Life's Solution

Inevitable Humans in a Lonely Universe

The assassin's bullet misses, the Archduke's carriage moves forward, and a catastrophic war is avoided. So too with the history of life. Rerun the tape of life, as Stephen J. Gould claimed, and the outcome must be entirely different: an alien world, without humans and maybe not even intelligence. The history of life is littered with accidents: any twist or turn may lead to a completely different world. Now this view is being challenged. Simon Conway Morris explores the evidence demonstrating life's almost eerie ability to navigate to the correct solution, repeatedly. Eyes, brains, tools, even culture: all are very much on the cards. So if these are all evolutionary inevitabilities, where are our counterparts across the Galaxy? The tape of life can run only on a suitable planet, and it seems that such Earth-like planets may be much rarer than is hoped. Inevitable humans, yes, but in a lonely Universe.

SIMON CONWAY MORRIS is Professor of Evolutionary Palaeobiology at the University of Cambridge. He was elected a fellow of the Royal Society in 1990, and presented the Royal Institution Christmas lectures in 1996. His work on Cambrian soft-bodied faunas has taken him to China, Mongolia, Greenland, and Australia, and inspired his previous book *The Crucible of Creation* (1998).

Pre-publication praise for *Life's Solution*:

'Having spent four centuries taking the world to bits and trying to find out what makes it tick, in the twenty-first century scientists are now trying to fit the pieces together and understand why the whole is greater than the sum of its parts. Simon Conway Morris provides the best overview, from a biological viewpoint, of how complexity on the large scale arises from simple laws on the small scale, and why creatures like us may not be the accidents that many suppose. This is the most important book about evolution since *The Selfish Gene*; essential reading for everyone who has wondered about why we are here in a universe that seems tailor-made for life.'

John Gribbin, author of *Science: A History*

'Are human beings the insignificant products of countless quirky biological accidents, or the expected result of evolutionary patterns deeply embedded in the structure of natural selection? Drawing upon diverse biological evidence, Conway Morris convincingly argues that the general features of our bodies and minds are indeed written into the laws of the Universe. This is a truly inspiring book, and a welcome antidote to the bleak nihilism of the ultra-Darwinists.'

Paul Davies, author of *How to Build a Time Machine*

'Is intelligent life in the Universe common or incredibly rare? Are even planets like the Earth rare? We won't really know until our searches are further advanced, but until then these debates pivot on the tension between contingency and convergence. Advocates of the first point to the unlikelihood of particular historical paths, while those favoring the second emphasize multiple paths to similar functional outcomes. In *Life's Solution* Conway Morris argues that the evidence from life on Earth supports a variety of paths leading toward intelligence. Our searches for life elsewhere are informed by such insights into life here.'

Christopher Chyba, Stanford University and the SETI Institute

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University of Cambridge

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For Zoë, with love

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Preface. The Cambridge sandwich

Writing in the *New York Review of Books*,[1] John Maynard Smith, one of Britain's greatest biologists, remarked 'If one was able to re-play the whole evolution of animals, starting at the bottom of the Cambrian (and, to satisfy Laplace, moving one of the individual animals two feet to its left), there is no guarantee – indeed no likelihood – that the result would be the same. There might be no conquest of the land, no emergence of mammals, and certainly no human beings'.[2] This review, written with characteristic flair and economy, was addressing three books on evolution, two by S. J. Gould and the third by E. Mayr. Maynard Smith was raising this issue because both the authors under review have been forthright in claiming that the emergence of human intelligence during the course of evolution has a vanishingly small probability. The logic of the argument, that because we are unique on this planet then nothing like us can occur elsewhere, is gently checked by Maynard Smith: 'This argument seems to me so manifestly false that I fear I must have misunderstood it'.[3] However, he, Mayr and Gould, and I imagine almost anyone else, would agree that the likelihood of 'exactly the same cognitive creatures – with five fingers on each hand, a vermiform appendix, thirty-two teeth, and so on'[4] evolving again if, somehow, the Cambrian explosion could be rerun is remote in the extreme.

