that has come to be known as the "argument from design." God's existence and greatness may be inferable (in this view) from the world at large, but proof of His goodness requires the acceptance of another concept: *purpose*, in the Aristotelian sense of final cause [HTHT 6].

Boyle rejected Aristotle's views on the nature of matter – the four elements of earth, air, fire, and water – and many other aspects of his natural philosophy, but accepted his views on "causes." Aristotle's paradigm required the actions of four separate causes for an event to occur, or for something to be created: material, formal, efficient, and final. Today we recognize only the efficient cause, which draws on the concept of an effector. The so-called "final cause" incorporates a paradigm from a different world, one in which nothing happens without a *reason*, and every event (and being) serves a *purpose*. The construction of a house – the classic example – requires not only bricks (material cause), blueprints (formal cause), and a construction crew (efficient cause), but also a purpose (final cause), in this case to provide a home for a family. This example is directly extrapolated to the natural world: birds would not have wings if the universe (according to Aristotle) or God (according to Boyle) did not *intend* for them to fly. A key postulate of natural theology is that these purposes are invariably *good*, which in turn "proves" God's benevolence. [Gould, following Darwin among others, discusses the limitations of this position in HTHT 2.] In such a world, can we doubt that that purpose must be, in some way, to serve God's greatest creation – man?

Boyle, as a mechanist, argued for a constrained version of this vision. He was familiar with the Epicureans, who argued long ago that final causes did not exist in nature. He supported these views for "the little things," such as water, rock, and snowflakes; the Great Watchmaker's natural laws control the behavior of these objects and substances, and they do not reflect God's goodness. He was also familiar with the Cartesians, who argued that if final causes did exist, man's mind would never be able to grasp or understand them. To this view, he ceded "the really big things" – the sun, the planets, and the stars; we have no idea why God made them. (Gould notes that this view acknowledges the smashing of the first pedestal; the sun was enormous, the stars incredibly far away, and earth was truly just a speck.) In the middle, however, was life: perfectly designed organisms and ecosystems that operated in perfect harmony. (Darwin would later note that neither of these statements was true in general.) Life on earth, Boyle argued, shows not only design but *purpose*, and the nature of that purpose (or final cause) – which is clearly to provide his favorite creation with what he needed to survive and, sometimes, to thrive – is evidence of God's goodness. In his words, from his 1688 treatise:

> The terraqueous globe and its productions . . . and especially the plants and animals 'tis furnished with, do . . . appear to have been designed for the use and benefit of man, who has therefore a right to employ as many of them as he is able to subdue . . . Therefore the kingly prophet had reason to exclaim: How manifold are thy works O Lord! How wisely hast thou made them all!

Gould points out that Boyle's concepts of science and religion were fundamentally intertwined [the opposite of the previous essay's NOMA concept]; to study the mechanisms of the universe was to study the mind of God. [Natural theology, it should be noted, played a pivotal role in the Enlightenment.] Perhaps ironically, the mechanistic view of the world that Newton and Boyle helped to create would eventually drive the notion of final cause completely out of science. Gould writes:

> We no longer believe that inorganic objects have intended purposes, defined either in human or in any other terms. As for organisms, we surely allow a notion of purpose in the vernacular sense that good designs have functions (yes, eyes evolved for seeing) – but we now view such functions as products of the efficient cause of natural selection, and not as conscious intentions either of organisms themselves or of a creating deity.

In fact, he states, it was natural selection that finally overthrew natural theology – and this illustrates the true revolutionary power of Darwin's idea. Yet, even 150 years later, most people still believe that Man is the epitome of *something*, and apart from the rest of nature – and thus on a pedestal. In Gould's words: "Boyle's argument – that good design implies benevolent purpose in the cosmos – provides a comfort and appeal that we have not been able to relinquish." The natural theology paradigm helps create the intellectual traditions that make Darwin's pedestal so impervious to destruction.

In closing, Gould poses the question, did even Darwin himself intend for his revised view of life to smash this pedestal – to demote man to just one species among millions? Darwin, the Victorian Gentleman, was always careful not to discuss this topic in his published writings. Quoting from some of his personal correspondence, however, Gould concludes that Darwin did believe that the "details" of living organisms (hence the essay's title) were, in fact, due to "chance" (Darwin's word), and gives some examples. Gould argues that Darwin meant this word in the sense of "contingency," or as the result of historical events so complex that they would not likely happen again, rather than in the dice-throwing sense. That is, Gould concludes, Darwin did explicitly recognize the falseness of the pedestal under discussion, even if he never publically (or even privately) called for its demolition.

