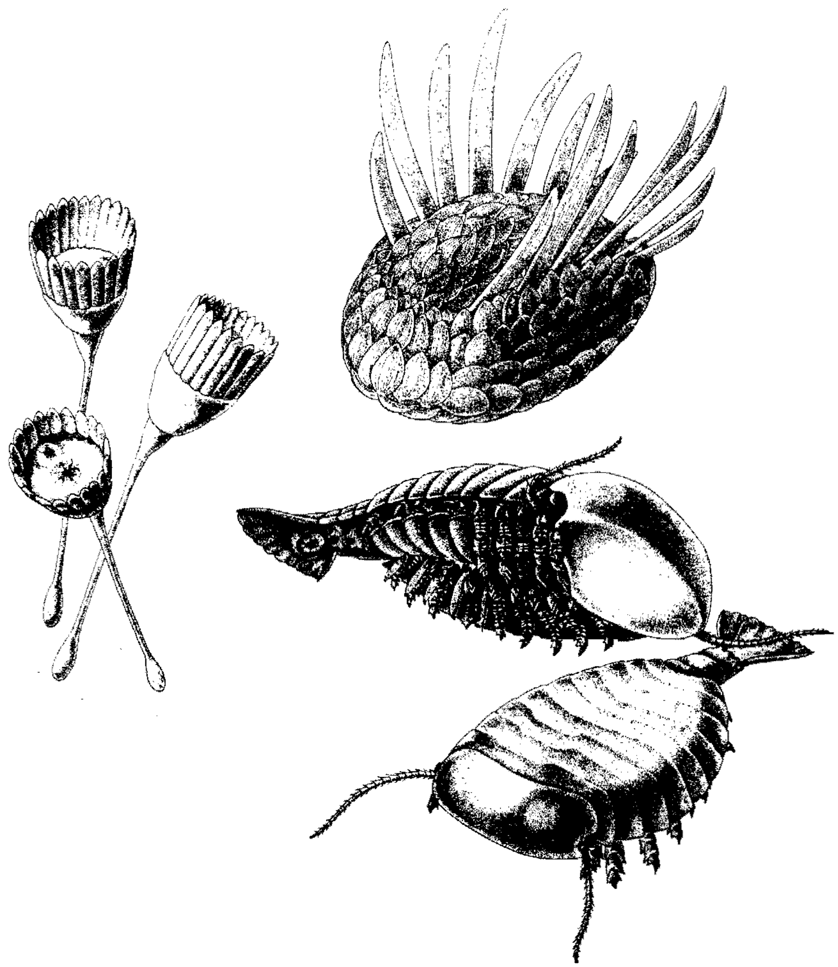

Wonderful Life

The Burgess Shale and the Nature of History

STEPHEN JAY GOULD

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To Norman D. Newell

Who was, and is, in the most noble word of all human speech, my teacher

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Lipalian interval ended up on the trash heap of history.

Scientists have a favorite term for describing a phenomenon like Walcott's allegiance to the Burgess shoehorn—overdetermined. The modern concept of maximal disparity and later decimation (perhaps by lottery) never had the ghost of a chance with Walcott because so many elements of his life and soul conspired to guarantee the opposite view of the shoehorn. Any one of these elements would have been enough in itself; together, they overwhelmed any alternative, and overdetermined Walcott's interpretation of his greatest discovery.

To begin, as we have seen, Walcott's persona as an archtraditionalist in thought and practice did not lead him to favor unconventional interpretations in any area of life. His general attitude to life's history and evolution implied stately unfolding along predictable pathways defined by the ladder of progress and cone of increasing diversity; this pattern also held moral meaning, as a display of God's intention to imbue life with consciousness after a long history of upward striving. Walcott's specific approach to the key problem that had focused his entire career—the riddle of the Cambrian explosion—favored a small set of stable and well-separated groups during Burgess times, so that a long history of Precambrian life might be affirmed, and the artifact theory of the Cambrian explosion supported. Finally, if Walcott had been at all inclined to abandon his ideological commitment to the shoehorn, in the light of contradictory data from the Burgess Shale, his administrative burdens would not have allowed him time to study the Burgess fossils with anything like the requisite care and attention.

I have labored through the details of Walcott's interpretation and its sources because I know no finer illustration of the most important message taught by the history of science: the subtle and inevitable hold that theory exerts upon data and observation. Reality does not speak to us objectively, and no scientist can be free from constraints of psyche and society. The greatest impediment to scientific innovation is usually a conceptual lock, not a factual lack.

