In the Blink of an Eye

How Vision Sparked the Big Bang of Evolution

ANDREW PARKER

BASIC BOOKS
A Member of the Perseus Books Group
New York

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sequence begins with a flat patch of light-sensitive cells sandwiched between a transparent protective layer and a layer of dark pigment. A graded-index lens appears at stage 6. Reproduced from a 1994 paper by Nilsson and Pelger with permission from the authors.

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Figure 10.2 From left to right: a butterfly wing photographed in black and white through a crystal ler under white plus ultraviolet light; through a crystal lens under ultraviolet light only; and through a glass lens under ultraviolet light only. To the human eye each wing appears black with two blue stripes. These images reveal that the lower stripe also reflects ultraviolet light, which transmits through the crystal lens but is absorbed by the glass lens.

Praise for *In the Blink of an Eye*

"A well-written book, containing much really interesting science and a good strong hypothesis that will surely stimulate others to praise, to criticize and try to refine or replace."

-*Washington Post Book World*

" Parker's research has that pop-science 'wow' factor—dramatic transformations over aeons of time, alien-like life forms, fragments of the secret of our own emergence."

-*Village Voice*

"Compelling."

-*Science News*

"[Parker is a] genius, a cool-headed logician with the soul of an artist. . . . [He] has managed to crack a mystery that evolutionists have fretted over since Darwin first sharpened his quill . . . *In the Blink of an Eye* might very well make him a celebrity."

-*Seed*

"Parker's ideas are fascinating."

-*Boston Globe*

"Parker will have more than a few palaeontologists choking on their cornflakes."

-*New Scientist*

"The outlines of [Parker's] argument are laid out with compelling logic and clarity, and his solution to the Cambrian mystery seems both brilliant and obvious: we must have been blind to miss it."

-*London Sunday Telegraph*

"*In the Blink of an Eye* presents its arguments the way a prosecutor presents a criminal case against the accused in a courtroom melodrama. . . . I don't think you can find a more reader-friendly introduction to evolutionary biology."

-*San Jose Mercury News*

"Full of fascinating scientific lore . . . The flash of unexpected insight that characterizes [Parker's] discovery is of the rarest kind, and with a book like *In the Blink of an Eye*, readers have a chance to share in one of those 'aha!' moments that happen so infrequently in the world of science."

-*Readerville Journal*

"[Parker's] clarity will thrill science fans, as will his revolutionary theory."

-*Booklist*

"Parker's conclusion is both convincing and surprisingly fresh . . . Compelling . . . Cutting-edge science, highly recommended."

-Kirkus (starred review)

"An informative work of easily accessible science."

-Boston Herald

"A young, brash zoologist . . . Parker makes a compelling case."

-San Diego Union Tribune

"An insightful glimpse into the mind of the scientist. . . [A] thought-provoking work."

-Library Journal

"A brilliant and eminently readable evolutionary detective tale . . . Parker's energy and intelligence are undeniable . . . [He] has led us down a remarkable trail and one hopes he has many others to explore."

-Roanoke Times

"[Parker's] central argument certainly deserves careful attention . . . fascinating examples."

-American Scientist

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To my parents

When you have eliminated the impossible, whatever remains, however improbable, must be the truth

SIR ARTHUR CONAN DOYLE, A Study in Scarlet (1887)

Preface

> The case [for the abrupt appearance of Cambrian fossils] at present must remain inexplicable . . . and may be truly urged as a valid argument against the views [on evolution] here entertained
>
> *CHARLES DARWIN, On the Origin of Species (sixth and final edition, 1872)*

The Big Bang in animal evolution was perhaps the most dramatic event in the history of life on Eart During this blink of an eye in such history, all the major animal groups found today evolved hard par and became distinct shapes, simultaneously and for the first time. This happened precisely 543 millio years ago, at the beginning of a period in geological history called the Cambrian, and so has becon known as the 'Cambrian explosion'. But what lit the Cambrian fuse?

Until now, we have been without an acceptable explanation for this extraordinary burst in evolutio - there is strong evidence against all the contending theories put forward. If time is given to consid most previous explanations, it becomes clear that in fact they explain a different evolutionary eve and not the Cambrian explosion, as will be introduced early on in this book. That these two even were once amalgamated had been extremely misleading. In short, we know very well *what* happen during evolution's Big Bang, indeed numerous books have already been written on this question, b we don't know *why* it happened. *Why* it happened is the puzzle this book sets out to solve.

