Richard Dawkins – Unweaving The Rainbow; Science, Delusion And The Appetite For Wonder

ISBN – 0-618-05673-4

PREFACE

The feeling of awed wonder that science can give us is one of the highest experiences of which the human psyche is capable. It is a deep aesthetic passion to rank with the finest that music and poetry can deliver. It is truly one of the things that makes life worth living and it does so, if anything, more effectively if it convinces us that the time we have for living it is finite. (x)

CHAPTER 1 – THE ANAESTHETIC OF FAMILIARITY

We are going to die, and that makes us the lucky ones. Most people are never going to die because they are never going to be born. […] Certainly those unborn ghosts include greater poets than Keats, scientists greater than Newton. We know this because the set of possible people allowed by our DNA so massively exceeds the set of actual people. […] [T]here is more to personal identity than genes, as identical twins (who separate after the moment of fertilization) show us. (1)

We live on a planet that is all but perfect for our kind of life: not too warm and not too cold, basking in kindly sunshine softly watered; a gently spinning, green and gold harvest festival of a planet. Yes, and alas, there are deserts and slums; there is starvation and racking misery to be found. But take a look at the competition. Compared with most planets this is paradise, and parts of earth are still paradise by any standards. (4)

Here, it seems to me, lies the best answer to those petty-minded scrooges who are always asking what is the *use* of science. In one of those mythic remarks of uncertain authorship, Michael Faraday is alleged to have been asked what was the use of science. 'Sir,' Faraday replied. 'Of what use is a new-born child?' […] If everything is judged by how 'useful' it is – useful for staying alive, that is – we are left facing a futile circularity. There must be some added value. At least a part of life should be devoted to *living* that life, not just working to stop it ending. This is how we rightly justify spending taxpayers' money on the arts. (5)

William Calvin […] emphasizes, as others have done before, the idea that thoughts do not reside in particular places in the brain but are shifting patterns of activity over its surface, units which recruit neighbouring units into populations becoming the same thought, competing in Darwinian fashion with rival populations thinking alternative thoughts. We don't see theses shifting patterns, but presumably we would if neurons lit up when active. (8)

[It would take about] 4 inches or 10 cm of book thickness to record the history of one millennium. […] If we want to read about Jesus, say, we must select a volume 20 cm from the ground of just above the ankle. […] To find Agamemnon in our pile of books, you'd have to stoop to a level about halfway up your shins. […] Archaeological traces suggest that fire was discovered by our *Homo erectus* ancestors, though whether they made fire, or just carried it about and used it we don't know. They had fire by half a million years ago, so to consult the volume in our analogy recording the discovery you'd have to climb up to a level somewhat higher than the Statue of Liberty. […] To read about Lucy and our australopithecine ancestors in Africa, you'd need to climb higher than any building in Chicago. The biography of the common ancestor we share with chimpanzees would be a sentence in a book stacked twice as high again. […] How high would the stack of books have to be in order to accommodate the page where the life and death of this trilobite [extinct arthropods/largest phylum of animals] it its shallow Cambrian sea, is perfunctorily celebrated? The answer is about 56 kilometers, or 35 miles. […] The first living creatures, the shared ancestors of the trilobite, of bacteria and of ourselves, have their ancient chemical lives recorded in volume 1 of our saga. Volume 1 is at the far end of the marathon bookshelf. Or right across Greece from the Adriatic to the Aegean. (12)

Fling your arms wide in an expansive gesture to span all of evolution from its origin at your left fingertip to today at your right fingertip. All the way across your midline to well past your right shoulder, life consists of nothing but bacteria. Many-celled, invertebrate life flowers somewhere around your right elbow. The dinosaurs originate in the middle of your right palm, and go extinct around your last ringer joint. The whole story of *Homo sapiens* and our predecessor *Homo erectus* is contained in the thickness of one nail-clipping. As for recorded history; as for the Sumerians, the Babylonians, the Jewish patriarchs, the dynasties of Pharaohs, the legions of Rome, the Christian Fathers, the Laws of the Medes and Persians which never change; as for Troy and the Greeks, Helen and Achilles and Agamemnon dead; as for Napoleon and Hitler, the Beatles and Bill Clinton, they and everyone that knew them are blown away in the dust from one light stroke of a nail-file. (13)

It has been estimated that the people alive today make up a substantial proportion of the humans that have ever lived. But this just reflects the power of exponential growth. (13)

CHAPTER 2 – DRAWING ROOM OF DUKES

Scientists may transform the world more effectively than politicians and statesmen, but that is not all they do, and certainly not all they could do. Scientists transform the way we think about the larger universe. They assist the imagination back to the hot birth of time and forward to the eternal cold, or, in Keats's words, to 'spring direct towards the galaxy'. (16)

Perhaps the best polity for the archaeologists would be to declare themselves a religion, with DNA fingerprints their sacramental totem. Facetious but, such is the climate in the United States at the end of the twentieth century, it is possibly the only recourse that would work. If you say, 'Look, here is overwhelming evidence from carbon dating, from

mitochondrial DNA, and from archaeological analyses of pottery, that X is the case' you will get nowhere. But if you say, 'It is a fundamental and unquestioned belief of my culture that X is the case' you will immediately hold a judge's attention. (20)

[T]there is an unexpected and pernicious alliance between the know-nothing fundamentalist religious right and the sophisticated academic left. A bizarre manifestation of the alliance is their joint opposition to the theory of evolution. That of the left is a compound of hostility to science in general, of 'respect' (weasel word of our time) for tribal creation myths, and of various political agendas. (21)

There are, of course, genuine philosophical difficulties. Is a truth just a so-far-unfalsified hypothesis? What status does truth have in the strange, uncertain world of quantum theory? Is anything ultimately true? On the other hand, no philosopher has any trouble using the language of truth when falsely accused of a crime, or when suspecting his wife of adultery. 'Is it true?' feels like a fair question, and few who ask it in their private lives would be satisfied with logic-chopping sophistry in response. Quantum thought experimenters may not know in what sense it is 'true' that Schrödinger's cat is dead. But everybody knows what is true about the statement that my childhood cat Jane is dead. (21)

I worry that to promote science as all fun and larky and easy is to store up trouble for the future. Real science can be hard (well, challenging, to give it a more positive spin) but, like classical literature or playing the violin, worth the struggle. If children are lured into science, or any other worthwhile occupation, by the promise of easy fun, what are they going to do when they finally have to confront the reality?[…] Science, like proper literary studies, can be hard and challenging but science is – also like proper literary studies – wonderful. […] *Of course* science is fun, in the sense that it is the very opposite of boring. It can enthrall a good mind for a lifetime. (23)

Good science fiction has no dealings with fairy-tale magic spells, but is premised on the world as an orderly place. There is mystery, but the universe is not frivolous not light-fingered in its changeability. […] Science fiction may tinker with the laws of nature, advisedly and preferably one law at a time, but it cannot abolish lawfulness itself and remain good science fiction. (29)

But it is true that scientists, more than, say, lawyers, doctors or politicians, gain prestige among their peers by publicly admitting their mistakes. […] Science progresses by correcting its mistakes, and makes no secret of what is still does not understand. (31)