What, however, of the emergence of more general biological properties? In considering some earlier views of R. C. Lewontin, who was uncertain as to whether 'general principles of biological organization'[5] existed, Maynard Smith was more upbeat: 'In seeking a theory of biological form, I would probably place greater emphasis than Lewontin on the principles of engineering design. I suspect that there are only a limited number of ways in which eyes can possibly work, and, maybe only a limited number of ways in which brains can work. But I agree that it would be good to know whether such principles exist, and, if so, what they are'.[6] Even though neither Lewontin nor Maynard Smith thought 'A description of all the organisms that have ever been'[7] could settle this issue,[8] *Life's Solution* sets out to demonstrate that what we already know gives some strong indicators of what must be: even in this book pigs don't fly.

The central theme of this book depends on the realities of evolutionary convergence: the recurrent tendency of biological organization to arrive at the same 'solution' to a particular 'need'. Perhaps the best-known example is the similarity between the camera-like eye of the octopus and the human eye (or that of any other vertebrate). As we shall see in this particular instance, where the camera-like eye has evolved independently at least six times, Maynard Smith's premise that 'only a limited number of ways in which eyes can possibly work' is amply confirmed. If this book happens to serve no other purpose than act as a compilation of evolutionary convergences, be it head-banging in mole rats and termites or matriarchal social structure in sperm whales and elephants, then that will be sufficient. But, of course, the net is in pursuit of a much bigger prey. Its main, but not ultimate, aim is to argue that, contrary to received wisdom, the emergence of human intelligence is a near-inevitability. My purpose is not to demonstrate the inevitability of a five-fingered organism, although in this context it is amusing to note that the famous panda's 'thumb' is, in one sense, convergent.[9] Nor is it my aim to find repeated examples of species with 32 teeth, even though we might note that there are a number of fascinating examples of dental convergence. And it is this that matters, not five of this or 32 of that, but the recurrent emergence of various biological properties.

This book has its anecdotes, from baboons operating railway signals to a harbour seal that spoke like an inebriated Bostonian, but there is a serious argument that takes us from the apparently arcane, such as the natural (and convergent) gyroscopes of insects, through to the convergences of the sensory modalities (vision, of course, but also olfaction, hearing and echolocation, electroreception, and so on) to agriculture, brain size, and culture. And there are four conclusions. First, what we regard as complex is usually inherent in simpler systems: the real and in part unanswered question in evolution is not novelty *per se*, but how it is that things are put together. Second, the number of evolutionary end-points is limited: by no means everything is possible. Third, what is possible has usually been arrived at multiple times, meaning that the emergence of the various biological properties is effectively inevitable. Finally, all this takes time. What was impossible billions of years ago becomes increasingly inevitable: evolution has trajectories (trends, if you prefer) and progress is not some noxious by-product of the terminally optimistic, but simply part of our reality.

There is, however, a paradox. If we, in a sense, are evolutionarily inevitable, as too are animals with compound eyes or tiny organelles that make hydrogen, then where are our equivalents, out there, across the galaxy? After all, the Milky Way has been available for colonization for at least a billion years, so in Enrico Fermi's famous words concerning putative extraterrestrials: 'Where are they?' To paraphrase much of this book, life may be a universal principle, but we can still be alone. In other words, once you are on the path it is pretty straightforward, but finding a suitable planet and maybe getting the right recipe for life's origination could be exceedingly difficult: inevitable humans in a lonely Universe. Now, if this happens to be the case, that in turn might be telling us something very interesting indeed. Either we are a cosmic accident, without either meaning or purpose, or alternatively . . .