The mention of a 'puzzle' and a 'search for clues' is very appropriate to the story behind t discovery of the *why*, and this book grew naturally into a detective story. After all, this topic wi emerge as real scientific crime. I have spent many years stumbling into different fields of science, a it was while travelling along this uneven road that I ended up at the doorstep of the Cambrian. Almo by themselves, the clues towards a Cambrian theory just kept on accumulating, and eventually, aft there were still no signs of evidence to the contrary, I became satisfied that the 'truth had remained'.

To uncover the real cause of the Cambrian explosion *all* the pieces of the puzzle are needed. Aft introducing the problem in Chapter 1, the following seven chapters of this book will be dedicated the more significant pieces. In the course of these chapters a multidimensional picture will be paint showing how life works today, what happened during the course of evolution on Earth an consequently, how life worked at different times in the geological past. Having been warned that t more technical terms I adopt the smaller my audience will be, I have responded by keeping scientif names and terminology to a minimum. I have tried to use, or even invent, common names of anima wherever possible, and must apologise if this method appears too simplistic or distractin Nonetheless, the most important, recurring scientific terms have necessarily survived the editori process.

By the beginning of the penultimate chapter, all the clues needed to solve the *why* of the Cambri explosion will have been presented. Scientific evidence will be extracted not just from biology, b also geology, physics, chemistry, history and art. Subjects such as eyes, colour, fossils, predator Egyptian statues, the deep sea and coral reefs will be entertained. What was the significance

Maxwell's breakfast or of Newton's peacock to our understanding of evolution? Might they be on par ~~with Charles Doolittle Walcott's monumental discovery of the Cambrian 'Burgess Shale'~~ fossi themselves? I feel that the Cambrian explosion is something worthy of anyone's time, and that th explanation of this event is worthwhile publicising. I hope readers will agree.

My road to the Cambrian was possible only because of some wonderful opportunities presented me, for which I am extremely grateful. In the first place there were Penny Berents and Pat Hutching who offered me my first position at the Australian Museum in Sydney. Here I was lucky enough t spend several years examining living and preserved specimens from every major animal group o Earth - an experience which contrasted greatly with my days studying animal diversity from textbook as an undergraduate. Then there were Jim Lowry and Noel Tait, at the Australian Museu and Macquarie University (Sydney) respectively, who registered my research for a Ph.D. degree, an taught me so much about animal diversity, ecology and evolution. But I also received considerab help and encouragement from many more members of the Australian Museum than I have space to li here. I am grateful to them all.

By now I had chosen to study seed-shrimps as my specialist subject, and received expert tuitio from Lou Kornicker at the Smithsonian Institution (Washington, DC) and Anne Cohen (Los Angele County Museum of Natural History). Their kindness and patience were important to my early caree But, as will be revealed in this book, seed-shrimps led me into a very unexpected and different subje - classical optics.

Michael Land (Sussex University), Sir Eric Denton (Marine Biological Association of the UK Plymouth) and Peter Herring (Southampton Oceanography Centre) in England had produced som inspiring work on optics and colour in animals. It was great to join in their subject, and I thank the for all the help they gave me, and for tolerating my strange enquiries. After training in the subject o animal structural colours I was ready to bother the optical physicists, particularly Ross McPhedra and David McKenzie (following a significant introduction by their colleague, Maryanne Large) Sydney University (although many others gave considerable time to my cause). Thanks to the physicists I quickly became familiar with an otherwise unfamiliar subject from its beginnings. And have found the application of optics to nature quite fascinating.

Looking forwards, sideways, or who knows which direction, I caught a glimpse of the Cambrian was steered around the subject of Cambrian biology by numerous palaeontologists. In particular I a grateful to Greg Edgecombe (Australian Museum), Simon Conway Morris (Cambridge Universit and the late Stephen Jay Gould (Harvard University) for thought-provoking discussions and commen on my work, and Des Collins (Royal Ontario Museum, Toronto, Canada) for the trip of a lifetime the famed 'Burgess Shale' quarry in the Canadian Rockies.

