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The Greatest Show on Earth

Richard Dawkins

About the Book

Charles Darwin, whose 1859 masterpiece *On the Origin of Species* shook society to its core, would surely have raised an incredulous eyebrow at the controversy over evolution still raging 150 years later.

The Greatest Show on Earth is a stunning counter-attack on creationists, followers of 'Intelligent Design' and all those who still question evolution as scientific fact. In this brilliant *tour de force* Richard Dawkins pulls together the incontrovertible evidence that underpins it: from living examples of natural selection to clues in the fossil record; from plate tectonics to molecular genetics.

The Greatest Show on Earth comes at a critical time as systematic opposition to the fact of evolution flourishes as never before in many schools worldwide. Dawkins wields a devastating argument against this ignorance whilst sharing with us his palpable love of science and the natural world. Written with elegance, wit and passion, it is hard-hitting, absorbing and totally convincing.

CONTENTS

THE GREATEST SHOW ON EARTH

THE EVIDENCE FOR EVOLUTION

RICHARD DAWKINS

For Josh Timonen

PREFACE

THE EVIDENCE FOR evolution grows by the day, and has never been stronger. At the same time, paradoxically, ill-informed opposition is also stronger than I can remember. This book is my personal summary of the evidence that the 'theory' of evolution is actually a fact – as incontrovertible a fact as any in science.

It is not the first book I have written about evolution, and I need to explain what's different about it. It could be described as my missing link. *The Selfish Gene* and *The Extended Phenotype* offered an unfamiliar vision[1] of the familiar theory of natural selection, but they didn't discuss the evidence for evolution itself. My next three books,[2] in their different ways, sought to identify, and dissolve, the main barriers to understanding. These books, *The Blind Watchmaker*, *River Out of Eden* and (my favourite of the three) *Climbing Mount Improbable*, answered questions like, 'What is the use of half an eye?' 'What is the use of half a wing?' 'How can natural selection work, given that most mutations have negative effects?' Once again, however, these three books, although they cleared away stumbling blocks, did not present the actual evidence that evolution is a fact. My largest book,[3] *The Ancestor's Tale*, laid out the full course of the history of life, as a sort of ancestor-seeking Chaucerian pilgrimage going backwards in time, but it again assumed that evolution is true.

Looking back on those books, I realized that the evidence for evolution itself was nowhere explicitly set out, and that this was a serious gap that I needed to close. The year 2009 seemed like a good time, it being the

bicentennial year of Darwin's birth and the 150th anniversary of *On the Origin of Species*. Not surprisingly, the same thought occurred to others, and the year has seen some excellent volumes, most notably Jerry Coyne's *Why Evolution is True*, I wrote a highly favourable review of his book in the *Times Literary Supplement*.

The working title under which my literary agent, the visionary and indefatigable John Brockman, offered my book to publishers was *Only a Theory*. It later turned out that Kenneth Miller had already pre-empted that title for his book-length response to one of those remarkable courtroom trials by which scientific syllabuses are occasionally decided (a trial in which he played a heroic part). In any case, I had always doubted the title's suitability for my book, and I was ready to shelve it when I found that the perfect title had been lurking on another shelf all along. Some years ago, an anonymous well-wisher had sent me a T-shirt bearing the Barnumesque slogan: 'Evolution, the Greatest Show on Earth, the Only Game in Town'. From time to time I have worn it to give a lecture with that title, and I suddenly realized that it was ideal for this book even if, in its entirety, it was too long. I shortened it to *The Greatest Show on Earth*. 'Only a Theory', with a precautionary question mark to guard against creationist quote-mining, would do nicely as the heading to Chapter 1.