Enough of backgrounds; what specifically is this book about? Here is a brief outline. Overall it is a sandwich. The central meat on convergences is in Chapters 6 to 10, flanked by thinner expositions in the form of the first five chapters and two end chapters, the last very short indeed. So, the first two chapters are introductory. They look at two extraordinarily effective biological systems. The first concerns the genetic code, how the building blocks of protein, the amino acids, are read off the DNA. This code is eerily effective, indeed it has been argued to be 'one in a million'. This raises the question of how life navigates to such precise end-points, an analogy being how the Polynesians in the great diaspora across the Pacific ever managed to find that remote speck of land that we call Easter Island. This is followed in the second chapter by a consideration of DNA, a molecule of iconic if not totemic significance. But for all its familiarity, DNA also turns out to be one of the strangest molecules in the Universe. A rather useful invention.

The next two chapters (3 and 4) consider how easy it is to make the molecules necessary for life, but paradoxically how difficult it is to make life itself. To some the universality of organic material, from immense interstellar gas clouds rich in carbon compounds to questing bipeds plodding around out-of-the-way planets, almost suggests the cosmos 'breathes' life; a Universe seeded with vital possibilities. Maybe so, but the trillion upon trillion tonnes of interstellar organics may still be a universal 'goo'. To be sure, they could be the essential ingredient for getting life started in terms of basic supplies, but the question of just how inanimate became animate has proved stubbornly recalcitrant. It should all be rather simple, especially if you worship at the crowded shrine of self-organization. Yet, somewhere, somehow the right question has not yet been asked, and not for want of trying.

So confident, however, is the majority that the emergence of life is a pre-ordained inevitability that the question of whether beyond the Earth there are any planetary homes available has only recently emerged. Thus Chapter 5 looks at what we know of the many peculiarities of our Solar System. Planets there will be aplenty, but suitable abodes for organic evolution might require very special sets of circumstances. This is an area that has been reviewed by such workers as Peter Ward and Donald Brownlee[10] and Stuart Ross Taylor,[11] but here I take the argument further as the ferment of discussion continues.

Chapters 6 to 10 are, as already mentioned, the heart of the book. They effectively track the story of evolutionary convergence, starting with the classic cases familiar to biologists as well as some very intriguing experiments, using bacteria, which allow evolutionary history to be rerun. That provides a framework of a sort, but the goal is to argue for the inevitable emergence of sentience. This is achieved by first (Chapter 7) looking, in some detail, at the sensory modalities. Eyes provide a superb story, but so too in their different ways do such features as balance, hearing, olfaction, echolocation, and electrogeneration: all are rampantly convergent. These complex systems can arise from very different starting positions, but again and again converge on the same evolutionary solution. Chapters 8 and 9 develop the story by seeing how certain features that we believe are peculiarly human, such as agriculture, human brains, and even advanced culture are each convergent.

This is not, emphatically, to say that humans are the only evolutionary outcome worth considering: clearly they are not. And this leads to the last two chapters (10 and 11), and a brief coda (Chapter 12). Too often evolutionary convergence is regarded as simply anecdotal, good for a bedtime story. Its importance is surely underestimated, and for two reasons. The first is scientific. Ideas on evolution about such features as adaptation and trends have been under fierce attack, especially by those who believe that if contingent happenstance dogs every step of evolution then assuredly the emergence of humans is a cosmic accident, leaving us free to make the world as we will, with such happy results as are plain to see. Yet convergence tells us two things: that evolutionary trends are real, and that adaptation is not some occasional cog in the organic machine, but is central to the explanation of how we came to be here. In principle, such ideas are in themselves so unremarkable as to require no comment, were it not for the ferocious attacks by such writers as S. J. Gould. What, one wonders, did he get so excited about, and how, one may ask, has our understanding of evolution really changed despite more than forty years of polemic?