CHAPTER 3 – BARCODES IN THE STARS

Newton's dissection of the rainbow in to light of different wavelengths led on to Maxwell's theory of electromagnetism and thence to Einstein's theory of special relativity. If you think the rainbow has poetic mystery, you should try relativity. (42)

To unweave the rainbow is to separate it into its components of different wavelengths. White light is a scrambled mixture of wavelengths, a visual cacophony. White objects reflect light of all wavelengths but, unlike mirrors, they scatter it into incoherence as they do so. This is why you see light, but not your face, reflected from a white wall. Black objects absorb light of all wavelengths. Coloured objects, by reason of the atomic structures of their pigments or surface layers, absorb light of some wavelengths and reflect other wavelengths. Plain glass allows light of all wavelengths to pass straight through it. Coloured glass transmits light of some wavelengths while absorbing light of other wavelengths. (44)

[I]t may be that nobody really understands quantum theory, possibly because natural selection shaped our brains to survive in a world of large, slow things, where quantum effects are smothered. This point is well made by Richard Feynman, who is also supposed to have said, 'If you think you understand quantum theory – you don't understand quantum theory!' […] Whatever a physicist's doubts about how to interpret quantum theory, nobody doubts its phenomenal success in predicting detailed experimental results. (50)

By unweaving starlight in spectroscopes we know that starts are nuclear furnaces, fusing helium out of the hydrogen that dominates their mass; then thrusting helium nuclei together in the further cascade of impurities which make up most of the rest of the elements forging the medium-sized atoms of which we are eventually made. (52)

Nobody knows if my sensation of redness matches yours, but we can easily agree that the light I call red is the same as the light that you call red and that, if a physicist measures it, it will be found to have a long wavelength. My subjective judgment is that violet looks redder than blue does, even thought it lies further away on the spectrum from red. Probably you agree. The apparent reddish tinge in violet is a fact about nervous systems, not a fact about the physics of spectrums. (53)

Enzyme molecules are often capable of coiling into more than one shape, and usually only one of them is desirable. Much of the work of natural selection over the millions of years has been to find 'decisive' or 'single-minded' molecules whose 'preference' for their favoured shape is much stronger than their tendency to coil into any other shape. Molecules with two alternative shapes can be a tragic menace. 'Mad cow disease', sheep scrapie and their human counterparts Kuru and Creutzfeldt-Jakob disease, are caused by proteins called prions which have two alternative shapes. […] The presence of one protein with the alternative shape induces others to come over to the rogue persuasion. An epidemic of misshapen proteins sweeps through the body like a cascade of falling dominoes. A single misshapen protein can infect a new body and trigger a new domino run. The consequence is death from spongy holes in the brain, because the protein in its alternative shape cannot do its normal job. (55)

Light waves travel so fast that we notice the Doppler shift only if we are moving very fast towards the source of light (in which case the light is shifted towards the blue end of the spectrum) or away from it (in which case the light is red-shifted). This is true of distant galaxies. The fact that they are fast receding from us was first discovered because of the

Doppler shift in their light. It is redder than it should be, shifted consistently towards the longwave, red end of the spectrum. (59)

When we look at a distant galaxy, we are looking far back into the past, for the light has taken billions of years to reach us. It has become faint, which is how we know it has come a great distance. The speed with which our galaxy is racing apart from the other galaxy has had the effect of shifting the spectrum towards the red end. The relationship between distance and velocity of receding is a lawful one […]. By extrapolating this quantitative relationship backwards we can estimate when the universe began expanding. Using the language of the now prevailing 'Big Bang' theory, the universe began in a gigantic explosion between ten billion an d20 billion years ago. […] Further developments of the theory, supported by all available evidence, suggest that time itself began in this mother of all cataclysms. You probably don't understand, and I certainly don't, what it can possibly mean to say that time itself began at a particular moment. But once again that is a limitation of our minds, which were only ever designed to cope with slow, rather large objects of the African savannahs, where events come well behaved and in order, and every one has a before. An event that has no before terrifies our poor reason. (60)

We have never been given any direct reason to suppose that we have company. In very different ways, the possibility that the universe is teeming with life, and the opposite possibility that we are totally alone, are equally exciting. (63)

CHAPTER 4 – BARCODES ON THE AIR

[Sound waves] are waves of compression and rarefaction (thickening and thinning) of the medium. In air, this means waves of increasing and then decreasing local barometric pressure. Our ears are tiny barometers capable of tracking high-speed rhythmic changes of pressure. Insect ears work in another way entirely. (66)

Suppose we sound one tuning fork with an oscillating frequency of 440 cycles per second, or 440 Hertz (Hz). We shall hear a pure tone, the A above middle C. What is the difference between this and a violin playing the same A, a clarinet playing the same A, and oboe, a flute? The answer is that each instrument includes admixtures of waves whose frequencies are various multiples of the fundamental frequency. Any instrument playing the A above middle C will deliver most of its sound energy at the fundamental frequency, 440 Hz, but superimposed will be traces of vibration at 880 Hz, 1320 Hz and so on. These are called harmonics, although the word can be confusing since 'harmonies' are chords of several notes that we hear as distinct. A 'single' trumpet note is actually a mixture of harmonics, the particular mixture being a kind of trumpet 'signature' that distinguishes it from, say, a violin playing the 'same' note. (71)

Since 1736, the Hudson's Bay Company kept records of the abundance of pelts brought in by Canadian fur trappers. […] The figures rise and fall in complicated mixtures of rhythms, which have been much analysed. Among the wavelengths that have been pulled out by these analyses is a prominent one of approximately four-year periodicity, and another of around 11 years. One hypothesis that has been suggested to account for the

four-year rhythms is a time-lagged interaction between predators and prey (a glut of prey feeds a plague of predators, who then nearly wipe our the prey; this in turn starves the predators, then the consequent drop in predator population allows a new boom in the prey population, and so on). As for the longer rhythm of 11 years, perhaps the most intriguing suggestion connects it with sunspots activity, which is known to vary on an approximately 11-year cycle. How the sunspots affect animal populations is open to discussion. Perhaps they change the earth's weather, which affects abundance of plan food. (74)

Perhaps the longest wavelength picked up by the unweaving of biological rhythms is a suggested 26-million-year cycle of mass extinctions. Fossil experts recon that more than 99 percent of the species that have ever lived have become extinct. Fortunately, the rate of extinction is, over the long term, roughly balanced by the rate at which new species are formed by the splitting of existing ones. […] Probably the worst of the bad times, the most devastating Armageddon, occurred at the end of the Permian era, about a quarter of a billion years ago. Around 90 per cent of all species became extinct in that terrible time, including on land many mammal-like reptiles. Earth's fauna eventually bounced back on to the denuded stage, but with a very different cast list: on land the dinosaurs stepped into the range of costumes left dead mammal-like reptiles. The next largest mass extinction – and the most talked-about – is the famous Cretaceous extinction of 65 million years ago, in which all the dinosaurs, and many other species with them both on land and in the sea, were wiped out, instantaneously as far as the fossil record can tell. In the Cretaceous event, perhaps 50 percent of all species went extinct, not as many as in the Permian but nevertheless this was a fearful global tragedy. Once again, our planet's devastated fauna bounced back and here we are, we mammals, descended from a few fortunate relicts of the once rich mammal-like reptile fauna. Now we, together with the birds, fill gaps left by the dead dinosaurs. Until, presumably, the next great extinction. (75-76)

