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'What is life?' as a problem in history

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WHAT IS LIFE? AS A MODERNIST MANIFESTO

The obviously true may be devilishly difficult to define – as best exemplified by Louis Armstrong's famous retort to a naively passionate fan's request for a definition of jazz: 'Man, if you gotta ask you'll never know.' It is similarly undeniable that Erwin Schrödinger's *What is Life?* ranks among the most important books in 20th century biology, but the reasons for its great influence seem oddly elusive. Brevity may be the soul of wit (as garrulous old Polonius told us), and short works are rare blessings in a profession that too often judges worth by literal ponderousness. But *What is Life?*, in its ninety pages, seems a bit too spare and too elliptical to carry such intellectual weight (though, in a ruthlessly practical sense, such brevity may define the essential differences between attention and oblivion in a profession dominated by doers rather than readers). For example, I think we may be confident of the correct, if necessarily conjectural answer to an old puzzle in 'iffy' history: how would the history of science have differed if Wallace had never lived and Darwin had thereby acquired the leisure to write the many-volumed work he intended, rather than the hurried 'abstract' known as the *Origin of Species?* The answer – since the intellectual world was clearly poised to accept evolution – must be: none whatsoever, except that Darwin would have had the same impact with many, many fewer people having read the book. Moreover, much of *What is Life?*'s intellectual foundation – Delbrück's early ideas on reasons for the gene's stability – turn out to be quite wrong (see Crow, 1992, p. 238). Why, then, are we so rightly celebrating this semicentenary?

First of all, the testimony of seminal importance by so many of the founders of modern molecular biology cannot be gainsaid. Jim Watson credits

Schrödinger's book as the decisive influence in persuading him to study the structure of the gene (see Judson, 1979). Francis Crick acknowledges a similar influence, but with the same puzzlement that so many others express: 'It's a book written by a physicist who doesn't know any chemistry. But . . . it suggested that biological problems could be thought about, in physical terms – and thus it gave the impression that exciting things in this field were not far off' (quoted in Judson, 1979, p. 109). (On the subject of puzzlement, consider Jim Crow's recent comment (1992, p. 238): 'Along with Gunther Stent, I don't know why the book had such an impact, but I do know what most impressed me at the time.')

Crow then provides an excellent epitome of the book's chief claims and insights – the second reason for its influence:

> Perhaps it was Schrödinger's characterization of the gene as an 'aperiodic crystal'. Perhaps it was his view of the chromosome as a message written in code. Perhaps it was his statement of life 'feeds on negative entropy'. Perhaps it was his notion that quantum indeterminacy at the gene level is converted by cell multiplication into molar determinacy. Perhaps it was his emphasis on the stability of the gene and its ability to perpetuate order. Perhaps it was his faith that the all too obvious difficulties of interpreting life by physical principles need not imply that some super-physical law is required, although some new physical laws might be.

I do not desire to denigrate this timely celebration by denying in any way the importance of *What is Life?*, but I do wish to suggest that Schrödinger's key claim for an almost self-evident universality in his approach to biology is both logically overextended, and socially conditioned as a product of his age. Furthermore, these features of limitation may help us to understand why a large subcommunity of biologists, including my own *confrères* in palaeontology and evolutionary studies, have been less influenced and impressed by Schrödinger's arguments, and remain persuaded that the answer to 'what is life?' requires attention to more things on earth than are dreamed of in Schrödinger's philosophy.

Schrödinger (1944, p. vii) begins his preface by identifying unification as the unquestioned dream and goal of science:

> We have inherited from our forefathers the keen longing for unified, all-embracing knowledge. The very name given to the highest institutions of learning reminds us, that from antiquity and throughout many centuries, the universal aspect has been the only one to be given full credit . . . We feel clearly that we are only now beginning to acquire reliable material for welding together the sum-total of all that is known into a whole.

Schrödinger presents this goal of unification as the unquestioned, almost logically necessary, yearning of all scientists in all ages. Quite the opposite is true. Unification was a definite aim of an explicit movement, embedded in particular social circumstances of Schrödinger's young adulthood; hopes for rational universality following the nationalistic carnage of the First World War. When we grasp the socially contingent character of this cardinal belief in unification, we can understand why Schrödinger's answer to 'what is life?' does not have general status, but must be seen as a transient product of one phase in 20th century history.