The transition from Walcott to Whittington is a premier example of this theme. The new view—as important an innovation as paleontology has ever contributed to our understanding of life and its history—was in no way closed to Walcott. Whittington and colleagues studied Walcott's specimens, using techniques and tools fully available in Walcott's time, in making their radical revision. They did not succeed as self-conscious revolutionaries, touting a new view in *a priori* assault. They began with Walcott's basic interpretation, but forged ahead on both sides of the great dialectic between theory and data—because they took the time to converse adequately with the Burgess fossils, and because they were willing to listen.

The transition from Walcott to Whittington marks a milestone that could hardly be exceeded in importance. The new view of the Burgess Shale is no more nor less than the triumph of history itself as a favored principle for reading the evolution of life.

THE BURGESS SHALE AND THE NATURE OF HISTORY

Our language is full of phrases that embody the worst and most restrictive stereotype about science. We exhort our frustrated friends to be "scientific"—meaning unemotional and analytic—in approaching a vexatious problem. We talk about the "scientific method," and instruct schoolchildren in this supposedly monolithic and maximally effective path to natural knowledge, as if a single formula could unlock all the multifarious secrets of empirical reality.

Beyond a platitudinous appeal to open-mindedness, the "scientific method" involves a set of concepts and procedures tailored to the image of a man in a white coat twirling dials in a laboratory—experiment, quantification, repetition, prediction, and restriction of complexity to a few variables that can be controlled and manipulated. These procedures are powerful, but they do not encompass all of nature's variety. How should scientists operate when they must try to explain the results of history, those inordinately complex events that can occur but once in detailed glory? Many large domains of nature—cosmology, geology, and evolution among them—must be studied with the tools of history. The appropriate methods focus on narrative, not experiment as usually conceived.

The stereotype of the "scientific method" has no place for irreducible history. Nature's laws are defined by their invariance in space and time. The techniques of controlled experiment, and reduction of natural complexity to a minimal set of general causes, presuppose that all times can be treated alike and adequately simulated in a laboratory. Cambrian quartz is like modern quartz—tetrahedra of silicon and oxygen bound together at all corners. Determine the properties of modern quartz under controlled conditions in a laboratory, and you can interpret the beach sands of the Cambrian Potsdam Sandstone.

But suppose you want to know why dinosaurs died, or why mollusks flourished while *Wiwaxia* perished? The laboratory is not irrelevant, and may yield important insights by analogy. (We might, for example, learn something interesting about the Cretaceous extinction by testing the physiological tolerances of modern organisms, or even of dinosaur "models," under environmental changes proposed in various theories for this great dying.) But the restricted techniques of the "scientific method" cannot get to the heart of this singular event involving creatures long dead on an earth with climates and continental positions markedly different from today's. The resolution of history must be rooted in the reconstruction of past events themselves—in their own terms—based on narrative evidence of their own unique phenomena. No law guaranteed the demise of *Wiwaxia*, but some complex set of events conspired to assure this result—and we may be able to recover the causes if, by good fortune, sufficient evidence lies recorded in our spotty geological record. (We did not, until ten years ago, for example, know that the Cretaceous extinction corresponded in time with the probable impact of one or several extraterrestrial bodies upon the earth—though the evidence, in chemical signatures, had always existed in rocks of the right age.)

Historical explanations are distinct from conventional experimental results in many ways. The issue of verification by repetition does not arise because we are trying to account for uniqueness of detail that cannot, both by laws of probability and time's arrow of irreversibility, occur together again. We do not attempt to interpret the complex events of narrative by reducing them to simple consequences of natural law; historical events do not, of course, violate any general principles of matter and motion, but their occurrence lies in a realm of contingent detail. (The law of gravity tells us how an apple falls, but not why that apple fell at that moment, and why Newton happened to be sitting there, ripe for inspiration.) And the issue of prediction, a central ingredient in the stereotype, does not enter into a historical narrative. We can explain an event after it occurs, but contingency precludes its repetition, even from an identical starting point. (Custer was doomed after a thousand events conspired to isolate his troops, but start again in 1850 and he might never see Montana, much less Sitting Bull and Crazy Horse.)

These differences place historical, or narrative, explanations in an unfavorable light when judged by restrictive stereotypes of the "scientific method." The sciences of historical complexity have therefore been demoted in status and generally occupy a position of low esteem among professionals. In fact, the status ordering of the sciences has become so familiar a theme that the ranking from adamantine physics at the pinnacle down to such squishy and subjective subjects as psychology and sociology at the bottom has become stereotypical in itself. These distinctions have entered our language and our metaphors—the "hard" versus the "soft" sciences, the "rigorously experimental" versus the "merely descriptive." Several years ago, Harvard University, in an uncharacteristic act of educational innovation, broke conceptual ground by organizing the sciences according to procedural style rather than conventional discipline within the core curriculum. We did not make the usual twofold division into physical versus biological, but recognized the two styles just discussed—the experimental-predictive and the historical. We designated each category by a letter rather than a name. Guess which division became Science A, and which Science B? My course on the history of earth and life is called Science B-16.