Perhaps the suggested 26-million-year cycle of mass extinction is caused by a rhythmic boost in the rate of comet strikes. But why should comets become more likely to hit us every 26 million years? […] It has been suggested that the sun has a sister star, and the two orbit each other with a periodicity of about 26 million years. This hypothetical binary partner, which has never been seen but which has nevertheless been given the dramatic name Nemesis, passes, once per orbital rotation, through the so-called Oort Cloud, the belt of perhaps a trillion comets which orbits the sun beyond the planets. (77)

The vocal 'cords' are really a pair of membranes which vibrate together in the breathing passage like a pair of woodwind reeds. Consonants are produced as more or less explosive interruptions of the air flow, caused by closure and contact of the lips, teeth, tongue and back of throat. Vowels vary in the same kind of way as trumpets differ from oboes. We make different vowel sounds rather as a trumpeter moves a mute in and out, to shift the preponderant sine waves summing into the composite sound. Different vowels have different combinations of harmonics above the fundamental frequency. The fundamental frequency itself, of course, is lower for men than for women and children, yet male vowels sound similar to the corresponding female vowels because of the pattern of harmonics. (77)

There is experimental evidence from measuring the hormone levels of female doves and canaries, as well as their behaviour, that the sexual state of females is directly influenced by the vocalizations of males, the effects being integrated over a period of days. The sounds from a male canary flood through the female's ears into her brain where they have an effect that is indistinguishable from one that an experimenter can procure with a hypodermic syringe. The male's 'drug' enters the female through the portals of her ears rather than through a hypodermic, but this difference does not seem particularly telling. […] [A] young male songbird teaches himself to sing by practicing; matching up fragments of trial song against a 'template' in his brain, a pre-programmed notion of what the song of his species 'ought' to sound like. In some species […] the template is build in, programmed by the genes. In other species […] it is derived from a 'recording' of another male's song, made early in the young male's life from listening to an adult. (80)

CHAPTER 5 – BARCODES AT THE BAR

[L]awyers in the United States have been knows to use the following reason for striking down potential jurors: the prospective juror is well educated in science, or has some knowledge of genetics or probability theory. What is the problem? […] Wouldn't it be an obviously good thing to have at least one or two people in the jury room who can redress the ignorance of their baffled colleagues? What kid of a lawyer is it who prefers a jury incapable of following the case that either attorney is making? The Answer is a lawyer who is more interested in winning than in seeing justice done. A lawyer, in other words. And it seems to be a fact that advocates, of both prosecution and defense, frequently disallow individual jurors specifically because they are educated in science. (84-85)

[N]umerous studies have shown that eye-witnesses, however convinced they may be, however sincere and well-meaning, frequently misremember even conspicuous details such as the colour of clothing and the number of assailants present. (86)

When we think about how we identify somebody, the face first leaps to mind. We are particularly good at distinguishing faces. […] We even seem to have evolved a special part of the brain set aside for the purpose, and certain kinds of brain damage disable our face-recognition faculty while leaving the rest of vision intact. (87)

It has been suggested that one reason charismatic leaders so often sport moustaches (Hitler, Stalin, Franco, Saddam Hussein, Oswald Mosley) is to make it easier for doubles to impersonate them. Mussolini's shaven head perhaps served the same purpose. (87)

Unlike our face, voice or handwriting, the DNA is most of our cells stays the same from babyhood to old age, and it cannot be altered by training or cosmetic surgery. Our DNA text has such a huge number of letters that we can precisely quantify the expected number shared by, say, brothers or first cousins as opposed to, say, second cousins or random pairs chosen from the population at large. This makes it useful not only for labeling individuals uniquely and matching them to traces such as blood or semen, but for establishing paternity and other genetic relationships. (91)

[F]undamental unit in DNA is the nucleotide base. Since there are 4 possible bases, the information content of each base is equivalent to 2 bits. […] We humans have 3,000 megabases or 6,000 megabits. […] We know from other evidence that, of the 3,000 megabase human genome, only about 2 per cent is actually used for coding protein synthesis. The rest is often called junk DNA. […] The surplus of unused DNA falls into various categories. Some of it looks like a real genetic information, and probably represents old, defunct genes, or out-of-date copies of genes that are still in use. These pseudo-genes would make sense if they were read and translated. […] There is plenty of junk DNA which not only isn't read but wouldn't make any sense if it were. There are huge stretches of repeated nonsense, perhaps repeats of one base, or alternations of the same two bases, or repeats of a more complicated pattern. Unlike the other class of junk DNA, we cannot account for these 'tandem repeats' as outdated copies of useful genes. This repetitive DNA has never been decoded, and presumably has never been of any use. (97-98)

The case of DNA fingerprinting suggests that lawyers would be better lawyers, judges better judges, parliamentarians better parliamentarians and citizens better citizens if they knew more science and, more to the point, if they reasoned more like scientists. This is not only because scientists value reaching the truth above winning a case. Judges, and decision-takers in general, might be better decision-takers if they were more adept in the arts of statistical reasoning and probability assessment. (113)

CHAPTER 6 – HOODWINK'D WITH FAERY FANCY

[In December of 1997 in 'Daily Mail'] the paper's highly paid astrologer tells us that 'slow-moving, powerful Neptune' is about to join 'forces' with the equally powerful Uranus as it moves into Aquarius. […] Note, accordingly, how little it means to say something like 'Neptune moves into Aquarius'. Aquarius is a miscellaneous set of start all at different distances from us which are unconnected with each other except that they constitute a (meaningless) pattern when seen from a certain (not particularly special) place in the galaxy (here). A constellation is not an entity at all, and so not the kind of thing that Neptune, or anything else, can sensibly be said to 'move into'. (115-116)

Because of light's finite speed, when you look at the great galaxy in Andromeda you are seeing it as it was 2.3 million years ago and *Australopithecus* staled the high veldt. You are looking back in time. Shift your eyes a few degrees to the nearest bright star in the constellation of Andromeda and you see Mirach, but much more recently, as it was when Wall Street crashed. The sun, when you witness its colour and shape, is only eight minutes ago. But point a large telescope at the Sombrero galaxy and you behold a trillion suns as they were when your tailed ancestors peered shyly through the canopy and India collided with Asia to rise the Himalayas. A collision on a large scale, between two galaxies is Stephan's Quintet, is shown to us at a time when on earth dinosaurs were dawning and the trilobites fresh dead. (116)