The self-styled 'unity of science movement' arose as a major aspect of logical positivism, developed by the Vienna School of philosophers during the 1920s. Associated primarily with Rudolf Carnap and Otto Neurath, both leading members of the *Wiener Kreis*, the unity of science movement held that all sciences share the same language, laws and methods, and that no fundamental differences exist between the physical and biological sciences, or (for that matter) between the natural and social sciences properly constituted.

The unity of science movement had great influence in biology, a field previously viewed by many as too idiosyncratic or descriptive to fall under the umbrella of generalized scientific theory (see Smocovitis, 1992, on the role of this doctrine in the evolutionary synthesis of the 1930s and 1940s). Schrödinger occupied an ideal position for translating the goals of this movement into biology. He was born and raised in Vienna and matriculated at the University of Vienna. He won a Nobel prize in physics – the 'focal' or 'highest level' science, towards which all others would be gathered in the fundamentally reductionist view of the unity of science movement, and of logical positivism in general. How could Schrödinger not anchor his book in a search for unification based upon physical laws?

If Schrödinger's belief in reductive unification flowed from the unity of science movement, then this movement, and its philosophical basis, also lay embedded within the even larger cultural force later known as 'modernism', with its profound influence upon such fields as art, literature, and architecture. Modernism, above all, sought reduction, simplification, abstraction, and universalism. In the hands of a master, like the architect Mies van der Rohe, modernist buildings (of the 'international style', named for the goal of universalism) may be elegant and powerful; but the thousands of derivative, substandard knock-offs, now cracking and deteriorating all over our planet, are the blight of Third World cities and the antitheses of legitimate regionalism and local pride.

What is Life? has usually been viewed as a timeless statement about the unchanging logic of science; I suggest an opposite reading as a social document representing the aims of the 'unity of science movement', as an expression of the larger worldview known as modernism. As such, the faults and strengths of Schrödinger's book are tied to the failures and successes of modernism in general. I can applaud much of modernism's spirit, particularly its optimism and its commitment to mutual intelligibility based on unity of principles. But I also deplore its emphasis upon standardization in a world of such beautiful diversity; and I reject the reductionism that underlies its search for general laws of highest abstraction.

In our generation, these widely recognized social faults of modernism (particularly its tendency to award hegemony to one fashion over other legitimate contenders) has spawned a countermovement known (with no great imagination) as 'postmodernism'. And whereas I regard much about postmodernism as rueful (from silliness in architecture to opacity in literature); and while postmodern 'improvements' must be viewed not as higher truths but as social signs of our own times (just as modernism reflected earlier decades), I nonetheless find much of enormous value in the general postmodernist rejection of modernism's search for single, abstract solutions. I particularly applaud postmodernism's emphasis on playfulness and pluralism, its approbation for the irreducible importance of local detail, and its conviction that, although truth itself may be unitary (many postmodernists would deny this claim as well, but here I part company from such tendencies to nihilism), our perspectives upon truth may be as multiply valid as our socially embedded modes of seeing. A postmodernist could scarcely credit any unitary answer to such a question as 'what is life?' – particularly an answer, like Schrödinger's, rooted in the modernist heartland of reduction to constituent basic particles.

In short, I love much of Schrödinger's book, while I regard its faults as expressions of general problems with the philosophy of modernism that permeates the work. As an evolutionary biologist committed to the study of whole organisms and their histories, I do not regard Schrödinger's answer as wrong, but only woefully partial, and scarcely touching some of the deepest issues in my field.

One could hardly propose a more congenial or more conciliatory form of reductionism than the argument advanced by Schrödinger as the centre-

piece of *What is Life?* – for he does not advance the haughty old Newtonian claim that biological beings are 'nothing but' physical objects of high complexity, and therefore ultimately reducible to conventional concepts developed by the queen of sciences. Schrödinger admits that biological objects are different and unique. They must ultimately be explainable by physical principles, but not necessarily the ones we know already. Therefore, biology will be as much help to physics (in providing material that will lead to discovery of these unknown laws), as physics can be to biology in finally supplying a unified explanation for all matters:

> From Delbrück's general picture of the hereditary substance it emerges that living matter, while not eluding the 'laws of physics' as established up to date, is likely to involve 'other laws of physics' hitherto unknown, which, however, once they have been revealed, will form just as integral a part of this science as the former. (Schrödinger, 1944, p. 69.)

Schrödinger then tries to deduce the nature of hereditary material from its failure to operate by physical laws known to apply to the smallest particles of nonliving matter:

> From all we have learnt about the structure of living matter, we must be prepared to find it working in a manner that cannot be reduced to the ordinary laws of physics. And that not on the ground that there is any 'new force' or what not, directing the behaviour of single atoms within a living organism, but because the construction is different from anything we have yet tested in the physical laboratory. (Schrödinger, 1944, p. 76.)

