Bully for Brontosaurus

BFB 1. George Canning's Left Buttock and the Origin of Species

The subject of this essay is the contingency of history. George Canning was a 19th century British politician, and a rival of one Lord Castlereagh. Castlereagh, we are told, was the man who negotiated relatively generous terms with the fledgling United States after the War of 1812 [as well as putting down the Irish rebellion of 1798, and helping to manage the coalition that defeated Napoleon]. Had Canning been in office instead, Gould argues, would likely have implemented far harsher terms on the US, which would have led to continued animosity between the two nations (first and foremost, over Canada). He also argues that Andrew Jackson's career might have gone differently, despite his victory at New Orleans.

A few years earlier, in 1809, Canning and Castlereagh had fought a duel. Canning was wounded in the buttock (and not the "thigh," as is commonly reported), while Castlereagh was unscathed. Had Castlereagh been killed in this duel, Gould argues, not only might British-US relations have taken a different course, but he would not have lived to meet a different fate in 1822 – suicide. The relevance of this involves the fact that Lord Castlereagh's nephew was none other than Robert FitzRoy, the captain of the *HMS Beagle* during Darwin's 1831-36 voyage. Castlereagh suffered from melancholia (depression); FitzRoy was concerned that he was predisposed to this condition, which was recognized even then as hereditary. Gould argues that FitzRoy's fear of suffering a bout of this condition during the stressing role of commander – no socialization allowed, even with officers – caused him to bring along a member of the upper class as a "friend," as was done occasionally during this period. FitzRoy was also interested in beefing up the exploration aspect of his mission, which was nominally a geologic survey of the South American coast, to improve his own chances for advancement. Charles Darwin became this person; he was of the right class, and grandson of the famous thinker Erasmus Darwin. Thus, Darwin's presence on the *Beagle* was the result of a series of unlikely events, one of which was the survival of FitzRoy's uncle's dual with George Canning. Gould adds that at this time, Darwin was not an evolutionist, and did not at all seem predisposed to become to become the man who would write *Origin of Species*.

Gould does not argue that evolution via natural selection would not have been discovered anyway, although he does suggest that Darwin would likely have played no role in it had he not sailed on the *Beagle*. The story would have been different, and history is all about details. Perhaps Jackson would have become President even if Castlereagh had died in 1809 and the US been humiliated after the Battle of New Orleans. The same argument can be applied to natural history, Gould believes. Were the outcomes of a few events just a bit different, there would be no humans today. [Gould discusses this latter theme in his 1989 book *Wonderful Life*.]

BFB 2. Grimm's Greatest Tale

Jacob Grimm (1785 – 1863) and Wilhelm Grimm (1786 – 1859), collectively known as the Brothers Grimm, are famous today for "Grimm's Fairy Tales." The brothers did not write any of these Germanic fables, which include Snow White and Rapunzel, but rather collected and documented them. While Wilhelm focused on cultural history, Jacob pursued the German language itself, publishing *Deutsche Grammatik* in 1819. This book discusses 19th-century German, but also the origin of the language as well; it is considered by many to be the first book in the field of linguistics, and documents many of the recently-discovered relationships between what has become known as the Indo-

European languages. It includes Grimm's Law [now often referred to as Rask's-Grimm's rule], which discusses the sequence by which the German "f"- sound (pronounced in English as "v") was derived from the Latin (and pre-Latin) "p"- sound in many words. This and other similar rules indicate a path of descent that is in some ways analogous to biological evolution.

What motivated Gould to write this essay was a 1988 publication by L. L. Cavalli-Sforza, et al in *Proceedings of the National Academy of Sciences* that suggests that there may be more than linguistics to this similarity. The publication is entitled "Reconstruction of Human Evolution: Bringing together Genetic, Archeological, and Linguistic Data." Cavalli-Sforza was a pioneer in using genetic analysis (primarily blood type and protein analysis in the 1960's, as this predated modern gene sequencing techniques) to identify relationships among different peoples. Despite its greater age, scientists did not think that linguistics could play a role in determining the relationships and migration paths of human races, for two reasons. The first was that it was generally believed that *Homo sapiens* evolved some 2 million years ago; language evolves so rapidly that the origins would surely have been lost to time. But more recent evidence, stemming in part from some of those genetic studies, suggested that we evolved only about 200,000 years ago, and first migrated out of Africa only 100,000 years ago. This, Gould argues, means that there is hope that linguistics may be able to play a role in deciphering human pre-history after all.

The second reason scientists doubted the utility of applying linguistics to the problems of human evolution is that people move around so much, and intermarry wherever they go. Gould notes that he lives in the land where, 500 years ago, the local languages were a completely different "phylum" than that which contained English; further, English itself is a mixture of a Germanic language (from the Anglo-Saxons) and a Latin-derived language (from the Norman conquest in 1066). In his personal case, he notes, his grandparents spoke Hungarian, which is itself non-Indo-European, and which is different yet again from Hebrew, which he presumes his more distant ancestors spoke. Yet despite this, one of the key factors of Cavalli-Sforza's paper is that, at least in places, there does appear to be a solid correlation between genetic groups and language groups. The exceptions are as interesting as well: Ethiopians, for example, are genetically African but linguistically Semitic. Gould does not know if this idea will prove valid, but notes that if it does, it could provide important additional information on our evolution and pre-history.

BFB 3. The Creation Myths of Cooperstown

This essay illustrates two interesting characteristics of the human mind. First, we have a great interest in the origin of things (including, of course, ourselves), to the point where "we readily construct myths when we do not have data . . . ." Second, we prefer these origins to be singular events that occur at specific moments in time, rather than an extended story of evolution. [All human cultures have some sort of creation myth, virtually all of which are consistent with this second point. Gould states many times in these essays that it is important to understand such modes of thinking, so that we can properly account for them when filtering external reality.] In this essay, he presents two disparate examples to illustrate the human preference for "beginnings," both of which are associated with Cooperstown, New York.

The first myth is "The Cardiff Giant" (Cardiff is a town near Cooperstown), a crude hoax that fooled no experts but enthralled the public and the media for several months in 1869. The Cardiff Giant was a gypsum statue of a naked man some 10 feet tall, produced and buried for subsequent "discovery," for the purpose of enriching the discoverer. Theories of believers were divided between those who thought the object represented an actual fossilized giant who lived long ago (including flesh!) and those who thought it was a statue constructed by an ancient, advanced race. Either theory, Gould notes, can account for the Cardiff Giant's popularity, because both appeal to our sense of singular and important moment long ago. The bubble burst not when scientists identified it as a fraud, but when the people who carved it came forward. The statue resides today in a shed behind a barn at the Farmer's Museum in Cooperstown.

The second myth involves the origin of America's national pastime, baseball. Gould received an invitation to attend the Baseball Hall of Fame induction ceremony in 1989 from Tom Heitz, chief of the baseball library there. Heitz, apparently a reader of Gould's monthly column, took the opportunity to contrast the true evolution of the sport (as documented in the baseball library) with the official creation myth involving Abner Doubleday. The legend is that Mr. Doubleday laid down the basic rules of baseball in a field in Cooperstown in 1837. As the documents clearly show, however, this myth was a fabrication instituted by A. G. Spalding – pitcher, sporting goods mogul, and founder of *Spalding's Official Base Ball Guide* – in 1908. (Spalding had set up a blue-ribbon panel a year earlier to determine baseball's origins, and then reported on its official findings.) In addition to serving the function of providing baseball with a defining moment and creator, it also stated that the sport had originated in America,. The truth, however, is that it was derived from English stick-and-ball games such as Rounders. (Abner Doubleday, it turns out, probably never even heard of baseball; but he was a Civil War hero from New York, and thus "worthy" of the myth.) The history of these games in England is largely unknown, because they were played by the lower classes and thus not as well documented as the upper classes' Cricket. But in America, there are fragments of an extended evolutionary tale. The game came over in colonial times, but was suppressed by the Puritans, who thought all games played by adults were an improper use of time. By the 1850's, several variants were in existence, but all were quite different from the modern version. There were four bases and three strikes, but – to name three major differences – the batter stood between home and first base, balls hit in any direction were in play (no "foul lines," making it difficult for spectators to watch), and outs resulted only when the running batter was "plugged" with the ball. Gould spends several pages detailing the development of the modern game up to the founding of the National League in the 1880's – his point being that baseball did not have a creation moment, but rather *evolved*. None of this, he points out, makes his favorite game any less great, or any less American.

BFB 4. The Panda's Thumb of Technology

Gould usually tries to avoid the use of analogies between biological evolution and cultural or technological evolution, he begins. The latter proceed by mechanisms that are essentially Lamarckian ("inheritance of acquired characters"), accounting for their much greater rate of change, while the former do not. Further, cultural and technological characters from different "phyla" can fuse, while biological groups that separate sufficiently never rejoin. Thus, such analogies can be deeply misleading. In this essay, however, he breaks his unwritten rule for one specific example of evolution in technology: the QWERTY keyboard. "QWERTY," named for the first six characters of the top row of letters on English-based computer keyboards, dates back to the early mechanical typewriters of the 1800's. In the 19th century, this layout was not universal; there were literally dozens of alternative key layouts. Further, this particular layout is famously sub-optimal, in terms of typing speed and other performance metrics. One particular alternative layout introduced in 1932, called DSK (for "Dvorak Simplified Keyboard"), holds all typing speed records. Yet today QWERTY is not only the reigning champion, it is the sole survivor. Gould poses three "evolutionary" questions regarding the success of this technological species, and then uses the answers to illustrate his views of analogous concepts in biological evolution. The three questions are: first, what was the original "reason" for the QWERTY layout; second, how did it come to dominate the field; and third, why has it not been displaced by superior designs? He draws details from an article by economic historian Paul A. David of Stanford University, entitled "Understanding the Economics of QWERTY: The Necessity of History."

Gould proceeds by challenging one of the most popular human-held views of the universe: Everything that exists has a purpose, and everything that happens does so for a reason. He quotes Alexander Pope's 1734 *Essay on Man*: "Whatever IS, is RIGHT." Pope was not arguing for the perfection of the universe, but simply that everything was the best that it could possibly be, given the tradeoffs and interactions between elements. Gould argues that this view reflects a "hope" – in this case, that an indifferent universe cares about us and our suffering. Darwin's mechanism of natural selection undermines this view. In part because of this, *Origin of Species* was largely unsuccessful in producing acceptance of Darwin's mechanism. Natural selection implies two "terrible truths" (Gould's phrase). The first is that the spectacular construction of a wing or an eye, or the balance between organisms in an ecosystem, does not reflect either a divine creator or laws of nature akin to those of physics, but are instead mere side effects of the struggle of individuals to survive and reproduce over time. The second is that the quirks of history play a key role in these struggles, as future modifications must operate within the constraints of past designs; this, in turn, essentially *precludes* optimal design. It is these very sub-optimized, "jury-rigged" components found in organisms today that are some of the best evidence we have that evolution has actually occurred. Gould references the Panda's "thumb" [TPT 1], really a modified wrist bone, as an example of what Darwin himself called a "contrivance." A contrivance is an indicator that the object has a *history* (with the implication that it could have turned out differently), as opposed to being the result of a causal law, which would produce the same result every time. Gould calls this "the principle of imperfection."

He now proceeds to the question, “What is the origin of the QWERTY layout?” Referencing Paul David, Gould says that we know that the design was invented by a Mr. C. L. Sholes in the 1860’s. His thought process is not documented, but it David notes that the second, “home” row of letters contains a long string in alphabetical order – DFGHJKL, with E and I removed – which suggests a line of reasoning. The presence of the letter R in the top row is a late addition; David suggests that this may have allowed salesmen to produce the word “TYPEWRITER,” then a brand name, using only keys in the top row. These attributes suggest a degree of contingency in this particular layout; the keys are not ordered at random, but there is a certain amount of what appears to be “chance” that Gould also sees in biological evolution. What about the missing vowels in the second row? David makes the case that their removal was a change intended to spread out keys that might be struck consecutively, for the deliberate purpose of *slowing down* the speed at which keys were struck. This was required in the early days because, if pressed too rapidly in succession, the keys would routinely stick at the point of impact with the paper and jam. That is, the modified layout reflects an “adaptation.” The machines rapidly improved, but the QWERTY layout remained – a “vestige” of an earlier adaptation that is no longer required, but remains nonetheless; a reminder of its past. Thus, he argues, this sub-optimal layout is a technological analog to the biological principle of imperfection, giving the essay its title.

If the QWERTY layout does not yield optimal typing performance, how did it come to dominate the market? In the 1880’s, there were numerous keyboard layouts. David shows that Sholes’ design happened to be picked by Remington, a major manufacturer. Remington worked with a famous typing teacher of the period, Ms. Longley of Cincinnati, who founded a chain of typing schools and produced a popular self-teaching pamphlet. She most likely would have been successful with any layout, but she happened to use Remington and QWERTY. Then, in 1888, another fortuitous event occurred: her program was challenged to a typing competition by a rival. In this well-publicized showdown, Ms. Longley’s champion – a Mr. McGurrin – won the day. As David notes, this was not because the keyboard layout was superior, but because Mr. McGurrin used a new typing technique – eight-fingered “touch typing,” rather than the standard four-fingered hunt-and-peck of the era. This victory gave QWERTY some additional momentum, and the (non-Darwinian) appreciation for a universal standard led other manufactures to abandon their keyboard layouts and adopt QWERTY. This, Gould argues, is analogous with his “contingency of history” argument for biological evolution; the present form is the result of a sequence of unlikely occurrences that, if the process could be repeated, would likely produce a different result. It also illustrates his view of evolutionary history as “early experimentation and later standardization” [TFS 16].

Finally, why was QWERTY not displaced by a superior design such as DSK? In both technology and biology, Gould attributes this to the power of incumbency. Once a standard has taken hold (or a niche occupied), it becomes very difficult to displace. Natural selection (in this view) is not all-powerful; superior designs can fail if a particular niche is already dominated by something else. [This is one area where Gould differs with Darwin. Darwin, using his metaphor of the wedge, argued that new designs would eventually displace old ones if they were superior. Gould argues in TFS 30 and ELP 21 that this may not, in general, be the case; it may take some "start over" event to displace an incumbent.]

[In the quote "Whatever IS, is RIGHT," Alexander Pope is specifically referring to the Great Chain of Being – see TFS 17 & 18 – and the importance of all people accepting their place in it. The more general view that all of nature reflects superb design and reflects the goodness of God became formalized as *Natural Theology* – the subject of several Gould essays, starting with HTHT 2. This view was fiercely satirized in 1759 by Voltaire in *Candide*. The name and beliefs of the pro-Pope character in this play, Dr. Pangloss, plays a prominent role in Gould's writings. In a 1977 presentation entitled *The Spandrels of St. Marco and the Panglossian Paradigm*, Gould and colleague Richard Lewontin charged the evolutionary community with effectively replacing the designing God of Pope and Natural Theology with what they considered to be a nearly omnipotent view of natural selection. Many of Gould's essays, including this one, critique the "adaptationist" or "strict Darwinist" view that natural selection is the exclusive mechanism driving the actual evolutionary history of life on earth.]

BFB 5. Bully for Brontosaurus

In 1989, the US Post Office joined a wave of dinosaur mania [see the next essay] and released a series of four "dinosaur stamps": *Tyrannosaurus*, *Stegosaurus*, *Pteranodon*, and *Brontosaurus*. Somehow, it became a national news story that the name of the last of these was officially incorrect; it should have been *Apatosaurus*, a name that at that time few non-professionals had ever heard. Was there a legitimate scientific issue at stake? Absolutely not, Gould tells us. *Apatosaurus* is the technically correct name, but *Brontosaurus* has been officially recognized as an acceptable substitute – since 1903. Gould uses this essay to discuss the rules by which species are named and how this process has evolved over time, and then follows with the story of the discovery of *Apato/Brontosaurus* and the origin of the dual names.

Establishing consistent names for the subjects of study is essential in all fields of science, and the use of universal Latin for organisms is a reflection of this requirement. There is an official organization known as the International Union of Biological Sciences, Gould tells us, which maintains and updates the *International Code of Zoological Nomenclature* (botanists have their own code). The group can trace its origin back to the famous tenth edition of Linnaeus's *Systema Naturae* in 1758 [see IHL 21]. From time to time, it is discovered that the same organism has been independently described by more than one source. When discovered, a decision must be made as to which name and description is to remain and which is to be discarded. The preference of Linnaeus was to keep the better, more accurate description; Gould refers to this criterion as "appropriateness." Since scientists are human, however, a problem arose: some taxonomists were simply renaming existing species with arguably more appropriate labels, thus effectively acquiring credit for the discovery. Among other things, this led to prolonged debates at meetings, rather than productive discussion. In response, the British Association for the Advancement of Science revised the official rules of nomenclature in 1842. They overreacted (Gould states) by stating that "priority" would become the sole criterion: whichever name appeared first in print would be the winner. Not surprisingly, this also led to problems: often professional and widely accepted names and descriptions of species would be overturned by discovery of an earlier, poorly written summary in an obscure journal. The rules were again modified in 1913, at a gathering of the International Zoological Conference in Monaco. This group adopted the "plenary powers decision," which emphasized priority, but allowed the International Commission on Zoological Nomenclature the power to grant exceptions. These rules were still in place when Gould published this essay in 1990.