I have been helped in various ways by many people, including Michael Yudkin, Richard Lenski, George Oster, Caroline Pond, Henri D. Grissino-Mayer, Jonathan Hodgkin, Matt Ridley, Peter Holland, Walter Joyce, Aaron Galonsky, David Noakes, Elisabeth Cornwell, Yan Wong, Will Atkinson, Latha Menon, Christopher Graham, Paula Kirby, Lisa Bauer, Owen Selly, Victor Flynn, Michael Kettlewell, Karen Owens, John Endler, Iain Douglas-Hamilton, Sheila Lee, Phil Lord, Christine DeBlase and Rand Russell. Sally Gaminara and Hilary Redmon, and their teams in

(respectively) Britain and America, have been wonderfully supportive and can-do-ish. On three occasions while the book was going through the final stages of production, exciting new discoveries were reported in the scientific literature. Each time, I diffidently asked if the orderly and complex procedures of publication might be violated to accommodate the new find. On all three occasions, far from grumbling at such disruptive last-minutemanship, as any normal publisher might, Sally and Hilary greeted the suggestion with cheerful enthusiasm and moved mountains to make it happen. Equally eager and helpful was Gillian Somerscales, who copy-edited and collated the book with literate intelligence and sensitivity.

My wife Lalla Ward has once again sustained me with unfailing encouragement, helpful stylistic criticisms and characteristically stylish suggestions. The book was conceived and begun during my last months in the professorship that bears the name of Charles Simonyi, and completed after I retired. In signing off as Simonyi Professor, fourteen years and seven books after our momentous first meeting, I would once again like to express my grateful appreciation to Charles. Lalla joins me in hoping that our friendship will long continue.

This book is dedicated to Josh Timonen, with thanks to him and to the small and dedicated band who originally worked with him to set up RichardDawkins.net. The web knows Josh as an inspired site designer, but that is just the tip of an amazing iceberg. Josh's creative talent runs deep, but the image of the iceberg captures neither the versatile breadth of his contributions to our joint endeavour, nor the warm good humour with which he makes them.

CHAPTER 1

ONLY A THEORY?

IMAGINE THAT YOU are a teacher of Roman history and the Latin language, anxious to impart your enthusiasm for the ancient world – for the elegiacs of Ovid and the odes of Horace, the sinewy economy of Latin grammar as exhibited in the oratory of Cicero, the strategic niceties of the Punic Wars, the generalship of Julius Caesar and the voluptuous excesses of the later emperors. That's a big undertaking and it takes time, concentration, dedication. Yet you find your precious time continually preyed upon, and your class's attention distracted, by a baying pack of ignoramuses (as a Latin scholar you would know better than to say 'ignorami') who, with strong political and especially financial support, scurry about tirelessly attempting to persuade your unfortunate pupils that the Romans never existed. There never was a Roman Empire. The entire world came into existence only just beyond living memory. Spanish, Italian, French, Portuguese, Catalan, Occitan, Romansh: all these languages and their constituent dialects sprang spontaneously and separately into being, and owe nothing to any predecessor such as Latin. Instead of devoting your full attention to the noble vocation of classical scholar and teacher, you are forced to divert your time and energy to a rearguard defence of the proposition that the Romans existed at all: a defence against an exhibition of ignorant prejudice that would make you weep if you weren't too busy fighting it.

If my fantasy of the Latin teacher seems too wayward, here's a more realistic example. Imagine you are a teacher of more recent history, and your lessons on twentieth-century Europe are boycotted, heckled or otherwise disrupted by well-organized, well-financed and politically muscular groups of Holocaust-deniers. Unlike my

hypothetical Rome-deniers, Holocaust-deniers really exist. They are vocal, superficially plausible, and adept at seeming learned. They are supported by the president of at least one currently powerful state, and they include at least one bishop of the Roman Catholic Church. Imagine that, as a teacher of European history, you are continually faced with belligerent demands to 'teach the controversy', and to give 'equal time' to the 'alternative theory' that the Holocaust never happened but was invented by a bunch of Zionist fabricators. Fashionably relativist intellectuals chime in to insist that there is no absolute truth: whether the Holocaust happened is a matter of personal belief; all points of view are equally valid and should be equally 'respected'.

The plight of many science teachers today is not less dire. When they attempt to expound the central and guiding principle of biology; when they honestly place the living world in its historical context – which means evolution; when they explore and explain the very nature of life itself, they are harried and stymied, hassled and bullied, even threatened with loss of their jobs. At the very least their time is wasted at every turn. They are likely to receive menacing letters from parents, and have to endure the sarcastic smirks and close-folded arms of brainwashed children. They are supplied with state-approved textbooks that have had the word 'evolution' systematically expunged, or bowdlerized into 'change over time'. Once, we were tempted to laugh this kind of thing off as a peculiarly American phenomenon. Teachers in Britain and Europe now face the same problems, partly because of American influence, but more significantly because of the growing Islamic presence in the classroom – abetted by the official commitment to 'multiculturalism' and the terror of being thought racist.