Many of the above people supported my move to Oxford University, and I thank Marian Dawkin and Paul Harvey for making that possible. And then there is the small matter of funding, witho which my research would never have begun. This commenced with research grants from th Australian Museum, Macquarie University and the Smithsonian Institution. Then came mo substantial funding (for three-year projects) from the Australian Biological Research Study t examine seed-shrimp diversity, and from the Australian Research Council to investigate structur colours in animals. Today I am fortunate to hold a Royal Society University Research Fellowshi which frees maximum time for research. That has been a huge help, but has been gratefully topped u with grants from the Engineering and Physical Sciences Research Council and the Natur

Environment Research Council in the UK. Also I am thankful to Somerville College, Oxford, fo making me a Research Fellow as supported by the Ernest Cook Research Fund.

Outside my research career, I have people to thank for their necessary help with this boo specifically. Cathy Kennedy, of the Oxford University Press, taught me the trade of writing for a audience beyond that of my academic peers, and must have been horrified by my first attempts - aft strict scientific conditioning, the popularisation of science is not easy! Peter Robinson of the Curt Brown literary agency in London helped to refine my technique. But it was the editors I worked wit particularly Andrew Gordon in the UK (and Amanda Cook in the US), who after struggling throug early drafts of half-science-half-popular-science, finally transformed my ideas into somethi readable. And I thank Jeremy Day of Day & Co., London, and the American scientist Ronald Watts fo sparking Chapter 10, which may not have happened without their stimulating discussions and intere in my Cambrian ideas.

Finally I thank my parents, other members of my family and a close friend for their continu encouragement and support of my research career.

1

Evolution’s Big Bang

> The explosive evolution during the Cambrian . . . one of the most enigmatic episodes in the history of life
>
> *DEREK BRIGGS, DOUGLAS ERWIN AND FREDERICK COLLIER (1994)*

> The ‘Cambrian explosion’ . . . a pivotal moment in the history of life
>
> *STEPHEN JAY GOULD, Wonderful Life (1989)*

> Why was there a radiation in the Cambrian? Our most sincere answer is that we do not know
>
> *JAN BERGSTRÖM (1993)*

Life as we know it

I have a clear memory of animal diversity classes as an undergraduate. Each week I would open m vintage textbook at a different chapter to find a meaningless black and white line drawing of representative from a new animal group, blending naturally into its background of page creases, i blots and previous students’ scribbles. All in all, the illustrations were hardly more exciting than th thick, blotted stamps of the antediluvian typewriter. They bore no relation to living creatures, n could one separate the extinct from the living.

A few years later I lowered my head under water in anticipatory awe of one of the world’s natur wonders. All I saw was a dark brown cloud. I had come too close to a cuttlefish for its liking. But the ink disappeared I adapted to the blaze of colours that strike the eye from every direction. The va diversity of life forms quickly became apparent in the shallow waters of Australia’s Great Barri Reef. Following my student experiences, I was wholly unprepared for my second introduction animal diversity. The antlers, domes, fans, brains and pipes of corals were the first to manife themselves. Polyps, each only a few millimetres across, are the living parts of corals which stretch o their tentacles to feed at night, appearing like small anemones or even upside-down jellyfish. The hard, supporting limestone structures stretch for over a thousand miles, forming the foundations this famous reef that is visible even from the moon.

Regardless of their external appearance and lifestyles, corals, anemones and jellyfish actual belong to the same higher classification of animals, known as a phylum (plural phyla) because the ~~share the same internal body plan. That is, the organisation of their internal parts - the nutrie~~ processing factories and oxygen transport systems - is similar. Back in the Great Barrier Reef, th complete spectrum of colours present among the corals was paralleled by an almost comple anthology of animal phyla. So began a journey into the unknown. The coral skeleton of the reef w decked out with gardens of sponges, which matched the corals in their diversity of shapes and colour The sponges provided shelter within their water-filled passageways for animals belonging to oth phyla. These lodgers include the bristle worms - a common group of animals that make up a phylu with earthworms and leeches. Some display shimmering opalescent or iridescent colours, like th bizarre-looking sea mouse, a worm whose appearance is best described as a hedgehog with th iridescence of a compact disc.

Sea gooseberries look like transparent variants of their fruit name-sakes, flashing with eig iridescent bands. These alien-like blobs of jelly have an internal body plan like no other group animals and so belong to a phylum of their own - the comb jellies. Starfish are not only obvio during the day but some glow at night with their bioluminescence, emerging from darkness like a extraterrestrial visitor. Starfish are related to common sea urchins and belong to the same phylum animals. Giant clams display fluorescent blues, greens and purples.