Gould now turns to a famous fossil-finding feud between E. D. Cope and O. C. Marsh. These two scientists and their teams raced each other to find (and name, thus gaining "professional credit") the most dinosaur, mammal, and other vertebrate bones in the American West in the late 1800's. In their haste, both men often published too quickly, with poor documentation and often based on only a small number of bones. O. C. Marsh discovered "both" *Apatosaurus* and *Brontosaurus*, in 1877 and 1879 respectively. Later, others went back to update and revise the messier remnants of this so-called "bone war"; in 1903, Elmer Riggs of the Field Museum of Chicago determined that the *Apatosaurus* was simply an immature *Brontosaurus*. Neither dinosaur name was well known at the time, and Riggs documented his findings in a single paragraph. In part, it reads: "In view of these facts the two genera may be regarded as synonymous. As the term '*Apatosaurus*' has priority, '*Brontosaurus*' will be regarded as a synonym." That is, both names are technically valid. However, the name *Brontosaurus* came to prominence due to the fact that Marsh's 1879 specimen was one of the most complete skeletons ever found. The specimen itself, along with numerous copies (all identified as "*Brontosaurus*"), entered the national consciousness via museum displays, Disney's 1940 film *Fantasia*, and numerous ad campaigns from companies such as Sinclair Oil. The name *Apatosaurus* remained essentially unknown until the Post Office entered the fray. At any time during the period between 1913 and 1989, someone could have filed a petition with the plenary powers office to officially change the name of this dinosaur to *Brontosaurus*; no one bothered. When the Post Office accidentally precipitated the crisis, it became too late; *Apatosaurus* gained currency. Gould ends with a tongue-in-cheek rant that "Apatophiles" deliberately attacked the stamp as a way of getting attention for their cause; *Apatosaurus* never could have displaced his preferred *Brontosaurus* (the latter meaning "thunder lizard," the former meaning only "deceptive lizard") under normal circumstances.

BFB 6. The Dinosaur Rip-off

This essay is more personal than most. Gould was motivated to write it by a large upswing in the popularity of dinosaurs in popular culture. Dinosaur kitsch is now everywhere, he states, from T-shirts that say "Bossosaurus" to lunchboxes and pajamas. This was not the case when he was growing up, he tells us; he was one of only a handful of dinosaur aficionados at the time, and recalls painful memories of being teased about it. Their contemporary popularity could be due to the fact that dinosaurs are "big, fierce, and extinct"; but this was still true 30 and 40 years ago. Perhaps, he offers, it is the result of new discoveries and interpretations: leaner, faster bodies, evidence of dinosaurs living in herds and caring for their young, and the recently-discovered catastrophic cause of their demise [HTHT 25]. In the end, he states, he simply does not understand it, but concludes that it is probably a fad, like the hula hoop, and therefore owes much to some undetermined but lucrative marketing strategy. [He returns to this theme in DIH 17, written shortly after the sensational book and movie *Jurassic Park*.]

Fad or not, he segues (with an elaboration on the use of this term in a postscript), the intellectual minority in this country should try to capitalize on it by bringing better teaching of dinosaurs, biology, and science in general in our elementary and secondary schools. Dinosaur names in particular could be used as a model for rote learning, currently unfashionable but exceptionally useful in limited doses. Dinosaur theories can be used to illustrate scientific reasoning. And perhaps, he continues, respect for dinosaurs may allow more interested youngsters to survive the rigors of youth with interest in intellectual pursuits intact. He laments the poor quality of education in the United States, and argues that it does not have to be this way – in fact, it is much better in many other countries, and was for a while here as well after the shock of Sputnik in 1957. He expresses respect and admiration for the underappreciated, underpaid teachers who work at these levels, and would greatly increase both their salaries and the schools' financial resources if he had the power to do so. He writes: "We live in a profoundly nonintellectual culture, but we are not committed to this attitude; in fact, we are scarcely committed to anything. We may be the most labile culture in all history, capable of rapid and massive shifts of prevailing opinions . . . ."

BFB 7. Of Kiwi Eggs and the Liberty Bell

This is one of Gould's essays that challenge the adaptationist view that every feature of an organism is shaped by natural selection (offering the individual a selective advantage). The subject is the kiwi, the small flightless bird of New Zealand. Kiwis are ratites, the order that includes ostriches and emus. The Kiwi lays eggs that are enormous in comparison to the size of its body; while the statistics vary, it is not uncommon for a four-pound bird to lay a one-pound egg. Such an unusual feature begs an explanation. The traditional, adaptationist approach is to start from the position that large eggs must offer the individual kiwi an advantage, and then to search for what this advantage might be. (This view therefore also implies that kiwis evolved from an ancestor of similar size, but with smaller eggs.) Gould acknowledges that the large eggs do allow the birds to be born very mature, complete with feathers. Further, the nutrients in the egg are so rich that the chick can go for several days after hatching without feeding, thus acclimating to its surroundings. However, Gould continues, this does not necessarily mean that large eggs are adaptive. He writes: "I like to identify this error of reasoning with a phrase that ought to become a motto: *Current utility may not be equated with historical origin*, or, when you demonstrate that something works well, you have not solved the problem of how, when, or why it arose." He references detailed studies by William A. Calder III of the University of Arizona in support of a plausible alternative; Calder's theory is that kiwis are dwarf moas.

Moas were also ratites and also lived in New Zealand, with some species estimated to weigh more than 500 pounds. Prior to the arrival of the Maori, there were no mammals in New Zealand other than bats and seals; as a result, flightless birds filled many of the niches that would normally be filled by mammals. (The kiwi is actually a burrowing animal, with downy feathers that resemble fur, and is generally nocturnal; it is thus the "official mammal" of New Zealand.) Moas were hunted to extinction by the Maori when they arrived around the year 1300. All species of kiwi are also endangered, due to the arrival of pigs, stoats, cats, and other invasive species brought by the Maori and, later, westerners.

Dwarfism appears across the animal kingdom. One important characteristic of this phenomenon is that all components of the animal are not "shrunk" equally. If kiwis represent the descendents of dwarf moas, then we may postulate that it was the kiwis that got small (while the eggs remained the same size), rather than the eggs that got big. Reduced overall size was probably adaptive, in that it allowed the kiwi to exploit the "burrowing animal" niche; but in this scenario, the relatively large eggs were simply a side effect. The oversized eggs were not fatal (due in part to the absence of predators), but did not offer any direct advantage to the forces of natural selection. Later, when the form had developed, the large eggs could then have been modified via co-optation [BFB 9] to provide some utility.

In support of this dwarf-moa hypothesis, Gould introduces the "hummingbird-to-moa curve" [analogous to the "mouse-to-elephant curve" for mammals discussed in ESD 22]. Egg weight of various bird species is plotted against adult body mass on a log-log scale; the result is a fairly consistent pattern, where as the adult weight grows smaller, so do their eggs – but not as rapidly. That is, smaller species of birds tend to have relatively large eggs for their size. However, kiwi eggs are enormous even considering this factor. Gould then discusses a related curve – the ratio of egg weight to adult weight *within a species*. This curve is almost flat (a slope of 0.15, versus a slope of 0.67 for the first curve and 1.00 for perfectly consistent scaling). If the kiwi and moa are grouped together in the same or very close species, then the relative size of kiwi eggs and moa eggs line up well. [More recent genetic evidence suggests that the kiwi is actually more closely related to the emu and cassowary than the moa.]

Gould closes with a cultural analogy to his biological motto. The Liberty Bell, located in Philadelphia, has an inspirational phrase molded into it – "Proclaim liberty throughout all the land unto all the inhabitants thereof" – followed by the line "Pass and Stow." Gould, assuming that this second line was part of the phrase, considered several things that it could have meant. He finally was told that Mr. Pass and Mr. Stow were the craftsmen who cast the bell. That is, this physical feature of the Liberty Bell has nothing to do with liberty or the beliefs of the founding fathers; it is merely an artifact of its origin.

BFB 8. Male Nipples and Clitoral Ripples

Gould begins this essay with a summary of Erasmus Darwin's (grandfather of Charles) views on the "transmutation of species", as represented in his 1794 treatise *Zoonomia, or* *the Laws of Organic Life*. *Zoonomia* is mostly about human physiology, but it includes some famous passages on evolution. Erasmus interpreted the development of the embryo, only recently discovered, as moving from the simple to the complex by some sort of progressive force. He speculated that life itself, via reproduction, might represent an analogous process, developing from simple monad to complex mammal over time. Gould sites passages from this book, focusing on one particular phrase: that the "filament" of life would possess the ability "to improve by its own inherent activity, and delivering down those improvements by generation to its posterity . . . ." From this, we see that Erasmus Darwin's view of evolution was Lamarckian in nature. (Lamarckism's bumper-sticker phrase is "the inheritance of acquired characteristics." However, this concept is not original with either of them). Gould points out that this mechanism implies the development and inheritance of *useful* characteristics. Stated another way, in his view, new structures arise for a purpose, or to serve a function. One of the few examples that Erasmus admits he cannot explain are male nipples. He was not the first; Plato himself wondered about them, postulating that in the distant past all humans were hermaphrodites. Gould adds that he has received more queries about the purpose of male nipples from interested readers over the years than any other question. Why do men have nipples?

The answer, Gould replies, does not lie in biological research, but in recognizing that the question rests on a false assumption: that every structure produced either by creation or by evolution (Lamarckian, Darwinian, or other) *must serve a purpose*. This is the "functionalist," "adaptationist," or "strict Darwinist" view. [Gould uses these terms interchangeably.] In fact, he states, male nipples do not serve a purpose; they offer no selective advantage whatsoever, nor have they ever. They exist because female nipples – which are adaptive – do, and male and female nipples develop from the same embryonic structure. Organisms are not simply collections of parts that can be optimized independently; it matters how the structures form, because the mechanism that changes one component is likely to affect other structures as well [but see ELP 17]. Gould references his example of the Panda's "thumb" [TPT 1], which is actually an enlarged wrist bone; it turns out that the corresponding bone in the rear legs is also somewhat enlarged, although the host does not appear to use these for anything. Referencing D. D. Davis's 1964 monograph on the Giant Panda, he states his belief that the bones in the back legs simply went along for the ride.

The functionalist community, Gould continues, does accept the non-adaptive nature of male nipples. However, they consider it a trivial and unimportant point in evolutionary theory. Offering his impression of the functionalist position, he writes: "Who cares? Let's concentrate on the important thing – the adaptive value of the female breast – and leave aside the insignificant male ornament that arises as its consequence. Adaptations are preeminent; their side effects are nooks and crannies of organic design, meaningless bits and pieces." Gould counters that these side effects are not always insignificant. He has written elaborate technical papers [as well as some essays, such as HTHT 11] arguing this position; here, though, in keeping with the anatomically sexual theme of this essay, he offers a second example: the female orgasm.

The male orgasm is correlated with ejaculation, an essential factor in reproduction, and is thus clearly adaptive. Female orgasm, however, is not required for conception to occur; is it adaptive? Gould notes something else: the primary site of the female orgasm is the clitoris, not the vagina. Anatomically, this is not surprising; the clitoris is the homolog of the penis, developed from the same embryonic component (via different sex hormones), and has the same number of sensitive nerve endings. But as a result, many women – perhaps most, according to the major sex surveys of Kinsey (1953; see TFS 10), Masters and Johnson (1966), and Hite (1976) – may enjoy sex, but do not regularly achieve orgasm during coitus. From the functionalist perspective, this poses a major problem: should not the *function* of orgasm in females be specifically tied to reproduction, as it is in males? The answer, Gould argues, is obvious once the bias of the near-omnipotence of functionalism is suspended: female orgasm, while fabulous, is simply not adaptive. It is a consequence of the common origin of male and female structures.

Unlike male nipples, Gould continues, this is not a trivial point. He discusses at some length Sigmund Freud's view that, during puberty, the source of the female orgasm was supposed to migrate from the clitoris to the vagina. This view was widely accepted in certain circles during the early and mid-twentieth century. Women that failed to accomplish this transition received the diagnosis of "frigid," and (in this paradigm) became vulnerable to neuroses and hysteria. Gould quotes Kinsey: "Some hundreds of women in our study and many thousands of the patients of certain clinicians have consequently been much disturbed by the failure to accomplish this biological impossibility." (Gould also references research showing that most female mammals can experience the equivalent of orgasm – but almost never during coitus. Rather, this is achieved by self-stimulation, or by rubbing their genitals against another member of their group – often female.) Gould references a number of contemporary papers that continue to offer adaptive arguments for the existence of the female orgasm (some continuing to imply that its source is the vagina); his point is that the underlying assumption that all significant features must involve an adaptive explanation remains strong. Gould references a conversation he had with Francis Crick many years before, "when my own functionalist biases were strong. He remarked, in response to an adaptive story I had invented with alacrity and agility to explain the meaning of repetitive DNA: 'Why do you evolutionists always try to identify the value of something before you know how it is made?'" Gould brushed this comment off at the time, but now recognizes that Crick's point was both valid and important; Sometimes "Why?" is the wrong question.

BFB 9. Not Necessarily a Wing

Darwin believed that evolution is a process of gradual but continuous change, with each intermediate stage favored by natural selection. In this view, macroevolution is essentially microevolution plus time. A fundamental implication of this perspective is that natural selection is a *creative* process as well as a destructive one, shaping new structures and producing new species. One of the first (and best) opponents of this view was British zoologist St. George Mivart (1827 – 1900). His argument, published in his 1871 work *The Genesis of Species* (parodying the title of Darwin's famous book), did not question the role of natural selection as the executor of the unfit, nor argue that it could not tweak or optimize an existing structure. It did, however, challenge the view that natural selection could, by itself, explain macroevolution. In order for it to do so, he pointed out, natural selection would require the first, initial stages of a structure such as a wing to be favored, before they could offer a selective advantage. Ten percent of a wing will not allow the host fly one-tenth as well; a threshold must be crossed before any aerodynamic benefit is achieved. And everyone, Darwin especially, agreed that natural selection acting today cannot select for a feature that will be useful sometime in the distant future. Some other mechanism must exist, Mivart argued, to produce the initial form of such a structure in the first place.

(In a parenthetical paragraph, Gould notes that Mivart was not arguing that this unknown mechanism could produce any conceivable change; he agreed with Darwin that this would require something akin to a miracle. Most of his book was about embryology and comparative anatomy, and his position was that the larger, macroevolution-triggering changes had to reflect pathways in the established development of the organism. Gould does not mention it here, but this is consistent with the view he presents in HTHT 14. Nonetheless, the rest of this essay essentially sides with Darwin's counterargument, presented below, and not with Mivart.)

Of all the critics of natural selection in the years after *Origin of Species* was published, Gould notes that Mivart was the only one Darwin formally responded to by name; he took Mivart's challenge very seriously, and added material to later editions of his book in response. The solution Darwin proposed, which has been accepted in principle ever since, goes by the phrase "functional change in structural continuity," and is also known as "functional shift" or "preadaptation." It comes in two forms, both of which Darwin discussed. The first involves an organ or structure that serves more than one function; under some circumstances, the secondary role may become the dominant one. The other occurs when two structures can perform the same function; Gould gives the example of lungs and gills in fish. In some fish, the gills took over the entire respiratory function, leaving the lungs free to become an air bladder. [Gould elaborates on this in ELP 7.] The origin of wings, Darwin felt, would fall into the first category. He and many others since then have proposed functions that proto-wings could have served.

In a review of the literature, Gould finds that many proposals infer some sort of aerodynamic function such as stabilization right from the start; but these all face the difficulty of inefficiency at small (that is, initial) sizes. There are several "functional shift" hypotheses for the utility of incipient proto-wings as well, from mating displays to insect traps, but the dominant proposal is thermal regulation. Only when the thermo-regulators (or whatever they were) developed and grew to the point where their aerodynamic properties became relevant did natural selection begin to modify them for flight.