Many, if not most, of the stars our there will be orbited by planets. The numbers are so vast that probably some of them have life forms, some have evolved intelligence and

technology. Yet the distance and times that separate us are so great that thousands of life forms could independently evolve and go extinct without it being possible for any to know of the existence of any other. […] Isaac Asimov has a dramatic illustration: it is as if al the matter of the universe were a single grain of sand, set in the middle of an empty room 20 miles long, 20 miles wide and 20 miles high. Yet, at the same time, it is as if that single grain of sand were pulverized into a thousand million million million fragments, for that is approximately the number of start is the universe. These are some of the sobering facts of astronomy, and you can see that they are beautiful. (117-118)

The vast majority of scientific studies of astrology have yielded no positive results whatever. A (very) few studies have suggested (weakly) a statistical correlation between star 'sign' and character. These few positive results turned out to have an interesting explanation. Many people are so well versed in star sigh lore that they know which characteristics are expected of them. They then have a small tendency to live up to these expectations – not much, but enough to produce the very slight statistical effects observed. A minimal test that any reputable method of diagnosis or divining ought to pass is that or *reliability*. […] Different astrologers, after all, presumably have access to the same books. Even if their verdicts are wrong, you'd think their methods would be systematic enough at least to agree in producing the *same* wrong verdicts! Alas, as shown in a study by G. Dean and colleagues, they don't even achieve this minimal and easy benchmark. (122)

William Thomson, first Lord Kelvin, was one of the most distinguished and influential of nineteenth-century British physicists. He was a thorn in Darwin's side because he 'proved', with massive authority but, as we now know, even more massive error, that the earth was too young for evolution to have occurred. He is also credited with the following three confident predictions: 'Radio has no future'; 'Heavier than air flying machines are impossible'; 'X-rays will prove to be a hoax.' (129)

On 30 August 1938, Orson Wells's still famous radio dramatization of H. G. Wells's The War of the Worlds provoked widespread panic and even some rumoured suicides among listeners who thought its opening scene was – as it purported to be – an authentic news bulletin announcing a Martian invasion. This story is often held up as evidence of the laughable gullibility of the American nation; rather unfairly, I have always thought, for an invasion from outer space is not impossible and, were it to happen, a sudden newsflash on the radio is exactly how we'd probably first hear of it. (137)

As Carl Sagan and others have pointed out, abduction-crazed humanoid aliens seem to be the modern counterpart of seventeenth-century demons and witches. (138)

The adult world may seem a cold and empty place, with no fairies and no Father Christmas, no Toyland or Narnia, no Happy Hunting Ground where mourned pets go, and no angels – guardian or garden variety. But there are also no devils, no hellfire, no wicked witches, no ghosts, no haunted houses, no daemonic possession, no gogeymen or ogres. (142)

True pattern	**Reason difficult to detect**
Sexual intercourse is statistically followed by birth about 266 days later	The exact interval varies around the average of 266 days Intercourse more often than not fails to result in conception. Intercourse is often frequent anyway, so it is not obvious that conception results from that rather than from, say, eating, which is also frequent.
Conception is relatively probably in the middle of a woman's cycle, and relatively improbable near menstruation	See above. In addition, women who don't menstruate don't conceive. This is a spurious correlation which gets in the way and even, to a naïve mind, suggests the opposite is truth.
Smoking causes lung cancer	Plenty of people who smoke don't get lung cancer. Many people get lung cancer who never smoked.
In a time of bubonic plague, proximity to rats, and especially their fleas, tends to lead to infection	Lots of rats and fleas around anyway. Rats and fleas are associated with so many other things, such as dirt and 'bad air', that it is hard to know which of the many correlated factors is the important one. I.e, again, there are spurious correlations that get in the way.

False pattern	**Reason easy to be misled**
Droughts can be brought to an end by a rain dance (or human sacrifice, or sprinkling goats' blood on a ferret's kidneys, or whatever arbitrary custom the particular theology lays down)	Occasionally, rains do chance to follow upon a rain dance (etc.) and these rare lucky strikes lodge in the memory. When the rain dance, say, is not followed by rain, it is assumed that some detail went wrong with the ceremony, or that the gods are angry for some other reason; it is always easy enough to find a sufficiently plausible excuse.
Comets and other astronomical events portend crises in human affairs	See above. Also, it is in the interests of astrologers to foster the myth, just as it is no doubt in the interests of priests and witch-doctors to foster the myths about rain dances and ferrets' kidneys.
After a run of ill-luck, good luck becomes more likely	If bad luck persists, we assume that the run of bad luck hasn't ended yet, and we look forward all the more to its eventual end. If bad luck does not persist, the prophecy is seen as fulfilled. We subconsciously define a 'run' of bad luck in terms of its end. Therefore it obviously has to be followed by good luck

(162)

A skinner box is a simple but versatile piece of equipment for studying the psychology of, usually, a rat or a pigeon. It is a box with a switch or switches let into one wall which the

pigeon (say) can operate by pecking. There is also an electrically operated feeding (or other rewarding) apparatus. The two are connected in such a way that pecking by the pigeon has some influence on the feeding apparatus. In the simplest case, every time the pigeon pecks the key it gets food. Pigeons readily learn the task. So do rats and, in suitably enlarged and reinforced Skinner boxes, so do pigs. (162)

As a Darwinian, I want to suggest that our willingness to be impressed at apparently uncanny coincidence (which is a case of our willingness to see pattern where there is none) is related to the typical population size of our ancestors and the relative poverty of their everyday experience. Anthropology, fossil evidence and the study of other apes all suggest that our ancestors, for much of the past few million years, probably lived in either small roving bands or small villages. Either of these would mean that the number of friends and acquaintances that our ancestors would ordinarily meet and talk to with any frequency was not more than a few dozen. A prehistoric villager could expect to hear stories of starling coincidence in proportion to this small number of acquaintances. If the coincidence happened to somebody not in his village, he wouldn't hear the story. So our brains became calibrated to detect pattern and gasp with astonishment at a level of coincidence which would actually be quite modest if our catchment area of friends and acquaintances had been large. Nowadays, our catchment area is large, especially because of newspapers, radio and other vehicles of mass news circulation. […] The very best and most spine-creeping coincidences have the opportunity to circulate, in the form of bated-breath stories, over a far wider audience than was ever possible in ancestral times. But […] our brains are calibrated by ancestral natural selection to expect a much more modest level of coincidence, calibrated under small village conditions. So we are impressed by coincidences because of a miscalibrated gasp threshold. Our subjective petwhacs [Population of Events That Would Have Appeared Coincidental] have been calibrated by natural selection in small villages, and, as is the case with so much of modern life, the calibration is now out of date. (177)

[E]very time you drink a glass of water you are imbibing at least one molecule that passed through the bladder of Oliver Cromwell. This follows by extrapolation from Wolpert's observation that 'there are many more molecules in a glass of water than there are glasses of water in the sea'. Newton's law that objects stay in motion unless positively stopped is counter-intuitive. So is Galileo's discovery that, when there is no air resistance, light objects fall at the same rate as heavy objects. So is the fact that solid matter, even a hard diamond, consists almost entirely of empty space. (179)