In his new quantum world, the 'probability mechanism of physics' (Schrödinger, 1944, p. 79) builds macroscopic order from molecular disorder – 'our beautiful statistical theory of which we were so justly proud because it allowed us to look behind the curtain, to watch the magnificent order or exact physical law coming forth from atomic and molecular disorder' (Schrödinger, 1944, p. 80). The complexity of hereditary material will require a new principle of order from order:

> The orderliness encountered in the unfolding of life springs from a different source. It appears that there are two different 'mechanisms' by which orderly events can be produced: the 'statistical mechanism' which produces 'order from disorder' and the new one, producing 'order from order' . . . Physicists were so proud to have fallen in with . . . the 'order-from-disorder' principle, which is actually followed in Nature . . . But we cannot expect that the 'laws of physics' derived from it suffice straightaway to explain the behaviour of living matter, whose most striking features are visibly based to a large extent on the 'order-from-order' principle. You would not expect two entirely

different mechanisms to bring about the same type of law – you would not expect your latch-key to open your neighbour's door as well. (Schrödinger, 1944, p. 80.)

These arguments led Schrödinger to his most famous inference, the one that secured such historical influence for his small book – the concept of the gene as an 'aperiodic crystal'.

'WHAT IS LIFE?' A QUESTION FOR PLURALISM

A titular problem

Given the context presented above, I trust that I shall not be deemed either too carping or too trivial if I state that my major problem with *What is Life?* resides in the implied claim of its title. Right on page one, Schrödinger states the question that his book will try to answer:

The large and important and very much discussed question is: How can the events in space and time which take place within the spatial boundary of a living organism be accounted for by physics and chemistry? (Schrödinger, 1944, p. 1).

(This formulation at least provides a stage as broad as an entire living creature, although *What is Life?* then goes on to discuss, almost exclusively, the physical nature of the hereditary material.)

In short, and in the spirit of reductive modernism, Schrödinger argues that we shall have our answer to 'what is life?' when we know what the smallest pieces of heredity are made of, and how they work in a universal mode. I do not deny the inestimable value of learning the nature and construction of genetic material. But does this knowledge give us an adequate answer to 'what is life?' Is there not more, very much more, that any sensible vernacular concept of such a question must include? From a purely parochial standpoint as a palaeontologist, I must reject Schrödinger's narrow formulation, for its acceptance makes my field irrelevant or, at best, entirely subsidiary. If knowing the physical nature of hereditary material answers 'what is life?' then why is my profession trying so hard to trace phyletic history on the grand scale of billions of years? At best, the earth could only be a stage for documenting details of a history specified by a theory developed entirely from understanding the nature of constituent matter in its smallest pieces. In this view, palaeontologists have no theory to develop from their macroworld, no constituent to supply towards a full answer of 'what is life?' We

can only document an actual, realized history, and such an activity becomes trivial if no theoretical insight can arise thereby.

Indigenous sources of reduction

What is life, then, beyond the working of its littlest pieces? Why did we ever think that we could adequately answer such a far-reaching question within such a restricted domain? – and why were so many of us fully satisfied with partial answers like Schrödinger's? In part, the blame lies in a series of traditions and social factors external to palaeontology and other subdisciplines of 'whole-organism' biology. Physics envy made the proclamations of great scientists in this field, particularly by Nobel laureates (for our disciplines are not honoured at all by such prizes), worthy of special respect (and, to a large extent, immune from searching criticism). The popularity of modernism gave undue clout to old reductionist foibles. Lack of sufficient pride in our own material (another consequence of reductionism and physics envy) made us more receptive to gurus from elsewhere.

But another set of factors arises from our own traditions and conventional forms of explanation – and we therefore have only ourselves to blame for too ready an acceptance of reductionism, and too willing an abandonment of our own phenomena as a rich source of theory for large parts of a full answer to 'what is life?' Classical Darwinism itself not only accepts but actively promulgates a style of reductionistic thinking that had rendered the geological stage theoretically irrelevant even before molecular genetics supplied an even harder version.

