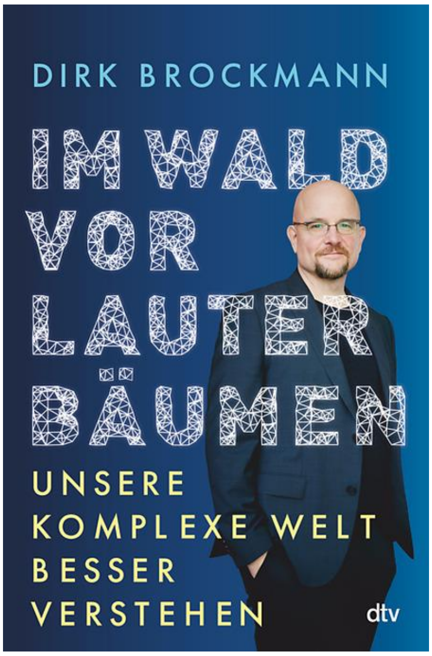

Dirk Brockmann

Do You See the Forest or the Trees? How to better understand our complex world.

240 pages
September 2021
With 80 b/w-illustrations

Stop looking at the trees and see the forest!

Discover hidden patterns in nature and society and what this will tell you about global crisis management: In an interconnected world, we need to think in a networked way and to examine complex phenomena, such as pandemics, climate crises and the destabilization of ecosystems, as parts of a larger whole. Complexity scientist Dirk Brockmann takes a look at the crises of our time, searching for patterns, regularities and similarities between them and the complex processes in nature. In doing so, he draws highly insightful connections – for example, between forest fires and epidemics, and between populism and fish in search of food - and reveals what we can learn from them. Can we save humanity, that is, ourselves? There is hope - if we have the courage to embrace reductionism, think in an anti-disciplinary way, and focus on cooperation.

• An internationally renowned researcher
• A highly topical subject, a novel approach to thinking; fascinatingly illustrated
• For readers of Yuval Noah Harari and Hans Rosling

Dirk Brockmann, born in 1969, is a professor at the Institute of Biology at Berlin's Humboldt University. He is also the head of a research group at the Robert Koch Institute. Previously, he was a professor of applied mathematics at Northwestern University in the US and a researcher at the Northwestern Institute on Complex Systems. He is particularly interested in the structures inherent to complex biological and social networks, and how these structures affect those processes that operate within them.

Sample Translation by Hayley Johns

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Come Together (p. 13 – 21)

The Beatles – Abbey Road

Welcome to this book. So that you know the score from the start: the book's title is meant metaphorically. You're not about to read a book about forests, although you will certainly learn something about them. There were other titles in the running: *Better to be complex than not at all easy*, *Researching like a Mushroom*, *C*, *Complexity*, countless others. In the end, we chose one. I say 'we', because many people with differing perspectives were involved in making this decision. Family, friends, colleagues, my publisher, my editor, my agent. A whole *network* of people worked *collectively, cooperatively, critically* and in *coordination*; sometimes the decision tipped in one direction, and sometimes in another. I had to write the book, however, on my own.

If you have the contents list in front of you, you will have realised that in my previous paragraph, I interwove the central themes of the book's chapters. Complex networks, coordination, criticality, critical tipping points, collective behaviour, cooperation; all concepts which help us to better understand our complex world. To sum it up in one sentence: on the whole, it is about recognising on the one hand similarities between complex natural phenomena, and on the other between complex social processes, joining the dots and learning something from these connections.