All of this is plausible, Gould continues, but it is purely speculative; the evidence for this is in the fact that there are so many *different* "just-so stories" (Gould's term, referencing Kipling) to explain wing origins. However, the thermo-regulation hypothesis has gained a significant boost due to the work of J. G. Kingsolver and M. A. R. Koehl; their work is the motivation for this essay. Kingsolver and Koehl worked with insect wings rather than bird wings, and focused on the heat absorption and/or dissipation capabilities of thin, flat surfaces rather than the insulating properties of feathers. They built model insects with proto-wings of various sizes, and tested them for both thermal and aerodynamic performance. They were able to establish two general sets of data. When studying thermal behavior, they found a rapid increase in performance as the structures scaled from zero to a certain size relative to the body of the model, followed by a leveling-off; once beyond a certain size, no further advantage was gained. When studying the aerodynamic behavior (using wind tunnels), the opposite pattern was observed; bigger structures worked better than medium-sized structures, but small structures offered negligible utility. In smaller insect models, the crossover point is not reached; but in larger models, there is a range where the proto-wings function both thermally and aerodynamically. While this series of experiments is not a substitute for historical data on the origin of insect wings, it does provide quantitative analysis on the viability of the functional shift hypothesis. In closing, Gould speculates that the human mind might be the product of a brain that grew above a certain threshold size for reasons unrelated to the adaptive benefits of consciousness.

(In an extended footnote, Gould discusses his dislike for the term "preadaptation." He feels that it implies a predisposition; that the feature "knew" that the later function was coming. Biologists know that this is not true, he acknowledges, but the term itself makes it more difficult to correctly explain this already-confusing concept. He discusses an alternative term that he and colleague Elizabeth Vrba developed, called "exaptation." [The terms "cooptation" and "co-opted adaptation" are now used in the literature as well.])

BFB 10. The Case of the Creeping Fox Terrier Clone

While attending a National Science Teachers Association convention in 1987, Gould took the opportunity to examine all of the biology textbooks that were being marketed in the exhibit hall. He found some concessions to the political forces of creationism, but on the whole was pleasantly surprised in this regard. He was much less happy about another trend, this one the fault of the science community itself: these high school textbooks all present a nearly identical story, using the same examples in the same order. Natural selection, for example, is always presented in contrast to Lamarckism, and via the example of the giraffe's neck; fossil evidence for evolution invariably discusses the horse lineage. Gould would accept the reasoning behind this approach, if it represented a well-honed optimum; but it does not. In fact, he states, the examples are misleading if not downright inaccurate. [He discusses problems with the giraffe neck example in LMC 16, and with the progression of horses in the next essay, BFB 11.] So why are all the textbooks the same, at least when it comes to discussing evolution? The answer, Gould charges, is that textbook writers (as well as writers of popular books on science) copy from one another, changing just enough to avoid copyright infringement; he refers to this as "cloning." It is encouraged by the recent "big business" nature of textbook publishing, he continues, but it has been going on for decades.

In support of this charge of textbook cloning, he selects an example that is both distinctive and repetitive: the example of a modern animal that is about the same size as *Hyracotherium*, the small, multi-toed animal that appeared some 60 million years ago and is the ancestor of modern horses. The almost universal measure of *Hyracotherium* size today is the fox terrier. (Gould states that he was about to write this phrase himself in another essay when he realized he had no idea how big a fox terrier was!) Using a research assistant and his personal library, he tracked down eighty-six similes for expressing the size of this animal, dating back to the formal description of *Eohippus* by O. C. Marsh in 1974. (It turns out that the same animal, under the different name of *Hyracotherium*, had been identified from fragments by Richard Owen in 1841. Gould prefers Owen's name *Eohippus*, meaning "dawn horse," but under the rules of naming organisms discussed in BFB 5, *Hyracotherium* takes precedence.) Marsh identified the animal as being about the size of a fox, and many later publications repeat this. In the early 20th century, two alternative animals were proposed: the house cat, and the fox terrier. The latter first appeared in 1904, Gould determined, in a popular article entitled *The Evolution of the Horse*. The author was Henry Fairfield Osborn, famous vertebrate paleontologist [see BFB 29] and president of the American Museum of Natural History in New York; the article was reprinted as a small book, and remained in print and for sale at the museum for fifty years. Gould uses a quasi-humorous tone to describe the eventual victory of the fox terrier simile over its competition (in Darwinian terms). His point is that cloning occurs. To add injury to insult, he notes that the weight of *Hyracotherium* has been revised upwards to some 50-55 pounds, while fox terriers weigh in at 15-20 pounds. The cloning of textbook material not only propagates errors; students, he argues, can pick up on the lack of effort and enthusiasm by the authors, and as a result are more likely to lose interest in the subject.

BFB 11. Life's Little Joke

Despite the careful and convincing reasoning in Darwin's 1859 *Origin of Species*, many believed that his theory still lacked a "smoking gun": an example of an evolutionary sequence in the fossil record that catches the process "in the act." In 1870, Thomas Huxley addressed the Geological Society of London, of which he was President, and argued that just such an example had been identified: the horse. He offered three (later four) sets of fossils from Europe and Asia that appeared to show a sequence from a small, three-toed animal, through intermediate stages that had one toe but large "dew claws," and then on to the modern one-toed *Equus*. This trend also indicated a continuous increase in overall size and tooth crown height, indicating a transition from a small, forest-dwelling browser to a much larger plains-dwelling grazer in Asia and Europe.

However, additional evidence from North America suggested that the horse actually evolved in the New World. The leading proponent of this theory was O. C. Marsh of Yale, famous vertebrate paleontologist and great collector of mammal and dinosaur bones [his "race" with E. D. Cope is mentioned in BFB 5]. Huxley met with him during an extended visit to the United States in 1876, and was quickly converted to Marsh's perspective. The American fossil record was considerably more complete, with extensive detail. He came to recognize that the Eurasian horse fossils represented four separate migrations from America, each one of which (except the last) died out. [Fossil evidence similar to Huxley's led a little-known Russian colleague of his, Vladimir Kovalevsky, to draw the same false-but-fruitful conclusion; Gould discusses this in LMC 7.] Horses continued to live in North America until about ten thousand years ago, approximately coincident with the end of the last ice age and the arrival of humans.

Huxley worked closely with Marsh to rewrite the public lecture on fossil horses that was his primary reason for coming to the United States in its bicentennial year. Together, they produced one of the most famous drawn figures in evolutionary biology (reproduced in the essay), entitled "Genealogy of the Horse." It presented a sequence of legs, toes, and teeth from six genera this time from *Eohippus* [or *Hyracotherium*; see previous essay] to *Equus*, spanning 60 million years, all from what is now the United States. Gould notes that this and similar figures appear in museums and textbooks all over the world.

Unfortunately, he continues, this wonderful example of "evolution in progress" contains a major flaw; this brings us to the main point of the essay. The diagram, and the model behind it, suggests that evolution is a linear process of continuous change within an existing population. This view – which represented Huxley's view of macroevolution – is that there is really no such thing as a "species," but only arbitrary delineations in a time-varying continuum. This is the "ladder" view of evolution; Gould rejects this for the non-linear "bush" view [see ESD 6], which argues that new species branch off relatively rapidly from existing stock, and then remain essentially unchanged until extinction. The evidence, which he discusses here for the specific case of the horse, is twofold. First, this is what seems to appear in the fossil record; the Eldredge/Gould model of punctuated equilibrium, he notes, was developed precisely to address this phenomenon. The second argument is that the fossil record also shows that many of these species coexisted for millions of years, often in the same area, indicating that one genus did not "morph" into the other. In the case of horses, he references data indicating that there was no general trend from small to large, three-toed to one-toed, or browser to grazer. The evolutionary picture is actually quite complicated, with many different lineages, and has been right from the start 60 million years ago. Gould references the famous American paleontologist G. G. Simpson, who is credited with disproving the linear model of horse evolution in the 1950's. Simpson argued that the entire lineage was one long series of three-toed browsers, with the one-toed grazer we know today representing an unusual side branch.

This brings us to the "little joke" of the essay's title. Biologists view a taxonomic group (such as a genus or family) as successful if it has diversified into a large number of species, and unsuccessful if it only contains one or a few – even if that one particular species has a large population. In this view, groups such as antelopes are successful, while groups such as horses are now relatively unsuccessful. In successful lineages, it is "obvious" that the ladder paradigm cannot be valid; which of the hundreds of living species would represent the top rung? What would the others represent? But in unsuccessful lineages, where there is only one surviving genus, the ladder – suggesting the culmination of a series of progressive events – can be applied. In Gould's words, this is Life's Little Joke. He writes: "The model of the ladder is much more than merely wrong. It never could provide the promised illustration of evolution progressive and triumphant – for *it could only be applied to unsuccessful lineages* [his italics]." He closes by noting another unsuccessful lineage to which the ladder model is often applied: primates in general, and *Homo* in particular. [He explores this explicitly in ELP 20.]

The essay includes a sub-theme, that of Cortez's use of the horse (among other things) to conquer the Aztecs in the early 16th century. There is irony, he notes, in the fact that Europeans used the last "imported" lineage of a long line of creatures that went extinct in North America to conquer the largest civilization on that continent at the time.

BFB 12. The Chain of Reason versus the Chain of Thumbs

This essay starts as a lament on the continuing role irrationalism in modern society. Gould acknowledges that it has always been a part of human culture, but expresses disappointment that broad access to quality education has not eradicated it. The continued success of tabloids such as the *Weekly World News*, which often prints stories that cannot possibly be true, is largely attributable (he claims) to the ignorance of their readership; were they savvier, such publications would not survive. Despite the impossibility of a complete and permanent victory over irrationality, he argues that it is important for the rationalists in society to keep fighting. He applauds the efforts of those who seek to debunk charlatans and those who try to pass off contacts with the spirit world, mysterious elixirs, and other false notions (for a fee) to a gullible public, from Harry Houdini to James Randi.

Gould presents a historical example on how to effectively attack a powerful and popular "fad" that promises its potential clients something that is not real. The case involves the work of Franz Anton Mesmer (1734 – 1815), whose name gave us the term "mesmerized." Mesmer, a German physician, had been working in Paris for several years by 1784, and was wealthy and well-connected. Mesmer's paradigm was that there was a single, subtle fluid that permeated the universe, manifesting itself as gravity or electricity in some cases, and as "animal magnetism" in its interactions with living material. More specifically, he claimed that all illnesses were caused by blockages and other constraints on the proper flow of this substance through the body, and that these illnesses could be treated with the proper techniques. Mesmer claimed to have mastered these techniques, which involved the use of magnets and substances that he "magnetized," including small vats of water and certain trees. Some of effects he produced were certainly real; in his charismatic presence, while being "treated," both men and women would begin to tremble, thrash about, scream, and faint – symptoms that were known as a "mesmeric crisis." Upon awakening, most would claim that they felt better; and in many cases, within a few days, they were cured of the ailment that had brought them to him. As he became more successful, he worked with many people simultaneously. In order to get the "magnetism" to flow through all people in the room, he would have them take the left thumb of their neighbor in the thumb and forefinger of the right hand (producing part of the essay's title), with the chain eventually connected to the vat of magnetized water.

Mesmer's success and popularity threatened several groups in established Paris society, from physicians to the scientific community to parts of the government itself. In response, Louis XVI appointed a Royal Commission in 1784 to investigate mesmerism; the panel was led by Antoine Lavoisier [BFB 24, LSM 5] and none other than Benjamin Franklin, emissary and polymath from the fledgling United States. While the committee was stacked against Mesmer, their approach and methodology was rigorous. (Gould credits details from the 1968 book, *Mesmerism and the End of the Enlightenment in France* by Robert Darnton.) The commission could not study the magnetic fluid itself, since (its proponents claimed) it was not directly observable in any way. They also decided against using "cures" as evidence, since there were many possible causes that could lead to these results – including, Gould notes, avoiding the physicians of the time with their often-toxic potions and techniques. This left investigations of the mesmeric crises. The commission performed a series of what today would be called controlled experiments to see if these effects were physical or psychological, and effectively proved the latter. (Mesmer himself did not cooperate, but one of his leading assistants – convinced of mesmerism's validity – did, with devastatingly negative results.)

Near the end of the essay, after celebrating the demolition of mesmerism at the hands of the rationalist-based committee, he writes of the continuing need for such battles: "[W]hatever our powers of abstract reasoning, we are also prisoners of our hopes. So long as life remains disappointing and cruel for so many people, we shall be prey to irrationalisms that promise relief."

BFB 13. Madame Jeanette

This essay first appeared in the *New York Times Magazine*. It contains two themes that Gould discusses in other essays, neither of which are directly related to natural history: continuity and excellence. He tells the personal story of how he and a friend from high school attended a performance of the New York All-City High School Chorus in 1988, thirty years after the two of them performed in the same group. Gould recalls his conductor, Peter J. Wilhausky – a great and intimidating artist who worked with city schools on weekends. Gould credits his time in that chorus, under Wilhausky's direction, as his first personal experience with true excellence. The taste left him wanting more, and, he believes, influenced him (and others) in his career pursuits. During their performance in 1958, at Carnegie Hall, Gould was deeply moved during the last piece – "Madame Jeanette" – when previous alumni in the audience stood and joined in.

Thirty years later, the chorus still existed, but much had changed. There were many other groups besides the chorus in the performance, including orchestra and jazz band. He noted with some sadness that the chorus itself had very few boys, and that the various groups had largely self-segregated into distinct ethnicities. There was more diversity in the choice of pieces as well; Gould is a great fan of diversity, but Wilhausky's method of inducing excellence involved focusing on specific classical works that demanded vocal interpretation, not merely tone accuracy. Perhaps diversity and excellence – both wonderful – are incompatible, he speculates. As the concert ended, however, an encore was presented: "Madame Jeanette." He and his friend stood and joined in.

BFB 14. Red Wings in the Sunset

Abbott H. Thayer (1849 – 1921) was a successful New England artist – his works are displayed in New York, Washington, and Chicago – and was also an amateur naturalist. Mixing the two fields, he is credited with discovering the principle of countershading in animals, an essential adaptation for stealthiness in both predators and prey. He also came to recognize the utility of "ruptive" (today, disruptive) patterning in animals and insects; both of these techniques were adopted with great success by the military during the First World War, and are today known as camouflage. While initially met with support by the scientific community, he later became a laughing stock when he claimed that, among other things, the adaptive function of the flamingo's bright orange-red color was – to camouflage itself against the rising and setting skyline! None other than Theodore Roosevelt wrote a scathing, hundred-page critique of Thayer's 1909 book *Concealing-Coloration in the Animal Kingdom*; Gould quotes several of his comments, which are ridiculing in tone but accurate. Gould adds that his first exposure to Thayer's work, in an introductory college science course, was as an example of illogical thinking. He states that he started this essay thinking it would present another example of the uncritical adaptationist thinking that he critiques in other essays. As he read Thayer's book and papers in preparation, however, he found – and proceeds to tell – a somewhat different story.

Thayer's interpretation of countershading, Gould begins, was a significant contribution. Countershading refers to the property of many animals of being dark on top and having lighter, often white, underbellies. The key to blending in is not simply to share the same color palette as the background, as most scientists (including Gould, he confesses) assumed. Animals see and recognize three-dimensional shapes in nature in large part by their shading: bright on top where the sunlight strikes directly, and darker underneath, in shadow. Countershading, by reversing the expected pattern, presents the illusion of "flatness." Thayer argued, probably accurately, that it was his artistic training that allowed him to appreciate this important nuance. He later came to appreciate the counter-intuitive notion that bright contrasting patterns could also aid in camouflage, by "breaking up" the apparent outline of the animal. Zebras, he argued, used stripes not only to blend in with reeds (which, it was noted, they rarely did), but to fool the lion's eye into not seeing any coherent pattern at all. [One zebra by itself will not actually succeed at this, but it has been shown that large numbers of overlapping zebras can confuse predators about the orientation and speed of an individual.]

At this time – and still today – animal coloration was seen to offer the host one of three possible adaptive advantages. [Gould does not discuss possible non-adaptive coloration patterns here.] The first is concealment; countershading clearly falls into this category. The second is advertisement; this includes everything from mating displays to intimidating effects such as "eye spots" on butterfly wings. The third is disguise, where animals pretend to be something else – for example, an insect that looks like a leaf or a twig, or one species that resembles another that a predator knows to be toxic [Batesian mimicry; see BFB 20]. After Thayer documented countershading, he continued to believe in this three-adaptation paradigm. However, after recognizing the concealing power of bright disruptive patterns, he began to slide into the formidable trap of thinking that his insights could explain not just some observations, but all of them. Specifically, he came to believe that all coloration patterns in nature were designed for concealment. One of the most difficult of all coloration patterns to explain via this worldview, he correctly surmised, were those of a single, uniform color (no countershading, and no disruptiveness). The example he chose was the flamingo.