Yet, convergence also opens another door. If the emergence of our sentience was effectively inevitable, then perhaps we should take rather more seriously the sentiences of other species? So too perhaps we should stand back and consider what a very odd set-up it is we inhabit, from the eerily efficient genetic code, to the deeply peculiar molecule DNA, to a set of biological organizations that repeatedly throw up complex structures, not least the brain. The late Fred Hoyle, no friend of most biologists, carried some strange ideas about the origins of biological complexity to his grave, yet his remark that the Universe was a set-up job rings strangely true. Having said that, if you happen to be a ‘creation scientist’ (or something of that kind) and have read this far, may I politely suggest that you put this book back on the shelf. It will do you no good. Evolution is true, it happens, it is the way the world is, and we too are one of its products. This does not mean that evolution does not have metaphysical implications; I remain convinced that this is the case. To deny, however, the reality of evolution and more seriously to distort deliberately the scientific evidence in support of fundamentalist tenets is inadmissible. Contrary to popular belief, the science of evolution does not belittle us. As I argue, something like ourselves is an evolutionary inevitability, and our existence also reaffirms our one-ness with the rest of Creation. Nevertheless, the free will we are given allows us to make a choice. Of course, it might all be a glorious accident; but alternatively perhaps now is the time to take some of the implications of evolution and the world in which we find ourselves a little more seriously. If you haven't put *Life's Solution* back on the shelf, please read on.

Acknowledgements

'To copy one paper is plagiarism, to copy many is scholarship': few academics are unfamiliar with one or other version of this gentle jibe. Moreover, given that my one area of vague scientific knowledge concerns fossil worms from the Cambrian it will be self-evident that to have been able to write this book I am heavily dependant on the expertise, knowledge, and enthusiasm of hundreds of workers. For this reason I have drawn upon a number of their quotations, which are of course fully acknowledged. This is not to say that the researchers I have cited would necessarily agree with the overall theme of *Life's Solution*, but I trust that in each case the context is clear and fair. Thus I hope that a book that flits from extraterrestrial amino acids to dolphin brains, from the eyes of spiders to the discovery of a Roman terracotta head in pre-Columbia Mexico, or Francis Galton calculating by smells, is understood as an exploration along a common theme rather than simply a jumble of half-digested facts. So first I must acknowledge the many authors whose work I have drawn on liberally. So too I thank the following friends for reading one or other section, and in a few cases the entire draft at one stage or another. Thus I record my gratitude to the following friends: Ken Catania, Stephen Clark, Rob Foley, Stephen Freeland, Jack Lissauer, Ken McKinney, Lori Marino, Ulrich Mueller, and Nick Strausfeld for their detailed critiques. In addition, many other colleagues provided illustrative material (also acknowledged in specific figures), particular insights, and information. Again, I am most grateful, and specifically I thank Rachelle Adams, Tim Bayliss-Smith, Curtis Bell, Yfke van Bergen, Quentin Bone, Graham Budd, Hynek Burda, John Chambers, Jenny Clack, Rod Conway Morris, James Crampton, Cameron Currie, Nick Davies, Eric Denton, Laurence Doyle, Doug Erwin, Albert Eschenmoser, Richard Felger, Russ Fernald, Larry Field, Siegfried Franck, Adrian Friday, Linda Gamlin, Liz Harper, Carl Hopkins, Ken Joysey, Harvey Karten, Jeyaraney Kathirithamby, Richard Keynes, Kuno Kirschfeld, David Kistner, Mike Land, Charley Lineweaver, Ken McNamara, Charles

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It is oxymoronic to say that the mistakes that remain are mine: of course they are. Nor can I promise that everything is up to date; it can't be, nor are my references intended to be exhaustive; they aren't. I hope, however, they are sufficient for the interested reader to begin to explore the literature.