Perhaps the saddest aspect of this linear ranking lies in the acceptance of inferiority by bottom dwellers, and their persistent attempt to ape inappropriate methods that may work higher up on the ladder. When the order itself should be vigorously challenged, and plurality with equality asserted in pride, too many historical scientists act like the prison trusty who, ever mindful of his tenuous advantages, outdoes the warden himself in zeal for preserving the status quo of power and subordination.

Thus, historical scientists often import an oversimplified caricature of "hard" science, or simply bow to pronouncements of professions with higher status. Many geologists accepted Lord Kelvin's last and most restrictive dates for a young earth, though the data of fossils and strata spoke clearly for more time. (Kelvin's date bore the prestige of mathematical formulae and the weight of physics, though the discovery of radioactivity soon invalidated Kelvin's premise that heat now rising from the earth's interior records the cooling of our planet from an initially molten state not long past.) Even more geologists rejected continental drift, despite an impressive catalogue of data on previous connections among continents, because physicists had proclaimed the lateral motion of continents impossible. Charles Spearman misused the statistical technique of factor analysis to designate intelligence as a single, measurable, physical thing in the head, and then rejoiced for psychology because "this Cinderella among the sciences has made a bold bid for the level of triumphant physics itself" (quoted in Gould, 1981, p. 263).

But historical science is not worse, more restricted, or less capable of achieving firm conclusions because experiment, prediction, and subsumption under invariant laws of nature do not represent its usual working methods. The sciences of history use a different mode of explanation, rooted in the comparative and observational richness of our data. We cannot see a past event directly, but science is usually based on inference, not unvarnished observation (you don't see electrons, gravity, or black holes either).

In no other way but this false ordering by status among the sciences can I understand the curious phenomenon that led me to write this book in the first place—namely, that the Burgess revision has been so little noticed by the public in general and also by scientists in other disciplines. Yes, I understand that science writers don't consult the Philosophical Transactions of the Royal Society, London, *and that hundred-page anatomical monographs can seem rather daunting to those unschooled in the jargon. But we cannot charge Whittington and colleagues with hiding the good news. They have also published in the general journals that science writers do read—principally* Science *and* Nature. *They have written half a dozen prominent "review articles" for scientific colleagues. They have also composed a good deal for general audiences, including articles for* Scientific American *and* Natural History, *and a popular guide for Parks Canada. They know the implications of their work, and they have tried to get the message across; others have also aided (I have written four essays on the Burgess Shale for* Natural History*). Why has the story not taken hold, or been regarded as momentous?*

An interesting contrast, hinting at a solution, might be drawn between the Burgess revision and the Alvarez theory linking the Cretaceous extinction to extraterrestrial impact. I regard these two as the most important paleontological discoveries of the past twenty years. I think that they are equal in significance and that they tell the same basic story (as illustrations of the extreme chanciness and contingency of life's history: decimate the Burgess differently and we never evolve; send those comets into harmless orbits and dinosaurs still rule the earth, precluding the rise of large mammals, including humans). I hold that both are now well documented, the Burgess revision probably better than the Alvarez claim. Yet the asymmetry of public attention has been astonishing. Alvarez's impact theory has graced the cover of Time, *been featured in several television documentaries, and been a subject of comment and controversy wherever science achieves serious discussion. Few nonprofessionals have ever heard of the Burgess Shale—making this book necessary.*

I do understand that part of this difference in attention simply reflects our parochial fascination with the big and the fierce. Dinosaurs are destined for more attention than two-inch "worms." But I believe that the major ingredient—particularly in the decision of science writers to avoid the Burgess Shale—lies with the stereotype of the scientific method, and the false ordering of sciences by status. Luis Alvarez, who died as I was writing this book, was a Nobel laureate and one of the most brilliant physicists of our century; he was, in short, a prince of science at the highest conventional grade. The evidence for his theory lies in the usual stuff of the laboratory—precise measurements made with expensive machinery on minute quantities of iridium. The impact theory has everything for public acclaim—white coats, numbers, Nobel renown, and location at the top of the ladder of status. The Burgess redescriptions, on the other hand, struck many observers as one funny thing after another—just descriptions of some previously unappreciated, odd animals from early in life's history.