He traveled to areas where flamingos lived, got down in the mud with them (as predators and prey would do), and came to a series of startlingly false conclusions. Flamingos can indeed resemble the sky near the horizon at dawn and dusk; Thayer argued that these birds were nocturnal, so this feature would be adaptive in the transition periods. However, this is not true; flamingos are active during the day. He argued that the "sunset" disguise would mask these birds both from submerged predators such as snakes and alligators, as well as from their food source. However, neither snakes nor alligators live in the shallow, highly saline bodies of water that flamingos inhabit [TFS 1], and their food source – mostly small crustaceans – are blind. These and many other mistakes were ridiculed by Roosevelt and others.

These attacks led Thayer to compound his mistake. He countered by arguing that the features in question need only be "adaptive" with regards to concealment once or twice in the animal's lifetime to be selected for. This implies, however, that his hypotheses are not testable in any practical or meaningful way. That is, such claims are not really science at all, but merely speculation. His fall as a naturalist was complete, although as noted, the practical aspects of his earlier arguments played an important role in the war that would soon follow. In the end, Gould states, Thayer was not so much guilty of unreason as he was of oversimplification, rationalization, and a bit of hubris regarding the magnitude of his genuine contributions.

BFB 15. Petrus Camper's Angle

Petrus Camper (1722 – 1789) was a Dutch physician, anatomist, naturalist, artist, and several other things as well. He is sometimes credited, Gould tells us, with being the godfather of craniometry, a term that refers to the techniques of measuring the shapes of skulls. In particular, Camper developed a parameter called the facial angle, which was one of the first quantifiable measures for comparing skulls. The facial angle is formed by the intersection of a horizontal line between the nostril and the ear opening, and a more vertical line that connects the bottom of the upper lip (or incisor, in skulls) with the most forward part of the forehead. In humans, this angle varies between about 70 and 90 degrees, with Africans toward the lower end, Caucasians nearer the higher end, and Orientals in between. Camper also noted that apes had smaller facial angles than any human (associated with a pronounced "muzzle"), and other animals and birds had smaller angles still. During the 19th century, craniometry in general and the facial angle in particular were used to "rank" species in the great chain of being [TFS 17], to rank races within humanity [TFS 18], and even individuals within races. Those with larger facial angles (closer to 90 degrees) were, their argument went, superior to those with smaller facial angles. Thus, Camper is recognized by some as one of the godfathers of scientific racism.

Ranking was not, however, the motivation behind Camper's studies. The extended title of his posthumous 1791 work summarizes the tale: *Physical dissertation on the real differences that men of different countries and ages display in their facial traits; on the beauty that characterizes the statues and engraved stones of antiquity; followed by the proposition of a new method for drawing human heads with the greatest accuracy.* It is the middle portion of the title that indicates Camper's purpose: using his skills as both an artist and a scientist, he was interested in quantifying "beauty," at least regarding human heads. He, along with many others, considered the sculpted figures of the Romans and Greeks to be more attractive than anyone living in his day. He also knew (from portraits on coins and so on) that most of the "real" Greeks and Romans were not as beautiful as their statues, and so he made it his goal to determine – quantitatively – the secret of their statues' attractiveness. He solved the puzzle when he came up with the facial angle; this angle was, on average 95 degrees for Roman statues and a full 100 degrees for Greek statues. (Beyond this, Gould states, the bulging foreheads begin to look deformed rather than sublime.)

His discovery also had practical applications for contemporary artists, as the third part of the title suggests; it provided a set of guidelines for drawing people of other races and of different ages more accurately. (It irritated Camper, Gould states, that African figures in European paintings looked like white people in blackface, and that the infant Jesus looked like a much older baby.) While Camper did believe that Caucasians were more beautiful than other races, he made no claims whatsoever about relative intelligence or worth, and at no time used words like "superior" and "inferior." In fact, Gould continues, Camper was a "liberal" of his day; he argued, based on his studies, that humans comprised a single species, with races representing mere variation – all thus presumably descended from Adam and Eve – rather than several species. [Gould touches on this battle between monogenists and polygenists in TFS 12.] It is common, he concludes, but nonetheless ironic, for a scientist's work to be misappropriated to support positions that are the opposite of what the inventor believed.

BFB 16. Literary Bias on the Slippery Slope

This essay tells two different stories of how Charles Doolittle Walcott (1850 – 1927) discovered the Burgess Shale in Canada, one of the most important fossil quarries in the world. The importance of the Burgess Shale is twofold. First, it captures a moment in time only a few tens of millions of years after the Cambrian Explosion, the brief period in which essentially all existing phyla of animals came into existence. Second, the sediments of the physically localized quarry preserve the soft parts of organisms as well as the hard parts; this is very rare, and permits special insight into the biology of the embedded fauna. Walcott, being a great geologist and paleontologist, recognized the importance of the site, but (Gould states) did not appreciate the uniqueness animals themselves; he incorrectly "shoehorned" them all into existing groups. [Gould discusses Walcott and the reinterpretation of the Burgess Shale fauna in ELP 15, and in his 1989 book *Wonderful Life*.]

However, this essay is not about the significance of the Burgess Shale or the Cambrian Explosion, but rather the story of how Walcott discovered the site in 1909. The canonical story, which Gould had read in several places and heard himself third-hand from someone who worked closely with him, is as follows. Mrs. Walcott – who often traveled with Charles on his expeditions – was approaching her husband's group on a mountain trail when her horse slipped on a piece of shale. The rock flipped over, exposing some beautifully-preserved fossils. Walcott badly wanted to capitalize on this piece of luck and find the source of this fossil-bearing shale, but night was falling on their last field day of the season, and the snow was already falling. He would have to wait for the following year to search for the source, hoping all winter that he would be able to even identify where the slippery rock had been found. Fortunately, the tale continues, after a week of searching the next season, he was able to find the quarry. This version of the story appeared in an obituary for Walcott that was written by his former research assistant and long-time friend, Charles Schuchert, and was also supported in an article written by Walcott's son (who was there, as a teenager) some 60 years later. This story has a lot going for it besides plausibility, Gould says – serendipity, a bit of Murphy's Law, and ultimate success after much persistence. However, little of it is true.

The real story, which Gould discovered by reading through Walcott's notebooks while visiting the Walcott Archives in the Smithsonian Institution in 1988, is less dramatic. (He notes that others appeared to have found the same entries in the journal, so he was not the first). Mrs. Walcott's horse did slip on a piece of shale, turning it over and exposing the fossils. However, this occurred on a fine day; the team spent the rest of the day breaking it apart and examining its contents. More importantly, this was not the team's last day; they remained a full week afterwards. Based on Walcott's entries in his diary, Gould is reasonably convinced that he found the quarry later that day or the next, and worked it with great success for the rest of their stay. There was a delay in returning to the site the next year, but it was not because the location was undetermined; it was because the snow had not yet melted when they first arrived. Walcott apparently stated at one point that the piece of shale had been dislodged from its site by a snow slide in the previous year; Gould speculates that this may have evolved into the season-ending snowstorm of the canonical tale.

Why does any of this matter? Gould offers two reasons. First, the discovery of the Burgess shale is one of the most important finds in all of paleontology, so there is some inherent value in getting the details right. The second and more important reason he gives is that the revision of the true story by knowledgeable people (and who clearly believed the more dramatic version) tells us something important about how humans, including scientists, think. Humans are storytellers [a theme he discusses more explicitly in DIH 27], and we can convince ourselves that our stories may be true; he refers to this as *literary bias*. [Gould presents two examples from his own life of "remembering" events that could not have happened in ELP 13.] We communicate concepts via stories, which by their nature involve the unusual, and are thus fundamentally different from most of nature and history. This attribute of human nature, he says, should be recognized when we discuss (for example) tales of human evolution, such as how our ancestors lived, and what they believed. How much of the "stories" we tell are based on evidence, and how much on the pathways by which our minds produce literature?

BFB 17. Glow, Big Glowworm

Vertebrates grow from babies to adults via a process that is, for the most part, continuous. Other organisms, however, undergo far greater morphological changes. Nonetheless, most peoople tend to think of insect larva as immature insect adults (or, more technically, imagoes), with a bias against the importance of the "less advanced" larval stage. Linnaeus himself coined these terms, and the meaning of the words themselves is significant. "Imago" means "image," and refers to the Platonic concept that this stage reflects the true nature, or "form," of the organism. "Larva," by contrast, means "mask."Gould states that he will not challenge, in this essay, the relative worth of children versus adults in animals such as ourselves; but he will object to the application of this metaphor to organisms that undergo more marked developmental changes.

To illustrate his point that, at least in some cases, the larval stage of an insect can be "more advanced" than the imago (using the language of the paradigm he is trying to skewer), he enlists the example of a New Zealand glowworm *Arachnocampa luminosa*. The adult form of this insect is an unremarkable fungus gnat that lives for a few days, mates, and dies. It does not have a mouth, and cannot eat; it is simpler, in terms of the number of organs, than the earlier stage. The glowworm larvae (not "worms," despite the use of the term) are more complex and quite remarkable. They cling to the ceilings of certain caves, and attract their food source via bioluminescence. (Gould mentions that boat rides through these caves, which he had an opportunity to take, are one of the main tourist attractions on the North Island. The cave roof appears to be studded with dim lights.) They form "nests" out of silk, which is common for spiders but unusual for insect larvae. They also emit numerous silk threads from these nests, covered with drops of a sticky substance, to trap flying insects. This identifies their second unusual feature: they eat other insects, rather than plant for fungal material. Often, the insects they trap are their own imagoes. Finally, there is the characteristic glow, which persists in the pupa and adult phases.

Gould is careful to state that is not suggesting that these larvae are more important that imagoes; rather, his purpose is to show that both represent different, important stages. He searches for a better metaphor for larva-imago than that of child-adult. He settles on Adam Smith's concept of the division of labor. Smith made the case that several people each doing part of a job – the classic example is manufacturing pins – can produce much more than if all the workers did all of the jobs. In this metaphor, the larva's "job" is to eat and grow, while the imago's job is to mate and reproduce.

The essay includes a discussion on the nature of random distributions. In his cave trip, Gould noticed that the patterns of light that the glowworms made did *not* resemble stars in the night sky. Stars tend to be "bunched" in certain ways that allow us to envision constellations; the glowworms were distributed in a more uniform, although non-periodic, way. This was because each larva had its own "keep-out zone" that others would not infringe on, while stars are distributed in a way that appears more truly random. Gould's physicist colleague, Ed Purcell, wrote a simple computer program that modeled "true" random patterns along with those with an exclusionary zone (the images are presented in a postscript). Most people, even most scientists, would probably choose incorrectly if asked which one was the random distribution. Randomness is far more "clumpy" than most people realize.

BFB 18. To Be a Platypus

This essay goes back and forth between describing the unique features of Australia's duck-billed platypus, and the nature of the debates western scientists have had over it since the creature first came to their attention. The platypus is about the size of a river otter and lives in a similar environment; it has feet that are also otter-like, and a tail that resembles that of a beaver. The animal is famous for appearing to be part mammal and part reptile, and also part bird. It has fur like a mammal, and is warm-blooded and has mammary glands (although the latter two facts took some time to establish), and it has the characteristic three-boned middle ear associated with all mammals [see ELP 6]. However, it lays eggs like a reptile. Further, its reproductive tract resembles that of a bird, with no uterus and the right side atrophied and unable to produce eggs. It also has an additional bone besides the clavicle in the shoulder girdle, which is again like reptiles but unlike other mammals. And then, there is the famous "duckbill." The rear end of the platypus is also highly unusual. While virtually all other mammals have three openings in their posteriors – one for liquid waste, one for solid waste, and one for birthing their offspring – "monotremes," as the collective name of platypuses and the related echidnas [next essay] implies, have only one orifice that serves all three functions. This pattern is standard in reptiles. Finally, the platypus has a sharp, hollow "spur" on its rear ankles that, in males, is connected to a gland containing poison; virtually no other mammals are venomous, although many reptiles (most notably snakes) are. The animal was first described scientifically around 1800, but only from skeletons and dead specimens. The animal itself was difficult to observe, as it was both in a remote part of the world (Australia), and lived unobtrusively in remote streams even there.

The existence of the platypus posed two different sets of puzzles to western scientists, with the chronological dividing line being the publication of *Origin of Species* in 1859. The early debate involved the correct placement of this animal in the existing taxonomy; was it a mammal with a beak and one rear orifice, or a reptile with fur and a mammalian middle ear? In the decades in which all such categories were understood to have been created, this "middle ground" creature demanded attention. Many of the leading scientists of the day became involved, and the focus of the debate soon settled on whether platypuses laid eggs. (It was discovered in 1824 that they did have mammary glands, but even these are highly unusual. Rather than having nipples, the structures are comprised of two long strips with pores that "leaked" milk that the babies would lap up.) The question was not settled until 1884, when a British expedition led by W. H. Caldwell sought and found them. They are small, less than an inch long, and usually laid in pairs in dens tunneled deep into riverbanks.

This discovery happened to coincide with the 25th anniversary of the publication of *Origin of Species*. By this time, Darwin's theory had removed the need to place the platypus into one of two static taxonomic categories. The revised view of life recognized that today's species evolved from earlier organisms. It was widely, although not universally, inferred that the platypus represented an intermediate step between reptiles (and/or birds) and mammals, and is associated with the concept of progress toward "mammal-ness." Gould references several oft-cited documents that use terms such as "primitive" and "undeveloped" to describe the platypus's reptilian features. But the platypus is not "less advanced" than other mammals because of these features, he proclaims. He reiterates his theme that the correct metaphor for evolutionary history is not a ladder, but a bush. The false reptile-platypus-mammal sequence falls squarely under the former paradigm, which is associated with the complete transformation a group from one form to another – and this almost never happens in nature, he states. Instead, he writes, it is important to note "the basic distinction between *early branching* and *undeveloped*, or *inefficient*, *structure*" (his italics). The correct way to interpret monotremes is to recognize that they branched off from an early mammalian line *after* the adoption of fur, warm-bloodedness, and the three-boned middle ear, but *before* the ancestors of marsupials and placental mammals diverged. Monotremes never stopped evolving; they simply took a different path. The platypus is very well adapted to its environment, Gould states, from its webbed feet to its waterproof fur. However, it has one particular adaptation that is, for lack of a better term, highly advanced: the famous "duck bill." This structure, unique to monotremes (and not homologous to the bill of a duck or any other animal), is studded with sensitive "electric field" sensors. It uses this organ to probe into the mud at the bottom of streambeds to find insect larvae and other invertebrate food sources. No other mammal has such a sense organ, and neurological studies have shown that it "maps" to more of the brain than any other organ. In fact, the platypus has flaps of skin that cover the eyes, ears, and nostrils when it dives; it hunts by use of this organ exclusively. The platypus is not primitive; it is just another surviving twig on the bush of life, but from a branching that occurred long ago and of which there are no other living orders, and only a few species. [Gould briefly refers to other orders of mammals that lived in South America until the formation of the Isthmus of Panama in TPT 28 and HTHT 27.]

BFB 19. Bligh's Bounty

The echidna – the term actually refers to two species, in two distinct genera – is an egg-laying mammal, like the platypus of the previous essay. It was formally described by Everard Home in 1802, and the monograph included a figure drawn by Captain William Bligh of *Mutiny on the Bounty* fame – hence the essay's title. (Bligh and the officers of his new ship, *Providence*, were served the animal that Bligh sketched for dinner during a stopover in Australia.) As was the case with the platypus, Home identified the echidna as an intermediate between reptile and mammal, imbued with an air of primitiveness. There were some scientists of the era that fought against this stigma, most notably the pre-

Darwinian French evolutionist Etienne Geoffroy Saint-Hilaire. (Geoffroy coined the name Monotremata, and argued unsuccessfully for this group to be recognized as a separate class of animals, neither mammals nor reptiles.) But the reputation stuck, and references to its primitive nature could be found up to the time Gould wrote this essay in 1985.

