IV. THE DRIVING FORCES AND PATTERNS OF EVOLUTION

11
10^{500}. The Darwinian Algorithm and a Possible Candidate for a 'Unifying Theme' of Big History

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Abstract

This article postulates another aspect of the long sought-after 'unifying theme' of Big History, in addition to the rise of complexity and energy flows. It looks briefly at the manifestation of the 'Darwinian algorithm', that is to say an algorithm of random variation and non-random selection, in many physical processes in the Universe: cosmology, geology, biology, culture, and even the occurrence of universes themselves. This algorithm also seems to gradually open more forms of variation and more selection paths over time, leading to a higher level of free energy rate density, or what we know as 'complexity'. In fact the complexity of the object under discussion seems to correspond to the available number of selection paths. The article closes with a bit of philosophical reflection on what the Darwinian algorithm and the rise of complexity could possibly mean for humanity and the future of the cosmos.

Keywords: *Universal Darwinism, random variation, non-random selection, complexity.*

One thing that the inaugural International Big History Conference in August 2012 made clear was that one of the major tasks of Big History in the coming years is to prove it can sustain research projects, just like any other genre of historical scholarship. As someone who entered the field to do precisely that, I know that such research is not only possible, it is essential – both to bridging the gap between the sciences and humanities and to our understanding of the history of life and the cosmos. The unique approach of Big History has suddenly opened up a vast horizon of research agendas, or, to put it another way, triggered a speciation event where hundreds of new niches have opened up, waiting to be filled. The ecological terrain is vast and the numbers that currently populate it are few. I urge anyone interested in researching in Big History to do so. The research comes in a variety of forms. There are, of course, Esther Quaedackers's Little Big Histories that cover the full 13.8 billion years of any subject – extending the Big History perspective to any line of inquiry. There are also research agendas that pursue debates and questions about a certain chunk of the grand narrative, but nevertheless hearken back to broad trends. Many of these are highlighted in the course we teach in Sydney, and many of these would make excellent fodder for graduate research projects that can be realistically achieved within a set timeframe. There are also more ambitious ideas that deal with the unifying themes of Big History, themes which encompass the full trajectory of the universe and underscore the full chronology of 13.8 billion years. In this short article, I have no intention of asserting that this is true, but I do wish to illuminate a research agenda to figure out if it is.

To explain what we are dealing with, let us go back. Our story begins with a bang. And there is no point asking what happened 'before' the Big Bang. That is the wrong sort of question. Thanks to space-time relativity, there was no 'before' the Big Bang. Time as we know did not exist before the universe did. What is more, at the moment of the Big Bang, we are talking about a singularity of such intense heat and such intense pressure that the laws of physics would have broken down. Trying to describe what happened 'before' the Big Bang using the rules with which humans are familiar is rather like trying to describe colour to a dog.[1] Accordingly, the Big Bang is the earliest start date on any historical timeline a human being may care to construct. A tiny fragment of a second later, or 0.0000000000000000000000000000000000000000001 seconds to be more precise, we already have the first major tick on our timeline. I insert the decimal to give the reader a full idea of the infinitesimal scale, something that the exponent leaves somewhat understated, but this is Planck time (10^{-43}) the smallest length of time that has any physical meaning. Gravity had come into being. Then we have the next major event on our timeline between 0.000000000000000000000000000000000001 seconds (10^{-36}) (and 0.00000000000000000000000000000001 seconds (10^{-32}) after the Big Bang. The universe cooled ever so slightly from Absolute Hot by a few degrees Kelvin, allowing strong nuclear and electroweak forces to become more distinct, completing the collection of fundamental forces that control the physical processes of our universe. Around the same time the universe inflated due to the creation of a false vacuum and the gravitational repulsion and negative pressure of scalar fields, and grew faster than the speed of light (which is around 300,000 km per second) to an enormous size while continuing to cool, and then

[1] And this absence of a conventional line of causality is what makes a twentieth century pseudo-scientific rehash of a medieval argument involving a supernatural First Cause so absurd (Craig 1979).

the scalar fields decayed into energy reheating the universe to its ultra-hot state. During the period of inflation, quantum fluctuations shaped the future growth of our universe, by creating minute variations in density, which were then inflated to such a large scale that they created the clumps of hydrogen and helium which in turn created our galaxies. These slight variations are mirrored in the temperature of Cosmic Background Radiation (CBR).[2] During the period of 10^{-36} and 10^{-32} seconds, most of the heavy lifting that set the physical processes of the universe in motion was accomplished. The clock was wound, the rules of the game were set, and the rest of the tale can be told with staggering accuracy using the familiar laws of physics.