The source of this book was the invitation by Trinity College, Cambridge, to deliver the Tarner Lectures for 1999, and I thank the Master and Fellows, especially Boyd Hilton, for their encouragement and support. I owe an enormous debt to several other people. First, I wish to thank wholeheartedly Sandra Last for her patience and stamina as smoothly and flawlessly draft after draft emerged. Next, I owe a debt of gratitude to the University of Cambridge and especially the Department of Earth Sciences, for allowing me time for such an enterprise. I also specifically wish to thank Sharon Capon and Dudley Simons for assistance with drafting and photography, and also to acknowledge the superb libraries in many departments, the University Library, and the unfailingly helpful librarians. So, too, I give thanks to Cambridge University Press, especially Sally Thomas, Alison Litherland, and Robert Whitelock, and to Bruce Wilcock and his skills in disentanglement.

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Abbreviations

GENERAL

ATP adenosine 5′-triphosphate, the triphosphate of the nucleotide adenosine, which plays a key role in the energetics of the cell. See also p. 25.

BP before the present; by convention taken as before 1950.

CHZ the Circumstellar Habitable Zone, the zone surrounding a star in which the evolution of life is both possible, and can be maintained for protracted intervals of time. See also pp. 83, 99–100.

DNA deoxyribonucleic acid, the nucleic acid that forms the basis of genetic inheritance in nearly all organisms. See also pp. 4, 23–24.

EOD electric organ discharge; the discharge of electricity from specialized tissues in fish. See p. 184.

IDO the enzyme indoleamine 2,3-dioxygenase.

JAR jamming avoidance response, exhibited by fish that use electrogeneration. See p. 186.

K/T the boundary between the end of the Cretaceous (K) period and the beginning of the Tertiary (T) era at about 65 Ma ago. The K/T event that occurred at this time resulted in a mass extinction. See pp. 94–95.

LPTM the late Paleocene thermal maximum, a warm interval that occurred during the Paleocene period at *c*. 55 Ma.

OZMA (Project) the first radio-telescope project to search for extraterrestrial signals, so named by Frank Drake in reference to organisms as strange as the Wizard of Oz. See p. 231.

PAHs polycyclic aromatic hydrocarbons; organic compounds with a carbon “network” that are abundant in the Universe. See p. 43.

RNA ribonucleic acid, a polynucleotide that conveys genetic information to the proteins in the cell. There are three forms: messenger RNA (mRNA), ribosomal RNA (rRNA), and transfer RNA (tRNA). See also pp. 4, 13, 44.
SETI the Search for Extraterrestrial Intelligence. See pp. 231–232.
TNA threo-nucleic acid. See pp. 52–53.
UV ultraviolet; electromagnetic radiation in the range between visible (violet) light and X-rays, i.e. with wavelengths from about 400 nm to 4 nm. Ultraviolet radiation is invisible to the human eye, but not to many animals.

SOME ABBREVIATIONS FOR UNITS

Length

cm centimetre, one-hundredth of a metre (0.3937 inch)
m metre (39.37 inches)
km kilometre, 1000 metres (approx. 0.621 mile)
nm nanometre, 10^{-9} metre, i.e. one millionth of a millimetre (0.03937 millionths of an inch).
AU astronomical unit, equal to the mean distance of the Earth from the Sun; 1.496×10^8 km or approx. 93 million miles.

Mass

g gram (0.03527 ounce)
kg kilogram, 1000 grams (2.2046 pounds)

Time

s second
Ga billion years (10^9 years)
Ma million years (10^9 years)

Frequency

Hz herz, frequency per second
kHz kiloherz, 1000 Hz
MHz megaherz, 10^6 herz.

Temperature

°C degree Celsius (0 °C is the freezing point of water, 100 °C is the boiling point of water).

K temperature on the Kelvin (thermodynamic) absolute scale (with 0 K as absolute zero); 1 degree $K = 1$ degree C; 0 °C is about 273 K and 100 °C is about 373 K.

Pressure

Pa Pascal, SI unit of pressure, equivalent to the pressure produced by a force of one newton applied (uniformly) over an area of one square metre; 10^5 Pa (100 kPa) is equivalent to 1 bar, or roughly 1 atmosphere.