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IN HOMAGE TO DARWIN

In which we explore Darwin's vision of a cooperative evolution.

In writing this book, we were overwhelmed by the recent deluge of new information about the evolutionary history of our own genus, *Homo*. We consulted an expert colleague, Professor Colin Groves, an authority on human evolution. He asked what our book was to be about. We answered that, in the light of modern discoveries, our aim was to put forward a very different view of Darwin's own, personal approach to evolution. The view of evolution, not Darwin's, usually portrayed in the popular press is of nature, red in tooth and claw, struggling for survival. It gives the impression that Darwin had thought that every living thing was at war with every other living thing. This is incorrect and we wanted to explore the complex dynamic cooperation among all life forms, including ourselves, that Darwin considered a constant theme of evolution.

'Good,' said Professor Groves, 'it's about time someone did'.

We were delighted to have the approval of a respected colleague. It certainly appears that this story is ready to be told.

At a time when the world is being driven by division and confrontation, it is heartening to look more closely at what Darwin has to say. In the last paragraph of his great work, *On the Origin of Species* (1859), Darwin makes an impassioned plea in a way that any man or woman familiar with the countryside could understand:

> It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through

> the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a manner, have all been produced by laws acting around us … There is grandeur in this view of life.

Later, in another great work, *The Descent of Man* (1871), he painted humans into this picture.

There is indeed grandeur in 'this view of life', of an evolutionary process, driven by ever-changing environments and the interactions and collaborations among life forms. The tangled bank is a microcosm, the world writ small. But what is true for tangled banks is true for a single cell or an elephant, for forests and prairies, for tundras and alpine pastures, for farms and cities, for communities and nations. All are subject to the same laws and all interact with adjacent ecological systems until the whole of life is a single operational entity. Humans may have added their social dimensions but the interaction with biophysical laws still applies. Environmental changes have unprecedented feedback systems which we do not yet understand.

The science is clear. The carbon of fossil trees and plants that lived 300 million years ago is now being burned to release carbon dioxide, which is changing the dynamics of the atmosphere. Modern forests, which extract carbon dioxide from the atmosphere and return oxygen in an endless cycle, are being felled or burned at an ever-increasing rate. The temperature is rising. Permafrosts, no longer permanent, are warming to release their greenhouse gases. The poles are melting, releasing floods of fossil water that are affecting ocean currents and influencing the weather (see, for example, Eggleton 2012).

The fabled butterfly that flaps its wings on one side of the globe and causes atmospheric disturbance on the other is hard at work. World ecology is changing and the existence of many plants and animals is threatened by human activities. Human populations are moving around the planet, whether willing or unwilling. Human communities differ on whether to curb industrial processes that bring affluence to some and misery to others.

It is an era of fragmentation – of knowledge, of interests, of politics and, most of all, of world systems. It is more obvious than ever before that humanity, by its ingenuity and ever-increasing population, is largely responsible for these changes. As we write, the need for collaboration

between nations is so strong that it surely demands a new world order, one where an understanding of Darwin's ideas can be as great a service to the twenty-first century as it was to his own.

Charles Darwin was far from the single-minded, conservative patriarch suggested by his public image. Rather, he was an open-minded and courageous risk-taker to the end. At a time when most people believed that the world as a whole was unchangeable, Darwin was brave enough to question that belief. Writing to his friend Joseph Hooker in January 1844, Darwin revealed the extent of his inner conflict between Christian fundamentalism and the open-ended evolution of species. He wrote, 'I am almost convinced (quite contrary to the position I started with) species are not (it is like confessing a murder) immutable'. Fifteen years later, his own conflict resolved, he allowed *On the Origin of Species* to be published and went on to profess an even greater heresy: human beings were also subject to evolutionary change.

Darwin's insights provide the means for us to understand ourselves, how we originated on this planet and even to imagine where we might be going next. He changed the world we live in: away from one specially created by a deity for humans, who were the only intelligent beings, giving them a right to exploit all of creation. We are still coming to terms with a living world whose dynamic systems choose their own direction, and in which all manifestations of life display their own form of intelligence, where humans are only one species among many.