Two features of the strict Darwinian worldview encourage reduction of the geological pageant of life's history at least to the momentary machinations of organisms, if not right down to the physicochemical nature of genetic material. First, the theory of natural selection identifies a unitary locus of causal change as the organism struggling for reproductive success – and explicitly denies active causal status to any 'higher' biological unit like species or ecosystems. The beauty and radicalism of Darwin's system lies largely in its denial of overarching ordering principles (like God's action in older theories), and its attribution of higher-order phenomenology (like the harmony of ecosystems or the good design of organic architecture), to consequences or spin-offs of lower-level causality.

Second, under the grand vision of uniformity, as preached so effectively by Darwin's guru Charles Lyell, all scales of time, and all magnitudes of events, flow smoothly upward as summations and extrapolations from observable causal happenings of minimal effect occurring in moments – the Grand Canyon as accumulated erosion, grain by grain, over millions of years; evolutionary trends as gradualistic accretions of minimal changes, generation after countless generation.

We note this causal smoothness from the smallest scales in Darwin's own construction of natural selection as an analogue to the observable, even smaller-scale processes of artificial selection in domestication and agriculture. If humans, with such imperfect knowledge, have wrought changes over centuries, think what a ruthlessly efficient nature can do in extrapolated vastness:

> As man can produce and certainly has produced a great result by his methodical and unconscious means of selection, what may not nature effect? Man can act only on external and visible characters: nature cares nothing for appearances . . . She can act on every internal organ, on every shade of constitutional difference, on the whole machinery of life . . . How fleeting are the wishes and efforts of man! How short his time! and consequently how poor will his products be compared with those accumulated by nature during whole geological periods. (Darwin, 1859, p. 84.)

Moreoever, nature's stage plays out little daily events into any needed magnitude through the simple agency of sufficient time. We need no new forces for larger scales, no catastrophes of global proportions. Reductionism works because the entire causal structure for the history of both earth and life lies fully exposed in minimal events of observable moments.

This belief in causal uniformity established a gradualistic credo responsible for a range of fallacies in our understanding of natural history – from comforting iconographies (see Gould, 1989) of life's history as a ladder of progress (for morphology) or a cone of increasing breadth (for diversity), to dogmas about the steady course of geological change, as well captured in the opening of Davies's recent review of Derek Ager's posthumous book on neocatastrophism:

> 'Fascist!' Among street politicians that is the ultimate abuse shouted as a prelude to yet more violent leftist action. 'Catastrophist!' In my early days that was the ultimate insult to be hurled at an Earth scientist who seemed to be straying outside the prevailing dogma of uniformitarianism . . . We preferred to believe that what was important in geohistory was nature's long-term gradualistic processes . . . Sedimentary strata formed in a marine environment were interpreted as the little-by-little accumulation of particles raining down on the sea bed over aeons of time. (Davies, 1993, p. 115.)

'WHAT IS LIFE?' AS A PROBLEM IN HIERARCHY AND HISTORY

In the pluralistic spirit of postmodernism, contemporary evolutionary theory is now moving away from the restrictive reductionism both of Schrödinger's sort (that 'what is life?' may be answered by knowing the physical nature of the smallest constituent parts) and of Darwin's (that higher-level processes and time scales can be explained as causal extrapolations from processes operating on individual organisms in the observable present). Two themes, hierarchy and the contingency of history, help us to realize that resolution at Schrödinger's or Darwin's level provides only partial answers to 'what is life?', and that many vital and legitimate questions contained in this conundrum of the ages require a body of theory – not just a phenomenology – operating at, and only extractable from, processes of time's macroscale and evolution's major transformations.

Hierarchy

Two separate themes, based on the general concept of levels of organization in times and magnitudes, preclude an adequate resolution of 'what is life?' at the scale of genes and their construction.

Hierarchy in the formulation of an evolutionary theory of selection. A kind of descriptive hierarchy was always acknowledged by the founders of modern evolutionary theory (see Dobzhansky, 1937 and the commentary in Gould, 1982), but these scientists generally accepted a causal reduction to changing gene frequencies within populations. Proposals for an explicit causal hierarchy within selection theory have inspired a major debate since the early 1970s. The mildest form of hierarchy holds that events of macroevolution, though fully consistent with microevolutionary theory, could not be predicted from tenets of the microworld and therefore demand direct attention to the phenomena of larger scale (Stebbins & Ayala, 1981).