LM C 16. The Tallest Tale

In a survey he made of high school biology textbooks, Gould found that every single one used the example of the giraffe's neck to illustrate the difference between Lamarck's theory of evolution ("inheritance of acquired characteristics") and Darwin's (natural selection). The canonical story given in all of these textbooks is, first, that long necks gave giraffes unique access to an important food source – the leaves of acacia trees. Lamarck, the story continues, suggested that the animal's short-necked ancestors physically stretched their necks by a small amount over their lifetimes, and that these physical changes were then passed on to their offspring, who worked to continue the trend. [This is an oversimplification of Lamarck's views; Gould discusses them at length in LSM 6.] Darwin countered with his familiar two-stage process: first random variation, and then natural selection of those giraffes with longer necks via preferential survival. Mendelian genetics, the story then concludes, proves Darwin was right and Lamarck was wrong; individual effort cannot alter one's genome.

It turns out that there are a number of flaws with this story. First, Lamarck never used the giraffe as an example (Gould quotes the one paragraph in all of his writing in which he mentions the animal at all). Second, Darwin's only reference to the giraffe in terms of natural selection in his early editions of *Origin of Species* refers only to the tail (which resembles, and functions as, a flyswatter). Elsewhere, he mentions the neck – but only to point out that it contains only seven vertebrae, the same number as most other mammals; his point being that the giraffe neck is a homologous structure to an antelope neck, and even a mouse neck.

So if neither Lamarck nor Darwin raised the issue to support their arguments, how did the tale originate? Gould concludes that it begins with St. George Mivart, a contemporary of Darwin's, and a believer in evolution but not in the mechanism of natural selection. Ironically, Mivart introduces the lengthening giraffe neck as a criticism of Darwin's theory! He points out, correctly, that giraffes require many other attributes to support the neck, including larger vertebrae to support the muscles and a bigger heart to pump the blood to the head. All of these would have to change together, Mivart argues, via the partially random process of natural selection. This is absurd, he concludes; there must be some other coordinating or directive force at work. Darwin responded to this important line of criticism by adding the only full additional chapter to *Origin of Species*, which appears in the sixth and final edition (1872) – the one found in bookstores and libraries today. His response – which Gould does not consider to be entirely satisfactory – is that all of these components varied independently over an extended period, with natural selection favoring the slightly better combinations. [This explanation led Darwin to conclude that evolution *had to be* a very, very gradual process. How these systems change in a self-supporting fashion under the more rapid paradigm of punctuated equilibrium is not addressed here, and in fact remains a fascinating and important problem in evolutionary and developmental biology today.]

From Mivart's criticism to the contemporary canonical tale is more difficult to track, but Gould found that it appears in its modern form in the classic 1918 textbook *The Origin and Evolution of Life* by Henry Fairfield Osborn [BFB 29], one of the dominant paleontologists of his era. Ironically, it appears that Osborn, or someone in between, missed the "sarcastic" nature of Mivart's argument. Since then, it has been endlessly repeated by textbook authors, who tend to copy from earlier works [BFB 10].

Another important problem with this story is that there is no actual evidence to support it. Giraffes comprise only a single species, and their only living relative is the short-necked okapi; the fossil record for giraffes is very poor, but what little evidence exists shows only short-necked animals. We do not know the circumstances under which the giraffe's neck took its current form. We may speculate that the driving selective force was access to a high-altitude food source; but it turns out that it serves many other purposes as well, including fighting with rivals, sexual foreplay, the obvious "lookout" function, and thermal regulation – giraffes can stand in the sun all day while other mammals must seek shade. In this light, the argument that it evolved to allow browsing of acacia leaves can be seen to be one of the "just-so stories" that Gould cautions against. The ability to feed in this manner could easily reflect the co-option of an attribute that was originally developed for other reasons, or for no adaptive reason at all. He reiterates one of his most important themes: "the dissociation of current utility from historical origin."