It is frequently, and rightly, said that senior clergy and theologians have no problem with evolution and, in many

cases, actively support scientists in this respect. This is often true, as I know from the agreeable experience of collaborating with the then Bishop of Oxford, now Lord Harries, on two separate occasions. In 2004 we wrote a joint article in the *Sunday Times*[1] whose concluding words were: 'Nowadays there is nothing to debate. Evolution is a fact and, from a Christian perspective, one of the greatest of God's works.' The last sentence was written by Richard Harries, but we agreed about all the rest of our article. Two years previously, Bishop Harries and I had organized a joint letter to the then Prime Minister, Tony Blair, which read as follows:

> Dear Prime Minister,
>
> We write as a group of scientists and Bishops to express our concern about the teaching of science in the Emmanuel City Technology College in Gateshead.
>
> Evolution is a scientific theory of great explanatory power, able to account for a wide range of phenomena in a number of disciplines. It can be refined, confirmed and even radically altered by attention to evidence. It is not, as spokesmen for the college maintain, a 'faith position' in the same category as the biblical account of creation which has a different function and purpose.
>
> The issue goes wider than what is currently being taught in one college. There is a growing anxiety about what will be taught and how it will be taught in the new generation of proposed faith schools. We believe that the curricula in such schools, as well as that of Emmanuel City Technology College, need to be strictly monitored in order that the respective disciplines of science and religious studies are properly respected.

Yours sincerely

The Rt Revd Richard Harries, Bishop of Oxford; Sir David Attenborough FRS; The Rt Revd Christopher Herbert, Bishop of St Albans; Lord May of Oxford, President of the Royal Society; Professor John Enderby FRS, Physical Secretary, Royal Society; The Rt Revd John Oliver, Bishop of Hereford; The Rt Revd Mark Santer, Bishop of Birmingham; Sir Neil Chalmers, Director, Natural History Museum; The Rt Revd Thomas Butler, Bishop of Southwark; Sir Martin Rees FRS, Astronomer Royal; The Rt Revd Kenneth Stevenson, Bishop of Portsmouth; Professor Patrick Bateson FRS, Biological Secretary, Royal Society; The Rt Revd Crispian Hollis, Roman Catholic Bishop of Portsmouth; Sir Richard Southwood FRS; Sir Francis Graham-Smith FRS, Past Physical Secretary, Royal Society; Professor Richard Dawkins FRS

Bishop Harries and I organized this letter in a hurry. As far as I remember, the signatories to the letter constituted 100 per cent of those we approached. There was no disagreement either from scientists or from bishops.

The Archbishop of Canterbury has no problem with evolution, nor does the Pope (give or take the odd wobble over the precise palaeontological juncture when the human soul was injected), nor do educated priests and professors of theology. This is a book about the positive evidence that evolution is a fact. It is not intended as an anti-religious book. I've done that, it's another T-shirt, this is not the place to wear it again. Bishops and theologians who have attended to the evidence for evolution have given up the struggle against it. Some may do so reluctantly, some, like Richard Harries, enthusiastically, but all except the woefully uninformed are forced to accept the fact of

evolution. They may think God had a hand in starting the process off, and perhaps didn't stay his hand in guiding its future progress. They probably think God cranked the universe up in the first place, and solemnized its birth with a harmonious set of laws and physical constants calculated to fulfil some inscrutable purpose in which we were eventually to play a role. But, grudgingly in some cases, happily in others, thoughtful and rational churchmen and women accept the evidence for evolution.

What we must not do is complacently assume that, because bishops and educated clergy accept evolution, so do their congregations. Alas, as I have documented in the Appendix, there is ample evidence to the contrary from opinion polls. More than 40 per cent of Americans deny that humans evolved from other animals, and think that we – and by implication all of life – were created by God within the last 10,000 years. The figure is not quite so high in Britain, but it is still worryingly large. And it should be as worrying to the churches as it is to scientists. This book is necessary. I shall be using the name 'history-deniers' for those people who deny evolution: who believe the world's age is measured in thousands of years rather than thousands of millions of years, and who believe humans walked with dinosaurs. To repeat, they constitute more than 40 per cent of the American population. The equivalent figure is higher in some countries, lower in others, but 40 per cent is a good average and I shall from time to time refer to the history-deniers as the '40-percenters'.