In the years since Darwin, his view of evolution has been distorted by his successors. Even while he was alive, it was variously rendered as 'nature red in tooth and claw', 'survival of the fittest' and 'the struggle for existence', with the emphasis on aggression between species and between individuals of the same species. Of course, individuals of the same species do compete with one another for access to resources – but it is a passive competition, brought about by living in the same geographical space. Generally, species are not at war with each other – even predators are not at war with their prey; they are focused on their own survival. Aggression, however, is a human concept applied erroneously to other living things. Among plants, some are designated as 'weeds'. This too is a human construct. Weeds are not aggressive; they are simply plants optimising their own survival by getting their share of available resources. Unfortunately, humans see them as a threat to the fruits of their labours on farms and gardens that are so far out of ecological equilibrium that

they cannot survive without constant attention. And sadly, humans seem to be the only animals to show purposeful aggression to others of their own species, to the point of systematically killing them. Among animals, lethal aggression is rare, and death, as occasionally occurs when two stags fight over a female, is rare 'collateral damage'. Darwin was, of course, aware of all this at the same time he was writing about the tangled bank.

It is time, 160 years later, to return to a view of evolution as Darwin envisaged it. Looking beyond the microcosm of the tangled bank, we can now see it as a global system of cooperation and mutual aid. Sadly, even well-meaning disciples distorted Darwin's original message. They were Victorians, with minds that were conditioned by the concept of *Rule Britannia* and conquest. The catchphrase 'survival of the fittest', coined by the enthusiastic Herbert Spencer, contributed nothing but a convenient empty and self-referential tag. Who are the 'fittest'? They are those that survive. Who are the survivors? They are the fittest. The British Establishment loved it, for humans were obviously the fittest, as the only intelligent beings, and the British were the fittest of all. An alternative view, 'collaborate and flourish', is a far better description of the course of evolution.

Now imagine that you are a traveller in space and time. With the speed of thought, in an instant that is unhampered by Einstein's Relativity, you can traverse vast distances and cross aeons of time. On your journey through the galaxy, your attention is caught by an unremarkable solar system, out near the edge. It becomes focused on a small stony planet with an iron core, third from its sun, with an atmosphere of carbon and sulphur gases, ammonia and nitrogen but no oxygen. There is nothing remarkable in that.

Lightning is glowing in the upper atmosphere but then something else catches your eye. Under your mental microscope it appears to be almost alive – perhaps it is alive. It is the first cell on the surface of this ball of rock, warmed by the life processes going on within it, and by the sun's energy from without. As the millennia go by, cells come and go; these are the ancient cells, trillions of which persist to this day. Eventually, after enough changes, a new and larger cell, a modern cell, appears. It is the entry point for the remarkable evolutionary journey that Darwin has described and which is taking place around us.

Darwin was very much a product of his century; a young, upper-middle-class man, with an extensive, intellectual and influential family background. There is nothing much in his early years to indicate that his

ideas would change the way in which humanity constructs its concept of the world. His career had begun to unfold along conventional Victorian lines; a mediocre student with an interest in natural history – he was a keen 'beetler', a collector of insects – with probably a good career beckoning in the church. He might reasonably have expected, with his connections, to finish up, one day, as a bishop, with time only to write the odd natural history letter to the Linnean Society.

What set Darwin apart from his particular cohort was the sense of adventure and inquiry that led him to accept the post of naturalist aboard the *Beagle*. He went off the Victorian rails and never regained them, for the voyage of the *Beagle* lasted five years. And it was a critical five years in the life of a young man, starting at his coming of age at 21. This is a period when he is normally being fitted into a productive life within his social set. In fact, Darwin was moulded into another shape entirely – a shape that was about as far away from Victorian convention as one could imagine. He was not, however, the first to consider the changes which created new species. His own grandfather, Erasmus Darwin, had already been laughed at for putting forward the same general principles.

Even before he embarked on the *Beagle* it was apparent that he possessed a great capacity for reason and objective analysis coupled with an ability to set out the logical steps in an argument. A trivial example – or perhaps not so trivial, in view of later events – is the letter in which he carefully lays out his father's objections to his accepting the offer of a post on the *Beagle* (Darwin 1887). His father had agreed to give his permission if Charles could persuade a much-admired uncle that it was a valuable opportunity. Charles drew up a list of the points that he had to refute:

1. Disreputable to my character as a Clergyman hereafter.
2. A wild scheme.
3. That they must have offered it to many others before me, the place of Naturalist.
4. And from its not being accepted there must be some serious objections to the vessel or expedition.
5. That I shall never settle down to a steady life hereafter.
6. That my accommodations will be most uncomfortable.
7. That you should consider it as again changing my profession.
8. That it would be a useless undertaking.

Darwin's careful advocacy prevailed. He obtained the support of the uncle and the world was changed.

To us, now, many of the objections raised by Darwin's father seem rather desperate, a father trying to dissuade a beloved son from undertaking a voyage that could easily end in disaster and death, while at the same time leaving these fears unsaid. Darwin treated each objection seriously, giving them equal weight and showing his capacity for the ordered and organised thinking that was so essential for his future work.