KINGDOM: Animalia
PHYLUM: Arthropoda
SUBPHYLUM: Crustacea
CLASS: Malacostraca
ORDER: Isopoda
SUBORDER: Oniscoidea
FAMILY: Porcellionidae
GENUS: Porcellio
SPECIES: scaber

Figure 1.1 The division of life into categories of different levels, using the woodlouse *Porcell scaber* as an example. There are thirty-eight phyla of multicelled animals.

They belong to the mollusc phylum along with another animal rather more infamous for its colour the blue-ringed octopus. During aggressive spells, the blue rings of this small octopus light up to wa of its deadly venom. The less familiar 'moss animals' live in colonies often with unusual shapes an colours, sometimes appearing like the mosses or lichens found on terrestrial rocks. Worms ar ubiquitous but hide a plethora of phyla, such as the 'ribbons', 'peanuts', 'arrows', 'acorns' an flatworms. Ribbon worms, as their name suggests, are ribbon-like in appearance and seem quite plac until they make their presence known with their powerful jaws. Peanut worms are less dangerous an have a swollen rear end. Its similarity to a peanut is questionable, but a brownish colour is the norm The acorn analogy is even less convincing, although arrow worms are more appropriately name Similarly, the flatworms are flat, and some of those capable of swimming by undulating their bodi possess colours that can shock.

Although very few insects are found in the sea, the crustacean representatives from the arthropo phylum are often at their most spectacular on the Great Barrier Reef, and include the crabs, lobste and shrimps. Another phylum that is best known for its terrestrial members is the Chordata. This nam may sound familiar because it is the group containing amphibians, reptiles, birds and mammal including humans. But the fishes of the reef, along with some lesser known animals such as sea squir and lancelets, also belong to this phylum and were once its only members.

Before leaving the water I found, in precisely the same place, the ink culprit, with about thirty of i comrades. The cuttlefish from the mollusc phylum formed an exact arc around me, tentacles to fac eye to eye. Their brown bodies instantaneously bleached as I moved towards them and they a retreated by precisely the same distance. Then their bodies displayed a wave of colour changes. Brov and white synchronised undulations rapidly flowed along the length of their bodies, then suddenly 'loud' red cut into the sequence, followed by a calming green as I retreated. Meanwhile, the regior housing their eyes remained silver, like mirrors.

Understanding the variety of life

The cuttlefish eye shows strong similarities to the human eye. This is an example of the evolutiona biologists' red herring - convergence. From similar basic building materials a comparable organ ha evolved independently to achieve the same function, in two different phyla. But we have learnt it the internal organisation of an animal that defines its phylum, not its external appearance. As we sa with the worms, the worm-like shape is shared by a number of phyla, but these are unrelated becau their internal constructions are very different. If a worm has a mouth but no anus it belongs to th flatworm phylum. Acorn worms are blessed not only with an anus but also a brain and, of importanc a pharynx (the front end of the gut). We also possess an anus, brain and pharynx, but not the bod shape of a worm. Now we can divide the body of any animal into two parts - the innards and the out layers (the 'skin' and 'shells').

The job of an evolutionary biologist is to make sense of the conflicting diversity of form - there not always a relationship between internal and external parts. Early in the history of the subject, became obvious that internal organisations were generally more important to the higher classificatio of animals than are external shapes. The internal organisation puts general restrictions on how a animal can exchange gases, obtain nutrients and reproduce. So we are more closely related to aco worms than to flatworms. Also, acorn worms are more closely related to us than to flatworms. Th complexity of an individual's development from embryo to adult mirrors the sophistication of intern organisation of the adult. To construct an animal with a complex but specific internal organisatio from a collection of just a few cells, a specific method of development is required. As one ca envisage, from a few cells more steps are required to form a human baby with all its intern complexity than a simple jellyfish - an infolded ball of three tissue layers. Now we can examine th reason why internal organisations carry so much weight in animal classification. It is worth taking th time to understand this subject since it forms the backbone of evolution.