LM C 17. Brotherhood by Inversion (Or, As the Worm Turns)

This essay begins by describing a rejected paradigm of a forgotten English physiologist, Walter H. Gaskell (1847 – 1914). The first half of Gaskell's career was spent studying the nervous and circulatory systems, and by all accounts did excellent work. Then, in mid-career, he changed gears and began to advocate a model he had developed to explain the origin of vertebrates; this was considered to be a major problem in biology at that time [see ELP 29]. (The oldest fish fossils – and thus, the oldest known vertebrates – were considerably younger than certain other phyla such as mollusks and arthropods. Today we recognize soft-bodied chordates that are as old as the latter, but these were not known at the time.) Like others of the period, Gaskell believed that evolution represented a progressive, advancing trend from the simple to the complex, from something like jellyfish to annelids (segmented worms), to arthropods, and then to vertebrates, where the trend continued from fish to amphibians to reptiles to mammals, and on up to man. Gaskell focused on the central nervous system (including the brain), and argued that this was the key structure in which this progressive trend toward complexity manifested itself.

Within all such progressive paradigms of the era, the most difficult chasm that proponents felt they had to traverse was the one between invertebrates (usually arthropods, and commonly crustaceans) and primitive fish. Arthropods and vertebrates do share some structural similarities: bilateral symmetry with sense organs at one end, a digestive tract, a circulatory system, and a nervous system. However, the differences are also extensive, including the structure and organization of the internal organs, and exoskeleton versus internal skeleton. One particular difference drew more attention within this community than all others: the relative locations of the central nerve and the digestive tract. In vertebrates, the central nerve runs down the dorsal (back) side of the creature, while in arthropods it runs down the ventral (belly) side. Gaskell's unique argument was that the transformation between the two groups occurred when the arthropod's ventral central nervous system grew upwards and enveloped the straight, dorsal arthropod digestive tract. As part of this process, the stomach (which in arthropods is in the front) was also enveloped with nerve tissue. This became the brain, whose ventricles (interior spaces between the brain folds) are thus explained as parts of the former digestive tract. Since this process renders the legacy digestive tract useless, Gaskell proposed that a new one must form – along the ventral side. Since there was no existing structure to convert to a digestive tract, he postulated that it arose from scratch. This mechanism made few converts, and he ended his career in the academic wilderness.

Is there anything to be learned from this story, other than the obvious benefits of caution in matters where so much remains unknown? Gould offers the following: when a well-respected professional proposes a "nutty" theory, it often pays to look at the context. In this case, Gould finds that Gaskell was motivated by his opposition to the alternative, "standard" model linking arthropods to vertebrates. This model was extrapolated from an older paradigm called "transcendental biology," which was popular on the European continent (less so in England and the United States) during the 19th century. This philosophical approach postulated a non-Darwinian form of evolution in which the plethora of modern organisms developed via rational, mathematical laws from a much smaller number – perhaps only one – "archetypal" Platonic form. [See ELP 4 for a related example involving vertebrates, and ELP 10 for one on plants. Gould was always intrigued by certain aspects of this perspective, in particular the limits or constraints that it placed on the power of evolution to reshape life.] One of the pioneers of transcendental biology was the great French scientist Etienne Geoffroy Saint-Hilaire. In Geoffroy's view, at some point in time there existed a prototypical animal that included both a central nerve and a digestive tract; which side was "up" remained a detail that would be resolved differently by arthropods and vertebrates. This led to some odd inferences, such as vertebrate ribs being homologs of arthropod legs (both reflect a "segmentation" process). Geoffroy himself did not argue for the principle of linear progress in evolution (in this case, from arthropods to vertebrates), but some who followed him did. The result was a school of thought that proposed that, at a critical juncture, an advanced crustacean "inverted itself" (rolled over on its back), which relocated the central nerve to the dorsal side – and in so doing became a primitive fish. [A leading proponent of "inversion theory" was William Patten – see ESD 29 & 30.] Of course, other changes would have to have taken place; the mouth opening, as an important example, would be located on the new "top" of the head. It must move, somehow, to the front or bottom. Gaskell found the inversion postulate to be unacceptably ugly, in the cavalier way it addressed this key moment in evolutionary history. If increasing complexity of the central nervous system represented the pathway of evolution, something more appropriate was required – so he developed one.