Convincing an uncle was not a particularly complex problem. Unravelling the processes that underlie the structure and distribution of coral reefs was. Simply stated, the problem was to understand how it is that coral forever grows upwards yet always remains at the same depth for optimum growth.

In the modern world view of plate tectonics and an ever-shifting Earth the answer seems obvious; the seabed must sink at the same rate that the coral grows and/or sea levels must rise. This was not so obvious in the mid-nineteenth century, given the state of knowledge then. His thoughts about coral reefs implied a connection between corals and a dynamic Earth that threatened the stability of the conservative world inhabited by Victorians. Darwin published his personal observations and the fruits of his subsequent researches in 1851, in a treatise entitled *Geological Observations on Coral Reefs, Volcanic Islands and on South America*. The section on the structure and distribution of coral reefs is a masterpiece of detailed scientific argument. In turn, he deals with atolls, barrier reefs and fringing reefs and brings them all together in an overarching hypothesis for their formation. Any doubter is buried under a mountain of facts and observations and is left with nowhere to go. This is the technique, compounded of great wisdom, organisation and thoroughness, that he used to such good effect in his great work, *On the Origin of Species*.

Darwin's other great attribute was to so enthuse others about his work that, if he asked for help, they felt privileged and eager to collaborate. In later years, he was beset by a mysterious illness, thought by some to have been due to stress brought on by his 'confessing a murder'. He found it difficult to leave Down House for more than a short time and made up for it by being a prolific correspondent. His letters are a delight to read, often light-hearted, always courteous, always generous, especially with praise for the ideas of others or in his gentle criticisms of them. In particular, he was always very generous and self-deprecating when

dealing with Alfred Russel Wallace, the co-discoverer of natural selection and whose earlier work he admired. The feeling was reciprocated. Darwin would sometimes indulge his exasperation with those who failed to see the point of an argument, but only in letters to close friends in whom he had absolute confidence. In this way he sat at the centre point of a great network of information that was coming to him from admirers and co-workers everywhere on the globe. In many ways he reflected the great phenomenon he was himself illuminating – thriving at the centre of a great system of collaborative work.

Even in Darwin's own lifetime, while he was writing *On the Origin of Species*, and after – he lived for another 23 years – facts corroborating evolution came pouring in. For example, in 1856 Louis Pasteur showed that fermentation is caused by microorganisms – that is, that decay and the return of nutrients to the environment to complete the great cycle of life and death is a function of living things. The 'cell doctrine' of Virchow in 1858 proclaimed that all cells arise from existing cells and sounded the death knell for the belief in spontaneous generation. Mendel's famous experiments on inheritance were published in 1868 but not translated into English until 1900. It is a minor tragedy that Darwin died unaware of them, because he was already thinking about the idea of inheritable 'particles' that he called gemmules. Miescher found and named 'nucleic acids', the important component of Mendel's particles, in the nuclei of cells in 1869. The details of all these pioneers may be found in any good history of biology, such as that of Singer (1959), and the first 40 years of the twentieth century have been summarised by Huxley (1942). It was a further 10 years before the structure of nucleic acid (DNA) was worked out by Watson and Crick (1953).

Thus, in the first half of the twentieth century, support for 'Darwinism', as it was then called, came thick and fast. In 1902, chromosomes were identified as carriers of genetic information, and William Bateson invented the term 'genetics' to describe the new scientific discipline that developed as a consequence. Chromosomes were found to be made up of strings of individual genes (the particles of inheritance). Studies of gene behaviour led to mathematical genetics and at last a sound theoretical basis for Darwin's natural selection was established.

As the century unfolded, more and more information about the various processes and manifestations of Darwin's natural selection accumulated. In 1942, Julian Huxley brought this all together in one great book and

Neo-Darwinism was born. The vast majority of biologists all over the world were now evolutionists. When Oswald Avery, in 1944, showed that DNA carried the hereditary information in a bacterium, attention became focused on DNA and an almost unseemly rush to elucidate its structure ensued. In 1948 Erwin Chargaff showed that, in the structure of DNA, the proportions of the chemical bases guanine (G), cytosine (C), adenine (A) and thymine (T) were rigidly controlled in any organism. Without this knowledge, the publication in 1953 of the famous paper by Watson and Crick that established the helical structure of DNA could not have occurred.

The second half of the twentieth century saw many more scientists at work than ever before in the history of humanity; Darwinism became a flood of such proportions that it is impossible to identify an orderly progression through the years. Here are some highlights.