What of other regions beyond the cosmic horizon of the visible universe? Our region endured a brief surge of inflation that explains small irregularities, the expansion rate, and the nature of further development. It would appear that there are other regions, each undergoing a different amount of inflation and developing physical properties vastly different to our own. Inflationary cosmology predicts that once inflation takes hold in one region, it causes accelerated expansion and inflation in other regions, producing a ripple effect (Guth 2007). Inflation is still underway in regions beyond our cosmic horizon. We are just one bubble where inflation has slowed down, like a hole in a block of Swiss cheese. Other regions in the 'multiverse', totally inaccessible to us, will also slow down in a runaway reproduction of universes. Until recently, we thought that one set of physical laws governed by a Grand Unified Theory was possible, and then we thought string theory illuminated a small number of possible sets of physical laws, now M-Theory shows that a vast number of functioning sets of physical laws with different properties, dimensions, and fundamental forces can exist and function (Duff 1998). The estimated number of sets of physical laws that is favoured by physicists at the present time is 10^{500} (Hawking and Mlodinow 2010: 118). That number embraces all the possible sets of physical laws that could form the basis for a universe when it cools down enough for those physical laws to become distinct, and it pops into existence, like a bubble in boiling water. These sets of laws fall together in the inflationary stage as a universe cools just a split second after the Big Bang (see, *e.g.,* Hawking 2001; Emiliani 1995: 82; Christian 2004: 27; Chaisson 2001: 126; Davies 1995: 28–35; Greene 2004: 312–313; Guth 1997: 20). Their formation appears to be the outcome of a random process (Barrow 2011: 214). Each set of laws determines density, temperature, fundamental forces, constants, dimensions, and whether or not things like matter exist. The actual number of universes based on those sets of physical laws is probably much higher,

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[2] The account of these events is given a decent treatment in many works, for instance, David Christian (2004: 24–27) and John Barrow (2011).

with many variations, but they all fall within the selection constraints of 10^{500}. Those universes that do not fall within those constraints do not get to exist.

Here is the fundamental basis for the Darwinian algorithm, a major research area in Big History. 10^{500} is therefore a very important number. It is the number of working sets of physical laws, the number of parameters in which a universe can occur. It is the primordial niche of all evolution, the foundation for an algorithm of random variation and non-random selection, a process that seems to arise time and time again alongside the rise of complexity in the universe (Dennett 1996: 48–61). The algorithm even seems to govern the formation of universes themselves. A Darwinian algorithm is anything that obeys a process of random variation and non-random selection. The game of 'universal natural selection' appears to be the first instance in the cosmic story where such an algorithm happens. The selection constraints appear to be the number of sets of physical laws in which a universe can start to exist. Universes appear randomly in inflationary space and only those universes that fall within the constraints of 10^{500} are non-randomly selected to form stable functioning universes. In such a scenario, universes are not constrained by any form of direct competition, but a form of 'niche selection' where the physical attributes of a universe that are capable of dwelling within a cosmic set of constraints make a form of non-random selection possible.

Nevertheless, that primordial niche is extremely wide, as you might expect from a form of selection that goes back to the birth of universes. To give you an idea of how many variations of sets of physical laws could exist, take a trillion of them, and then multiply that trillion by a trillion. Then another trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × trillion × × trillion × trillion. By comparison, 10^{14} is the number of years before the end of star formation, when every single last star will flicker out and the universe will wander in a cosmic graveyard of pitch black.[3] 10^{40} is roughly the number of years before the death of matter (Adams and Laughlin 1997). And 10^{100} is roughly the number of years before the total heat death of our universe.[4] The number of different sets of physical laws that form the game of cosmic selection is greater still. That is the magnitude of 100^{500}. Some of those universes that arise would operate without electromagnetism. Some of those universes would never form clumps of hydrogen and helium, and by extension stars and galaxies. Some of those universes would never form atoms at all.

[3] 100 trillion years (Adams and Laughlin 1999: 35–39).

[4] If total heat death is indeed what awaits it. There are a number of possible scenarios and perhaps others undiscovered (Adams and Laughlin 1997).