CHAPTER 8 – HUGE CLOUDY SYMBOLS OF A HIGH ROMANCE

All over the world, ceremonies are based upon an obsession with things *representing* other things that they slightly resemble or resemble in one respect. […] To take another common practice, professional rainmakers frequently imitate thunder or lightning, or they conjure a miniature 'homeopathic dose' of rain by sprinkling water from a bundle of twigs. Such rituals can become elaborate and costly in time and effort. Among the Dieri of central Australia, rainmaking wizards symbolically *representative* of ancestor gods, were bled (dripping blood *represents* the long-for rain) into a large hole inside a hut especially

built for the purpose. Two rocks, intended to *stand for* clouds and presage rain, were then carried by the two wizards some 10 or 15 miles away, where they were placed atop a tall tree, to *symbolize* the height of the clouds. Meanwhile, back at the hut, the men of the tribe would stoop low and, without using their hands, charge at the wall and butt their way through with their heads. They continued butting back and forth until the hut was destroyed. The piercing of the walls with their heads *symbolized* the piercing of the clouds and, they believed, released rain from real clouds. As an added precaution, the Great Council of the Dieri would also keep a stockpile of boys' foreskins in constant readiness, because of their homeopathic power to produce rain (do penises not 'rain' urine – sure eloquently evidence of their power?) (181-182)

It is truly appalling (as well as desperately sad) that Rosalind Franklin, whose X-ray diffraction photographs of DNA crystals were crucial to Watson and Crick's success, was not allowed in the common room of her own institution and was therefore debarred from contributing to, and learning from, what might have been crucial scientific shop talk. It also may be true that women typically can bring a point of view to scientific discussions which men typically do not. But 'typically' is not the same thing as 'universally', and the scientific truths that men and women eventually discover (albeit there may be statistical differences in the kinds of research that they are drawn to) will be accepted equally by reasonable people of both sexes, once they have been clearly established by members of either sex. And no, reason and logic are *not* masculine instruments of oppression. (191)

Development is change in the form of a single object, as clay deforms under a potter's hands. Evolution, as seen in fossils taken from successive strata, is more like a sequence of frames in a cinema film. One frame doesn't literally change into the next, but we experience an illusion of change if we project the frames in succession. With this distinction in place, we can quickly see that the cosmos does not evolve (it develops) but technology does evolve (early aeroplanes are not moulded into later ones but the history of aeroplanes, and of many other pieces of technology, falls well into the cinema frame analogy). Clothes fashions, too, evolve rather than develop. (193)

Does time have a directional arrow? Is the driving motor of evolution internal or external? Does evolution proceed gradually or in sudden jumps? (194)

A macromutation is a dramatic error, a change so large that, in extreme cases, its possessor would be classified in a different species from its parents. […] If such a macromutant spawned a new species […] we should describe the abrupt evolutionary origin of the new species as a saltation or evolutionary jump. […] The new species comes into existence in a brief episode of rapid evolutionary change which, although gradual in the sense that parents don't spawn an instant new species in a single generation, is fast enough to look like an instant in the fossil record. The change is spread over many generations so small, step-by-step increments, but it looks like a sudden jump. This is either because the intermediates lived in a different place (say, on an outlying island) and/or because the intermediate stages passed too rapidly to fossilize – 10,000 years is too short to measure in many geological strata, yet it constitutes ample time for quite major evolutionary change to accumulate gradually in small steps. (196-197)

The standard neo-Darwinian view of the evolution of diversity is that a species splits into two when two populations become sufficiently unalike that they can no longer interbreed. Often the populations begin diverging when they chance to be geographically separated. The separation means that they no longer mix their genes sexually and this permits them to evolve in different directions. The divergent evolution might be driven by natural selection (which is likely to push in different directions because of different conditions in the two geographical areas). Or it might consists of random evolutionary drift (since the two populations are not genetically held together by sexual mixing, there is nothing to stop them drifting apart). In either case, when they have evolved sufficiently far apart that they could no longer interbreed even if they were geographically united again, they are defined as belonging to separate species. (200)

[A]s you go back and backing geological time, the gap between any pair of animal groups becomes smaller and smaller. The further back in time you go, the closer you approach the uniting of these different kinds of animals in their single common ancestor species. (201)

A small mutation, representing a minor step away from a parent which has proved its ability to survive by virtue of being a parent, has a good chance of surviving for the same reason, and it may even be an improvement. A gigantic, phylum level mutation is a leap into the wild blue yonder. (206)

CHAPTER 9 – THE SELFISH COOPERATOR

Where common chimpanzees often resort to violence, and even cannibalism, bonobos say it with sex. They seem to copulate in all possible combinations at every conceivable opportunity. Where we might shake hands, they copulate. Make love not war is their watchword. (211)

It is not widely understood that altruism at the level of the individual organism can be a means by which the underlying genes maximize their self-interest. (212)

The genes that exist in many copies in the population are the ones that are good at making copies, which also means good at surviving. […] Surviving in individual bodies in ancestral environments. That means surviving in the environment typical of the species: in a desert for camels, up trees for monkeys, in the deep sea for giant squids, and so on. The reason individual bodies are so good at surviving in their environments is mainly that they have been build by genes that have survived in the same environment for many generations, in the form of copies. […] The genes that survive in camels will, to be sure, include some that are particularly good at surviving in deserts, and they may even be shared with desert rats and desert foxes. But more importantly, environment consisting of the other genes that are typically found in the species. So, the genes of a species become selected to be good at cooperating with teach other. […] It is not the genes of any given individual that cooperate particularly well together before in that combination, for every genome in a sexually reproducing species is unique (with the usual exception of identical twins). It is the genes of a species at large that cooperate, because they have met before,

often, and in the intimately shared environment of the cell, thought always in different combinations. What they cooperate at is the business of making individuals of the same general type as the present one. (213-214)

[G]enes, for all that they are the separate units naturally selected in the Darwinian process, are highly cooperative. Selection favours or disfavours single genes for their capacity to survive in their environment, but the most important part of that environment is the genetic climate furnished by other genes. The consequence is that cooperating suites of genes come together in gene pools. Individual bodies are as unitary and coherent as they are, not because natural selection chooses them as units, but because they are built by genes that have been selected to cooperate with other members of the gene pool. They cooperate specifically in the enterprise of building individual bodies. But it is an anarchistic, 'each gene for itself' kind of cooperation. (217-218)

[T]he forest [is] an anarchistic federation of selfish genes, each selected as being good at surviving within its own gene pool against the background of the environment provided by all the others. (221-222)

Aerobic respiration, an elaborate set of biochemical cycles and chains whereby energy trapped from the sun is released from organic molecules, goes on in the mitochondria, the minute organelles that swarm inside our cells. (225)

The idea of coopting bacteria to perform some difficult biochemical trick has frequently resurfaced in more recent evolution. Deepsea fish have luminous organs to signal to each other and even to find their way about. Rather than undertake the difficult chemical task of making light, they have coopted bacteria that specialize in the skill. The luminous organ of a fish is a bag of carefully cultured bacteria, which give off light as a spin-off from their own biochemical purposes.[…] Not only do animals and plants participate in complicated webs of interaction with each other, and with individuals of other species, in populations and communities like a tropical rainforest or a coral reef. Each individual animal or plant is a community. It is a community of billions of cells, and each one of those billions of cells is a community of thousands of bacteria. I'd go further and say that even a species' 'own' genes are a community of selfish cooperators. (228-229)