To return to the enlightened bishops and theologians, it would be nice if they'd put a bit more effort into combating the anti-scientific nonsense that they deplore. All too many preachers, while agreeing that evolution is true and Adam and Eve never existed, will then blithely go into the pulpit and make some moral or theological point about Adam and Eve in their sermons without once mentioning that, of

course, Adam and Eve never actually existed! If challenged, they will protest that they intended a purely ‘symbolic’ meaning, perhaps something to do with ‘original sin’, or the virtues of innocence. They may add witheringly that, obviously, nobody would be so foolish as to take their words literally. But do their congregations know that? How is the person in the pew, or on the prayer-mat, supposed to know which bits of scripture to take literally, which symbolically? Is it really so easy for an uneducated churchgoer to guess? In all too many cases the answer is clearly no, and anybody could be forgiven for feeling confused. If you don’t believe me, look at the Appendix.

“I still say it’s only a theory.”

Think about it, Bishop. Be careful, Vicar. You are playing with dynamite, fooling around with a misunderstanding that’s waiting to happen – one might even say almost bound to happen if not forestalled. Shouldn’t you take greater care, when speaking in public, to let your yea be yea and your nay be nay? Lest ye fall into condemnation, shouldn’t you be going out of your way to counter that already extremely widespread popular misunderstanding and lend active and enthusiastic support to scientists and science teachers?

The history-deniers themselves are among those that I am trying to reach in this book. But, perhaps more

importantly, I aspire to arm those who are not history-deniers but know some – perhaps members of their own family or church – and find themselves inadequately prepared to argue the case.

Evolution is a fact. Beyond reasonable doubt, beyond serious doubt, beyond sane, informed, intelligent doubt, beyond doubt evolution is a fact. The evidence for evolution is at least as strong as the evidence for the Holocaust, even allowing for eye witnesses to the Holocaust. It is the plain truth that we are cousins of chimpanzees, somewhat more distant cousins of monkeys, more distant cousins still of aardvarks and manatees, yet more distant cousins of bananas and turnips … continue the list as long as desired. That didn't have to be true. It is not self-evidently, tautologically, obviously true, and there was a time when most people, even educated people, thought it wasn't. It didn't have to be true, but it is. We know this because a rising flood of evidence supports it. Evolution is a fact, and this book will demonstrate it. No reputable scientist disputes it, and no unbiased reader will close the book doubting it.

Why, then, do we speak of 'Darwin's *theory* of evolution', thereby, it seems, giving spurious comfort to those of a creationist persuasion – the history-deniers, the 40-percenters – who think the word 'theory' is a concession, handing them some kind of gift or victory?

WHAT IS A THEORY? WHAT IS A FACT?

Only a theory? Let's look at what 'theory' means. The *Oxford English Dictionary* gives two meanings (actually more, but these are the two that matter here).

> **Theory, Sense 1:** A scheme or system of ideas or statements held as an explanation or account of a group of facts or phenomena; a hypothesis that has

> been confirmed or established by observation or experiment, and is propounded or accepted as accounting for the known facts; a statement of what are held to be the general laws, principles, or causes of something known or observed.
>
> **Theory, Sense 2:** A hypothesis proposed as an explanation; hence, a mere hypothesis, speculation, conjecture; an idea or set of ideas about something; an individual view or notion.

Obviously the two meanings are quite different from one another. And the short answer to my question about the theory of evolution is that the scientists are using Sense 1, while the creationists are – perhaps mischievously, perhaps sincerely – opting for Sense 2. A good example of Sense 1 is the Heliocentric Theory of the Solar System, the theory that Earth and the other planets orbit the sun. Evolution fits Sense 1 perfectly. Darwin's theory of evolution is indeed a 'scheme or system of ideas or statements'. It does account for a massive 'group of facts or phenomena'. It is 'a hypothesis that has been confirmed or established by observation or experiment' and, by generally informed consent, it is 'a statement of what are held to be the general laws, principles, or causes of something known or observed'. It is certainly very far from 'a mere hypothesis, speculation, conjecture'. Scientists and creationists are understanding the word 'theory' in two very different senses. Evolution is a theory in the same sense as the heliocentric theory. In neither case should the word 'only' be used, as in 'only a theory'.