And some of those universes would be based on properties, fundamental forces, and dimensions that, once again, in trying to understand how they operated using the physical concepts with which we are familiar in this universe would be like trying to explain colour to a dog.

From this primordial niche comes a vast array of scholarly works that recognise the Darwinian algorithm in a variety of universal processes. At the cosmic level, Lee Smolin and E. R. Harrison have both proposed models for universes themselves, with those more likely to produce black holes or intelligent life, respectively, being favoured (Smolin 1997; Harrison 1995: 193). Both remain highly speculative and favour a hereditary connection between universes. At the end of the day such selection criteria and heritability may not even be required since the number 10^{500} is so large that it covers every variation to make inheritance between universes unnecessary and yet still mathematically finite, making non-random selection possible. Wojciech Zurek has created a model whereby the predictable physics of the Newtonian realm emerge from the chaos of the quantum world – a model that recently gained some new evidence (Zurek 2003; Burke *et al.* 2010: 1–4). If this is correct, then it provides an explanation for the uncertainty in quantum physics. The chaos at the quantum level does not abrogate the idea that the universe functions in a certain way, as would-be scientific determinists have lamented, because the very randomness at the quantum level is fundamental to the prevailing system. In the geological realm, Robert Hazen *et al.* have proposed an evolutionary model for the generation of new minerals (Hazen *et al.* 2008). While making sure to clarify that the model differs from biology, the authors highlight several places where selection, punctuation, and gradients for change are present, exponentially increasing the number of mineral types throughout geological history, from stellar nebulae, through planetary accretion, and all the changes thereafter. But the most thorough examination of the Darwinian algorithm in areas beyond the realm of biology has been within cultural evolution. The idea was first pioneered by Donald Campbell and later revived by Richard Dawkins, and then most effectively, in my opinion, developed by Peter Richerson and Robert Boyd (Campbell 1960; Dawkins 1976; Boyd and Richerson 1985). In cultural evolution, any ideas, knowledge, beliefs, values, skills, and attitudes that are more practical or more appealing, are easier to learn or are better geared toward survival, are more likely to lead to social prominence than others, spread more easily from person to person. Those cultural practices that lead to early death or social stigma are less frequent or simply disappear (Richerson and Boyd 2005: 5–12). From so simple a beginning, came a flood of works on cultural evolution in recent years.[5] It also provoked a great deal of debate.[6] Two of the most rig-

[5] Many works have been written on the subject, though I believe Richerson and Boyd remain the most successful at explaining it. Richard Dawkins, by contrast, as recently as *The God Delusion*

orous bits of research, in my opinion, have been Lake and Venti's work on nineteenth century bicycle technology and Ritt's work on the formation of dialects and new languages (Lake and Venti 2009; Ritt 2004). Finally, at the recent conference, my colleague and fellow big historian, Christian Jennings, and I have discussed how Darwinian algorithms are used to fill a range of useful functions in the computer realm. Not all mechanisms of information in a computer are processed in a Darwinian algorithm. But since the 1970s, numerous programs have employed a 'genetic algorithm' which is a search heuristic that mimics the process of natural evolution. The computer automatically finds better ways to run programming through a game of variation and selection. It is currently employed in bioinformatics, engineering, economics, chemistry, mathematics, and more. Various entities of the universe are simply different forms of information – whether energy flows, DNA, or cultural ideas – and they seem to be processed by the same algorithm just as information in a computer. It is not the place of this article to confirm or deny the accuracy of the assertions cited above, but rather to exhort big historians to future research, especially on any project that ties these various manifestations of the Darwinian algorithm together into one theory. The spectre of the algorithm has already been spotted by a number of scholars working in a number of disciplines. This could be what unites them all – an elegantly simple process, a form of variation, selection, and preservation that underwrites all things.