I loved Luie Alvarez for the excitement that he injected into my field. Our personal relationship was warm, for I was one of the few paleontologists who liked what he had to say from the outset (though not always, in retrospect, for good reasons). Yet, de mortuis nil nisi bonum *notwithstanding, I must report that Luie could also be part of the problem. I do appreciate his frustration with so many paleontologists who, caught by traditions of gradualism and terrestrial causation, never paid proper attention to his evidence. Yet Luie often lashed out at the entire profession, and at historical science in general, claiming, for example, in an already infamous interview with the* New York Times, *"I don't like to say bad things about paleontologists, but they're really not very good scientists. They're more like stamp collectors."*

I give Luie credit for saying out loud what many scientists of the stereotype think but dare not say, in the interests of harmony. The common epithet linking historical explanation with stamp collecting represents the classic arrogance of a field that does not understand the historian's attention to comparison among detailed particulars, all different. This taxonomic activity is not equivalent to licking hinges and placing bits of colored paper in preassigned places in a book. The historical scientist focuses on detailed particulars—one funny thing after another—because their coordination and comparison permits us, by consilience of induction, to explain the past with as much confidence (if the evidence is good) as Luie Alvarez could ever muster for his asteroid by chemical measurement.

We shall never be able to appreciate the full range and meaning of science until we shatter the stereotype of ordering by status and understand the different forms of historical explanation as activities equal in merit to anything done by physics or chemistry. When we achieve this new taxonomic arrangement of plurality among the sciences, then, and only then, will the importance of the Burgess Shale leap out. We shall then finally understand that the answer to such questions as "Why can humans reason?" lies as much (and as deeply) in the quirky pathways of contingent history as in the physiology of neurons.

The firm requirement for all science—whether stereotypical or historical—lies in secure testability, not direct observation. We must be able to determine whether our hypotheses are definitely wrong or probably correct (we leave assertions of certainty to preachers and politicians). History's richness drives us to different methods of testing, but testability is our criterion as well. We work with our strength of rich and diverse data recording the consequences of past events; we do not bewail our inability to see the past directly. We search for repeated pattern, shown by evidence so abundant and so diverse that no other coordinating interpretation could stand, even though any item, taken separately, would not provide conclusive proof.

The great nineteenth-century philosopher of science William Whewell devised the word consilience, meaning "jumping together," to designate the confidence gained when many independent sources "conspire" to indicate a particular historical pattern. He called the strategy of coordinating disparate results from multifarious sources consilience of induction.

I regard Charles Darwin as the greatest of all historical scientists. Not only did he develop convincing evidence for evolution as the coordinating principle of life's history, but he also chose as a conscious and central theme for all his writings—the treatises on worms, coral reefs, and orchids, as well as the great volumes on evolution—the development of a different but equally rigorous methodology for historical science (Gould, 1986). Darwin explored a variety of modes for historical explanation, each appropriate for differing densities of preserved information (Gould, 1986, pp. 60–64), but his central argument rested on Whewell's consilience. We know that evolution must underlie the order of life because no other explanation can coordinate the disparate data of embryology, biogeography, the fossil record, vestigial organs, taxonomic relationships, and so on. Darwin explicitly rejected the naive but widely held notion that a cause must be seen directly in order to qualify as a scientific explanation. He wrote about the proper testing of natural selection, invoking the idea of consilience for historical explanation:

> Now this hypothesis may be tested—and this seems to me the only fair and legitimate manner of considering the whole question—by trying whether it explains several large and independent classes of facts; such as the geological succession of organic beings, their distribution in past and present times, and their mutual affinities and homologies. If the principle of natural selection does explain these and other large bodies of facts, it ought to be received (1868, vol. 1, p. 657).

But historical scientists must then proceed beyond the simple demonstration that their explanations can be tested by equally rigorous procedures different from the stereotype of the "scientific method"; they must also convince other scientists that explanations of this historical type are both interesting and vitally informative. When we have established "just history" as the only complete and acceptable explanation for phenomena that everyone judges important—the evolution of the human intelligence, or of any self-conscious life on earth, for example—then we shall have won.

Historical explanations take the form of narrative: E, the phenomenon to be explained, arose because D came before, preceded by C, B, and A. If any of these earlier stages had not occurred, or had transpired in a different way, then E would not exist (or would be present in a substantially altered form, E′, requiring a different explanation). Thus, E makes sense and can be explained rigorously as the outcome of A through D. But no law of nature enjoined E; any variant E′ arising from an altered set of antecedents, would have been equally explicable, though massively different in form and effect.

I am not speaking of randomness (for E had to arise, as a consequence of A through D), but of the central principle of all history—*contingency*. A historical explanation does not rest on direct deductions from laws of nature, but on an unpredictable sequence of antecedent states, where any major change in any step of the sequence would have altered the final result. This final result is therefore dependent, or contingent, upon everything that came before—the unerasable and determining signature of history.