At the genetic level all is selfish, but the selfish ends of genes are served by cooperation at many levels. As far as the genes themselves are concerned, the relationships among our 'own' genes are not, in principle, different from the relationship between our genes and mitochondrial genes, or our genes and those of other species. All genes are being selected for their capacity to flourish in the presence of the other genes – of whatever species – whose consequences surround them. Collaboration within gene pools to make complex bodies is often called co-adaptation, as distinct from co-evolution. Co-adaptation usually refers to the mutual tailoring of different bits of the same kind of organism to other bits. (231)

Natural selection, they say, is a purely negative process. It weeds out the unfit. How can such a negative weeding-out play the *positive* role of building up complex adaptation? A large part of the answer lies in a combination of co-evolution and co-adaptation, two process which […] are not so very far apart. Co-evolution, like a human arms race, is a

recipe for progressive build-up of improvements. […] If predators get better at their job, prey have to follow suit just to stay in the same place. And vice versa. The same goes for parasites and hosts. Escalation begets further escalation. This leads to real progressive improvement in equipment for survival, even if it does not lead to improvement in survival itself. […] The other answer is co-adaptation, the mutual evolution of genes in the *same* gene pool. In the cheetah gene pool, carnivorous teeth work best with carnivorous guts and carnivorous habits. Herbivorous teeth, guts and habits form an alternative complex in an antelope gene pool. At the gene level […] selection puts together harmonious complexes, *not* by choosing whole complexes but by favouring each part of the complex within gene pools that are dominated by the other parts of the complex. (232-233)

CHAPTER 10 – THE GENETIC BOOK OF THE DEAD

In mammals, Y chromosomes are found only in males and do not exchange genes with other chromosomes. […] Male mammals have one X chromosome (inherited from the mother, plus one Y chromosome inherited from the father), while females have two X chromosomes (one from each parent). (236)

A gene will have spent more than its fair share of time in ancestral bodies that possess whatever qualities the gene encodes – long legs, thick horns, or whatever it may be especially if it is a dominant gene. Almost as obviously, all genes are likely to have spent more of their ancestral time in successful than in unsuccessful bodies. […] If, like some deer, seals and monkeys, the species is one in which the males form dominance hierarchies and dominant males do most of the reproducing, it will follow that the genes of the species will have more experience of dominant male bodies than of subordinate ones. (237)

Seals have some of the most harem-dominated societies in the animal kingdom. In some populations, more than 90 per cent of the copulations are achieved by fewer than 10 per cent of the males. The bachelor majority of males, while biding their time awaiting their moment to depose one of the harem-bossing bulls, are alert for opportunities to sneak copulations with temporarily unguarded females. But, for such an alternative male strategy to have been favoured by natural selection, there must be at least a significant trickle of genes that have sneaked down the generations via stolen copulations. […] At least some genes record subordinate males in their ancestral experience. (238)

The species changes over evolutionary time. In any one generation, of course, the species consists of the set of its individual members alive at that time. Obviously this set changes as new members are born and old members die. This change in itself does not deserve to be called benefiting from experience, but the statistical distribution of genes in the population may systematically move in some specified direction, and that is ‘species experience’. If an ice age is creeping up, more and more individuals will be seen to have thick hairy coats. Those individuals that happen to be the hairiest in any one generation tend to contribute more than their fair share of offspring, and hence genes for hairiness, to the next generation. The set of genes in the whole population – and therefore the

genes likely to the direction of more and more genes for hairiness. The same thing is going on for other kinds of genes. As the generations go by, the whole set of genes of a species – the gene pool – is carved and whittled, kneaded and shaped, so that it becomes good at making successful individuals. It is in this sense that I say that the species is learning from its experience in the art of building good individual bodies, and it stores its experiences in coded form in the set of genes in the gene pool. Geological time is the timescale over which species become experienced. The information that the experience packs away is information about ancestral environments and how to survive them. (239)

If you find an animal's body, a new species previously unknown to science, a knowledgeable zoologist allowed to examine and dissect its every detail should be able to 'read' its body and tell you what kind of environment its ancestors inhabited: desert, rainforest, arctic tundra, temperate woodland or coral reef. The zoologist should also be able to tell you, by reading its teeth and its guts, what it fed on. Flat, millstone teeth and long intestines with complicated blind alleys indicate that it was a herbivore; sharp, shearing teeth and short, uncomplicated guts indicate a carnivore. The animal's feet, its eyes and other sense organs spell out the way it moved and how it found its food. Its stripes or flashes, its horns, antlers or crests, provide a read-out, for the knowledgeable, of its social and sex life. (239)

In most species, including ourselves, both male and female contain most of the genes for being either male or female. The differences lie in which genes are turned on. We al have genes for making penises and genes for making uteruses, regardless of our sex. ('Sex' is correct, by the way, not 'gender'. Gender is a grammatical technical term, applied to words not creatures. In German, a girl's gender is neuter but her sex female. Amerindian languages typically have two genders, animate and inanimate. The association of gender with sex in some groups of languages is incidental. It is quite a good joke that the politically inspired euphemism – saying gender when you mean sex – is consequently a piece of Western imperialism). (246)

Ants, termites and other social insects species […] have sterile workers, often divided into several 'castes' – soldiers, media (middle-sized) workers, minor (small) workers, and so on. Every worker, whatever its caste, contains the genes that could have turned it into any other caste. Different sets of genes are switched on under different rearing conditions. It is by regulating these rearing conditions that the colony engineers a useful balance of different castes. Often the differences among castes are dramatic. In the Asian ant species *Pheidologeton diversus*, the large worker caste (specialized for bulldozing smooth paths for other colony members) is 500 times heavier than the small caste, who do all the normal duties or a worker ant. (252-253)

Mice and rats have been described as animal weeds. […] They are generalists, opportunists, carrying genes that helped their ancestors to survive through probably a considerable range of ways of life; and pre-agricultural genes are in them yet. […] From earlier still, the DNA of all mammals must describe aspects of very ancient environments as well as more recent ones. The DNA of a camel was once in the sea, but it hasn't been there for a good 300 million years. It has spent most of recent geological history in deserts, programming bodies to withstand dust and conserve water. Like sandbluffs carved into fantastic shapes by the desert winds, like rocks shaped by ocean waves,

camel DNA has been sculpted by survival in ancient deserts, and even more ancient sea, to yield modern camels. (254)