History has since relegated both of these "nutty" theories (Gould's term) to the dustbin. Today, we recognize that these two phyla have been evolving independently for over 500 million years, and so "simple" arthropods did not evolve into "complex" vertebrates – by any mechanism. Interestingly, however, the demise of these linearly progressive views of evolution did not come with the publication of *Origin of Species* in 1859. It came later, with the formation of the modern evolutionary synthesis in the 1930's. This paradigm emphasizes the power of natural selection as a *creative* force, one that could produce similar results (such central nerves and digestive tracts) from almost any starting point. This phenomenon – convergence – is also behind the independently-evolved wings of birds, insects, and pterosaurs (reptiles). In a worldview where the organism is just putty in the hands of natural selection, the similarities of arthropod and vertebrate anatomy are not due to homology (as Geoffroy argued), but to convergence. Each phylum independently developed both a nervous system and a digestive tract from a shared primitive ancestor that probably had neither. The modern synthesis predicted that we should expect to see very few detailed similarities in their genomes, since natural selection is so powerful and since they diverged so long ago. Gould references Ernst Mayr's 1963 classic *Animal Species and Evolution*:

> In the early days of Mendelism there was much search for homologous genes that would account for such similarities. Much that has been learned about gene physiology makes it evident that the search for homologous genes is quite futile except in very close relatives.

Except, Gould continues, it now turns out that Geoffroy was actually partially correct! Modern gene sequencing techniques (this essay was first published in 1997) demonstrate that there is far more similarity in arthropod and vertebrate genomes than anyone had suspected. He offers three examples. First, the genes that control segmentation in insects is also present in vertebrates. Although not responsible for segmentation of the embryonic vertebral column (thus falsifying Geoffroy's argument that human ribs are the homologs of insect legs), it is involved in the segmentation of the mid- and hind-brain. Second, the formation of eyes in insects and vertebrates, and also mollusks such as the squid – long held as another classic example of convergent evolution – also share several important developmental genes (called *Pax-6* in vertebrates). That is, eyes actually appear to be homologs among these three phyla, at least at some level. Finally, there are the genes that regulate the embryonic development of the nervous system. Gould writes:

> [In vertebrates,] the *chordin* gene codes for a protein that patterns the dorsal (top) side of the developing embryo, and plays an important role in the formation of the dorsal nerve cord. When [De Robertis and Sasai, Holley, Francois, and others] searched for a corresponding gene in *Drosophila* [the fruit fly, an arthropod], they discovered, to their surprise, that *chordin* shares sufficient similarity with *sog* [a gene found in insects] to make a confident claim for common ancestry and genetic homology. But *sog* is expressed on the ventral (bottom) side of *Drosophila* larvae, where it acts to induce the formation of ventral nerve cords. Thus, the same gene by evolutionary ancestry builds both the dorsal nerve tube in vertebrates and the ventral nerve cords of *Drosophila* – in conformity with Geoffroy's old claim that vertebrate backs are arthropod bellies, and that the two phyla can be brought into structural correspondence by inversion.

[Gould does not elaborate on the subject here, but the common role of these regulatory genes across phyletic boundaries supports one of his early claims – made in 1977's *Ontogeny and Phylogeny* and his 1979 presentation *The Spandrels of San Marco* – that "structuralism" or "formalism" should not have been so completely displaced from evolutionary theory by adaptationism. It is directly tied to his views on biological constraints and the lingering effects of natural history.]

LM C 18. War of the Worldviews

"As I have often emphasized in these essays, the study of error provides a particularly fruitful pathway to understanding human thought. Truth just is, but error must have reasons." Gould is writing about Percival Lowell (1855 – 1916), famous Boston patrician and builder of the private Lowell Observatory near Flagstaff, Arizona. It was from this facility that Lowell captured the world's imagination when he reported the existence of an advanced, dying civilization on Mars, peaking with his 1906 book *Mars and Its Canals*. For Gould, the aspect of Lowell's work that offers insight is not how he came to see Martian canals, or seasonally changing Martian vegetation, neither of which turned out to exist; rather, it is how he came to extrapolate from these (incorrect) observations the presence of intelligent life. [Lowell's vision also spawned some classic science fiction, including the H. G. Wells novel that the essay's title puns.] This is relevant today, Gould will argue, because many people share some of the same (false) views of how life evolves – on earth, and perhaps elsewhere.