Gould attacks the charge of monotreme primitiveness (and thus, by implication, inferiority) in this essay the same way as in the previous one: he follows the logic of those who argue for "advanced" and "primitive" animals, and highlights a different part of the organism which, by itself, would lead to the opposite conclusion. In this case, the feature is brain size and intelligence. Drawing on the mouse-to-elephant scale [introduced in ESD 22 and TPT 29] that compares brain weight to the total weight of the animal, echidnas come out at the high end for insectivores. (The more common species of echidna eats termites.) Further, the cerebrum has many deep folds in it, like the brains of smarter animals such as primates. (Oddly, Gould notes, the platypus brain is almost perfectly smooth.) The echidna also does very well in laboratory tests of animal intelligence, such as navigating mazes, learning procedures, and remembering. Since intelligence is invariably held by those who "rank" animals as the single most important defining characteristic, the echidna poses a problem. It is all too common, Gould charges, for scientists to try to rationalize their way out of this dilemma (usually by finding some difference between the brains of echidnas and other intelligent animals and "declaring" it to be the truly relevant feature), rather than questioning the underlying ladder-versus-bush assumption.

BFB 20. Here Goes Nothing

Gould begins this essay with Darwin's reaction to a paper by Henry Walter Bates that he was asked to review for publication in 1863. The paper discussed what is now known as Batesian mimicry in insects, which occurs when an uncommon insect avoids predation by resembling a common but poisonous one. The classic example is the resemblance of the viceroy butterfly to the monarch butterfly; as a larva, the latter eats plants that make it noxious to birds. Darwin was sufficiently excited by Bates' paper that he added a section to his last edition of *Origin of Species* on it. He particularly appreciated the way it could be used to undermine the creationist viewpoint, Gould states. Creationism can explain mimicry the same way it explains everything else – God made it that way – but this becomes more difficult when the details of the models and mimics are observed. It is intuitively convincing that one insect would "evolve" to resemble another in order to survive and reproduce.

However, this also posed a problem for Darwin: how did the mimicking transformation begin? What selective advantage would only a vague resemblance offer its host? This problem arises often enough in evolutionary biology that it has its own name: the problem of "the incipient stages of useful structures." Both Darwin and Gould have written about the solution to this dilemma [see, for example, BFB 9 and ESD 12]. Darwin's response (as well as Gould's) is that the feature in question first arose, in all likelihood, for other reasons, and was only later co-opted for its current function.

Darwin, following Bates, noted that the groups of butterflies that vary most widely in form are those that produce mimics. Such inherent variable morphology did not arise for mimicry (inferred because most members of the group are not mimics), but once a small group *fortuitously* came to resemble a model, natural selection went to work and optimized the design.

Gould offers a second example of this process, this time involving reproduction in certain families of frogs. Most frogs lay their eggs in water and depart. A number of species, however, have found ways for the adults to carry these developing eggs with them, not only until they hatch, but until they complete the tadpole phase and become small adults. Some carry the eggs with them via a gelatinous material that binds them to their legs. Others have managed to evolve "pouches" on their backs or bellies to tote the young around in. Still others – including a species found by, and named for, Darwin himself – raise the tadpoles in the throat pouches that are primarily used for croaking (a mating call). An even more extreme adaptation, performed by two species of Australian frog in the genus *Rheobatrachus*, is to brood the young in the stomach of the adult; these creatures are the stars of this essay.

Using the stomach for a brood pouch poses certain problems. First, the parent cannot eat for the duration; and second, the mechanism of digestion has to be turned off somehow, or the organ will perform its primary function. The first problem is addressed via "stretch detectors" that can readily fool the digestive system into thinking that the stomach is full of food rather than of offspring, thus suppressing hunger. The second, careful studies showed, is a response to the presence of a hormone called prostaglandin in the eggs and tadpoles. The presence of this chemical causes the part of the stomach that produces the digestive fluids to retract and grow dormant. But this poses the same problem that mimicry did: how could such a mechanism have evolved "gradually," as Darwin's theory seems to require? The answer is also the same: the presence of prostaglandin in the eggs did not evolve to support the unusual brooding mechanism, but must have been *already present*, and thus available for co-optation. The original adaptive function of this hormone, if there even is one, is not known; such are the quirks of evolutionary history.

Gould closes with a larger statement about how large-scale evolutionary changes probably occur. He writes: "We glimpse in the story of *Rheobatrachus* a model for the introduction of creativity and new directions in evolution (not just a tale of growing bigger or smaller, fiercer or milder, by the everyday action of natural selection.) Such new directions, as Darwin argued in resolving the problem of incipient stages, must be initiated by fortuitous prerequisites, thus imparting a quirky and unpredictable character to the history of life. These new directions involve minimal changes at first—since the fortuitous prerequisites are already present, though not so utilized, in ancestors." He is reminded of a famous evolutionary cartoon in which a lobe-finned fish is making the first foray onto land. The caption reads, "Here goes nothing." Gould likes this; most often such events lead only to death, but sometimes the "nothing" becomes something. (In a postscript, he notes that one of the two stomach-brooding frog species appears to have become extinct.)

BFB 21. In a Jumbled Drawer

Gould begins with a personal anecdote about joining Harvard's faculty in 1969 as the curator of fossil invertebrates at the Museum of Comparative Zoology. This facility, founded in 1859 by the great Swiss-American naturalist, Louis Agassiz (1807 – 1873), has in its inventory 15,000 drawers of fossils – many brought from Europe by Agassiz himself. Gould made it a point, when he first arrived, to open every single one of those drawers; the task took him two weeks. The drawers were beautifully laid out, but many had clearly had not been opened in some time; some fossils were still wrapped in newsprint from the 19th century. One drawer, however, was a jumbled mess. It contained a note, apparently to forestall the wrath of Professor Agassiz, that "the janitor did it," singling him out by name. The note was signed by N. S. Shaler, and dated from 1869. Gould instantly recognized the name of Nathanial Southgate Shaler; although largely forgotten today, he was an important student and professionally ally of Agassiz, and a famous and well-liked lecturer at Harvard for decades. The note dated to a time before Shaler had established himself or received tenure, and in this period of his youth (Gould claims) he was so afraid of Agassiz's famous wrath that he wrote the obsequious note and left the fossils "as they were" for fear of laying them out incorrectly. As Gould's discovery shows, he had no need to fear; the drawer was not reopened for a full century. [Gould demonstrates in TFS 16 that it is not unusual to make significant discoveries in old museum collections.] The janitor retained his job.

Gould then turns to the worldviews of Agassiz and Shaler. Agassiz was a truly great naturalist [ELP 29 & 30], and is also credited with discovering the ice ages [TFS 7]. However, he was also a committed creationist, and saw each species as representing an idea in the mind of God. His timing was unfortunate; he founded the museum at Harvard the same year Darwin published *Origin of Species*. He gathered the best American students of natural history around him at Harvard, and was by all accounts very generous with his time and encouragement to his students. However, he insisted on intellectual control over everything his students did; this included rejection of the concept of evolution in general, and of Darwin's views on the unguided capriciousness of natural selection in particular. Instead, his view of the world was one where order and progress reigned; this certainly made him popular with the Brahmins of Boston, with whom he mingled and who supported his projects. It was inevitable that his young, independently-minded students would rebel. Most left, taking the best of what they had learned (plus evolution) to start new natural science departments across the United States. The one outstanding student that remained was N. S. Shaler.

Shaler, like his mentor, was by all accounts an excellent and beloved teacher. Also like his mentor – perhaps due to unquestioning loyalty – he remained a creationist long after he should have. (Gould notes that he used his position to support "nativist" and racist positions and public policy, also like Agassiz – see TPT 16). When he finally came to accept evolution, it was not Darwin's version, but a form of neo-Lamarckism, where organisms (especially man) played a role in their own development. Importantly, he kept the most essential part of Agassiz's worldview: that of a caring and powerful creator who oversaw all. (Gould identifies both Agassiz and Shaler as believers in a form of natural theology [ELP 9, LMC 15].) Shaler offered a probability-oriented argument against Darwin's theory. There are any number of improbable events that had to occur, he states, in order for man to be here at all – a point that Darwin would agree with. The cumulative effects are so improbable, he continues, that we are forced to conclude that the path to our existence must have been overseen by a God that could and did influence the outcome. [Gould defines the anthropic principle as the view that the universe, or the laws of nature, are the way they are specifically so that intelligent life would eventually arise, thus implying a powerful designer. He attacks such arguments in TFS 26.] This view continually reappears, he notes.

The counterargument that Gould offers comes from a close friend of Shaler, someone who also had an important connection to Agassiz: William James (1842 – 1910). William James [brother to novelist Henry James] went on to become a physiologist, psychologist, philosopher, and one of the leading intellectual lights of late 19th century America. He spent his professional career at Harvard, but in his youth, he was one of six students that Agassiz took on a trip up the Amazon River in 1865. (Like Shaler, he came to admire Agassiz; but unlike him, he questioned his entire worldview right from the start. Gould speculates that there might be a connection between Shaler's choice to go along with a politically powerful mentor rather than remain independent, and his fall into obscurity. James remained independent, and is still well-known today.) James's counter to Shaler's "probability" argument is that it does not apply; since we cannot run the history of life over again, we really have no rigorous way of determining – scientifically – how unlikely our existence is.

In a postscript, Gould draws on a personally rewarding series of exchanges he had with former President Jimmy Carter on this subject. Carter, he learned, believes in a modern view of natural theology: that God's existence and goodness – despite the wars that he himself has worked so hard to mitigate – can still be inferred from the nature of His Creation. As a living natural theologian, he asked Gould a question about his "Tape of Life" argument from his 1989 book *Wonderful Life*. (Gould, noting the decimation of so many phyla of organisms within a few tens of millions of years after their appearance in the Cambrian Explosion, states that if the tape of life were re-wound, erased, and played again, today's fauna would likely be very different. In particular, he notes, our own chordate ancestor might not have survived, leaving the modern world without fish, reptiles, birds, mammals – or humans.) Could not this argument be turned around, Carter asks, and used to support the view of natural theologians (including Shaler and even Agassiz)? Which is more unlikely, he asks Gould, the fact that we are here despite the events of the late Cambrian and so many cataclysms since, or that there is an invisible hand out there playing an active role? In numerous other essays, Gould's point is that we are, in fact, "lucky" to be here. How lucky? Gould falls back on James' counterargument: since we really cannot replay the tape of life, there is no way to know.

BFB 22. Kropotkin Was No Crackpot

Westerners have traditionally interpreted the social significance of natural selection in one of two ways. The first, referencing the motto "survival of the fittest," uses Darwin's theory to justify class structure, racism, sexism, imperialism, and richer rich and poorer poor; "it is nature's way." The second, claiming that since nature is "red in tooth and claw" [Tennyson's phrase; see DIH 6 for Gould's impression of the associated work, *In Memoriam*], makes the argument that the function of society is, or should be, to allow humans to rise above base and cruel nature. (Gould states his position here and elsewhere [for example, HTHT 2 and LMC 14] that Darwin's theory and nature in general have nothing to say about morality or ethics. Here he writes: "Evolution might, at most, help to explain why we have moral feelings, but nature can never decide for us whether any particular action is right or wrong.")

However, Gould had recently read an article in *Isis* (a leading journal in the field of history of science) by Daniel P. Todes that identifies a third "ethical" reading of natural selection that existed for several decades in 19^{th}-century Russia. Darwin's work was highly influential there, but the Russian literature was ignored in the West, and then buried by the 1917 revolution. However, one particular Russian scientist lived in exile in England during this period, and published several articles on this alternative viewpoint in 1888 (in English) that were later collected into a book called *Mutual Aid*. Gould had heard of the author, Petr Kropotkin, but – based on the impression he had received in a college course – thought of him as "daftly idiosyncratic." His main theme was that there was a moral or ethical lesson to be learned from Darwin's theory of evolution via natural selection, but unlike both western alternatives, it was a positive one: that cooperation, at least as much as competition, determines who will survive and reproduce. Todes' article, "Darwin's Malthusian Metaphor and Russian Evolutionary Thought, 1859 – 1917," showed Gould that Kropotkin's book actually represented the mainstream position of an entire branch of scholarship, and was not as "daft" as he had thought.

In *Origin of Species*, Darwin used the phrase "the struggle for existence" to describe natural selection. Gould quotes a passage where Darwin identifies this expression as a metaphor, sometimes referring to direct competition between individuals of the same species for a limited resource, but other times referring to competition between an individual and the environment. Others following Darwin, including his champion T. H. Huxley, came to focus on the "gladiatorial" aspect of competition between individuals. Darwin himself considered it to be the dominant category of struggle, as his metaphor of the wedge [ELP 21, DIH 34] suggests. This metaphor portrays life on earth as a log completely covered by wood-splitting wedges; for a new wedge (representing a species) to bite into the log's surface (that is, to establish itself), it must displace another.

The Russians, however, while acknowledging the role of direct competition, came to believe that Darwin's other interpretation of the struggle for existence – that is, against the environment – was underappreciated, and was perhaps even the more important of the two. Struggle against the environment, they argued, tended to reward cooperation rather than competition. The Russian scientific community, according to Todes' paper, pointed to Malthus's argument (population will always outstrip the food supply), and the British attraction to it, as the source of their problem. It was rarely true in practice, they claimed; even in times of starvation, it was uncommon to see two animals of the same species fighting over a remaining scrap. They attributed the West's perspective on "struggle" as individual competition as an infatuation with their new economic paradigm of capitalism. (Gould notes that the West tended to view Kropotkin's arguments, when they read them at all, as the result of muddle-headed socialist thinking; this is what was implied in his college course.)

Kropotkin was no armchair naturalist; like Darwin, he had spent five years (1862 – 1866) in a remote setting, in his case as a military officer stationed in Siberia. In that harsh environment, intra-species competition due to high population densities was never a factor – this was the opposite of the tropical environments Darwin (and Wallace) explored on their travels. Kropotkin had read Darwin's book, and was greatly taken with it; he looked for natural competition in Siberia, but rarely found it. "Instead," Gould writes, "he continually observed the benefits of mutual aid in coping with an exterior harshness that threatened all alike and could not be overcome by the analogues of warfare and boxing." Siberia, in Darwin's metaphor, would be a mostly bare log with only a few wedges trying desperately to hang on.

Gould concludes that Kropotkin and the Russian school of thought is, to some degree, valid. Perhaps it overemphasizes the role of cooperation between members of the same species in nature, but no more than the West emphasizes competition. Both behavioral mechanisms, he believes, appear in nature. He does criticize Kropotkin on two points. First, Gould states, natural selection acts exclusively on individuals, not on populations or an entire species as Kropotkin sometimes implies, although he often explicitly states that "selection for mutual aid directly benefits each individual in its own struggle for personal success." [Gould often writes as a mainstream Darwinist in this regard – see ESD 33 – but elsewhere, he alludes to a suspicion that natural selection can also operate at levels other than the individual, both above and below – see HTHT 13. This latter perspective is also a theme in his final, technical work, *The Structure of Evolutionary Theory* (2002).] His second criticism is more philosophical: he still opposes using nature as a source of guidance in human moral and ethical life. He remains as wary of arguments that find kindness and mutuality intrinsically in nature as he is of those that find cruelty and exploitation there. [He elaborates on this in ESD 32.]

BFB 23. Fleeming Jenkin Revisited

There is a story, taught to students of evolutionary biology in college, that a little-known Scottish engineer named Fleeming Jenkin made an argument so cogent that convinced Charles Darwin to alter a later edition of *Origin of Species*. The issue involved "sports," a now-archaic term for offspring that differ significantly from their parents. Darwin argued, according to the story, that sports could play an important role in the evolution of species. Jenkin's essay, published in 1867 in a journal called the *North British Review*, showed that this could not be the case, and Darwin had to concede the point. The concession, the story continues, was unnecessary; Jenkin's argument was based on a false theory of genetics called "blending inheritance," popular among scientists before Mendel's genetics was rediscovered in 1900, but neither he nor Darwin knew this at the time.

While in college, Gould came across a copy of the relevant issue of *North British Review*, and proudly made a copy of Jenkin's article. Then, years later, he stumbled upon a biography of Jenkin by none other than Robert Louis Stevenson. While the book itself was "stylized" to suggest the subject's near-perfection (a popular style in those days), it was sufficient to convince Gould that Jenkin was not a "little-known engineer." In fact, he worked closely with Lord Kelvin on the first transatlantic cable and several other important technical and social problems of the day. (In a postscript, Gould reports that he was also active in the field of economics, and was the first Brit to draw and understand "supply and demand" curves.) If this part of the canonical story were false, Gould wondered, what else might be wrong? He decided to investigate. He read a book by Peter J. Vorzimmer entitled *Darwin: The Years of Controversy*, which discusses this subject, and then re-read Jenkin's paper in light of it.