As for the claim that evolution has never been 'proved', proof is a notion that scientists have been intimidated into mistrusting. Influential philosophers tell us we can't prove anything in science. Mathematicians can prove things – according to one strict view, they are the only people who

can – but the best that scientists can do is fail to disprove things while pointing to how hard they tried. Even the undisputed theory that the moon is smaller than the sun cannot, to the satisfaction of a certain kind of philosopher, be proved in the way that, for example, the Pythagorean Theorem can be proved. But massive accretions of evidence support it so strongly that to deny it the status of 'fact' seems ridiculous to all but pedants. The same is true of evolution. Evolution is a fact in the same sense as it is a fact that Paris is in the Northern Hemisphere. Though logic-choppers rule the town,[fn1] some theories are beyond sensible doubt, and we call them facts. The more energetically and thoroughly you try to disprove a theory, if it survives the assault, the more closely it approaches what common sense happily calls a fact.

I could carry on using 'Theory Sense 1' and 'Theory Sense 2' but numbers are unmemorable. I need substitute words. We already have a good word for 'Theory Sense 2'. It is 'hypothesis'. Everybody understands that a hypothesis is a tentative idea awaiting confirmation (or falsification), and it is precisely this tentativeness that evolution has now shed, although it was still burdened with it in Darwin's time. 'Theory Sense 1' is harder. It would be nice simply to go on using 'theory', as though 'Sense 2' didn't exist. Indeed, a good case could be made that Sense 2 *shouldn't* exist, because it is confusing and unnecessary, given that we have 'hypothesis'. Unfortunately Sense 2 of 'theory' is in common use and we can't by fiat ban it. I am therefore going to take the considerable, but just forgivable, liberty of borrowing from mathematics the word 'theorem' for Sense 1. It is actually a mis-borrowing, as we shall see, but I think the risk of confusion is outweighed by the benefits. As a gesture of appeasement towards affronted mathematicians, I am going to change my spelling to 'theorum'.[fn2] First, let me explain the strict mathematical usage of theorem, while at the same time clarifying my

earlier statement that, strictly speaking, only mathematicians are licensed to *prove* anything (lawyers aren't, despite well-remunerated pretensions).

To a mathematician, a proof is a logical demonstration that a conclusion necessarily follows from axioms that are assumed. Pythagoras' Theorem is necessarily true, provided only that we assume Euclidean axioms, such as the axiom that parallel straight lines never meet. You are wasting your time measuring thousands of right-angled triangles, trying to find one that falsifies Pythagoras' Theorem. The Pythagoreans proved it, anybody can work through the proof, it's just true and that's that. Mathematicians use the idea of proof to make a distinction between a 'conjecture' and a 'theorem', which bears a superficial resemblance to the *OED*'s distinction between the two senses of 'theory'. A conjecture is a proposition that looks true but has never been proved. It will become a theorem when it has been proved. A famous example is the Goldbach Conjecture, which states that any even integer can be expressed as the sum of two primes. Mathematicians have failed to disprove it for all even numbers up to 300 thousand million million million, and common sense would happily call it Goldbach's Fact. Nevertheless it has never been proved, despite lucrative prizes being offered for the achievement, and mathematicians rightly refuse to place it on the pedestal reserved for theorems. If anybody ever finds a proof, it will be promoted from Goldbach's Conjecture to Goldbach's Theorem, or maybe X's Theorem where X is the clever mathematician who finds the proof.

Carl Sagan made sarcastic use of the Goldbach Conjecture in his riposte to people who claim to have been abducted by aliens.