The DNA code of G, C, A and T base sequences has been worked out, and a new discipline, genomics, is providing seemingly unlimited insights and opportunities. The science of ecology has been put on a formal footing, and out of this has arisen the disciplines of social ecology and social evolution that are so important for understanding humanity. The old, formerly discredited, Lamarckian theory of the inheritance of acquired characteristics, which Darwin did not, in fact, dismiss, has emerged as the new science of epigenetics. It now transpires that changes in DNA can occur during an individual's lifetime and they can be inherited by offspring. Symbiosis, that we might call cooperative biology, is now recognised as a major driver of Darwinian evolution and is the subject of this book.

Darwin clearly recognised the source of the grandeur of his 'tangled bank'; it was the collaboration that connects all the changing forms of life on planet Earth. After Darwin, it is hard to imagine a time when the general belief was of a world that was created some 4,000 years ago and in which all forms of life had remained unchanged since.

The subtitle of *On the Origin of Species* is: 'by means of natural selection or the preservation of favoured races in the struggle for existence'.

While Darwin's writings have proved to be timeless, it is still necessary to take account of the changing times. The term 'races' here would have been interpreted as 'species' or 'families'. In his third chapter he explains that the environment in which living organisms exist is limited and finite.

Members of the same species depend on the same resources. When resources are short, they may be in competition with each other, while one of their survival techniques can be collaboration within and between species.

Darwin is at pains to emphasise that, allowing for this, 'the relation of organism to organism is the most important of all relations' (*Origin*). We can now add to this cell/cell relationships – in a developing embryo, for example many cells 'sacrifice' themselves for the common good by succumbing to a 'programmed cell death'.

The 'struggle' is perhaps best explained by a fable. Imagine that two people swimming in the sea get caught in a rip. Both will struggle to survive but they struggle against the current, not each other. If neither of them is a good swimmer, both may be drowned. However, if one is a good swimmer, that person may be able to save both themself and the other. At some later date the one who was saved may be in a position to drag someone else from a different danger. Interaction can influence which species characteristics are preserved and which are lost, due partly to chance, and partly to the changing state of the environment. Survival rests on connections among the participants and compatibility with the impersonal environment.

On its 'splash page', the Darwin Project (www.thedarwinproject.com), concerned primarily with human evolution, proclaims that 'in the *Descent of Man*, Charles Darwin wrote *only twice* of "survival of the fittest" – but *95 times about* love!' (italics in original). Love is an extreme form of interdependent cooperation displayed by humans and, in some form, perhaps as maternal care, by higher animals.

Pyotr Kropotkin, in his book *Mutual Aid*, describes his observations of wildlife in the harsh climate of Siberia and how he was struck by the many examples of positive interaction that it displayed. He noted that Darwin wrote in *The Descent of Man*:

> … how, in numberless animal societies, the struggle between separate individuals for the means of existence disappears, how struggle is replaced by co-operation, and how that substitution results in the development of intellectual and moral faculties which secure to the species the best conditions for survival.

Darwin *was* the cutting edge of his time and could not possibly have known what we now know. On the other hand, his recognition of the connections between all living things, between life forms and the

environment, and between human beings and the rest of the world, has given us the understanding of the world we have today and the world we may expect tomorrow. He did not make the mistake of expecting the world to stay the same, as his work on coral reefs shows. Evolutionary pressures continue today, with the influence of human social activity triggering greater changes than ever before.

And this is what our book is about: the golden thread of cooperative evolution winds its way through our narrative. A look at its title might suggest to a casual browser that we are joining the authors of the *How Darwin Got It Wrong* genre. Most definitely we are not, although we acknowledge that, occasionally, Darwin fell into error – for example, thinking that evolutionary change is always slow; attempting to explain biological inheritance without knowledge of genes; and limited recognition of the effects of inevitable changes in the environment.

Darwin's genius was to recognise the underlying principle of *natural selection*: uncontrolled reproduction produces more offspring than the environment can bear, so they strive to find ways to a share of scarce resources. Offspring do not exactly resemble their parents. They vary, and this variation is the raw material of evolution. We perceive, by hindsight, those that have turned out to have had, statistically, a better chance of survival are more likely to be those that live long enough to contribute to the next generation. Then the process of selection is repeated. Natural selection is an iterative process; many trillions of repetitions have taken life from the first cell to the blue whale and the human being.