Darwin recognized variation within populations as the raw material upon which natural selection would work. In his view, this variation took two forms. The first, which he called "individual differences," were small but appeared often in a population. The mating of two individuals with the same difference would produce more offspring with those differences. The second form of variation was what was known at the time as "single variations," and referred to colloquially as "sports." These were individuals that differed markedly from their parents; the proverbial black sheep (the offspring, it is implied, of two white sheep). Since sports varied to a larger degree than those with only individual differences, Darwin had to consider whether they could play an important or even dominant role in evolution. The problem was, with whom would the sport mate? Could the new features make their way into the population at large via the interbreeding of the sport's offspring, if the characteristic was suitably adaptive? Darwin, the ultimate "gradualist," did not favor this argument, but felt obliged to consider it. All of this is discussed in his longest work, *Variations of Plants and Animals Under Domestication* (1868).

It is at this point that Jenkin's essay enters the picture. The real thrust of this paper was to attack (albeit politely) Darwin's entire theory of natural selection. Gould summarizes this critique, breaking it into four parts. The first agrees that natural selection can "tweak" an animal to become bigger or hairier, but argues that there are limits to this that are quickly reached. He offers the example of racehorses; breeding led to much faster animals at first, but after a few generations the process seemed to stagnate. Darwin, and most biologists today (including, in this essay, Gould), argued that the animal would eventually "re-normalize" (in the natural environment, if the feature was adaptive, given a sufficient amount of time) about the new state, and vary again from that point. [This paradigm uses the metaphor of a pool table; species are billiard balls that can be moved into almost any configuration via the externally-applied force of natural selection. Darwin's cousin, Francis Galton, argued that the species would be better represented by a multifaceted polyhedron, which resisted small changes. Gould discusses this in ELP 27.] Jenkin rejected this paradigm completely; in his view, a horse would never evolve via natural selection into a different, faster species.

The second part of the paper considered sports as an alternative source of raw material for selection. Both Darwin and Jenkin believed in a form of genetics called "blending inheritance," which was a popular model of the day. It had been known since antiquity that features such as the height and skin color of offspring tended to be in between those of the parents. It was assumed that the genetic mechanism, whatever it was, was continuous like a fluid, and would "blend" to form the progeny. Jenkin's essay argued (using a profoundly racist example) that no single large-scale variation, no matter how advantageous, could spread throughout a population under the blending paradigm. The third part of the essay argued, via his friend and colleague Lord Kelvin's ultimately flawed arguments [TFS 8], that the earth had not been in existence long enough for natural selection to produce the world we see today. The forth part was a challenge to Darwin's view that the continuity of forms in the living and fossil world are, in and of themselves, evidence of evolution; Gould sides with Jenkin on this point.

Collectively, Jenkin intended the four parts of this essay to be an attack on natural selection as a whole. Darwin was apparently unfazed. He did, however, *appreciate* Jenkin's second argument (regarding sports), and used it to justify abandoning a position that he never liked. That is, he made no concession; rather, he referenced one part of Jenkin's essay for his own purposes. He simply ignored Jenkin's charge that the more gradual mechanism he proposed for natural selection would not work either.

(Modern genetics recognizes genes as discrete particles that do not dilute during reproduction. Instead, they are either found – in one or the other of the parent's contributions, or both – or they are not. So-called "recessive" genes may be propagated for several generations showing no external evidence of their existence, and then manifest themselves. The 20^{th}-century field of population genetics [discussed in HTHT 26] shows how a novel gene can diffuse through a population over time. As to the apparently continuous distribution of height or skin color, population genetics also shows that these features are controlled by several different genes. The result is that a statistical distribution of discrete genetic alleles can, in fact, result in the appearance continuous variation.)

What, then, is the point of this essay? Well, he states, there are a number of issues that appear in this debate that are still at least partially unresolved. From the essay: "[O]ld arguments usually repay our close attention because we often stop discussing the fundamentals once an orthodoxy triumphs, and we need to consult the original debates in order to recover the largest issues – perhaps never really resolved but merely swept under the rug of concord." For example, was Darwin really correct that macroevolution is nothing more than microevolution plus time, or are other mechanisms involved? How far can natural – or artificial – selection take us? Gould states here that he prefers Darwin's view to Jenkin regarding the limits on what selection can do over time. [Elsewhere, however, he expresses support for additional macroevolutionary mechanisms; see TPT 18, HTHT 15, TFS 24 and ELP 22.]

BFB 24. The Passion of Antoine Lavoisier

As he often does in these essays, Gould starts with a specific fact or item, and then methodically "zooms out" to show that it lies within a larger generality. In this case, he begins with an old document that he recently acquired, published in 1802. It is the printed "first and last lecture" from a course in biology taught in Paris, a common practice at the time, by a professor who managed to survive the French Revolution. Besides the direct subject matter, it indirectly refers to one of the great French scientists who did not survive the Reign of Terror: Antoine-Laurent Lavoisier. Lavoisier (1743 – 1794), Gould explains briefly, was a leading light of the Enlightenment, and is often referred to as the father of modern chemistry. He is credited with finally dethroning the earth-air-fire-water model of alchemy and replacing it with the beginnings of the modern element-based science, providing both practical and theoretical guidance. During the early days of the revolution, he worked as the "director of gunpowder," and his technical contributions there made the French army more formidable against the attacking Prussians and Austrians. He is also largely responsible for inventing the metric system. However, before the revolution, he was a private tax-collector in a country in which that role was outsourced by the government to the equivalent of private enterprise. The system was notoriously corrupt and universally hated; after the revolution began to turn violent, all such tax collectors were rounded up, and then later charged with trumped up capital crimes. The essay's title, Gould tells us, is a double entendre on the word "passion"; it refers to both Lavoisier's passion for science (the modern usage), and his passion, or suffering (the older usage), on the Guillotine.

Contrary to legend, Gould notes that Lavoisier's end was not due to an anti-intellectual fervor – the legendary but mythical line at his sentencing was "[T]he Republic does not need scientists." While such movements do arise at such times, Lavoisier's fate was entirely due to his pre-revolutionary source of income. However, another quote from the period was actually spoken: the great French mathematician Joseph Louis Lagrange did remark, "It took them only an instant to cut off that head, but France may not produce another like it in a century."

Lagrange's statement allows Gould to zoom out another stage, where he notes a general trend in the nature of change: things tend to get better gradually and bad suddenly. (This point is made in the recently-acquired document that he referenced at the beginning of the essay.) He refers to his as the Great Asymmetry, referring generally to painstaking creation and instantaneous destruction. It extends far beyond human culture, and includes the realm of mass extinctions. While there can be a positive side to catastrophic events – the extinction of the dinosaurs made our own evolution possible, and the occasional revolution can overcome stagnancy – they are, by his reckoning, heavily weighted toward the negative. He offers human-induced extinctions as another example where, geologically speaking, animal life has suffered a disaster. Some argue, he says, that extinctions today open niches for tomorrow's new life forms. He takes no solace in this at all: the timescale of evolution is ranges from ten thousand to ten million years or more, and thus offers nothing to anything that can be described as human culture. He closes with a plea for a role for reason in government; "The Republic needs scientists." [He elaborates on the timescale of evolution and human-induced extinctions in ELP 2. He discusses the Great Asymmetry again in ELP 19, LSM 10, and again in his four short pieces on the events of September 11 at the end of IHL. Gould writes about Lavoisier's contributions to geology in LSM 5.]

BFB 25. The Godfather of Disaster

In the essay "Uniformity and Catastrophe" [ESD 18], Gould wrote that Charles Lyell succeeded in establishing geology as a science in large part by throwing speculative catastrophism entirely out of earth studies. In Lyell's uniformitarian view, the geologic processes that we observe today – gradual erosion, coupled with the occasional flood, earthquake and volcanic eruption, plus "deep time" – are not only sufficient to explain our planet's natural history, but are the *only* agents that should be considered in a mainstream scientific field. [Lyell actually overestimated the amount of geologic time that was available; see TFS 8.] Those who proposed models involving speculative catastrophes as the mechanism behind earth's current geological configuration came to be known as "world makers" or "system builders." In this essay, Gould discusses one of the first and most important of these speculative catastrophic models, and examines the thought process of its creator, William Whiston. (Two other models that preceded it, Gould states, are Thomas Burnet's 1681 *Sacred Theory of the Earth* and John Woodward's 1695 *Toward a Natural History of the Earth*, indicating that Whiston's efforts were within the intellectual mainstream at the time. [Gould discusses Burnet's work in ESD 17 and his 1987 book *Time's arrow, time's cycle*.]) As is often the case in these essays, Gould is relatively kind to Whiston, explaining the man and his model in the context of his time. At the essay's end, he points out that the steady-state-with-occasional-catastrophic-punctuations model of earth's history is making a comeback with respect to Lyell's slow-but-continuous-change model in both geology and paleontology, albeit this time with data to support it; this gives the essay its title. [He does not mention punctuated equilibrium specifically in this essay, but it is clearly implied.]

William Whiston (1667 – 1752) was a mathematician and theologian during an interesting and dynamic time in England's history. Isaac Newton had published his masterwork *Principia* in 1687, completing the revolution that placed the sun at the center of a solar system that was itself only one of many, and establishing that the force that held the planets in orbit was the same one that held us to earth's surface: gravity. The 1680's were also a time of heightened astronomical interest for another reason; a very bright comet appeared in the skies in 1680, followed by another in 1682 that Edmund Halley reasoned, using Newton's theory, was periodic and would return in 75 years. [Halley published and largely paid for publication of Newton's *Principia*.] Comets, historically one of the most terrifying phenomena in the night sky, could now be explained in terms of planet-like bodies that were also orbiting the sun, rather than omens or supernatural objects. It was in this context that Whiston, trying to merge the "established truths" of scripture with the "new truths" of Newton's laws, published his *New Theory of the Earth* in 1696. (The full title, which incorporates what we would today call an abstract, is: *A New Theory of the Earth from its Original to the Consummation of all things, Wherein the Creation of the World in Six Days, the Universal Deluge, and the General Conflagration, as laid down in the Holy Scriptures, are shewn to be perfectly agreeable to Reason and Philosophy*.)

Despite *New Theory's* appearance of being an argument in deductive reasoning – with "postulates," "lemmas," and "solutions" – it is decidedly not, Gould says; it is an extreme example of special pleading and selective interpretation [thus validating Lyell's objections more than a century later]. Nonetheless, Gould is lenient in his criticism; Whiston was not trying to meet the modern criteria of science, a term that had not even been invented at that time. In part, Gould continues, Whiston was simply carried away with these recent discoveries, much as some of Gould's contemporaries were so excited by the recent discovery of a comet or asteroid impact at the end of the Cretaceous period [HTHT 25] that some proposed that all mass extinctions in earth's history might be explainable in terms of impacts [TFS 30]. However, there is no getting around the fact that Whiston's work was speculative in the extreme, and not rigorous even by the standards of his own day. (These shortcomings were noted at the time; none other than Jonathan Swift parodied the views of Whiston and others in his famous 1726 book *Gulliver's Travels*.)

Whiston's treatise focuses on "explaining" five key biblical events by drawing on Newton's laws and the new, partial understanding of comets. The first of these is the six days of creation, which Whiston argued applied only to our solar system and not the only-recently-appreciated universe as a whole. He proposed that the earth began as a comet, in a highly elliptical orbit and with a totally opaque atmosphere. (The size of comets was not known at the time, and it seemed reasonable to assume that they were the same size as planets.) God then circularizes the orbit of this comet – either by suspending his own natural laws, or working within the constraints of those that Newton had discovered. (Since Newton's laws were really God's laws, he implied, it did not really matter which.) Once earth's orbit was circularized, with no rotation (so that one day equals one year) and no inclination (so there were no seasons), the atmosphere "cleared." This accounted for the observed separation of light from darkness, as described in scripture, and the appearance of the sun and moon in the sky (which had been there previously, he argued); Whiston's view is that this is how the six "days" – thus really six years – would have appeared to human observers. The second event that demanded explanation was The Fall, or the expulsion of Adam and Eve from the Garden of Eden. This was correlated with the more rapid, daily rotation of the earth, producing winds, and the tilt of its inclination to its modern amount of some 23 degrees, leading to seasons. The mechanism behind these changes, which Whiston argued is required under the new rational Newtonian paradigm, was the impact of another comet with earth.

The third and most challenging event to explain was the Deluge, or Noah's flood. Whiston's model of the earth was a solid core, covered by water, on top of which floated a thin crust that contained our oceans and continents. He argued that the Deluge was a response to a near-miss with another large comet. This produced two phenomena. The first was forty days of rain, produced when earth's atmosphere became saturated with water when it passed through the comet's tail. The second was an upwelling of more water from the depths (as specified in scripture), due to extreme tidal forces (understood via Newton) rupturing the boundary between earth's surface and the underlying water layer.

The remaining two events were in the future: the coming conflagration, followed by the consummation, the two of which were to be separated by the coming millennium of Christ's reign on earth (as described in the books of Daniel and Revelation). The former, Whiston argued, with its purifying fire, would result from the interaction with another comet that would strip away earth's cooling atmosphere and move the entire planet closer to the sun. The consummation would be the result of a final, direct hit by another comet that would either destroy the earth completely or knock it into an extremely elliptical orbit, effectively returning the earth to its original status as a comet.

Before we completely condemn all aspects of Whiston's *New Theory*, Gould writes, it is important to recognize the impact it had at the time. Whiston would later be dismissed from Cambridge University and tried twice (but not convicted) for heresy, not for this treaties, but for other unorthodox views involving Christianity. At the end of his life he was perceived, Gould adds, "as a prophet by some and as a crank by most." But in his time and long after, *New Theory* was widely accepted as a successful fusion of scripture and rationalism. [The second claim, while common, is inappropriate; his hypotheses, such as they were, were inherently untestable, and there was no evidence for any of them other than the current form of the earth itself.] Newton himself – to whom Whiston dedicated it – was so impressed with it that he chose Whiston to succeed him at Cambridge. Newton, Gould notes, also wrote extensively about scripture; most of these works have remained unpublished, but are remarkably consistent with views like those of Whiston. Gould references James Force's 1985 study, *William Whiston, Honest Newtonian*, on this topic.

BFB 26. Knight Takes Bishop?

One of the most famous events in the public history of Darwinism is the debate that took place between Thomas Henry Huxley, "Darwin's bulldog" (or the "knight" of the essay's title) and the bishop of Oxford, Samuel Wilberforce, on June 30, 1860, at a meeting at the British Association for the Advancement of Science. [Gould mentions in LSM 17 that Wilberforce had just written a scathing review of *Origin of Species* in the *Quarterly Review*, England's leading literary journal.] The meeting took place in the largest room of Oxford's Zoological Museum, and was packed with some 700 spectators. Officially, the purpose of the meeting was a presentation by a visiting scientist that touched on Darwin's theory of evolution, made public. Unofficially – and the reason for the large crowd of upper-class non-scientists – was that both Huxley and Wilberforce were on the agenda, nominally to discuss the presentation, but really to engage in the first public debate over Darwin's theory of evolution. Both Huxley and Wilberforce did speak, and legend has it that a famous exchange between them occurred, with Huxley winning a smashing victory for science and evolution over religious dogmatism.

The meeting certainly occurred; Gould notes that while on a sabbatical at Oxford in 1970 [he states it was 1971 in LSM 17], he occupied a small office that had been partitioned out of the very room where the debate took place. A small brass plaque on the wall identified it as such. What was actually said is more difficult to determine; no formal notes were taken. The legendary version – which first appeared in books by Darwin's son and Huxley's son, both published several decades later – is as follows. Wilberforce spoke first, speaking sarcastically and in disparaging terms about both evolution and those who advocate it. Near the end, he rhetorically asked Huxley if he claimed to be related to an ape via his grandfather or his grandmother. When it was Huxley's turn to speak, he countered with great passion, arguing that Wilberforce was misrepresenting Darwin's positions – perhaps deliberately. He then closed with an answer to Wilberforce's rhetorical question. In the standard version, Huxley stated that he would rather be descended from an ape than from someone who deliberately used his intellectual facilities to distort and misrepresent a legitimate scientific debate. (In the more pointed version, Huxley – notoriously anticlerical – is credited with stating that he would rather be descended from an ape than a bishop. Huxley himself later denied this version of the tale.) After his retort, chaos broke out, and the meeting was dissolved. The battle over evolution between science and rationalism on one side, and religion and dogma on the other, had been joined.