Many scientists and interested laypeople, caught by the stereotype of the "scientific method," find such contingent explanations less interesting or less "scientific," even when their appropriateness and essential correctness must be acknowledged. The South lost the Civil War with a kind of relentless inevitability once hundreds of particular events happened as they did—Pickett's charge failed, Lincoln won the election of 1864, *etc., etc., etc.* But wind the tape of American history back to the Louisiana Purchase, the Dred Scott decision, or even only to Fort Sumter, let it run again with just a few small and judicious changes (plus their cascade of consequences), and a different outcome, including the opposite resolution, might have occurred with equal relentlessness past a certain point. (I used to believe that Northern superiority in population and industry had virtually guaranteed the result from the start. But I have been persuaded by recent scholarship that wars for recognition rather than conquest can be won by purposeful minorities. The South was not trying to overrun the North, but merely to secure its own declared borders and win acknowledgment as an independent state. Majorities, even in the midst of occupation, can be rendered sufficiently war-weary and prone to withdraw by insurgencies, particularly in guerilla form, that will not relent.)

Suppose, then, that we have a set of historical explanations, as well documented as anything in conventional science. These results do not arise as deducible consequences from any law of nature; they are not even predictable from any general or abstract property of the larger system (as superiority in population or industry). How can we deny such explanations a role every bit as interesting and important as a more conventional scientific conclusion? I hold that we must grant equal status for three basic reasons.

1. *A question of reliability.* The documentation of evidence, and probability of truth by disproof of alternatives, may be every bit as conclusive as for any explanation in traditional science.

2. *A matter of importance.* The equal impact of historically contingent explanations can scarcely be denied. The Civil War is the focus and turning point of American history. Such central matters as race, regionalism, and economic power owe their present shape to this great event that need not have occurred. If the current taxonomic order and relative diversity of life are more a consequence of "just history" than a potential deduction from general principles of evolution, then contingency sets the basic pattern of nature.

3. *A psychological point.* I have been too apologetic so far. I have even slipped into the rhetoric of inferiority—by starting from the premise that historical explanations may be less interesting and then pugnaciously fighting for equality. No such apologies need be made. Historical explanations are endlessly fascinating in themselves, in many ways more intriguing to the human psyche than the inexorable consequences of nature's laws. We are especially moved by events that did not have to be, but that occurred for identifiable reasons subject to endless mulling and stewing. By contrast, both ends of the usual dichotomy—the inevitable and the truly random—usually make less impact on our emotions because they cannot be controlled by history's agents and objects, and are therefore either channeled or buffeted, without much hope for pushing back. But, with contingency, we are drawn in; we become involved; we share the pain of triumph or tragedy. When we realize that the actual outcome did not have to be, that any alteration in any step along the way would have unleashed a cascade down a different channel, we grasp the causal power of individual events. We can argue, lament, or exult over each detail—because each holds the power of transformation. Contingency is the affirmation of control by immediate events over destiny, the kingdom lost for want of a horseshoe nail. The Civil War is an especially poignant tragedy because a replay of the tape might have saved a half million lives for a thousand different reasons—and we would not find a statue of a soldier, with names of the dead engraved on the pedestal below, on every village green and before every county courthouse in old America. Our own evolution is a joy and a wonder because such a curious chain of events would probably never happen again, but having occurred, makes eminent sense. Contingency is a license to participate in history, and our psyche responds.

The theme of contingency, so poorly understood and explored by science, has long been a mainstay of literature. We note here a situation that might help to breach the false boundaries between art and nature, and even allow literature to enlighten science. Contingency is Tolstoy's cardinal theme in all his great novels. Contingency is the source of tension and intrigue in many fine works of suspense, most notably in a recent masterpiece by Ruth Rendell (writing as Barbara Vine), *A Fatal Inversion* (1987)—a chilling book describing a tragedy that engulfs the lives and futures of a small community through an escalating series of tiny events, each peculiar and improbable (but perfectly plausible) in itself, and each entraining a suite of even stranger consequences. *A Fatal Inversion* is so artfully and intricately plotted by this device that I must view Rendell's finest work as a conscious text on the nature of history.

Two popular novels of the past five years have selected Darwinian theory as their major theme. I am especially intrigued and pleased that both accept and explore contingency as the theory's major consequence for our lives. In this correct decision, Stephen King and Kurt Vonnegut surpass many scientists in their understanding of evolution's deeper meanings.