> Occasionally, I get a letter from someone[2] who is in 'contact' with extraterrestrials. I am invited to 'ask

> them anything’. And so over the years I’ve prepared a little list of questions. The extraterrestrials are very advanced, remember. So I ask things like, ‘Please provide a short proof of Fermat’s Last Theorem’. Or the Goldbach Conjecture … I never get an answer. On the other hand, if I ask something like ‘Should we be good?’ I almost always get an answer. Anything vague, especially involving conventional moral judgements, these aliens are extremely happy to respond to. But on anything specific, where there is a chance to find out if they actually know anything beyond what most humans know, there is only silence.

Fermat’s Last Theorem, like the Goldbach Conjecture, is a proposition about numbers to which nobody has found an exception. Proving it has been a kind of holy grail for mathematicians ever since 1637, when Pierre de Fermat wrote in the margin of an old mathematics book, ‘I have a truly marvellous proof … which this margin is too narrow to contain.’ It was finally proved by the English mathematician Andrew Wiles in 1995. Before that, some mathematicians think it should have been called a conjecture. Given the length and complication of Wiles’s successful proof, and his reliance on advanced twentieth-century methods and knowledge, most mathematicians think Fermat was (honestly) mistaken in his claim to have proved it. I tell the story only to illustrate the difference between a conjecture and a theorem.

As I said, I am going to borrow the mathematicians’ term ‘theorem’, but I’m spelling it ‘theorum’ to differentiate it from a mathematical theorem. A scientific theorum such as evolution or heliocentrism is a theory that conforms to the Oxford dictionary’s ‘Sense 1’.

> [It] has been confirmed or established by observation or experiment, and is propounded or accepted as accounting for the known facts; [it is] a statement of what are held to be the general laws, principles, or causes of something known or observed.

A scientific theorum has not been – cannot be – proved in the way a mathematical theorem is proved. But common sense treats it as a fact in the same sense as the 'theory' that the Earth is round and not flat is a fact, and the theory that green plants obtain energy from the sun is a fact. All are scientific theorums: supported by massive quantities of evidence, accepted by all informed observers, undisputed facts in the ordinary sense of the word. As with all facts, if we are going to be pedantic, it is undeniably possible that our measuring instruments, and the sense organs with which we read them, are the victims of a massive confidence trick. As Bertrand Russell said, 'We may all have come into existence five minutes ago,[3] provided with ready-made memories, with holes in our socks and hair that needed cutting.' Given the evidence now available, for evolution to be anything other than a fact would require a similar confidence trick by the creator, something that few theists would wish to credit.

It is time now to examine the dictionary definition of a 'fact'. Here is what the *OED* has to say (again there are several definitions, but this is the relevant one):

> **Fact:** Something that has really occurred or is actually the case; something certainly known to be of this character; hence, a particular truth known by actual observation or authentic testimony, as opposed to what is merely inferred, or to a conjecture or fiction; a datum of experience, as

> distinguished from the conclusions that may be based upon it.

Notice that, like a theorum, a fact in this sense doesn't have the same rigorous status as a proved mathematical theorem, which follows inescapably from a set of assumed axioms. Moreover, 'actual observation or authentic testimony' can be horribly fallible, and is over-rated in courts of law. Psychological experiments have given us some stunning demonstrations, which should worry any jurist inclined to give superior weight to 'eye-witness' evidence. A famous example was prepared by Professor Daniel J. Simons at the University of Illinois.[4] Half a dozen young people standing in a circle were filmed for 25 seconds tossing a pair of basketballs to each other, and we, the experimental subjects, watch the film. The players weave in and out of the circle and change places as they pass and bounce the balls, so the scene is quite actively complicated. Before being shown the film, we are told that we have a task to perform, to test our powers of observation. We have to count the total number of times balls are passed from person to person. At the end of the test, the counts are duly written down, but – little does the audience know – this is not the real test!

After showing the film and collecting the counts, the experimenter drops his bombshell. 'And how many of you saw the gorilla?' The majority of the audience looks baffled: blank. The experimenter then replays the film, but this time tells the audience to watch in a relaxed fashion without trying to count anything. Amazingly, nine seconds into the film, a man in a gorilla suit strolls nonchalantly to the centre of the circle of players, pauses to face the camera, thumps his chest as if in belligerent contempt for eye-witness evidence, and then strolls off with the same insouciance as before (see here). He is there in full view for nine whole seconds – more than one-third of the film – and

yet the majority of the witnesses never see him. They would swear an oath in a court of law that no man in a gorilla suit was present, and they would swear that they had been watching with more than usually acute concentration for the whole 25 seconds, precisely because they were counting ball-passes. Many experiments along these lines have been performed, with similar results, and with similar reactions of stupefied disbelief when the audience is finally shown the truth. Eye-witness testimony, 'actual observation', 'a datum of experience' – all are, or at least can be, hopelessly unreliable. It is, of course, exactly this unreliability among observers that stage conjurors exploit with their techniques of deliberate distraction.