The real story appears to be significantly different. Gould spent some time tracking down published accounts and known private letters on the meeting, and uses these to express his own best guess as to what happened. First, he notes, Wilberforce did speak about Darwin's theory as advertised, mostly in derision, and did ask a question about apes and Huxley's ancestors. His principle technical charge was that Darwin was merely speculating, and therefore his entire position was without scientific merit. Huxley then spoke; but not for very long, and apparently, not very convincingly. The meeting did not break up immediately afterwards; there were other speakers, one of which was botanist and Darwin convert Joseph Hooker. It was without Hooker who vociferously countered Wilberforce's arguments and who charged him with deliberate distortion of Darwin's positions, reiterating that Darwin's evidence was indirect but definitely not speculative. (The meeting then ended formally, without chaos.) Huxley did, however, express an angry retort, similar to the one reported, to Wilberforce's rhetorical question. This retort did excite members of the audience – at least those who could hear him. (Huxley was not yet the great public speaker that he would later become.)

Gould adds that more insight on the meaning of the actual events can be inferred in a letter from a Canon Farrer (who was present) to Darwin's son Leonard in 1899 (again, some forty years later). Farrer wrote that Wilberforce's main rhetorical misstep at the meeting was in challenging Huxley's lineage via his *mother's* side of the family as well as his father's side; in Victorian England, this was considered a crossing of the line into rudeness. Huxley's response was effectively to point out, and object to, this breach of etiquette. Gould ends this essay with two observations. First, he quotes a letter written by Huxley, in which he expresses admiration for Hooker's performance; this event may have been what motivated Huxley to enter the realm of public speaking, an arena that he had avoided prior to this. Second, Gould states his lament that this meeting has been interpreted as the start of a battle between science and religion. As he states elsewhere [LMC 14, most explicitly], science and religion are not natural adversaries. Rather, the same struggle is *within* each of these groups; the struggle between questioning and reason on one side, and authority and non-rational dogma on the other. He notes that Canon

Farrer was both a member of the clergy and a friend to rationalism. [Without saying so explicitly, the essay does imply that it was at this meeting that conservative forces in the British clergy and elsewhere were put on notice that the Darwinists would put up a fight.]

BFB 27. Genesis and Geology

Gould begins by stating that many well-meaning religious people write to him with an offer of compromise on Genesis and science: If the six days of creation are treated as a metaphor for six long periods of time, could not both be valid? Alas, no, Gould replies, for two reasons, one specific and one general. Neither of these reasons are new, for the question has been asked and answered many times before. He references a protracted debate on this very topic that played out on the pages of the important British magazine *The Nineteenth Century* in 1885 and 1886, between two aging giants. On the side of uniting Genesis and natural history was W. E. Gladstone, classical scholar as well as former (and soon to be again) Prime Minister of England, then 76. On the other side was T. H. Huxley, who had just retired at age 60. Gould presents several quotes from each from the back-and-forth exchanges, clearly relishing the courteously insulting style of the debate as well as the content.

Gladstone's key technical argument was that the sequence in which life was created, especially on the fifth and sixth days – first the fish and whales of the sea, and then the winged fowl of the air on the fifth day, followed by land animals, including creeping things and beasts, and then finally man on the sixth day. Does this not follow the actual progression that science has found? And how, he continued, could the ancients who wrote the Bible have known this to be so without divine inspiration? Huxley's counter (and the "specific" reason referred to above) is four-fold. First, the order is simply not correct; the fossil record clearly shows that birds appeared *after* land animals, not before. Secondly, the anatomy of birds shows that they are descended from land animals, and so could not have preceded them. (Gladstone, like virtually all 1880's Victorian gentlemen, accepted the fact of evolution, but not the secular mechanism of natural selection.) Third, the geological record shows that animals on the land, sea, and air continued to arise throughout natural history, rather than each being confined to a specific period. Fourth, Huxley argued, Gladstone cannot simply ignore the events of the third day, in which plants – and specifically grasses and fruit trees – were created. These are known to be late arrivals on the scene, well after the origin of mammals. In summary, the first (specific) argument is that Genesis and natural history do *not* become compatible simply by removing the fundamentalist constraint that a "day" must be 24 hours.

The second, more general reason is simply that the Bible is not a textbook on natural science. It says nothing that should be taken seriously (Huxley and Gould argue) about the origin or age of the universe; but that is because such things are *outside the scope of religion*. Religion and ethics are about how to treat one another, and the importance of love, faith, and justice. Those who argue that science can be used to identify moral versus immoral behavior (Huxley and Gould also argue) are just as wrong in their view of science and religion as the fundamentalists they condemn. [Gould elaborates on this theme, which he comes to refer to as "non-overlapping magisteria," in LMC 14, and in his 1999 book *Rocks of Ages*.]

Gould ends with an additional point on the story of Genesis. Gladstone, he argues, saw the creation story in terms of *addition*; each day, something more was added. Gould prefers a different metaphor, that of *differentiation*. He sees each day as dividing an existing "substance" into subcomponents – light from darkness, land from sea, then the fish from the ocean and the animals from the land. (In a footnote, he states that after writing this essay he saw a mosaic of the Genesis story at the cathedral of San Marco in Venice that was based on the differentiation metaphor. He writes specifically about this in one of his last essays, IHL 20.) The relevance of these two metaphors to natural history, he concludes, is not which is true – both appear, he claims – but that these metaphors represent "modes of thinking" in human beings. There are not really very many of these, and so to properly understand what we *think* we see in nature, it is important to understand the metaphors we use to describe it.

BFB 28. William Jennings Bryan's Last Campaign

Many people know that William Jennings Bryan was a great populist orator and politician during the late 19th and early 20th centuries, and was nominated by the Democratic Party for President three times, losing each time. Most also know that he volunteered to prosecute John Scopes in the case over the legality of teaching evolution in Tennessee schools in the so-called "Monkey Trial" of 1925 [HTHT 20], where he was humiliated at the hands of Clarence Darrow and died a few days after the trial's conclusion. Most people do not know, however, that Bryan was almost solely responsible for getting the laws against the teaching of evolution on the books in the first place. Gould, basking in the glow of victory after the 7-2 decision by the Supreme Court in the 1987 case (in which he was a witness) that found the teaching of creationism in school to be unconstitutional, decided to try to understand the man who brought forth the uniquely American fundamentalist resistance movement to teaching evolution. Bryan, after all, had been a champion of many progressive causes, including women's suffrage, direct election of senators, the progressive income tax, and independence for the Philippines. He had always fought for the farmer and worker against the rich and powerful. How could such a man have ended his career rallying disorganized fundamentalists to the cause of irrational anti-science?

Most biographies, Gould tells us, suggest that Bryan's later years were a period of decline or retreat. A smaller faction, which Gould comes to join, argues that his position was fully consistent with his progressive views. As early as 1904, there is plentiful documentation that he had grave misgivings about evolution. These objections were not based on concerns about his ancestry, although he acknowledged not being ready to accept that a lineage to apes. Rather, his concern was with the social implications. Gould quotes Bryan from 1904: "The Darwinian theory represents man as reaching his present perfection by the operation of the law of hate – the merciless law by which the strong crowd out and kill off the weak. . . . I prefer to believe that love rather than hatred is the law of development." His general unease turned to action during World War I (after having resigned as Wilson's Secretary of State), when he read two books. The first, *Headquarters Night* by Vernon Kellogg (1917), was written by a Stanford professor who had been admitted to the Kaiser's inner circle in Germany before America joined the war. Kellogg went to Europe as a pacifist, but came to realize that Germany's militarism would not be stopped without force. The German views of the importance of warfare, conquest, and the superiority of their own race and culture, he learned in open dinner conversations, were primarily and explicitly rationalized by their interpretation of Darwin's theory. In their view, natural selection meant "might makes right," and to believe anything else was naïve weakness. The second book, Benjamin Kidd's *The Science of Power* (1918), added that industrialists were also using Darwin's theory to justify their exploitation of the workers, in what came to be called "social Darwinism" by critics. In both cases, these authors noted that scientists readily volunteered their prestige and support to these arguments. Gould knew this to be true; he had written an entire book on this topic, 1981's *The Mismeasure of Man*.

Bryan, Gould continues, came to see evolution as an insidious propaganda scheme taught in colleges by supporters of a ruling elite who wanted to undermine the religious values of "love thy neighbor" and "turn the other cheek." He decided to counterattack by working to pass laws to prevent the teaching of evolution in public schools, starting in 1920. He especially attracted fundamentalists with his argument that evolution was godless, a point that others challenged [next essay], but his main concerns were that teaching evolution bred militarism and exploitation.

At this point, Gould states his three major technical objections to Bryan's analysis. First, Bryan is confusing evolution – the paradigm that organisms are related by lines of descent – with natural selection, Darwin's proposed mechanism. Second, natural selection – "survival of the fittest" – does not always, or even often, require direct competition with members of one's own species. Cooperation can be a part of survival as well; Gould refers to the arguments of Kropotkin [BFB 22]. The third is Gould's familiar argument that nature, including Darwin's theory of natural selection, has nothing whatsoever to say about moral conduct. He acknowledges that this last argument has had a very problematic history. He points out that the very book that John Scopes was tried for teaching out of, *A Civic Biology* by George William Hunter (1914), misuses science to justify clearly immoral behavior. In a section entitled "Parasitism and Its Cost to Society – The Remedy," the author writes that "bad heredity" runs in families, and the offspring of these lineages are literally parasites on society. While we cannot simply kill them, he continues, we can and should lock them away and perhaps sterilize them – for the biological health of the public at large. [One of the essays that Gould was most proud of, "Carrie Buck's Daughter" (TFS 20), discussed the technical fallacy as well as moral injustice of such charges.] Bryan was wrong in his analysis and very wrong in his solution, Gould concludes, but he correctly identified a serious problem and tried to address it. All of us, scientists included, can benefit from a steady diet of humility.

BFB 29. Essay on a Pig Roast

One of the most widely-used arrows in the quiver of modern creationistism is the story of how scientists found a single tooth in Nebraska, identified it as a human ancestor, and used this to justify that man evolved from apes. It turned out that the tooth belonged to a pig! This true story, which took place from 1922 to 1927, is used by creationists to attack along three fronts. First, how can anyone believe evolutionists if they cannot tell a monkey from a pig? Second, how credible can scientists be if they can go so far as to name a species – any species – based on a single worn tooth? (Gould notes later it was actually two worn teeth.) And third, capitalizing on a painting of this "human ancestor" that appeared in the popular press: how seriously can we take a science that claims to be able to describe an entire unknown animal from one of its teeth? [All three arguments attempt to undermine the credibility of acquiring "truth" via the methods of science, as opposed to faith or appeal to authoritative sources. None actually challenge the evidence of evolution directly.] Gould tells the full, embarrassing story in this essay, and argues that it is really a positive story for science; for it was scientists, not creationists, who uncovered the error.

The story begins with William Jennings Bryan's nationwide campaign to pass laws prohibiting the teaching of evolution in public schools [see the previous essay]. One of the people who most publically challenged this campaign was Henry Fairfield Osborn, head of the American Museum of Natural History in New York. Osborn was almost the opposite of "the Great Commoner" from Nebraska; he was "arrogant, patrician, and archconservative" (Gould's description), with an enormous ego and nothing but contempt for everything Bryan had ever stood for. They had one important thing in common, however; both were devoutly religious. Much of the actual battle involved competing interpretations of the Bible, with verses being tossed about left and right.

The debate began on Sunday, February 26, 1922, when a widely-read "op-ed piece" written by Bryan appeared in the New York Times. He wrote: "The real question is, Did God use evolution as his plan?" Bryan conceded that, if it were true that man evolved from ape, we would all have to accept it; but at that point (he argued), there was no evidence to support it, and the social and religious consequences of doing so were grave. Osborn was invited by the *Times* to respond, which he did with an op-ed piece of his own on the following Sunday. He countered in two ways. First, he wrote, Bryan was wrong; there was extensive evidence supporting the theory of evolution. (Regarding humans, fragments of "Java Man" – now classified as *Homo erectus* – had been discovered in 1891, and Neanderthals were then being recognized as distinct from modern humans. Also, in 1912, "Piltdown Man" [TPT 10] was identified in England, adding weight to Osborn's argument. Later, Piltdown Man would be recognized as a hoax, adding another rhetorical weapon to the creationist's arsenal.) Osborn's second counter was that evolution is not incompatible with religion in any case. He quoted Job (12:8): ". . . . speak to the earth, and it shall teach thee."

At almost exactly this moment, a rancher and semi-professional geologist and fossil hunter named Harold J. Cook found a worn molar tooth that appeared to belong to an upper primate (ape or human) in sediments that were about 10 million years old, along with many other fossils. Cook had come to know both Osborn and his colleague, William Gregory, a leading expert on primate teeth, and he sent the tooth to Osborn. Under other circumstances, Osborn might have waited for more and better evidence before publishing (as he apparently did for an earlier tooth from the same species and same location). But the tooth was found in Nebraska, Bryan's home state – the taste of victory was apparently too great to resist. With Gregory's qualified support, he published two different papers, both sharing the title of "*Hesperopithecus*, the First Anthropoid Primate Found in America." The name *Hesperopithecus* means "ape of the western world," and by formally naming it, he was committing some of his professional prestige to its validity. He openly taunted Bryan in the press with its discovery.

Comparative anatomy is a very powerful but very subtle field of scientific study [see HTHT 7], and had been established for more than a century by this time. It works by noting fine details in living and extinct organisms, particularly bones and teeth. It had been established that most vertebrate species, or at least genera, were unique enough to be able to support definite identification from a small subset of the skeleton. Teeth, it turns out, are especially rich in the sorts of details that permit such identifications. One of the curiosities of nature is that the molars of certain members of the swine family closely resemble those of modern humans. The differences between them are clear in the cusps of the biting surfaces, but in this case they had been worn down by erosion. The resemblance was well-known, and Osborn, Gregory, and Cook knew (and in some cases, even wrote) that the two could be easily confused. In this case, they were: larger field expeditions to the area in 1925 and 1926 found copious amounts of much better preserved material, and it quickly became obvious that the tooth belonged to a species of peccary, a relative of the domestic pig. Gregory published an article in the journal *Science* in 1927, entitled "*Hesperopithecus* Apparently not an Ape or a Man." Osborn simply acted like the entire episode never happened; he never spoke or wrote of it again. [Gould does not mention it here, but Bryan was not around to get the last laugh; he died in 1925.]

Did Osborn jump to conclusions, based on tenuous data and in the throes of a personal agenda? The answer is probably yes, Gould concludes. In Osborn's defense, however, Gould points out that his professional writings on *Hesperopithecus* did couch his anthropoid conclusions in some degree of uncertainty. More importantly, he did make careful copies of the tooth and shipped them to experts around the world for their opinions, rather than hiding it away in a vault. (One of the people he sent it to, G. Elliot Smith, was so convinced of its human origin that he commissioned an artist to paint a scene with *Hesperopithecus* in it. The artist, having no idea what the creature looked like, based it on what was known of *Homo erectus*. The picture first appeared in the *Illustrated London News* in 1922, and has been a staple of creationist imagery ever since.) Osborn also encouraged, and participated in, the field trips that uncovered the conflicting information. And while he never publically admitted he was wrong, others in his circle did, and the community moved on. If creationists were sincere, Gould adds, they would do the same with some of the examples they have offered that have been completely debunked; he refers specifically to the limestone deposits along the Paluxy River in Texas, where real dinosaur tracks lie next to what some claimed were human footprints (implying that dinosaurs and humans coexisted, and thus also implying a much younger earth). As to the lines of creationist attack presented at the beginning, Gould's point is that *of course* scientists are sometimes wrong; the strength of their learning paradigm is that they can *correct* their mistakes. The *Hesperopithecus* episode, Gould summarizes, while embarrassing, should not be swept under the rug; it is really a success story for science as a whole.

BFB 30. Justice Scalia's Misunderstanding

Contrary to popular belief, Gould begins, "science" is not really about developing big picture theories about the origin of the universe or the origin of life. Scientists, like other people, wonder about these things; but the strength of science is that it limits itself to what it can measure and test. A possible explanation for the origin of, say, stars, is scientific only if it can be tested; if not, it is merely speculation. It is perhaps counterintuitive that this approach has led to a far better understanding of the universe than those that ask such big picture questions directly. Real science is about the tedious, measurable details.