That might sound a bit generic and abstract. So let me give you an example. On 15th September 2008, the US investment bank Lehman Brothers filed for bankruptcy. The collapse of one of the biggest banks in history, one of the richest in tradition, formed the epicentre of the global financial crisis which had begun about a year previously, leading to a loss in share values totalling around $400 billion and sending a shockwave through the global economy. Lehman Brothers left behind debts of $200 billion and immediately had to make 25000 employees redundant. Up until that point, investment banks like Lehman Brothers had been deemed 'too big to fail', because the sheer weight of the corporation on the global financial market had been so great that people assumed that state intervention would save such a company from going under, for the consequences would be disastrous. Even today, it is still controversially discussed among industry experts. They debate which factors and mechanisms actually caused this crisis, why nobody had seen it coming, and for what reason the world's most prominent economists, such as Alan Greenspan (chair of the US Federal Reserve until 2006), publicly declared that the current theories, assumptions and methods of economics portray reality in a flawed way. This idea was floated for quite some time, because as early as 2006, two years before the worldwide financial crisis, the US Federal Reserve organised a conference together with the most important American economic colleges, at which scientists and experts from the field of mathematics, physics, ecology and economics got together to consider anew the topic of 'systemic risk' in financial markets, and to learn how to better understand the conditions under which markets might become destabilised or collapse in a short space of time. Ideas, insights and theoretical models from the field of ecology made a significant contribution to this conference. Since the mid-1970s, ecological science had focused on the question of what makes ecological networks so stable. Their stability is, in a way, surely evident through their existence over many hundreds of millions of years. Ecosystems are highly dynamic, strongly interconnected, heterogeneous systems which can quickly adapt to different conditions and, despite often highly disruptive influences, are able to rebalance themselves. At the conference, many insights from ecology were transposed into an economic context and with them, connections between, on the face of it, completely different areas – economics and ecology – were forged. A little while later, in a short article entitled 'The ecology of bankers', the renowned theorists Simon Levin and Robert May (1936-2020) discussed many of these connections.

This book is about these kinds of bridges between apparently unrelated areas or phenomena. Both Simon Levin and Robert May are or were among the most high-profile and influential scientists, who searched for parallels between biological and social phenomena and inspired a whole generation of complexity theorists. One was originally a mathematician, the other a theoretical physicist, but their most important work was published in ecology, epidemiology, social sciences and economics.

Whenever I am asked about my education or my work these days, my answer goes like this: "My background is in theoretical physics." I've given up replying, "I'm a physicist." Why? That is quite straightforward. It's not just about giving the correct information; it is about what people hear when you say it. The right images have to be conjured in the recipients' heads. This is not always the case with the response “I’m a physicist,” because I do not deal with the typical themes of physics. To the subsequent question as to what my specialism is, I mostly reply, “complexity theory,” “complexity,” “complexity studies,” or simply “complex systems.” Then the conversation either dries up, or the person will want to know all about it, in which case, I give them a copy of this book.

Originally, I studied theoretical physics and maths, but today my attitude towards the former is much like that towards the village near Braunschweig in which I was born. I feel an emotional proximity to it, sometimes homesickness for it; I visit regularly but still not often enough. I still know my way around and the skills I learnt growing up there are still there, ready as ever. Just as I physically left my village, I left the field of traditional physics fairly early on. Quite soon, aside from phenomena of pure physics, I found myself particularly interested in those from other disciplines. In my thesis, I wrote about the respiration of mammals, how it is controlled, and so on. From this came my interest in neural networks in the early 1990s, when these were in their infancy and not yet known as Artificial Intelligence (AI) because computers were much too slow. Before I took up a position in biology, though a physicist by training, I was a professor in applied mathematics in the US. Everything was a bit mixed up.

After the neural networks, I occupied myself with saccades. These are our quick, jerky eye movements, such as when we look at an image or read, because we can really only see clearly in the centre of our field of vision. You can test this by moving this book a hand’s breadth to the left or right while keeping your gaze fixed straight ahead and trying to carry on reading. In short, we see almost nothing clearly – we just don’t notice it. ‘It’s all in your head,’ they say; our brains lead us to believe that we are seeing clearly. This is an idea which we will take up again later in the book. If you take a closer look at how people view an image, for example, and trace this with lines, which is how these saccades move across a work, you will be left with a seemingly random scribble. But within this scribble, there are hidden structures, statistical and universal regularities, known as power laws. I’ll come back to these. Our eyes scan an image neither in an orderly manner from top-left to bottom-right (as they do when reading), nor does our focus jump around erratically. Typically, our eyes make a great deal of small saccades and only rarely bigger jumps. This pattern appears in many different places in nature too. If, for example, you were to trace the routes taken by albatrosses in search of food, flying for miles on end across the ocean, or to plot the migrations of the Brazilian spider monkey through the jungle, you would find a pattern of movement which, on the face of it, barely differs from the scribble of the eyes' movement pattern.