King's *The Tommyknockers* (1987) fractures a tradition in science fiction by treating extraterrestrial "higher intelligences" not as superior in general, wiser, or more powerful, but merely as quirky hangers-on in the great Darwinian game of adaptation by differential reproductive success in certain environments. (King refers to this persistence as "dumb evolution"; I just call it Darwinism.)* Such equivocal success by endless and immediate adjustment breeds contingency, which then becomes the controlling theme of *The Tommyknockers*—as the aliens fail in their plans for earth, thanks largely to evasive action by one usually ineffective, cynical, and dipsomaniacal English professor. King muses on the nature of controlling events in contingent sequences, and on their level of perceived importance at various scales:

*Our agreement on the theme, if not the terminology, provides hope that even the most implacable differences in style and morality may find a common meeting ground on this most important of intellectual turfs—for Steve is the most fanatical Red Sox booster in New England, while my heart remains with the Yankees.

> I would not be the one to tell you there are no planets anywhere in the universe that are not large dead cinders floating in space because a war over who was or was not hogging too many dryers in the local Laundromat escalated into Doomsville. No one ever really knows where things will end—or if they will. . . . Of course we may blow up our world someday with no outside help at all, for reasons which look every bit as trivial from a standpoint of light-years; from where we rotate far out on one spoke of the Milky Way in the Lesser Magellanic Cloud, whether or not the Russians invade the Iranian oilfields or whether NATO decides to install American-made Cruise missiles in West Germany may seem every bit as important as whose turn it is to pick up the tab for five coffees and a like number of Danish.

Kurt Vonnegut's *Galápagos* (1985) is an even more conscious and direct commentary on the meaning of evolution from a writer's standpoint. I feel especially gratified that a cruise to the Galápagos, a major source of Vonnegut's decision to write the book, should have suggested contingency as the cardinal theme taught by Darwin's geographic shrine. In Vonnegut's novel, the pathways of history may be broadly constrained by such general principles as natural selection, but contingency has so much maneuvering room within these boundaries that any particular outcome owes more to a quirky series of antecedent events than to channels set by nature's laws. *Galápagos,* in fact, is a novel about the nature of history in Darwin's world. I would (and do) assign it to students in science courses as a guide to understanding the meaning of contingency.

In *Galápagos,* the holocaust of depopulation arrives by the relatively mild route of a bacterium that destroys human egg cells. This scourge first gains a toehold by striking women at the annual international book fair in Frankfurt, but quickly spreads throughout the world, sterilizing all but an isolated remnant of *Homo sapiens.* Human survival becomes concentrated in a tiny and motley group carried by boat beyond the reach of the bacterium to the isolated Galápagos—the last of the Kanka-bono Indians plus a tourist and adventurer or two. Their survival and curious propagation proceeds through a wacky series of contingencies, yet all future human history now resides with this tiny remnant:

> In a matter of less than a century the blood of every human being on earth would be predominantly Kanka-bono, with a little von Kleist and Hiroguchi thrown in. And this astonishing turn of events would be made to happen, in large part, by one of the only two absolute nobodies on the original passenger list for "the Nature Cruise of the Century." That was Mary Hepburn. The other nobody was her husband, who himself played a crucial role in shaping human destiny by booking, when facing his own extinction, that one cheap little cabin below the waterline.

Contingency has also been an important theme in films, both recent and classic. In *Back to the Future* (1985) Marty McFly (Michael J. Fox), a teen-ager transported back in time to the high school attended by his parents, must struggle to reconstitute the past as it actually happened, after his accidental intrusion threatens to alter the initial run of the tape (when his mother, in an interesting variation on Oedipus, develops a crush on him). The events that McFly must rectify seem to be tiny occurrences of absolutely no moment, but he knows that nothing could be more important, since failure will result in that ultimate of consequences, his own erasure, because his parents will never meet.

The greatest expression of contingency—my nomination as the holotype* of the genre—comes near the end of Frank Capra's masterpiece, *It's a Wonderful Life* (1946). George Bailey (Jimmy Stewart) has led a life of self-abnegation because his basic decency made him defer personal dreams to offer support for family and town. His precarious building and loan association has been driven to bankruptcy and charged with fraud through the scheming of the town skinflint and robber baron, Mr. Potter (Lionel Barrymore). George, in despair, decides to drown himself, but Clarence Odbody, his guardian angel, intervenes by throwing himself into the water first, knowing that George's decency will demand another's rescue in preference to immediate suicide. Clarence then tries to cheer George up by the direct route: "You just don't know all that you've done"; but George replies: "If it hadn't been for me, everybody'd be a lot better off. . . . I suppose it would have been better if I'd never been born at all."