It has been poetically suggested that the remote marine apprenticeship of all land is reflected in the biochemistry of the blood, which is said to resemble a primeval salt sea. Or the liquid in a reptile's egg has been described as a private pond, relic of the actual ponds in which the larvae of distant, amphibious ancestors would have grown. To the extent that animals and their genes bear such a stamp of ancient history it will be for good functional reason. […] When our remote ancestors lived in the sea, many of our biochemical and metabolic processes became geared to the chemistry of the sea – and our genes became a description of marine chemistry – for functional reasons. But (this is an aspect of our 'selfish cooperator' argument) biochemical processes become geared not only to the external world but to each other. The world to which they became fitted included the other molecules in the body and the chemical processes in which they partook. Thereafter, when remote descendants of these marine animals moved out on to the land and became gradually more and more fitted to a dry, airy world, the old mutual adaptation of biochemical processes to each other – and incidentally to the chemical 'memory' of the sea – persisted. […] Our DNA is a coded description of the worlds in which our ancestors survived. […] We are digital archives of the African Pliocene, even of Devonian seas; walking repositories of wisdom out of the old days. You could spend a lifetime reading in this ancient library and die unsated by the wonder of it. (256)

CHAPTER 11 – REVEAVING THE WORLD

For we are blissfully unaware of what a formidably clever thing we do every second of our waking lives when we see and recognize objects. The sense organs' task of unweaving the physical stimuli that bombard them is easy compared with the brain's task of reweaving an internal model of the world that it can then make use of. (258)

[N]ervous systems exploit the massive redundancy in all sensory information. Redundancy is jargon from the world of information theory, originally developed by engineers concerned with the economics of telephone line capacity. Information, in the technical sense, is surprise value, measured as the inverse of expected probability. Redundancy is the opposite of information, a measure of unsurprisingness, of old-hatitude. Redundant messages or parts of messages are not informative because the receiver, in some sense, already knows what is coming. (259)

Everything that we know about the world outside our skulls comes to us via nerve cells whose impulses chatter like machine guns. What passes along a nerve cell is a volleying of 'spikes', impulses whose voltage is fixed (or at least irrelevant) but whose rate of arriving varies meaningfully. (260)

Most nerve cells are biased to signal changes in the world. […] There might be one class of nerve cells that fire only at the onset of sounds and a different class of cells that fire only when sounds go off. […] Sense organs are set up to signal, economically, the discontinuities in the world; and the brain, assuming correctly that the world doesn't

change capriciously and at random, uses the information to construct an internal virtual reality in which the continuity is restored. (260-261)

[T]he brain constructs a virtual world which is more complete that the picture relayed to it by the senses. The information which the senses supply to the brain is mostly information about edges. But the model in the brain is able to reconstruct the bits between the edges. As in the case of discontinuities in time, an economy is achieved by the elimination – and later reconstruction in the brain – of redundancy. This economy is possible only because uniform patches exist in the world. If the shades and colours in the world were randomly dotted about, no economical remodeling would be possible. Another kind of redundancy stems from the fact that many lines in the real world are straight, or curved in smooth and therefore predictable (or mathematically reconstructable), ways. (262)

In the retina, all the cells along a straight line fire and most of these impulses are redundant. The nervous system economizes by using a single cell to register the line, labeled with its angle. Straight lines are economically specified by their position and direction alone, or by their ends, not by the light value of every point along their length. The brain reweaves a virtual line in which the points along the line are reconstructed. (263)

[T]he set of nervous filters constitutes a kind of summary description of the norm, of the statistical properties of the world in which the animal lives. […] The genes of a species come to constitute a statistical description of the worlds in which its ancestors were naturally selected. Now we see that the sensory coding units with which the brain confronts the environment also constitute a statistical description of that environment. They are tuned to discount the common and emphasize the rate. (265)

Paul MacCready […] in 1985 constructed a half-sized flying replica of the giant Cretaceous pterosaur *Quetzalcoatlus*. This huge flying reptile, with a wingspan comparable to that on a light aircraft, had almost no tail and was therefore highly unstable in the air. John Maynard Smith, who trained as an aero-engineer before switching to zoology, pointed out that this would have given advantages of manoeuverability, but it demands accurate moment-to-moment control of the flight surfaces. Withougt a fast computer to adjust its trim continuously, MacCready's replica would have crashed. The real *Quetzalcoatlus* must have had an equivalent computer in its head, for the same reason. Earlier pterosaurs had long tails, in some cases terminated by what looks like a ping-pong bat, which would have given great stability, at a cost in manoeuverability. It seems that, in the evolution of late, almost tailless pterosaurs like *Quetzalcoatlus*, there was a shift from stable but unmanoeuvrable to manoeuvrable but unstable. The same trend can be seen in the evolution of manmade aeroplanes. (275)

You and I, we humans, we mammals, we animals, inhabit a virtual world, constructed from elements that are, at successively higher levels, useful for representing the real world. Of course, we feel as if we are firmly placed in the real world. […] If it is very good, and the only time we notice it at all is on the rare occasions when it gets something wrong. When this happens we experience an illusion or a hallucination. (275-276)

The British psychologist Richard Gregory […] regards seeing as active process in which the brain sets up hypotheses about what is going on out there, then tests those hypotheses against the data coming in from the sense organs. One of the most familiar of all visual illusions is the Necker cube. The drawing is a two-dimensional pattern of ink on paper. Yet a normal human sees it as a cube. The brain has made a three-dimensional model based upon the two-dimensional patter on the paper. This is, indeed, the kind of thing the brain does almost every time you look at a picture. The flat pattern of ink on paper is equally compatible with two alternative three-dimensional brain models. Stare at the drawing for some seconds and you will see it flip. The facet that had previously seemed nearest to you will now appear farthest. Carry on looking, and it will flip back to the original cube. The brain could have been designed to stick, arbitrary, to one of the two cube models, say the first of the two that it hit upon, even though the other model would have been equally compatible with the information from the retinas. But in fact the brain takes the other option of running each model, or hypothesis, alternately for a few seconds at a time. Hence the apparent cube alternates, which gives the game away. Our brain constructs a three-dimensional model. It is virtual reality in the head. (276)

[F]lies are capable of flicking their head completely upside down. Von Holst and Mittelstaedt succeeded in fixing a fly's head in the inverted position using glue. […] Normally, whenever a fly turns its body, the model in its brain is told to expect a corresponding movement of the visual world. But as soon as it took a step, the wretched fly with its head upside down received data suggesting that the world had moved in the opposite direction to the one expected. It therefore moved its legs further in the same direction in order to compensate. This caused the apparent position of the world ot move even further. The fly ended up spinning round and round like a top, at ever-increasing speed – well, within obvious practical limits. (281)

A brain that is good at simulating models in imagination is also, almost inevitably, in danger of self-delusion. How many of us as children have lain in bed, terrified because we thought we saw a ghost or a monstrous face staring in at the bedroom window, only to discover that it was a trick of the light? […] Our simulation software can also, if we are drugged, or feverish, or fasting, produce hallucinations. Throughout history, people have seen visions of angels, saints and gods; and these have seemed very real to them. Well, of course they *would* seem real. They are models, put together by the normal simulation software. The simulation software is using the same modeling techniques as it uses ordinarily when it presents its continuously updated edition of reality. No wonder these visions have been so influential. […] Remember that all our heads contain powerful and ultra-realistic simulation software. Our simulation software could knock up a ghost or a dragon or a saintly virgin in no time flat. It would be child's play for software of that sophistication. (282)