Before Lowell, in the 1870's, the Italian astronomer Giovanni Schiaparelli reported seeing *canali* (the Italian word for "channels") on Mars, but the word was mistranslated into English as "canals," implying artificial construction. Lowell then "saw" them too; Gould then proceeds to trace Lowell's train of thought, which is as follows. Plant life implies animal life (Lowell argued); both plants and animals evolve toward greater complexity (a false notion of evolution that is the real subject of this essay); planetary cooling provides motivation for progress (a common belief among Northern Europeans during the Victorian era); Mars has cooled more than Earth (true, due to its smaller size as well as larger distance from the sun); and therefore, Mars must be host to a civilization more advanced than our own. Thus, the straight lines must literally be canals to bring water from the polar icecaps to the equatorial deserts, required to keep the civilization from dying out in the face of planetary-wide dehydration. (Gould tells us that several of his contemporaries not only failed to see the canals, but found Lowell's reasoning ridiculous. Alfred Russell Wallace, the co-developer of natural selection, wrote that if they were water-transport canals, then most of the water would evaporate in transit.)

Gould then turns our attention to the contemporary publication (1996) of an article by NASA scientists in the journal *Science*, which discusses the analysis of a meteorite that had once been part of Mars. This rock contains cracks that had been filled in by sediments while on Mars some 3.6 billion years ago, indicating the presence of water. It was ejected from the planet by an asteroid impact some 15 million years ago, and then fell in Antarctica some 13 thousand years ago. Chemical and isotopic analysis of the sediment material provided certain signatures that might be, but might not be, associated with life. Also present are microscopic structures that could be the remnants of bacteria. This is possible, Gould acknowledges – they are about the right size, liquid water was present, and there were bacteria on earth at this time – but there are inorganic explanations as well.

However, he is taken aback by the intense publicity the NASA press conference received. Gould suspects that the reason that the press and the public were so impressed by the possibility of bacterial life on Mars is that, like Lowell, many people harbor a misunderstanding about the progressive nature of evolution: that, once any form of life appears at all, it is only a matter of time until intelligent life appears. On Mars, this progressive trend was snuffed out when the planet froze and dehydrated; but indications of bacterial life on Mars would imply that it can form readily easily (probably true, Gould agrees), which in turn would imply that there is plenty of intelligent life in the universe. It is the last step that is unjustified; getting to bacteria is the easy part, not the hard part, of getting to "consciousness." Referencing his 1996 book *Full House*, he notes that earth is still dominated by bacterial life, and that multicellular life of all types is a minor, albeit interesting, sideshow. Evolution is not progressive, and our own contemplative existence is the product of a large number of improbable events.

Having said that, he expresses great hope that bacterial life did form on Mars, and that some continues to live in the more protected regions below the surface. This is because, he states, there are so many questions about the fundamental nature of life that we cannot understand without another separate example of how it might work. All life on earth – all of it – uses the same DNA and RNA structure, and employs certain chemicals such as ATP. Is this because this is the only possible solution, or instead because it happened to develop on earth at a time when there was no competition? The only way to ever truly determine the answer to these and other questions is to find another independent example of life – and bacterial life would do just fine.

LM C 19. Triumph of the Root-Heads

One of the great misunderstandings of Darwin's theory is that natural selection produces global *progress* (greater complexity, for example). It does not; rather, it produces only better adaptation to the local environment. [Darwin, as Gould notes is essays such as ELP 21, did believe in a form of evolutionary progress – but this was separate from the mechanism of natural selection itself.] Darwin pointed out that parasites, which are usually simplified descendents of free-living ancestors, are as much a product of natural selection as wings or eyes. Since the introduction of his theory, one particular group of parasites – the Rhizocephala (literally "root heads") – have been repeatedly used to illustrate this point. Rhizocephala most often parasitize crabs, and are now recognized as a type of barnacle. In the most commonly discussed genus, *Sacculina* (literally "little sac"), the adult is nothing more than a bag containing ovaries and eggs – no other organs – connected to a series of root-like tubes inside the crab that transfer nourishment from the host.

However, Gould reports, it turns out that the Rhizocephala are not so simple after all. Their life cycle is very complex, and some of the pre-adult stages include unique structures. Further, the behavior of this parasite at a biochemical level is remarkable. Gould offers this essay as an example of an exception that proves the rule of non-progressive evolution, where he notes the use of the word "prove" in this usage actually means "test." He also uses this case to challenge another common bias: that in nature, only the adult stage matters [also see BFB 17]. He draws on the 1884 monograph on *Sacculina* by Yves Delage, and several contemporary papers by the Danish biologist Jens T. Høeg and his colleagues.