The stronger form departs from Darwin's key claim that organisms are the exclusive locus of natural selection (or from the even more reductionist argument of Dawkins (1976) and others that genes may serve as such ultimate 'persons'). The hierarchical theory of natural selection holds that biological objects at several ascending levels in a structural hierarchy of inclusion – genes, organisms, and species prominently among them – may all act (simultaneously) as legitimate foci of natural selection. (Species are natural objects, not abstractions, and they maintain all the key properties – individuality, reproduction, and heredity – that permit a biological entity to act as a unit of selection.) If species are important units of selection in their own right, and if much of evolution must be understood as differential selective success of species rather than extrapolated predominance of favoured genes in populations, then evolutionary pattern – an important component of 'what is life?' – must be studied in the fullness of species durations, that is, directly in geological time (see Stanley, 1975; Vrba & Gould, 1986; Lloyd & Gould, 1993; Williams, 1992).

The earth's behaviour. Even if natural selection could, in principle, build evolution at all scales by simple cumulation, the earth must behave in a congenial manner to permit the gradualist throughput. If the earth be so unruly that slowly accumulating sequences are derailed or reset by occasional catastrophes of major import, then the causes of overall evolutionary pattern are complex – and the component attributable to rare occurrences of great moment cannot be grasped by traditional uniformitarian study of ordinary current events.

The virtual proof (Krogh *et al.*, 1993) of the Alvarez hypotheses of mass extinction by meteoritic impact at the close of the Cretaceous period (Alvarez *et al.*, 1980) has fuelled a general reexamination and willingness to admit an important role for such events and processes at higher levels in hierarchies of times and magnitudes. Davies (1993, p. 115) continues his critique of classical uniformitarianism:

> Now all is changed. We are rewriting geohistory. Where once we saw a smooth conveyor belt, we now see a stepped escalator. Upon that escalator the treads are long periods of relative quiescence when little happens. The risers are episodes of relatively sudden change when the landscape and its inhabitants are translated into some fresh state. Even the most staid of modern geologists are invoking sedimentary surges, explosive phases of organic evolution, volcanic blackouts, continental collisions, and terrifying meteoroid impacts. We live in an age of neocatastrophism.

Consider just three examples of macroevolutionary phenomena, all much discussed during the past twenty years, that must constitute a major part of any satisfying answer to 'what is life?' yet cannot be adequately resolved by understanding the construction of genetic material, or by any sensible extrapolation from this microlevel alone. (1) Evolutionary trends in a world of punctuated equilibrium (Eldredge & Gould, 1972; Gould & Eldredge, 1993), where directionality results from differential success of biased subsets of stable species within clades, and not from anagenetic transformation within lineages, and where a substantial component of differential species success occurs by irreducible selection at the species level itself. (2) Mass extinctions that are more rapid (some triggered by true catastrophes on scales of moments to days with main killing effects perhaps spreading only to centuries or millennia), more profound in effect, more frequent in occurrence, and more different in causality than we had ever imagined in our previously favoured Lyellian mode. (3) The restriction in time and magnification in effect for episodes of origin in life's history, particularly for the 'Cambrian explosion' that initiated virtually all the major designs of multicellular life. The Cambrian explosion has now been restricted by new and rigorous radiogenic age dates to a period of only 5 million years or so (Bowring *et al.*, 1993). Contrary to previous, conventionally progressivist, views that only the precursors of modern forms arose in this event, a thirty year restudy of the Burgess Shale (the spectacular, soft-bodied fauna from the Middle Cambrian period, just following the explosion) suggests that the range of these initial anatomical designs exceeded modern boundaries (despite more than 500 million years of subsequent time to generate new anatomies), and that the history of life since the Cambrian explosion has been largely a story of reduction in initial possibilities. With one exception (Bryozoa at the beginning of the subsequent Ordovician period), no new phylum has arisen in the fossil record since the Cambrian explosion. Whatever genetic and developmental setting permitted this cardinal event, it was not business as usual, to be simply extrapolated from Darwinian changes in modern populations (see Whittington, 1985; Gould, 1989). We cannot begin to answer 'what is (multicellular) life?' without understanding such events.

History's contingency

Apply all the conventional 'laws of nature' type explanations you wish; add to this panoply all that we will learn when we grasp the laws and principles of higher levels, greater magnitudes and longer times – and we will still be missing a fundamental piece of 'what is life?' The events of our complex natural world may be divided into two broad realms – repeatable and predictable incidents of sufficient generality to be explained as consequences of natural law, and uniquely contingent events that occur, in a world full of both chaos and genuine ontological randomness as well, because complex historical narratives happened to unfurl along the pathway actually followed, rather than along any of the myriad equally plausible alternatives.