Clarence, in a flash of inspiration, grants George his wish and shows him an alternative version of life in his town of Bedford Falls, replayed in his complete absence. This magnificent ten-minute scene is both a highlight of cinematic history and the finest illustration that I have ever encountered for the basic principle of contingency—a replay of the tape yielding an entirely different but equally sensible outcome; small and apparently insignificant changes, George's absence among others, lead to cascades of accumulating difference.

Everything in the replay without George makes perfect sense in terms of personalities and economic forces, but this alternative world is bleak and cynical, even cruel, while George, by his own apparently insignificant life,

*"Holotype" is taxonomic jargon for the specimen designated to bear the name of a species. Holotypes are chosen because concepts of the species may change later and biologists must have a criterion for assigning the original name. (If, for example, later taxonomists decide that two species were mistakenly mixed together in the first description, the original name will go to the group including the holotype specimen.)

had imbued his surroundings with kindness and attendant success for his beneficiaries. Bedford Falls, his idyllic piece of small-town America, is now filled with bars, pool halls, and gambling joints; it has been renamed Pottersville, because the Bailey Building and Loan failed in George's absence and his unscrupulous rival took over the property and changed the town's name. A graveyard now occupies the community of small homes that George had financed at low interest and with endless forgiveness of debts. George's uncle, in despair at bankruptcy, is in an insane asylum; his mother, hard and cold, runs a poor boarding house; his wife is an aging spinster working in the town library; a hundred men lay dead on a sunken transport, because his brother drowned without George to rescue him, and never grew up to save the ship and win the Medal of Honor.

The wily angel, clinching his case, then pronounces the doctrine of contingency: "Strange, isn't it? Each man's life touches so many other lives, and when he isn't around he leaves an awful hole, doesn't he? . . . You see, George, you really had a wonderful life."

Contingency is both the watchword and lesson of the new interpretation of the Burgess Shale. The fascination and transforming power of the Burgess message—a fantastic explosion of early disparity followed by decimation, perhaps largely by lottery—lies in its affirmation of history as the chief determinant of life's directions.

Walcott's earlier and diametrically opposite view located the pattern of life's history firmly in the other and more conventional style of scientific explanation—direct predictability and subsumption under invariant laws of nature. Moreover, Walcott's view of invariant law would now be dismissed as more an expression of cultural tradition and personal preference than an accurate expression of nature's patterns. For as we have seen, Walcott read life's history as the fulfillment of a divine purpose guaranteed to yield human consciousness after a long history of gradual and stately progress. The Burgess organisms had to be primitive versions of later improvements, and life had to move forward from this restricted and simple beginning.

The new view, on the other hand, is rooted in contingency. With so many Burgess possibilities of apparently equivalent anatomical promise—over twenty arthropod designs later decimated to four survivors, perhaps fifteen or more unique anatomies available for recruitment as major branches, or phyla, of life's tree—our modern pattern of anatomical disparity is thrown into the lap of contingency. The modern order was not guaranteed by basic laws (natural selection, mechanical superiority in anatomical design), or even by lower-level generalities of ecology or evolutionary theory. The modern order is largely a product of contingency. Like Bedford Falls with George Bailey, life had a sensible and resolvable history, generally pleasing to us since we did manage to arise, just a geological minute ago. But, like Pottersville without George Bailey, any replay, altered by an apparently insignificant jot or tittle at the outset, would have yielded an equally sensible and resolvable outcome of entirely different form, but most displeasing to our vanity in the absence of self-conscious life. (Though, needless to say, our nonexistent vanity would scarcely be an issue in any such alternative world.) By providing a maximum set of anatomically proficient possibilities right at the outset, the Burgess Shale becomes our centerpiece for the controlling power of contingency in setting the pattern of life's history and current composition.

Finally, if you will accept my argument that contingency is not only resolvable and important, but also fascinating in a special sort of way, then the Burgess not only reverses our general ideas about the source of pattern—it also fills us with a new kind of amazement (also a *frisson* for the improbability of the event) at the fact that humans ever evolved at all. We came *this close* (put your thumb about a millimeter away from your index finger), thousands and thousands of times, to erasure by the veering of history down another sensible channel. Replay the tape a million times from a Burgess beginning, and I doubt that anything like *Homo sapiens* would ever evolve again. It is, indeed, a wonderful life.

A final point about predictability versus contingency: Am I really arguing that nothing about life's history could be predicted, or might follow directly from general laws of nature? Of course not; the question that we face is one of scale, or level of focus. Life exhibits a structure obedient to physical principles. We do not live amidst a chaos of historical circumstance unaffected by anything accessible to the "scientific method" as traditionally conceived. I suspect that the origin of life on earth was virtually inevitable, given the chemical composition of early oceans and atmospheres, and the physical principles of self-organizing systems. Much about the basic form of multicellular organisms must be constrained by rules of construction and good design. The laws of surfaces and volumes, first recognized by Galileo, require that large organisms evolve different shapes from smaller relatives in order to maintain the same relative surface area. Similarly, bilateral symmetry can be expected in mobile organisms built by cellular division. (The Burgess weird wonders are bilaterally symmetrical.)