Those who are interested in Darwin's theory of evolution often wish vainly that they could, in the modern idiom, 'channel' the great man himself. Few of us could take this idea further. In 2000, however, in *Dear Mr Darwin*, the late Gabriel Dover started an imaginary correspondence with Darwin – from his last resting place in Westminster Abbey. Darwin, obliging as ever, 'commented' on the discoveries of the last 150 years.

Like Dover, we have tried to imagine what Darwin would have made of the last 150 years of biological discovery. We do this with due homage to Darwin's original vision of a collaborative world, a vision that had become obscured, even in his own time. This book attempts to explain how Darwinian evolution by natural selection works, and where it might go next. It tells stories of cooperation between different organisms with different genetic backgrounds and between organisms that share the same

genetic heritage. It tells of the origin of modern cells, of multicellular organisms, of symbiosis and of social collaboration. Along the way it explores the crucial influence of human interpretations of natural systems, and of solar energy in promoting organisation in the systems through which it flows. Finally, it deals with our own origins and the origins of our social choices.

Evolution thus began when life's first, ancient, cells spread across the globe with all the time in the Solar System at their disposal, probing the Earth, seeking the conditions for their own survival, leaving behind the trail of their explorations inscribed in their DNA – some copies of which you, the reader, still have in your cells. The appearance of the modern cell is the result of the first great act of cooperative evolution between ancient cells. It is the first spinning of the evolutionary threads that are now woven into a planetary phenomenon.

With time, some of these threads intertwine. Complexity increases. Sometimes, however, some seem to stop – removed from an endlessly changing environment to remote ones of great stability. These become the living fossils: the coelacanth, which was common 400 million years ago, survives in the deepest oceans; the recently discovered Wollemi pine is a 200-million-year relict from the old continent of Gondwana. Others turn back on themselves, like the white, blind denizens trapped in the ocean depths or in dark, underground caves. Yet others, disadvantaged by the changing conditions to which it is beyond their capacity to respond, die out. The survivors spread outward; they meet each other and, invigorated by the increased opportunities for cooperation so afforded, diversify and spread further. They encounter obstacles and grow around them, gradually occupying all available livable space, from the top of Everest to the bottom of the Mariana Trench, kilometres above and below the surface of the continents.

Some threads travel through time together, join with other threads to make their own domain of life forms. Some of these are familiar. Animals with backbones or those, like insects, with their skeletons on the outside; plants with cones; plants with flowers; plants that still live in water. Some, like the lichens, or the single-celled Protista, or the surviving colonies of ancient cells, are everywhere and you may never even have noticed them. Eventually, they form a continuous, 3-billion-year-old net of interaction covering the globe. It is everywhere and touches everything. It is the tangled bank writ large.

All organisms that ever lived spend much of their time acquiring sufficient food and other resources and establishing productive relationships with others in their environments. Many find themselves in the right place at the right time, with the right portfolio of attributes, but others are less fortunate. They find themselves in the wrong place, where the appropriate conditions just do not come together in the right way.

Sometimes, although they seem at first to be lucky, they do not form the relationships with others that are necessary for prolonged survival. Frequently, however, an association between two dissimilar kinds becomes a permanent partnership that enhances the chance of their mutual survival; as the algae and fungi that form lichens, or the lions and hyaenas that share the kill on the African veldt – or the interdependent urban and rural modern humans.

It may be that breeding regimes are such that they leave fewer offspring than some of their better-resourced neighbours. Sometimes they survive with help from others of their own kind, like shoals of fish or flocks of birds or prides of lions. In the case of human communities, 'it takes a village to raise a child'. This is our argument: all the great evolutionary successes depended, primarily, on cooperation rather than competition.

The book moves on to explore how Darwinian evolution by natural selection works, and where it might go next. It tells stories of cooperation between different organisms with different genetic backgrounds and between organisms that share the same genetic heritage. It tells of the origin of modern cells, of multicellular organisms and of symbiosis. Along the way it explores the crucial role of solar energy in promoting organisation in the systems through which it flows. Finally, it deals with our own origins and the origins of our society.

The impact of social Darwinism on humanity in all its aspects is beyond the scope of this story, which is about one aspect of the evolutionary process. There is a plethora of books that are concerned with the way the human world changed after the publication of *Origin*. For those interested, we recommend Desmond (1989), Desmond and Moore (1991) and Browne (2003). The website of the Darwin Project is at www.thedarwinproject.com.

We tell the story of cooperative evolution with due homage to Darwin's original vision of a collaborative world that has become obscured. We are so very fortunate to have access to another 150 years' worth of biological research that was not available to Darwin. We have tried, as Gabriel Dover did in his *Dear Mr Darwin*, to imagine what Darwin might have made of it.

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