It may also have a trajectory. If the Darwinian algorithm is present, if not instrumental, at every stage in the rise of complexity in the universe, it may be that this pattern tends ever more to greater forms of complexity. And it would appear that the number of possible outcomes is relative to the complexity of the process under discussion, hence why relatively few outcomes make it from the quantum to the Newtonian level, why only a few thousand variations emerge from the geological level, whereas in biological evolution the number of possible selection paths is increased manifold, and the number of cultural variations is exponentially greater still. When we arrive at something as complex as culture and modern human society, with a free energy rate density 25 times higher than the average product of genetic evolution and 500,000 times higher than the Milky Way, there are a mind-boggling number of combinations of ideas and

(Dawkins 2006: 228) claimed Susan Blackmore (1999) held that honour. A number of other works have also been written on the subject: Stephen Shennan (2002), Ruth Mace, Clare J. Holden, and Stephen Shennan (2005) – particularly David Bryant, Flavia Filiman, and Russell Gray (2005) who advocate the NeighborNet program to plot trees for both vertical and horizontal transmission for all the Indo-European languages, John Ziman (ed., 2000), and a close runner up to Richerson, Boyd, and Black more is Stephen Shennan (2009), notable for its many in-depth investigations.

[6] For instance, see Joseph Fracchia and R. Lewontin 2005: 1–13, 14–29, and 30–41, in several back and forth exchanges. Fracchia and Lewontin's misunderstanding of what cultural evolution actually led both sides to more or less repeat the same arguments at each other.

innovations. The rate of complexity seems to increase with the number of viable selection paths.

Table

Generic Structure	Free Energy Rate Density (erg s↑(–1) g↑ (–1))
Galaxies (*e.g.,* Milky Way)	1
Stars (*e.g.,* Sun)	2
Planets (*e.g.,* Earth)	75
Plants (biosphere)	900
Animals (*e.g.,* human body)	20,000
Brains (*e.g.,* human cranium)	150,000
Society (*e.g.,* modern human culture)	500,000

Source: Chaisson 2001: 139.

At the recent conference, I asked futurist and IBHA board member, Joseph Voros what sort of complexity we might expect to see from an intelligent species capable of harnessing increasing levels of energy, that is, the power of stars and the galaxy, known as Type II and Type III civilisations. He said that another exponential increase in free energy density was less likely than an increase in the complexity of networks. It would appear, for the time being, cultural evolution and the complexity it bestows is the highest point in this process of which we are yet aware. Others may open up that we cannot predict, but it is worthwhile to understand exactly what cultural evolution involves. There are two tiers of human evolution. The first is genetics, which operates in the same way as for other organisms. Those genes gave humans a large capacity for imitation and communication. Those two things enabled the second tier. Culture operates under similar laws, but on a much faster scale. Cultural variations are subject to selection and the most beneficial variations are chosen. Unlike genes these variations can be transmitted between populations of the same generation and can be modified numerous times *within* that generation. Like a highway overpass looming over older roads, cultural evolution can blaze along at a much faster rate of speed. Ultimately, culture accumulates. Population pressure compels some of this accumulation to be geared toward increasing the human ability to extract resources from the environment. This process raises the carrying capacity, which produces more people, which produces more accumulation, which in turn raises the carrying capacity. The cycle continues and grows in complexity. If expressed as a general principle, it may be said that the rate of growth of the carrying capacity of a human population is relative to the number and connectivity of variant innovations.

The second evolutionary tier of culture, a swifter form of evolution, should not come as a surprise in a Darwinian algorithm. Gradually through natural selection, not only do species become better at surviving, they become better at evolving. This follows the logic that improving the *rate* of your improvement of your survival chances is just as naturally selected for, since it also improves the rate of your survival. Logically, a third tier is likely to emerge where our growing knowledge allows us to directly guide the evolution of our genes. If we discard the manmade concept of tiers, in a sense through a relatively short evolutionary process of 200,000 years, our genes have evolved the ability to develop more rapidly and efficiently. The universe is composed of webs of energy of varying complexity. Life-forms are entities that harvest energy to perpetuate their complexity, to spread it, and even to increase it. Human history has been dominated by this hunt for resources. Our evolution, both genetic and cultural, has ultimately been geared toward aiding this hunt. Standard evolution can be defined as the change in the traits of a population of organisms through successive generations to sustain or increase their complexity. Human evolution can be described as the change in traits and behaviours between populations of the same generation and through successive generations to sustain or increase their complexity.