The dictionary definition of a fact mentions '*actual observation* or authentic testimony, as opposed to *what is merely inferred*' (emphasis added). The implied pejorative of that 'merely' is a bit of a cheek. Careful inference can be more reliable than 'actual observation', however strongly our intuition protests at admitting it. I myself was flabbergasted when I failed to see the Simons gorilla, and frankly incredulous that it had really been there. Sadder and wiser after my second viewing of the film, I shall never again be tempted to give eyewitness testimony an automatic preference over indirect scientific inference. The gorilla film, or something like it, should perhaps be shown to all juries before they retire to consider their verdicts. All judges too.

Admittedly, inference has to be based ultimately on observation by our sense organs. For example, we use our eyes to observe the printout from a DNA sequencing machine, or from the Large Hadron Collider. But – all intuition to the contrary – direct observation of an alleged event (such as a murder) as it actually happens is not necessarily more reliable than indirect observation of its consequences (such as DNA in a bloodstain) fed into a well-constructed inference engine. Mistaken identity is more

likely to arise from direct eye-witness testimony than from indirect inference derived from DNA evidence. And, by the way, there is a distressingly long list of people who have been wrongly convicted on eye-witness testimony and subsequently freed – sometimes after many years – because of new evidence from DNA. In Texas alone, thirty-five condemned people have been exonerated since DNA evidence became admissible in court.[5] And that's just the ones who are still alive. Given the gusto with which the State of Texas enforces the death penalty (during his six years as Governor, George W. Bush signed a death warrant once a fortnight on average),[6] we have to assume that a substantial number of executed people would have been exonerated if DNA evidence had been available in time for them.

This book will take inference seriously – not *mere* inference but proper scientific inference – and I shall show the irrefragable power of the inference that evolution is a fact. Obviously, the vast majority of evolutionary change is invisible to direct eye-witness observation. Most of it happened before we were born, and in any case it is usually too slow to be seen during an individual's lifetime. The same is true of the relentless pulling apart of Africa and South America, which occurs, as we shall see in Chapter 9, too slowly for us to notice. With evolution, as with continental drift, inference after the event is all that is available to us, for the obvious reason that we don't exist until after the event. But do not for one nanosecond underestimate the power of such inference. The slow drifting apart of South America and Africa is now an established fact in the ordinary language sense of 'fact', and so is our common ancestry with porcupines and pomegranates.

We are like detectives who come on the scene after a crime has been committed. The murderer's actions have vanished into the past. The detective has no hope of

witnessing the actual crime with his own eyes. In any case, the gorilla-suit experiment and others of its kind have taught us to mistrust our own eyes. What the detective *does* have is traces that remain, and there is a great deal to trust there. There are footprints, fingerprints (and nowadays DNA fingerprints too), bloodstains, letters, diaries. The world is the way the world should be if this and this history, but not that and that history, led up to the present.

The distinction between the two dictionary meanings of 'theory' is not an unbridgeable chasm, as many historical examples show. In the history of science, theorums often start off as 'mere' hypotheses. Like the theory of continental drift, an idea may even begin its career mired in ridicule, before progressing by painful steps to the status of a theorum or undisputed fact. This is not a philosophically difficult point. The fact that some widely held past beliefs have been conclusively proved erroneous doesn't mean we have to fear that future evidence will always show our present beliefs to be wrong. How vulnerable our present beliefs are depends, among other things, on how strong the evidence for them is. People used to think the sun was smaller than the Earth, because they had inadequate evidence. Now we have evidence, which was not previously available, that shows conclusively that it is much larger, and we can be totally confident that this evidence will never, ever be superseded. This is not a temporary hypothesis that has so far survived disproof. Our present beliefs about many things may be disproved, but we can with complete confidence make a list of certain facts that will never be disproved. Evolution and the heliocentric theory weren't always among them, but they are now.