This little story explains in two ways why this book came about in any case, and what it is about. On the one hand, it is about seeing, about new perspectives and about how the correct pictures come to be in our heads. Just like with our saccades, we put together a scene we have observed in our heads by focusing one after the other on some elements more clearly (small saccades) and they link and interlace to become a whole (large saccades), so is this book intended to lead you through diverse themes and concepts, revealing links which you perhaps may not have expected. In each chapter, I will give you an account of different phenomena: cooperation, criticality, critical tipping points, complex networks, collective behaviour and coordination. If everything goes according to plan, the image 'nature and society from the perspective of complexity studies' should be automatically revealed in your head, and you will recognise how these topics are interrelated. It's not just the letter 'C' that they have in common.

This book's second concern is that you should be enchanted by the connections and similarities it uncovers between very different social and natural phenomena, and that you should want to understand them. Maybe it's the same for you as it is with me. If you find a connection, a relationship between very different things, this insight has a magical quality, particularly if the connection isn't immediately clear. How can it be that the movement of our eyes has similarities to the movement of albatrosses and spider monkeys? And how do you work out these correlations? Where is the connection? What conclusions can we draw from it?

Back then, when I researched eye movements, I simply wanted to know how we perceive the world around us and compose it in our heads. When it became clear to me that the movement patterns of our eyes were similar to albatrosses' flight paths and that clearly a fundamental law was lying concealed within, I happened upon the idea of measuring humans' patterns of movement. That was in 2004, and back then, there were no smart phones with GPS. Nevertheless, together with my former colleagues, Lars Hufnagel and Theo Geisel, I researched the movement of more than a million bank notes in the US, which were part of the then popular internet game 'Where's George?' (www.wheres-george.com). Lo and behold, even in the movement profiles of people, it became apparent that there was a very similar pattern, one of universal regularities. And so it came about that I came to be so interested in human mobility and the global spread of epidemics via air travel. Modelling the spread of infectious diseases is still an important aspect of my scientific work now and, owing to the spread of the COVID-19 pandemic, it has inevitably returned to the public conscience. What I'll be working on in five years' time, I don't yet know.

Many of my colleagues who also see themselves as complexity scientists have led similarly erratic paths through the scientific disciplines, some of which you will encounter in this book. These routes are not uncommon and, in the very next chapter, you will find out why.

The idea for this book has long simmered within me. For the past five years, I have held a well-attended lecture at Humboldt University's Institute for Biology, entitled 'Complex Systems in Biology'. Students typically come from a background in biology, but also from many other disciplines. Every year, I get the impression that the search for similarities between the most diverse of phenomena and the integrated approach to complexity theory is something that fascinates many people.

The event for me as a university lecturer was a huge challenge because, in order to understand these relationships more deeply, it's helpful to have a solid foundation in mathematics and physics, but I couldn't assume that my students had this. So I considered how it might be possible to convey the subject matter without mathematics. For the lecture, I then designed Complexity Explorables (www.complexity-explorables.org), a collection of interactive, web-based computer simulations which explain different complex systems, such as ecology, biology, social sciences, economics, epidemiology, physics, neuroscience and other areas. If you can't fall back on mathematics, it helps to really 'live' systems and to play with them, so interactive computer simulations can be very useful. It was from this context that the idea for the book grew, one that would make the concept of complexity accessible to the general public.