But these phenomena, rich and extensive though they are, lie too far from the details that interest us about life's history. Invariant laws of nature impact the general forms and functions of organisms; they set the channels in which organic design must evolve. But the channels are so broad relative to the details that fascinate us! The physical channels do not specify arthropods, annelids, mollusks, and vertebrates, but, at most, bilaterally symmetrical organisms based on repeated parts. The boundaries of the channels retreat even further into the distance when we ask the essential questions about our own origin: Why did mammals evolve among vertebrates? Why did primates take to the trees? Why did the tiny twig that produced *Homo sapiens* arise and survive in Africa? When we set our focus upon the level of detail that regulates most common questions about the history of life, contingency dominates and the predictability of general form recedes to an irrelevant background.

Charles Darwin recognized this central distinction between *laws in the background* and *contingency in the details* in a celebrated exchange of letters with the devout Christian evolutionist Asa Gray. Gray, the Harvard botanist, was inclined to support not only Darwin's demonstration of evolution but also his principle of natural selection as its mechanism. But Gray was worried about the implications for Christian faith and the meaning of life. He particularly fretted that Darwin's view left no room for rule by law, and portrayed nature as shaped entirely by blind chance.

Darwin, in his profound reply, acknowledged the existence of general laws that regulate life in a broad sense. These laws, he argued, addressing Gray's chief concern, might even (for all we know) reflect some higher purpose in the universe. But the natural world is full of details, and these form the primary subject matter of biology. Many of these details are "cruel" when measured, inappropriately, by human moral standards. He wrote to Gray: "I cannot persuade myself that a beneficent and omnipotent God would have designedly created the Ichneumonidae with the express intention of their feeding within the living bodies of Caterpillars, or that a cat should play with mice." How, then, could the nonmorality of details be reconciled with a universe whose general laws might reflect some higher purpose? Darwin replied that the details lay in a realm of contingency undirected by laws that set the channels. The universe, Darwin replied to Gray, runs by law, "with the details, whether good or bad, left to the working out of what we may call chance."

And so, ultimately, the question of questions boils down to the placement of the boundary between predictability under invariant law and the multifarious possibilities of historical contingency. Traditionalists like Walcott would place the boundary so low that all major patterns of life's history fall above the line into the realm of predictability (and, for him, direct manifestation of divine intentions). But I envision a boundary sitting so high that almost every interesting event of life's history falls into the realm of contingency. I regard the new interpretation of the Burgess Shale as nature's finest argument for placing the boundary this high.

This means—and we must face the implication squarely—that the origin of *Homo sapiens,* as a tiny twig on an improbable branch of a contingent limb on a fortunate tree, lies well below the boundary. In Darwin's scheme, we are a detail, not a purpose or embodiment of the whole—"with the details, whether good or bad, left to the working out of what we may call chance." Whether the evolutionary origin of self-conscious intelligence in any form lies above or below the boundary, I simply do not know. All we can say is that our planet has never come close a second time.

For anyone who feels cosmically discouraged at the prospect of being a detail in the realm of contingency, I cite for solace a wonderful poem by Robert Frost, dedicated explicitly to this concern: *Design.* Frost, on a morning walk, finds an odd conjunction of three white objects with different geometries. This peculiar but fitting combination, he argues, must record some form of intent; it cannot be accidental. But if intent be truly manifest, then what can we make of our universe—for the scene is evil by any standard of human morality. We must take heart in Darwin's proper solution. We are observing a contingent detail, and may yet hope for purpose, or at least neutrality, from the universe in general.

I found a dimpled spider, fat and white,
On a white heal-all, holding up a moth
Like a white piece of rigid satin cloth—
Assorted characters of death and blight
Mixed ready to begin the morning right,
Like the ingredients of a witches' broth—
A snow-drop spider, a flower like a froth,
And dead wings carried like a paper kite.

What had that flower to do with being white,
The wayside blue and innocent heal-all?
What brought the kindred spider to that height,
Then steered the white moth thither in the night?
What but design of darkness to appall?—
If design govern in a thing so small.

Homo sapiens, I fear, is a "thing so small" in a vast universe, a wildly improbable evolutionary event well within the realm of contingency. Make of such a conclusion what you will. Some find the prospect depressing; I have always regarded it as exhilarating, and a source of both freedom and consequent moral responsibility.