CHAPTER 12 – THE BALLON OF THE MIND

The brain of any animal has been described as its on-board computer. It does not work in the same way as an electronic computer. It is made from very different components. These are individually much slower, but they work in huge parallel networks so that, by

some means still only partly understood, their numbers compensate for their slower speed, and brains can, in certain respects, outperform digital computers. (286)

One authority has said that the evolution of the human brain over the last million years or so is 'perhaps the fastest advance recorded for any complex organ in the entire history of life'. […] Compared with the skulls of other apes, the modern human skull, at least the bulbous part that houses the brain, has blown up like a balloon. (287)

Australopithecus […] braincase was about the same size as a modern chimpanzee's The main difference between Lucy or Mrs Ples (famous Australopithecines) and a chimpanzee lay not in the brain at all, but in the Australopithecine habit of walking upright on two legs. Chimps only occasionally do. The blowing up of the brain balloon spanned three million years from *Australopithecus* through *Homo habilis*, then *Homo erectus*, through archaic *Homo sapiens* to modern *Homo sapiens*. […] Moore's law states that the capacity of computers of a given physical size doubles every 1.5 years. […] From Lucy to Homo sapiens, brain size has approximately doubled every 1.5 million years. Unlike Moore's law for computers, there is no particular reason to think that the human brain will go on swelling. In order for this to happen, large-brained individuals have to have more children than small-brained individuals. (288-289)

For some reason, many people take grave political offence at the suggestion that some individuals are genetically cleverer than others. But this must have been the case when our brains were evolving, and there is no reason to expect that facts will suddenly change to accommodate political sensitivities. (289)

The atomic bomb is said to depend upon a chain reaction. […] When the unstable nucleus of uranium 235 breaks up, energy is released. Neutrons shooting out from the break-up of one nucleus may hit another and induce it to break up as well, but that is usually the end of the story. Most of the neutrons miss other nuclei and shoot off harmlessly into empty space, for uranium, though one of the densest of metals, is 'really', like all matter, mostly empty space. […] On their own scale, the atomic nuclei in a metal are far more spaced out than gnats in a swarm, and a particle expelled by one decaying atom is quite likely to have a clear run out of the swarm. If, however, you pack in a quantity (the famous 'critical mass') of uranium 235 which is just sufficient to see to it that a typical neutron expelled from any one nucleus is on average likely to hit one other nucleus before leaving the mass of metal altogether, a so-called chain reaction gets going. On average, each nucleus that splits causes another to split, there is an epidemic of atom-splitting, with an exceedingly rapid release of heat and other destructive energy, and the results are only too well known. (290)

In the case of the evolution of the human brain, I suspect that we are looking for something explosive, self-feeding, like the chain reaction of the atomic bomb. […] The appeal of this idea is its power to explain why, among a set of African ape species with chimpanzee-sized brains, one suddenly raced ahead of the others for no very obvious reason. It is as though a random event nudged the hominid brain over a threshold, something equivalent to a 'critical mass', and then the process took off explosively, because it was self-feeding. What might this self-feeding process have consisted of? […] A minor improvement in hardware, perhaps a slight increase in brain size, which would have

gone unnoticed had it not enabled a new software technique which, in turn, unleashed a blossoming spiral of co-evolution? […]

Nobody knows how [language] began. There doesn't seem to be anything like syntax in non-human animals and it is hard to imagine evolutionary forerunners of it. […] Like other species, we have a limited repertoire of basic sound, the phonemes, but we are unique in recombining those sounds, stringing them together in an indefinitely large number of combinations to mean things that are fixed only by arbitrary convention. […] Nobody knows whether our ancestors' language went through a prototype stage with a small vocabulary and a simple grammar before gradually evolving to the present point where all the thousands of languages in the world are very complex. […] A social world in which there is language is a completely different kind of social world from one in which there is not. […] In the new social world where language first burst on the scene, there must have been dramatic natural selection in favour of individuals genetically equipped to exploit the new ways. […] it is almost impossible to overestimate the advantages that could have been enjoyed by individuals able to excel in taking advantage of the new world of language. It is not just that brains became bigger to cope with managing language itself. It is also that the whole world in which our ancestors lived was transformed as a consequence of the invention of speaking. […]

Most of our hominid ancestors have been hunter gatherers. […] They can read patters of footprints, disturbed vegetation, dung deposits and traces of hair to build up a detailed picture of events over a wide area. […] Properly read, such spoors amount to maps and pictures, and it seems to me plausible that the ability to read such maps and pictures might have arisen in our ancestors before the origin of speech in words. […]

[B]allistic movements, such as throwing projectiles at a distant target, make special computational demands on nervous tissue. […] The conquering of this particular problem, perhaps originally for purposes of hunting, equipped the brain to do lots of other important things as a by-product. […] How does the nervous system achieve the feat of releasing the projectile at exactly the right moment, tailored to the speed of arm movement? […] There are other skilled movements, like hammering a nail, which are effectively ballistic, even if the tool or weapon doesn't leave our hand. All the computation has to be done in advance: 'dead reckoning'. […] [The] nervous systems, being slow, […] the whole sequence of [ballistics] […] is programmed in the brain as a pre-recorded list of individual muscle twitch commands, packeted away in the order they are to be released. […] No one timing circuit can achieve the accuracy of a !Kung hunter throwing a spear. […] There must be lots of timing circuits working in parallel, their effects being averaged to reach the final decision of when to release the projectile. […] Having developed a population of timing and sequencing circuits for one purpose, why not turn them to other ends? Language itself relies upon precise sequencing.

[T]he 'meme' [is] a unit of cultural inheritance. […] A meme is […] anything that replicates itself from brain to brain, via any available means of copying. […] Anything that spreads by imitation, as genes spread by bodily reproduction or by viral infection, is a meme. […] An elephant's DNA and a virus's are both 'Copy Me' programmes. The difference is that tone of them has an almost fantastically large disgression: 'Copy me by building an elephant first.' But both kinds of program spread because, in their different ways, they are good at spreading. […] Memes could not spread but for the biologically valuable tendency of individuals to imitate. There are plenty of god reasons why imitation should have been favoured by conventional natural selection working on genes.

Individuals that are genetically predisposed to imitate enjoy a fast track to skills that may have taken others a long time to build up. (292-305)

The individual organism […] is not fundamental to life, but something that emerges when genes, which at the beginning of evolution were separate, warring entities, gang together in cooperative groups, as 'selfish cooperators'. The individual organism is not exactly an illusion. It is too concrete for that. But it is a secondary, derived phenomenon, cobbled together as a consequence of the actions of fundamentally separate, even warring, agents. […] The mind is a collection of fundamentally independent, even warring agents. […] Whether or not these agents are to be identified with memes […] the subjective feeling of 'somebody in there [little man in the brain] may be cobbled, emergent, semi-illusion analogous to the individual body emerging in evolution from the uneasy cooperation of genes. (308-309)

However it began, and whatever its role in the evolution of language, we humans, uniquely among animalkind, have the poet's gift of metaphor: of noticing when things are like other things and using the relation as a fulcrum for our thoughts and feelings. This is an aspect of the gift of imagining. (311)