To my mind, the field of complexity studies already gives us helpful perspectives and insights. In January 2000, the famous physicist Stephen Hawking (1942-2018) was asked in an interview for the new millennium about his predictions for the coming century. He replied, "I think the next century will be the century of complexity." Hawking thought of complexity as a useful approach to understand current developments and to cope in the crises of our time, its core element being to search for similarities and connections, focusing on what things have in common, as well as on very different branches of science. Because natural disasters, globalisation, economic crises, pandemics, the loss of biodiversity, wars, terrorism, the climate crisis, effects of digitisation, and conspiracy theories cannot each be taken in isolation. Not only are these crises already enormously complex and multifaceted in their own right, but they are also highly interconnected with each other.

In order to solve these problems and to better combat current and impending catastrophes, we have to think in a joined-up way. We have to be able to recognise which elements are essential and, much more importantly, which details can be ignored. We have to look for fundamental mechanisms, patterns and regularities. To this end, it's about more than a purely qualitative description of phenomena. The mechanisms, patterns and rules are very useful if they not only help to describe a system, but also to predict how things may react to changes in external conditions. Therefore, complexity theory already offers here an effective addition to traditional scientific strategies. In the chapters that follow, you will encounter many examples from very different areas, whose relationship to each other first becomes discernible in the fundamental rules which underlie them. In a world where you can carry around with you practically the entirety of human knowledge on your smartphone, we can concentrate our thoughts on dynamic relationships, without having to plunge into specific disciplines or silos of knowledge.

You can read this book conventionally, from start to finish. Or chapter by chapter in reverse, that works too. The book itself is actually a network and, like circles, networks have no beginning and no end. Having said that, it is advisable to start with the chapter *Complexity*. You can then read the chapters *Coordination*, *Complex Networks*, *Criticality*, *Critical Tipping Points*, *Collective Behaviour* and *Cooperation* in any order you wish. The book network diagram is a rough guide for its thematic orientation.

Why complexity research is so important today (p. 43 – 47)

Every level of the scientific landscape is traversed by limits, or borders. Similarly to the way that Germany is made up of federal states, and that these in turn are comprised of cities and parishes, which are also divided into separate communities, there is the field of natural sciences, the humanities, politics and many more. The natural sciences fan out into physics, chemistry, biology, ecology, geology and countless others. Teaching and research positions at universities are sometimes so highly specialised that their holders must surely feel confined in terms of subject matter. In this respect, this development is a logical consequence, since more and more knowledge is accumulated in different areas, and it appears almost impossible to know exactly what the current state of research is in even the smallest area. Konrad Lorenz once said that experts know more and more about less and less, until they know everything about nothing. Students specialise very early on and it is becoming ever rarer that they have time to take diversions into other academic areas. It becomes a form of academic provincialism, which is bad news, especially when it comes to understanding complex themes.

Let's come back to the example of the COVID-19 pandemic. Even this phenomenon cannot be understood in isolation with methods or expert knowledge from virology or epidemiology. Psychological processes play a roll, as do mobility and contact networks, human behaviour, political dynamics; everything is interwoven. For this reason, it may seem a good idea at first glance to bring together experts from different specialist areas, to share their knowledge and gain a mutual understanding of which facts must be considered and which elements are influential. Plus – to listen to each other. This is fundamentally useful but also problematic, from time to time, when each party either misunderstands the respective 'language' and mindset of the other disciplines, or cannot comprehend them at all. If you have ever taken part in a discussion with a dozen professors in Germany about a complex interdisciplinary topic, you will know that it is not uncommon for the emphasis to be put on broadcasting rather than receiving – we would rather teach than learn. But in communication, it is not just about transmitting knowledge – it is also about perspectives and ways of thinking. Often this is where worlds collide. 'Focused' academics perceive their small subject area to be 'bigger' and 'more important'. If you consider a complex phenomenon with this attitude, reality becomes distorted. To give a simple example: if you showed a photographer, a perfumier and a politician the same picture of a face, they would probably perceive very different images because of their professions, giving the individual elements of the face different emphasis. These caricatures in our heads are completely natural and are shaped by the things with which we surround ourselves.