We now know that there is no hard-and-fast division between the organic and inorganic world. As such, life can be (somewhat coldly) defined as a series of physical processes that contain a hereditary program for defining and directing molecular mechanisms that actively extract matter and energy from the environment that are converted into building blocks for the perpetuation and reproduction of those physical processes (Spier 2010: 77). Life is the only thing in the universe that does this. Stars, minerals, and the rest of the inorganic world do not actively seek out matter and energy from the environment. Even objects as gigantic as stars burn their fuel like lamps and candles and eventually flicker out. This has been proceeding since the beginning of the universe. Eventually every single last tiny slow burning star will be extinguished. Only life has the agency to go out and extract energy from the environment to keep itself going. We do not just sit still and wait for death to take us. We fight – for a time. If we want to preserve our vast complexity, we have to continue harvesting matter and energy to keep ourselves going. All other considerations are secondary. It is the bottom line of human history. During most, if not all, of our history, the quest to extract matter and energy to perpetuate our existence has been the overriding theme (Spier 2010: 116). It is the battle with disorder, chaos, entropy, and the second law of thermodynamics which we have carried on since the very beginning of our existence, and it is a battle that physicists believe we must eventually and inevitably lose.

This brings me to the topic of how the Darwinian algorithm relates to how we perceive ourselves in the grand narrative and how Akop Nazaretyan at the recent conference exhorted big historians to provide the world with non-exclusive 'meanings of life' – beyond religion and ideology that inevitably vilify the infidel and the 'other' – to ideas of meaning that bind the entire human race together in common cause (Nazaretyan 2010). If the Darwinian algorithm prevails at many stages in the rise of complexity in the universe, then it is possible that the evolution of life and species capable of cultural evolution is just another stage in this trajectory, just like star formation or planetary accretion. At risk of sounding sensationalist and glib, two things that I abhor, I must state that research in this direction may *possibly* provide us with something approaching a secular and objective 'meaning of life' that unites us all.

There are as many as 10^{500} possible sets of physical laws for universes. Each of these sets of physical laws governs the evolution of a universe in various ways. Our universe is 13.7 billion years old, very complex life on Earth about 550 million, and the human race as we know it only about 200,000. Our local star is middle-aged and will last only another 5 billion years and will boil the Earth's surface dry in well under 3 billion. If the human race does not destroy itself in the meantime, it has hundreds of millions of years to exist and evolve on Earth, after which time we could venture out into other solar systems and long outlast the death of our own. We could huddle around the fires of hundreds of thousands of stars in the habitable section of the Milky Way for nearly a trillion years and more stars would be produced in the centre of the galaxy and eventually spread out and be used too. But unless we somehow learn to create stars ourselves, in 100 trillion years every single last dim little star will have flickered out and the universe will become a cosmic graveyard, where bodies of dead stars and planets will wander in pitch black. Until, of course, the energy that creates matter itself (which, remember, is really just a congealed form of energy) in 10^{40} years will grow feeble and matter will cease to exist, and then after a period of 10^{100} years, even black holes will cease to exist, and the universe will be an empty orb of weak cosmic radiation – a victim of Heath Death.

Here is the grim fate to which we must resign ourselves that also seems to indicate that our story and the story of the universe itself is ultimately and objectively pointless. Yet, the notion of the Darwinian algorithm of random variation and non-random selection governing processes in the universe as disparate as geology, biology, and culture, indicates another interesting possibility. Life is the only entity in the universe that actively harvests energy rather than just burning down and in only the last 250 years human beings have mastered the atom and figured out how to harness energy in impressive magnitudes. The next 'spontaneous' rise of complexity in the universe will be down to intelligent life. Current physical processes in the universe indicate a future of heat death. But those calculations do not take the evolution of intelligent life into account. That grim fate for the universe may be avoided. It is very difficult to see why the wheels are churning when we ourselves are inside the machine. We have millions, billions, if not trillions of years before us, to devise a way to keep the lamps of the galaxy lit, energy flowing, and the universe itself from 'dying'. And, perhaps most profoundly of all, life itself may have been another one of those ever-present Goldilocks conditions: an entity that keeps harvesting and creating energy to perpetuate the complexity of the universe. Like tiny white cells in the human body, our small and seemingly insignificant species may nevertheless have an extremely important role in the universe. Our fates might be bound together. It may be why we are here. In that sense, the 'meaning of life' is a fairly easy question. The question of the 'meaning of the universe', on the other hand, is a much more difficult proposition.