These contingent events, although mistrusted and downgraded by traditional science, should be embraced as equally meaningful, equally portentous, equally interesting, and even equally resolvable as the more conventional predictabilities. Contingent events are indeed unpredictable, but this property flows from the character of the world – and becomes thereby as immediately meaningful as anything else presented by nature – and not from limitations of our methodologies. Contingent events, though unpredictable at the onset of a sequence, are as explainable as any other phenomenon after they occur. The explanations, as contingent rather than law-based, do require a knowledge of the particular historical sequence that generated the result, for such resolutions must be in the narrative rather than deductive mode. But many natural sciences, including my own of palaeontology, are historical in this sense, and can provide such information if the preserved archive be sufficiently rich.

A downgrader of contingency might admit all the foregoing claims, and still respond: yes, I grant your two realms, but science is only about the 'upper' domain of generality. The 'lower' region of contingency is small and flat, weighted down by the grandness above, and only the space of funny little details that have no importance in nature's basic working. The key to my argument lies in the denial of this common conceptualization, and in the restructuring of contingency's domain as equally broad and important as anything deducible from natural law – for contingency's domain embraces questions of the common form: 'why this, and not any one of a thousand something elses?'

The major argument may best be put as a historical or psychological observation. In our arrogance, but also in our appropriate awe, we tend to

pose our deepest biological questions as generalities to be resolved by natural law: why must life run by natural selection on substrates built from nucleic acid codes? What in ecological theory will tell us why the earth houses so many insects and so few pogonophorans? What, after all, is life? (as a predictable phenomenon that would evolve again in the same manner and cannot be much other than it is). Yet most of these questions arise because we want so desperately to understand something just as puzzling, and much more particular: who are we as human beings, and why are we here? Protagoras was right in his famous aphorism that 'man is the measure of all things' (to be read either as a statement of ultimate humanism or as a narrow parochial claim). Now we, as a single species, the end product of a contingent sequence that could never have led to anything like us if any among thousands of preceding steps had unfolded even slightly differently (as each plausibly might have done) – we who are contingent entities, not predictable inevitabilities – lie firmly within the domain of contingency. And questions that are truly and deeply about us in particular, even if conventionally framed as inquiries about timeless essentials, are inquiries to be answered in terms of contingency.

Tiny differences in the realm of contingent history, seemingly inconsequential to any observer at the time, cascade to utterly disparate outcomes that fundamentally alter 'what is life?' Contingency is not the domain of trivial things alone. Contingency's theme, moreover, is fractal, and pervades all scales of life's history from biospheric cataclysms to particularities of single lineages. Why is *Homo sapiens* here? – the question that truly prompts our inquiry into 'what is life?' (as we will admit in honest moments). Go down the fractal scales and find contingency throughout. We are here because the death roster of anatomical products of the Cambrian explosion did not include a small and 'unpromising' chordate group represented in the Burgess Shale by the genus *Pikaia*. (Any replay of life's tape through the Burgess lottery would have yielded an entirely different cast of surviving lineages; in this sense, any group alive today owes its existence to contingent fortune.) Step down to the survival of mammals. No late-Cretaceous bolide (the ultimate random bolt from the blue), and dinosaurs would still be dominating the world of terrestrial vertebrates, with mammals probably still restricted to rat-sized creatures in the interstices of their world (dinosaurs had so dominated mammals for more than 100 million preceding years so why not for an additional 65 million?). Step down to a lineage of apes 10 million years ago in African forests. On this replay, climatic drying does not occur, forests do not convert to savannas and grasslands. The lineage stays in the persistent forest as apes – doing quite well in an alternate today, thank you.

Schrödinger wrote of his formative likes and dislikes: 'I was a good student, regardless of the subject. I liked mathematics and physics, but also the rigorous logic of the ancient grammars. I hated only memorizing 'chance' historical and biogeographical dates and facts.' How ironic that a great pioneer in a scientific revolution that placed quantum randomness into a new framework for nature's laws should have so dismissed the contingent form of event-chanciness in the macroworld as beyond the pale of scientific interest for being merely historical. 'What is life?' is surely, as Schrödinger held, a question to be answered in the domain of nature's laws. But 'what is life?' is every bit as much a problem in history.

Buckminster Fuller, a modern prophet, often said that 'unity is plural and, at minimum, is two'. Nature's laws and history's contingency must work as equal partners in our quest to answer 'what is life?' For an ancient prophet once stated (Amos 3:3): 'Can two walk together, except they be agreed.'

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