The internal organisations, methods of development from embryo to adult and external shapes animals are governed by their genes, the set of instructions carried by the chromosomes within th cells. Copious genes govern internal organisation and development. In contrast, the external shape an animal is generally under the control of considerably fewer genes. But what governs the gen themselves? First we need to take another look at convergence - similarities in external shap between animals with different internal organisations.

By external parts of animals I refer to the materials, colours and shapes of the outer layers. The have a closer association with the environment than do internal organisations. The environme includes physical factors, such as temperature and light conditions, and biological factors, such as th animal neighbours. The external parts of an animal, in particular, must be adapted to its specif environment, and they may do so within broad limits set by the internal body plan. If two animals liv in the same type of environment, they may share comparable external parts, regardless of the internal organisations. This is possible because the external parts are controlled by a relatively sma number of genes, and the chances of those genes mutating to code for the same structures in differe species are not remote. If we roll two dice, the chances of both landing on a six are 36 to 1. Eve though many more than two genetic mutations will be involved in the evolution of external body part single mutations can be retained and accumulated. Consequently if a lamp shell and a razor she which belong to different phyla, live on the same type of sand into which they burrow, but also requi protection from the same predators, it is not surprising that they share a similar external shape possibly an optimal design. But their internal organisations remain very different. Intern organisations are under the control of many more genes, which *all* have to mutate at the same time initiate a new internal body plan. Unlike external architectures, internal body plans cannot be built u gradually because usually they can't function in intermediate stages. This is a monumental differen between the mechanisms that control internal body plans and external parts. A spine on the outside o an animal can begin as a small bump, then pass through intermediate stages from a large bump to long, pointed spine. Importantly, all intermediate stages can exist in their own right because the provide some advantage for their host. But for a change in body plan that involves the abru appearance of blood space, or a sudden flipping upside-down of everything internal, for exampl there can be no intermediate stages. Internal body plans cannot be constructed stepwise, and so a less influenced by the environment. Hence convergence of internal body plans does not occur. If w roll a thousand dice, the chances of them all landing on a six are 1,000,000,000,000,000,000 to 1 extremely improbable.

Charles Darwin and Alfred Russel Wallace were first to realise that evolution, an ever-branchin process, is the mechanism responsible for animal diversity. Because modifications in the physical an biological environments are taking place continuously, species must also change continuously t maintain an optimal design (or as near as possible to it). This is adaptation. So a modification in th environment can be thought of as a pressure on the local animals to change. Hence the term 'selectio pressure' was introduced.

A minor selection pressure may result in a slight modification in a local animal. An animal walkin on the sea floor may develop slightly broader feet to prevent it from sinking if the sand or mu becomes softer. A weighty selection pressure may result in a considerable modification in a loca animal. The introduction of a new food source may lead to the evolution of new mouthparts and limb for movement. A collection of modifications in a population can lead to a new species, all within single phylum. The fewer the modifications between species, the closer their evolutionary relationsh or branching point on the evolutionary tree. Here I have been talking about external characters onl Animal phyla today have unique internal organisations, and a mixture of unique and share (convergent) external characters. But did their internal organisations evolve *in tandem* with the characteristic shapes? And *when* did these both evolve? These questions lead us to the maj evolutionary problem that this book will attempt to solve. They will be asked again a little later in th chapter when, after an exploration of the history of life on Earth, they will be easier to digest.

The Cambrian explosion in brief

Thirty-eight animal phyla have evolved on Earth. So only thirty-eight monumental genetic even have taken place, resulting in thirty-eight different internal organisations. Members of these phy possess a variety of appearances - or external forms - as we have explored on the Great Barrier Ree Think of the protective spines, swimming paddles, burrowing shapes, grasping arms, eyes and colour We have also seen that sometimes the same forms can occur in members from different phy (convergence), but in general each phylum contains a characteristic variety of external forms.

The first fossils from the time 543 to 490 million years ago were found in the Cambrian Hills Wales. Hence this period became known as the ‘Cambrian’ (as named by the great Cambridg geologist Adam Sedgwick). It follows that the time span prior to 543 million years ago is called th Precambrian (the Precambrian can be further divided). What if I stated that, based on extern characters, 544 million years ago there were perhaps three phyla? Most people would picture scenario where the number of phyla simply increased gradually from three to thirty-eight over the pa 544 million years. Along this trail of thought, 320 million years ago there might have been som twenty distinguishable phyla. Such a steady progression involves a type of process known as ‘micr evolution’. Darwin and Wallace thought along these lines.