At any rate it remains an open possibility – and it has significance for us today, not just trillions of years from now. Albert Camus (1913–1960), a French writer and philosopher, once said that in all philosophy there is only one problem, and that is suicide – judging whether life is or is not worth living amounts to the most fundamental question of philosophy (Camus 1942: 15). In the secular scientific narrative of Big History, we are robbed of traditional answers to that question. In a cold, often cruel, empirical universe based on fact and not on fantasy, we do not have access to the pre-packaged meaning, morality, and life purpose that animates religious culture. What we are left with is a universe that evolved from impersonal physical laws and is so vast as to reduce all the trials of daily life and indeed all human history to a state of woeful insignificance. The universe does not owe you a sense of purpose. It does not owe you a sense of comfort. Lacking an objective scientifically reinforced meaning of life and purpose to existence, where the universe has no higher role for living things, there ultimately is no point. In such a state of affairs that is the hard, grim, inevitable fact. You are an accident of physics, kept alive by an evolutionarily instilled fear of death that translates into a multitude of subjective, often paltry, excuses for why you have not yet opened your throat. Even good answers to that question, like the noble scientific curiosity to explore the universe, or love, or duty, or stubbornness (KBO, the motto from British trenches in the First World War, keep buggering on), just sound like provisional reasons so we can move on and stop thinking about it. Even now the reader's mind may be racing, reminding themselves of their own reasons for living. And perhaps these subjective excuses are all we can ever hope to achieve. The Darwinian algorithm, however, returns to the question of an objective secular scientific meaning of life and whether life is or is not worth living – the fundamental question of philosophy.

Research on the Darwinian algorithm may be crucial in a variety of ways. From it we might attain a greater sense of where humanity fits in the history of the universe. We might identify some of the processes that govern human development and also identify the universal context in which humanity faces the distant future. From here it may be possible to establish an objective sense of human purpose in the universe, though the validity of this last step is far from certain. And when I use words like 'meaning' and 'purpose' I do not engage with the idea of strong emergentism and those scientists who are using concepts of strong emergence to revive 'religiosity' and the feelings of 'awe', 'creation', 'enchantment', 'transcendence', 'reverence', 'gratitude', and 'objective and universal morality', normally associated with the traditional religions.[7] I have no desire to replace religion with science or anything else for that matter in an increasingly secular age.[8] I am content to let such feelings of 'religiosity' go. Empirical work on the Darwinian algorithm should not be optimistic or indulge in mysticism. To mature intellectually in the twenty-first century, one must stop being such a child and admit that the questions of existence and morality are not as clear-cut as old religions had led us to believe, the answers are not often uplifting, and it is harder to take refuge in feelings of reverent religiosity today than it was in the time of your ancestors. Science will not revive those feelings. Being perpetually confused and scared is part of being an adult in the twenty-first century. We are in the process of casting aside old fairy tales. Now is not the time to be inventing new ones. But it is my fear that research on the Darwinian algorithm will be just another desperate grasp at a comforting myth. I remain characteristically pessimistic about its prospects, but it is too interesting a possibility to pass up. But the possibility may fail and join the ranks of other pathetic exploits in pseudo-science, in which case there is very little besides subjective reasoning between you and the stark contemplation of the grand unfolding tale of 13.8 billion years.

Paul Dirac (1902–1984), English theoretical physicist who predicted the existence of antimatter, and whose brother, Felix, committed suicide in 1925, wrote his entire philosophy of life on three pages of a notebook in 1933, in which he said:

> My article of faith is that the human race will continue to live forever and will develop and progress without limit. This is an assumption that I must make for my peace of mind. Living is worthwhile if one can contribute in some small way to this endless chain of progress (quoted in Farmelo 2009: 221).

There is, of course, absolutely no guarantee that humanity or our descendant species will not go extinct, and much to indicate the contrary as we enter

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[7] The most explicit statement to this effect is Ursula Goodenough and Terrence Deacon, 'The Sacred Emergence of Nature' (Goodenough and Deacon 2006).

[8] See also Stuart Kauffman, 'Beyond Reductionism: Reinventing the Sacred' (Kauffman 2006), and also the seminal (and less proselytising) works on emergence, Stuart Kauffman (1993, 1995), and also Terrence Deacon's recent ode to emergence, *Incomplete Nature: How Mind Emerged from Matter* (Deacon 2011), which was not well received by experts, for example: Jerry Fodor (2012), in addition to lingering allegations of plagiarism.

the bottleneck of the twenty-first century. But perhaps Dirac is right, despite this assumption. Perhaps, within the Darwinian algorithm, life is worthwhile if we can contribute in some small way to the rise of complexity in the universe – a strange, blind, but inexorable process that has been proceeding for 13.8 billion years.

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