Gould begins with a discussion of the life cycle of the female rhizocephalans. Each begins its life as a *nauplius*, which is a larval form of most crustaceans and associated with the so-called dispersal stage. After several molts, it enters the next phase: the cyprid larva. (This phase occurs only in barnacles, and allowed 19th century scientists to classify them.) The cyprid larva has two appendages that allow it to move along the surface it intends to bond to (a rock in the case of most barnacles, but a crab in this case), and an organ that creates the glue used to cement it to the surface. The third phase is unique to rhizocephalans, and is called the *kentrogon*. The kentrogon contains a unique organ known colloquially as the "injection stylet," and is in fact a sharp, narrow tube that is capable of penetrating the crab's exoskeleton. This tube is too narrow for more than a few cells to pass through. So, another unique (and apparently unnamed) few-celled or even single-celled phase is produced; it is similar to one or more fertilized embryos, but comes in the middle of the life cycle as opposed to the beginning. Each injected cell can move within the crab's body, and each is capable of forming the final, adult phase of the parasite, but typically only one does. It does this by first developing the internal "root" system, and then by forming the external sac that emerges through the crab's abdominal opening. The crab normally uses this opening to exude its own egg sac.

Gould next discusses how the parasite takes virtually complete control of the crab's life. Crabs are sensitive to all types of parasites, and work constantly to keep them from getting a foothold. The roothead is able to suppress this behavior in its host by the time it forms the external sac. This is probably done via hormones; the crab is rendered infertile, and both male and female crabs become "feminized" to the point where they take care of the roothead's external sac as if it were its own egg case. This includes keeping the sac itself clean and free of other parasites, and in some species engaging in "dispersal behavior" (standing on the tips of its legs and waving its abdomen up and down to disperse the larvae) when the roothead's larvae are released. The parasite, for its part, does not kill the host, which can live for several years in this condition. It simply turns the crab into a feeding machine for its own exclusive benefit.

The male rhizocephalan's life cycle adds an additional twist. Its free-swimming stages are the same as those of the female. However, it does not settle on the body of a crab like the female does; rather, it attaches itself to the external sac of the female roothead. It then forms its own unique structure, the *trichogon*, which looks like a small worm and is comprised of a small number of undifferentiated cells. The trichogon moves into one of two narrow apertures in the female sac, where it resides and produce sperm. Other females in the animal kingdom will store male sperm for extended periods, but the trichogon is still a distinct phase of the male rhizocephalan's life cycle. Since it depends on the female roothead for all nourishment, it is in some ways a parasite within a parasite.

In summary, rhizocephalans are "devolved" from complex, free-living ancestors, but they are not so simple after all. They are, however, spectacularly well-adapted to their local environment, which in turn makes them an effective illustration of Darwin's view of natural selection. Gould concludes by arguing that, despite being "complex," these adaptations counter the view of progress in evolution for a different reason: it demonstrates how inappropriate the very concept of progress is. Root heads are neither better nor worse than barnacles simply because "they live on crabs instead of rocks . . . [or] because the adult looks like a bag rather than a set of gills enclosed in a complex shell." He continues: "Do we prefer seahorses over marlins, bats over aardvarks? Such questions are foolish and diversionary."

LM C 20. Can We Truly Know Sloth and Rapacity?

Gould poses the age-old questions, "What would it be like to be another animal? How would I perceive the world, and what sort of awareness of it would I have?" (Gould uses the interesting phrase "perceptual and conceptual" in this context.) He asks these questions within the context of having returned from a recent visit to Costa Rica, where he spent time observing sloths and vultures [“raptors,” hence the title].

Sloths are unusual mammals; they belong to a very small order called Endentata that includes only themselves, armadillos, and a few genera of anteaters. Endentates, it turns out, have a lower and more variable body temperature than any of the other orders of mammals (placentals, marsupials, and monotremes). They also are an exception to the otherwise-common mammalian feature of seven neck vertebrae (mice to giraffes – he references LMC 16 for the latter); one group has nine, and as a result individuals are able to turn their heads three-quarters of the way around. Their most famous characteristic is their extraordinary slow pace; they move at an average speed of about 0.2 miles per hour, and a top speed of about 1 mile per hour. Over the centuries, this has brought derision from many different cultures of anthropocentric humans. Gould presents quotes from several writers of natural history, most notably Buffon [see LSM 4], most of whom seem genuinely offended by this animal. He then returns to the question: if we were a sloth, would we perceive humans and other animals as moving in “fast forward?” Gould laments that we will never know.