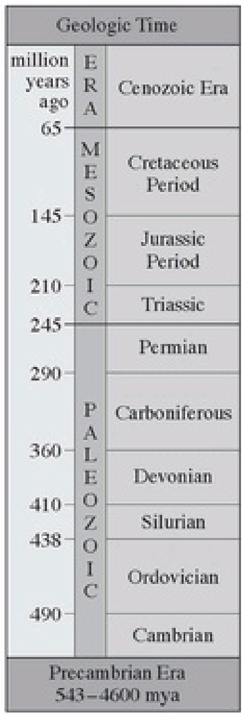

Figure 1.2 The geological timescale and epochs.

Revolutions in evolutionary theory have occurred since Darwin’s time. Now we know that th history of life on Earth has been dominated by long periods of gradual evolution - ‘micro-evolution’ or even a complete standstill. But these periods ended abruptly as they were replaced by ‘macr evolution’ - short but prolific bursts in evolutionary activity, hence a so-called ‘punctuate equilibrium’ model for evolutionary history. Darwin and others of his time cannot be blamed fo overlooking macro-evolution because its discovery was a consequence of twentieth-century foss finds and the development of modern biochemical techniques, encompassing genetics and the biolog of ~~development from embryos to adults. Events that cause macro-evolution include a~~ fast development from embryo to adult form, the development of sexuality in juvenile forms, and th turning on or off of *major* genes.

With all this in mind, I should like to change the facts and state that 544 million years ago the were indeed three animal phyla with their variety of external forms, but at 538 million years ago the were thirty-eight, the same number that exists today.[1] In this case the vast diversity of bod architectures observed on the Great Barrier Reef would all have appeared during a five-million-ye interval (some researchers say fifteen), beginning 543 million years ago. In fact such an interpretatio is closer to the truth, and this particular five-million-year interval hosts the subject matter of this boo - the 'Cambrian explosion'. The Cambrian explosion is the evolutionary episode in which all anim phyla attained complex external forms. In other words, it is the event during which animal phy changed from all looking the same to looking different. Now that I have introduced the Cambria explosion, can I end the first chapter of this book here? Unfortunately not. Such a simple descriptio of the spectacular transition in evolution from Precambrian to Cambrian times does not provide a fa description of how today's diversity of life came into being. We cannot consider only the externa appearances of animals but need also to think of their internal body plans. To understand what th Cambrian explosion *really* is, this is essential. Previous explanations of the Cambrian explosion hav been greatly simplified by the definition 'the sudden evolution of all animal phyla'. This flippa approach to the most dramatic event in the history of life is misleading in the extreme, and has led to number of false explanations for the cause of the event. The crux of the problem here is that intern body plans and external parts have been treated collectively, and their evolution is thought to hav occurred simultaneously. This is not true. The Cambrian explosion is all about external body par only. But we have learnt of the great significance of internal body organisations to animal diversi and should study this subject further if only to provide the outside pieces of the jigsaw puzzle to b solved in this book - *what caused the Cambrian explosion?* The story of internal body plan histo takes us deep into the Precambrian.

Up till now we have been measuring time in units of millions if not billions of years. Suc quantities are hard for us to make sense of. We think of ancient history as perhaps a couple o thousand years ago. Ten thousand years would be extremely difficult to conceptualise, a hundre thousand, let alone a million, inconceivable. So hundreds of millions of years of evolution are wa beyond the realms of the most vivid human imagination. If it is of any help, I began to conceptuali one million years after seeing the immense valleys in Hawaii that have been formed by one millio years of running water. These perfectly triangular valleys that terminate at the coast are over 10 metres deep. But a million years ago they did not exist, and the north-west coast of Hawaii had continuous cliff face with a flat top. As volcanoes formed inland, so did streams or small rive terminating at the coast. The action of this running water gradually wore a groove into the surface the ground. And over a million years, water can form a groove 100 metres deep - this is worth thinkin about. During such a time period, and without taking space into account, even outcomes with almo negligible odds can emerge. But only when the process in question can change gradually, where eac step or small change is saved, and the process can then proceed from a new starting point with th change firmly in place. This line of thought will be continued in this chapter with Sir Andre Huxley's criticism of a 'jumbo jet in a junkyard'.