In 1987, the Supreme Court struck down a Louisiana law that mandated the teaching of "creation science" along with evolution in public schools by a 7-2 vote, on the grounds that it promoted a particular religious view and thus was in conflict with the Constitution. Gould, wondering what possible rationale could explain the lack of unanimity in this decision, read Justice Antonin Scalia's dissent to seek the answer. (This dissent was joined by Chief Justice William Rehnquist.) His conclusions are that Scalia holds a false understanding of what science is, and an incorrect view of what it is that evolutionists actually study. His views are consistent with the main, two-fold (and conflicting) views that creationists offer in their attempts to equate creation science with science. The first is that creation science is *not* religion in disguise, but a mode of inquiry that is as rigorous as science. (Mainstream scientists, they argue, simply refuse to accept their legitimate techniques.) The second is that creation science *is* religious in nature, but that *science is also*; this is, they argue, because scientists are searching for the ultimate origin of things, which is an inherently religious undertaking. But this is precisely what science does *not* do, Gould states. Newton did not attempt to understand the origin of gravity; rather, he determined the rules by which it operated, making testable predictions and checking the results. Similarly, Darwin did not investigate the origin of life; he investigated patterns of differences and similarities between organisms, and postulated a mechanism for how "modification with descent" could produce today's fauna from earlier fauna. (Gould notes that chemistry, or perhaps the physics of self-ordering systems, might someday yield testable hypotheses on life's origin, but that standard evolutionary biology never will – it is outside of its scope.) Gould was struck by the number of times – more than a dozen, he claims – that Scalia used the phrase "the search for life's origin" when referring to evolution in his dissent. In oral arguments, Scalia pointedly asked about a secular example involving a different view of the world's origin: Aristotle's "unmoved mover." This question again shows that Justice Scalia misunderstands both the questions that science attempts to answer, and the methods by which scientists go about this task. Gould states that if a group proposed teaching Aristotle's views as a legitimate mode of scientific thinking, he would object just as strenuously as he would to creation science, and for the same reason: the hypothesis is not testable, and therefore is not science.

[Scalia's dissent was unusual in another way – it advocated *mandating* the teaching of creation science along with evolution on the grounds of *supporting academic freedom*. In this case, he argued, the freedom was not for the teachers, but for the students, who were (in his view) entitled to not be indoctrinated. On a separate note, it is also interesting the debate focused on the origin of life, rather than the origin of Man.]

To illustrate the point that Justice Scalia's misunderstanding is not original with him, Gould spends a large part of the essay discussing a similar case from the late 18^{th} century. James Hutton, considered one of the founding fathers of the science of geology, argued for a cyclical geologic process that created new mountains as well as eroding existing ones. While wrong in the particulars, he succeeded in convincing the western world that restoring forces did exist within the earth, and that the earth must be ancient – far older than the 6000 years of biblical literalists. [Hutton's tale is presented in HTHT 6.] One of the most famous quotes in all of geology is the last sentence of his 1788 treatise *Theory of the Earth*: "The result, therefore, of our present enquiry is, that we find no vestige of a beginning – no prospect of an end." Hutton did not mean that the earth had existed, and would exist, forever. Rather, he meant that the earth was currently operating like a cyclical machine. His studies focused exclusively on the operation of that machine, and not its origin or its ultimate fate; he considered these to be *outside the scope* of what he could study. In this way [although not in others – see HTHT 6], he was operating as a modern scientist. Importantly, he was also misunderstood – then and now. Then, some thought he was advocating for an earth that always existed, and was therefore accused of atheism; for if the earth was never created, the argument went, there would be no need for a creator. Today, many geologists falsely believe that Hutton was declaring his independence from the dogmatic church authorities by arguing for "deep time." This is also wrong; Hutton was deeply religious, and based his model on a theological argument. He simply believed that, to start and stop "machine earth," God would use means other than those that could be studied by science.

BFB 31. The Streak of Streaks

One of the definitions of randomness in mathematics is that each event in a sequence is uncorrelated with those that have gone before. Thus, when flipping coins, the probability that heads will come up on a certain toss is 50 per cent – even if the previous ten tosses have all been heads. Randomness has no "memory" of previous events, and is not influenced by them. One might think that in far more complex systems, such as humans playing professional basketball, the outcome of any shot (basket or no basket) might be non-random. Players are known to have "hot hands" or to go cold; it seems reasonable to assume that a string of consecutive baskets by a player gives him confidence, putting him into a rhythm or "the zone," while the opposite can happen after several consecutive misses. Stanford psychologist Amos Tversky decided to test this hypothesis by gathering statistics on every basket made by the Philadelphia 76ers for a season. What he found was that, for each player, the probability of making a basket was uncorrelated (made no difference) with whether his previous shot had gone in. He also examined "runs" (streaks of consecutive baskets made), and found that they agreed quite well with what would be expected based the average shooting percentage of that player. In short, in the sport of basketball at least, there are not really any hot hands or cold streaks; just probability distributions, skewed (of course) by the overall talent of the player.

The larger significance of these findings comes from the fact that most people find this conclusion surprising. Humans do not think in probabilistic terms very well. We perceive patterns in the random "clumping" of sequences (Gould references his postscript at the end of BFB 17); most cultures appear to have arranged the randomly distributed stars in the night sky into constellations, each in a unique way. More importantly, we also tend to assign significance to these patterns, such as the apparent myth of the hot hand and many others. To psychologists, this tells us something important about how the mind works. Tversky and his colleague Daniel Kahneman argue that humans "match to type" rather than thinking in a manner that is more conducive to recognizing random distributions. We tend to look, they argue, for the "essence" of a thing, and then compare what we see to this presumed essence. Scientists have, for the past several hundred years, sought patterns in nature with some success (along with many failures). The overall significance of the lesson of "match to type" thinking is that scientists, and the intellectually curious in general, need to be aware that the mind tends to operate in this way. This awareness can help us recognize when we are seeing "patterns" that may not really exist [see, for example, TFS 30].

All of this is, in reality, merely a pretext for talking about Joe DiMaggio's famous 56-game hitting streak in 1941. DiMaggio was Gould's favorite player growing up, and the source of this essay is a book review of Michael Seidel's 1988 book *Streak: Joe DiMaggio and the Summer of 1941*. (A different version of this essay first appeared in the *New York Review of Books*, rather than Gould's monthly column in *Natural History* magazine.) Most streaks in baseball follow the "random distribution" profiles of Tversky and Kahneman, but one (and only one) stands out as truly improbable; DiMaggio's consecutive-game hitting streak. Gould clearly relishes this fact, and includes some anecdotes about interactions with the baseball legend during and after his career.

BFB 32. The Median Isn't the Message

This brief essay, which first appeared in *Discover Magazine* in 1985, is the only one in which Gould does more than mention his experience with cancer. He was diagnosed with abdominal mesothelioma, he tells us, in July 1982. Surgery quickly followed; only afterwards did he get the opportunity to research the medical literature to get a sense of his prognosis. The news was not good; the median life expectancy was reported to be eight months after diagnosis. But Gould, being more familiar with the underlying meaning of statistics than most people, actually took heart in this. Humans struggle with probabilities and statistical distributions, he says. Most people would read the previous statement and infer that they would live about another eight months, and then die. (This is consistent with the "match to type" psychological mechanism discussed in the previous essay.) Members of the biological community, however, understand that variation is fundamental, “nature’s only irreducible essence,” and that what the prognosis means is that half of the people with that diagnosis will live for less than eight months while the other half will live longer. A few, he found, would live a lot longer, because the profile is “right-skewed.” (In “median” calculations, one person living ten years balances out only one person living, say, four months. This differs from “mean” calculations, in which one person living ten years would require many people living only four months to balance the “average” out to eight months.) He quickly found that he possessed all of the known characteristics that would put him on the part of the distribution that would exceed the median life expectancy: relative youth, early diagnosis, and access to state-of-the-art health care. (He also notes that he participated in a new, experimental technique that offered the hope of improving the life expectancy for all.) He adds that he had one other factor going for him, one that many physicians consider the most important: a positive outlook. Some of this, he says, is due to his inherently optimistic personality and strong will to live; but some of it, he proposes, is the result of his proper understanding of statistics and the meaning of “median.” For once, he argues, statistics manifested itself as a source of vitality and optimism, rather than the cold-blooded sterile methodology that most people associate with the term. [Gould did indeed beat the odds, living for almost another 20 years before succumbing to a different form of cancer in 2002.]

BFB 33. The Ant and the Plant

Gould begins by lamenting the human fascination with size, and in particular the notion that “bigger is better.” This is perhaps, he quips, the result of his relatively short stature, which he tells us is five feet, seven and one-half inches. This perceived value of size extends to genetics; earlier scientists assumed that more complex organisms would contain more genes. This is not at all the case, however; the genome size of certain species of salamanders dwarfs that of mammals. This can be explained away, however, via the later discovery that most genetic material does not actually “code” for anything, and is often composed of long strings of repeated, apparently useless sequences known as “junk DNA.” Another way to measure the magnitude of genetic material (probably no better than the first) is via the number of chromosomes. Humans have 23 pairs; fruit flies have only four, which makes them attractive for genetic research. In this essay, Gould examines the extremes: the multicellular organisms with the smallest and largest number of chromosomes. His traditional approach to these essays is to extrapolate a more general conclusion from his specific examples; but in this case, he states at the end, he can come up with nothing. Sometimes size – big or small – is simply interesting by itself.

In 1887, Theodor Boveri (1862 – 1915) discovered that a certain species of nematode had exactly one pair of chromosomes in its sex cells. (Boveri, Gould tells us, was the leading cytologist – student of cellular architecture – of the 19th century. He was the first to recognize that it was the chromosomes, rather than the nucleus as a whole, that carried the genetic information. He also determined that each chromosome carried only part of this information; prior to this, scientists had thought that each chromosome carried all of it.) This rule held only for the sex cells, however; after the fertilized nematode egg began to divide, the chromosome would also, eventually fragmenting into some 70 pairs. Then, almost a hundred years later in 1985, scientists Michael Crosland and Ross Crozier came across a species of ant in Australia that had a single, stable pair of chromosomes in all of their cells. Further, like all ants, this species is genetically haplodiploid [ESD 33]. This means that the females have the usual two pairs of chromosomes (and are thus diploid), while the males have only a single example copy of each chromosome (and are thus haploid). Since there is only one pair in this case, male members of this ant species contain the absolute minimum of a single, individual chromosome. Gould notes that these ants act pretty much like all other ants.

Organisms with the largest number of chromosomes do not, as one might expect, belong to the most complex animals. In fact, most of the records are held by plants, for the reason that plants tend to "double" the number of chromosomes more readily than animals. This process, known as polyploidy, can happen multiple times, leading to very large numbers of chromosomes. Since only one chromosome is required to maintain the existing function, these other pairs can mutate to form new genes, as long as the results do not prove toxic. However, in plants, the changes from one copy to another are often relatively minor. The winner is a species of fern, with some 630 pairs of chromosomes, each dividing correctly (at least most of the time). Ferns are relatively simple organisms, even by plant standards.

BFB 34. The Face of Miranda

One way of differentiating the "hard sciences," such as physics and chemistry, from the "soft sciences," a term that Gould applies to evolutionary biology as well as to psychology and sociology, is that the former are essentially independent of history, while the latter are not. Every hydrogen atom is essentially identical to every other hydrogen atom across space and time, as are simpler molecules such as methane, calcium carbonate (the primary component of limestone), and even amino acids (the building blocks of proteins). At some point, however, molecules come into existence that are complex enough to be uniquely associated with certain forms of life; these molecules – proteins, for example – are today (thanks to Darwin) recognized as the product of certain historical events. Had those historical events been different, a slightly altered molecule might exist instead. The techniques used to study these history-dependent sciences must differ from the "controlled, reproducible experiments" of the hard sciences, in large part because the systems involved are just too complicated. Instead [as discussed in HTHT 9], a different set of techniques must be employed. Terrestrial geology has traditionally been placed closer to the hard sciences than the historical ones – and, as Gould argues in several essays, it should be moved closer to the middle, especially after the new-found recognition of the importance of catastrophic geological events [HTHT 25].

What about the surfaces of planets and moons? In an earlier essay [ESD 24], Gould himself advocated that a single, non-historical factor should dominate what these surfaces should look like: physical size. He discussed two engines that produced surface change: atmospheres and plate tectonics. The first process removed craters and other surface features via the processes of erosion; the second recycles the surface by deforming, re-melting, and re-forming it. The earth employs both of these mechanisms, he argued, while the moon uses neither. The moon is not massive enough (not enough "size") to hold an atmosphere. It also has a large surface-area-to-volume ratio [ESD 21], due again to size, that allows internal heat to escape at a higher rate, leading to thicker and therefore less movable crust. As he discussed in the earlier essay, photographs of Mercury (about the size of the moon) and Mars (in between the size of the moon and earth) provided support for this size-dominated model.

Then came NASA's Voyager, which took high-resolution images of the moons of Jupiter, Saturn, Uranus, and Neptune (along with the planets themselves). Every moon turned out to be unique in some way; the diversity was staggering. Gould wrote this essay just after Voyager encountered Uranus and its moons, one of the innermost being Miranda. Gould's model, which he abandoned after the Jupiter fly-by, would have predicted that the surface of this relatively small body should be "moon-like" in appearance: heavily cratered, with no signs of change in billions of years. Instead, Voyager showed that the dominant structures on Miranda's surface – including a series of massive, parallel ridges at odd angles to each other called "the chevron" – are due to large-scale quasi-catastrophic events. That is, rather than being dominated by the steady-state physical laws of gravity and thermal transport (which are in turn relatively simple functions of size), the surface of Miranda also reflects major events. In other words, it has a complex, partially unique, and non-reproducible "history." He adds that he is not depressed that his earlier model was wrong, but rather encouraged; one can learn more from having a model proved wrong than supported by direct evidence.

BFB 35. The Horn of Triton

Most people agree that certain individuals have changed history; had these people not been born, the world today would be significantly different. On the other end of the spectrum of knowledge is physics; every proton is like every other proton, and it makes no difference *which* water molecule is present in a particular chemical reaction. In between these areas of study is the realm of natural history. Many argue that the history of life on earth is one of inevitability; that the variations in the actual events "average out" over time. One of Gould's favorite themes is that natural history does not belong on the physics side of this divide, but rather in the middle; the laws of physics and chemistry matter, but so do individual events. In support of his view, he offers two recent examples from nature.

The first comes from the work of Jane Goodall, who had recently completed 25 years in the field with the chimpanzees of Gombe. She relates a story that for about four years, one female chimp named Passion, with her daughter, apparently killed almost every baby born to the group. Their behavior ended as suddenly and mysteriously as it began; all of the females then became pregnant, producing a small "baby boom" which propagated through the demography of the group for decades. More generally, the population of the colony was dominated by three "rare events" (Goodall's term), rather than a more average process: a polio epidemic, the attack and killing of one sub-band by another, and the baby-killing behavior of Passion. The second event involved the deaths of hundreds of kiwis in New Zealand over a six-week period, apparently by a single German

Sheppard that had gone ferial. (The dog was shot, and the killing stopped.) The population was decimated, and could have been eliminated completely had the dog not been killed; Kiwis have no natural enemies, and were easily detected and dispatched by the invasive attacker. Kiwis reproduce slowly, and the population will not recover for decades, if ever.

Perhaps, Gould continues, the degree of scaling involved between local catastrophes and regional trends does average out such events. That is, at a larger scale, perhaps predictability takes over. He offers three reasons for opposing this view. First, he states, scale is relative. Biologically speaking, humans are a minor branch on the evolutionary tree of life; does this mean that nothing in the field of anthropology is significant to science? [He discusses the timescale of species formation after extinction again in DIH 2.] Second, he notes that chaos theory suggests that there are indeed cases where small changes at one level can, in fact, produce major differences at higher levels. [Chaos theory had become popular about the time he wrote this, due to the newly-available power of computers to generate beautiful "fractal" patterns.] The third argument is that the "averaging" power of statistics disappears when only a small number of events are considered. There are parts of nature and natural history, he states, that appear to fall into this category. [One of his favorites is an asteroid impact.]

The list of sciences that must be recognized as having a "historical" component to them must now include the surfaces of planets and their moons. Gould wrote this essay in 1989, shortly after Voyager completed its fly-by of Neptune and its moons. The simple, physics-of-size-only model discussed in ESD 24 and BFB 34 had already proven to be hopelessly inadequate. Triton, Neptune's largest moon, is still small enough that it should have been paved (according to this model) with perfectly preserved craters. Like Uranus's Miranda and numerous other objects that Voyager had photographed, it was not; it has a crumpled surface with few craters, and also apparently active volcanoes. The complexity of all of these objects should not be a cause for despair, he reiterates; history is not a bad thing.

He closes with an appreciation for the sheer beauty of the images Voyager has taken in its twelve-year journey. The operators clearly understood the aesthetic importance of their work as well, for they took one final picture of a crescent Neptune with the smaller crescent Triton off to the side (reproduced in the essay). The image had little scientific value, but seeing the "horns" (as celestial crescents have traditionally been called) of these bodies together makes a powerful and moving image.