Biologists often make a distinction between the *fact* of evolution (all living things are cousins), and the *theory* of what drives it (they usually mean natural selection, and

they may contrast it with rival theories such as Lamarck's theory of 'use and disuse' and the 'inheritance of acquired characteristics'). But Darwin himself thought of both as theories in the tentative, hypothetical, conjectural sense. This was because, in those days, the available evidence was less compelling and it was still possible for reputable scientists to dispute both evolution and natural selection. Nowadays it is no longer possible to dispute the fact of evolution itself – it has graduated to become a theorum or obviously supported fact – but it could still (just) be doubted that natural selection is its major driving force.

Darwin explained in his autobiography[7] how in 1838 he was reading Malthus's *On Population* 'for amusement' (under the influence, Matt Ridley suspects,[8] of his brother Erasmus's formidably intelligent friend, Harriet Martineau) and received the inspiration for natural selection: 'Here, then I had at last got a theory by which to work.' For Darwin, natural selection was a hypothesis, which might have been right or might have been wrong. He thought the same of evolution itself. What we now call the fact of evolution was, in 1838, a hypothesis for which evidence needed to be collected. By the time Darwin came to publish *On the Origin of Species* in 1859, he had amassed enough evidence to propel evolution itself, though still not natural selection, a long way towards the status of fact. Indeed, it was this elevation from hypothesis towards fact that occupied Darwin for most of his great book. The elevation has continued until, today, there is no longer a doubt in any serious mind, and scientists speak, at least informally, of the *fact* of evolution. All reputable biologists go on to agree that natural selection is one of its most important driving forces, although – as some biologists insist more than others – not the only one. Even if it is not the only one, I have yet to meet a serious biologist who can point to an alternative to natural selection as a driving force of

adaptive evolution – evolution towards positive improvement.

In the rest of this book, I shall demonstrate that evolution is an inescapable fact, and celebrate its astonishing power, simplicity and beauty. Evolution is within us, around us, between us, and its workings are embedded in the rocks of aeons past. Given that, in most cases, we don't live long enough to watch evolution happening before our eyes, we shall revisit the metaphor of the detective coming upon the scene of a crime after the event and making inferences. The aids to inference that lead scientists to the fact of evolution are far more numerous, more convincing, more incontrovertible, than any eye-witness reports that have ever been used, in any court of law, in any century, to establish guilt in any crime. Proof beyond reasonable doubt? *Reasonable* doubt? That is the understatement of all time.

[fn1] Not my favourite Yeats line, but apt in this case.
[fn2] For the sake of decorum / Pronounce it theorum.

CHAPTER 2

DOGS, COWS AND CABBAGES

WHY DID IT take so long for a Darwin to arrive on the scene? What delayed humanity's tumbling to that luminously simple idea which seems, on the face of it, so much easier to grasp than the mathematical ideas given us by Newton two centuries earlier – or, indeed, by Archimedes two millennia earlier? Many answers have been suggested. Perhaps minds were cowed by the sheer time it must take for great change to occur – by the mismatch between what we now call geological deep time and the lifespan and comprehension of the person trying to understand it. Perhaps it was religious indoctrination that held us back. Or perhaps it was the daunting complexity of a living organ such as an eye, freighted as it is with the beguiling illusion of design by a master engineer. Probably all those played a role. But Ernst Mayr, grand old man of the neo-Darwinian synthesis, who died in 2005 at the age of 100, repeatedly voiced a different suspicion. For Mayr, the culprit was the ancient philosophical doctrine of – to give it its modern name – *essentialism*. The discovery of evolution was held back by the dead hand of Plato.[fn1]

THE DEAD HAND OF PLATO

For Plato, the 'reality' that we think we see is just shadows cast on the wall of our cave by the flickering light of the camp fire. Like other classical Greek thinkers, Plato was at heart a geometer. Every triangle drawn in the sand is but an imperfect shadow of the true *essence* of triangle. The lines of the essential triangle are pure Euclidean lines with length but no breadth, lines defined as infinitely narrow and as never meeting when parallel. The angles of the essential triangle really do add up to exactly two right