The second creature that Gould observed and pondered was the turkey vulture. Famous for soaring and circling for hours, and then for feeding in groups on large dead animals, vultures have also generated many scathing “reviews” over the centuries. Gould wonders, are vultures excited when they catch a whiff of rotting flesh from a mile in the air? Does decaying meat actually smell “good” to a vulture? Upon returning to his library in Boston, he found that there has been a lot of work on how vultures detect food sources, dating back to James Audubon. In 1826, Audubon presented a paper showing that some vultures, at least, had no sense of smell at all. Charles Darwin read of this, and performed his own experiments with Andean condors while on his *Beagle* voyage, coming to similar conclusions. Other vultures, it turns out, do have a sense of smell; this was not conclusively resolved until the 1960s.

Gould closes by considering the more general question of whether there would be anything to “perceive” at all – that is, do animals possess consciousness? He normally tries to avoid this debate, he reports, because it invariably devolves into a semantic argument about the precise definition of the word “consciousness.” Few people today believe in the Cartesian view that animals are unfeeling machines, but – as Gould has argued before – there remains something unique about the human mind that manifests itself in language, art, and religion. His opinion is that he would be able to learn a lot from 60 seconds inside the mind of a bird or a mammal, if perhaps not a flatworm. In his words: “Vultures must have an aesthetic, and sloths must have a sense of pace.”

LM C 21. Reversing Established Orders

Gould has collected a limited number of examples of “reversals of the established order” in nature over time, he tells us, and now has four – enough to write an essay. By “reversals,” he is referring to cases in which members of a commonly perceived “lower group” kill and eat members of a higher group. He considers the following criteria:

predator versus prey; primitive versus advanced (in the old "great chain of being" sense, where vertebrates are more advanced than, say, mollusks); and large versus small. He has two reasons for maintaining an interest in this topic. The first is his inherent egalitarianism, and his objection to the fact that many people draw on the supposed existence of rankings in nature to justify their social and cultural biases. He writes, ". . . conventional support for established orders usually relies upon claims for the naturalness of 'dualisms' and 'hierarchies.' In creating dualisms, we divide a subject into two contrasting categories; in imposing hierarchy upon these dualisms, we judge one category as superior, the other as inferior." Thus, if he can demonstrate some exceptions to these hierarchies in nature, perhaps he can weaken the foundation of those beliefs.

The second reason for his continuing interest in reversals involves the question of where nature draws the line between laws and contingency; that is, between invariably repeated phenomena and inherently unpredictable outcomes. This essay considers this question (without answering it) in the realm of ecosystems. Most naturalists, including Darwin, believed that there were definite rules for such systems, although they may sometimes be difficult to determine; Gould is not so sure, and offers these examples as food for thought.

As prologue, he briefly mentions the two common examples of the Venus flytrap and the pitcher plant, both plants ("lower") that eat insects ("higher"), and in some cases even small vertebrates. His selected examples are less widely known. The first is a case in which flies eat toads, rather than the other way around. In this case, the "flies" are actually large horsefly larvae, and the toads are small hatchlings – considerably smaller than the larvae – but the point remains. The second example involves lobsters in one group, and snails in the other. Snails form the natural diet of many crustaceans. Gould reports on an article regarding two islands off the coast of South Africa, in which the coastal waters of one contain lobsters and the other did not. The authors of the paper transferred a thousand tagged lobsters from one island to the other. To their surprise, all were quickly killed – by whelks, a type of marine snail. The smaller whelks attacked the lobsters in large numbers, weighing them down to prevent escape. The snails then stripped the lobsters of flesh in about an hour.

The third example involves fish and dinoflagellates; the latter are a type of microscopic algae. It has long been known that large algal blooms can and do kill fish. This was, up until recently, assumed to be an unintended consequence of dinoflagellate activity, even after it was determined that the fish were dying from a neurotoxin rather than (say) oxygen depletion. Another intriguing article, however, concludes that the algae deliberately release the toxin in order to feed on sloughed-off tissue from the dying fish. Algae kill the fish for food!

The fourth and final example involves sponges and arthropods. Sponges are the simplest, and therefore considered to be the most primitive, of all multi-cellular organisms. The vast majority of sponges are filter feeders, but some that live in nutrition-poor water – usually very deep – have actually become carnivorous. These sponges grow long fibers with sharp needles on them that behave much like Velcro; these fibers can capture small crustaceans. The sponge continues to produce filaments that grow over the "more advanced" arthropod, enveloping it in about 24 hours and consuming it within a few days. Thus, we have four reversals, and therefore four more reasons to reconsider our hierarchical preconceptions of life.