To avoid such distortions, it is extraordinarily important, even if you are a specialist, to visit other areas every once in a while, and to take in others' perspectives.

In Germany, the chasm between scientific disciplines and the humanities is particularly deep. There is little communication or transfer between them. Because of this, and because neither party speaks nor understands the language of the 'others', sometimes discoveries are made in one area that the other would be interested in, if only they knew about them.

Happily, though, a small revolution is slowly getting started. More and more researchers are making the connections between the natural and social sciences, extracting common, fundamental mechanisms and universal commonalities which form the basis of totally different phenomena. The field of complexity studies encourages this in particular and does not care for the barriers or caricatures in peoples' heads. This is why it is so important – it builds bridges.

Now, there are several institutes around the world which pursue an antidisciplinary approach and the philosophy of complexity theory, as well as relying on linking traditional disciplines. At the renowned Santa Fe Institute in New Mexico, a diverse team of very different scientists is working together, looking for connections between ecology and economics, between evolutionary processes in nature and linguistics, and between conflict research and collective behaviour in animals. At the Northwestern Institute on Complex Systems in Chicago, at which I myself play a role, I have collaborated on diverse projects with political scientists, social scientists and linguists. In Turin, the Institute for Scientific Interchange was founded, where the topics of digital epidemiology, network research and brain research are carried out under one roof. In Vienna, the Complexity Science Hub was brought to life, with a focus on topics such as health, cryptofinance, science of cities, and econo-physics, all of which are methodically linked together. Complexity had arrived – although evidently late in Germany. Here, we unfortunately haven't yet taken these ideas to heart. Antidisciplinary thinking is still not very popular and is still relatively unknown. There might be cultural reasons for this. Maybe in this country, there are still too many barriers in our heads, the differences still outweighing the similarities. But perhaps now this is changing.

Ecosystems, the climate and tipping points (p. 139 – 145)

The state an ecosystem assumes depends heavily on the stability of climactic conditions. The reverse is also true. Global ecosystems determine and stabilise the climate. If strong changes occur rapidly within ecosystems by crossing tipping points, local climate systems can also be caused to alter. We can understand the climate by thinking of it as a network of dynamic subsystems, such as the Amazon rainforest or ocean currents, which all influence each other in turn. In the meantime, we know from climate models that different regional factors, known as 'tipping elements', could exist in either one of two states, which in turn influences the other elements. In 2005, thirty-six climate experts met in Berlin at a workshop on 'Tipping Points in the Earth System'. They summarised the elements which were politically relevant, at which degree of global warming they might tip, and when sudden and serious changes to the climate could occur. The results are alarming.

Greenland's icecap is, for example, one such tipping point. If it begins to melt, the temperature will rise further because of the landmass that will become exposed, which will then further accelerate the melting. In less than 300 years, in the case of a critical warming of 3°C, Greenland could be completely ice-free. That would lead to a rise in sea levels from between 2 to 7m, with massive consequences. The Amazon rainforest is a further example of a climate tipping point. At 3 to 4°C of warming, the combination of deforestation and even more serious desertification, because of the huge El Niño systems on the South American Pacific coast, which are becoming more frequent, could lead to a loss of the rainforest within just fifty years, likewise with unpredictable consequences for the world's climate systems.

One of the climate's most influential tipping points is what is known as the thermohaline ocean circulation, by which water of different temperatures ('thermo') and salt concentrations ('haline', meaning 'salty') is driven around the globe. Like a huge conveyor belt of ocean currents, this circulation connects four out of the five oceans together and moves warmth and water masses over many thousands of kilometres. The Gulf Stream is one of this conveyor belt's most important strands. If the ice caps in Greenland and the Arctic were to melt due to a rise in the Earth's temperatures, melted fresh water would flow into the North Atlantic and would restructure the thermohaline Atlantic current, bringing it to a standstill, which would quickly have dramatic consequences for the planet and push other tipping points over the edge. The slow and steady global warming, caused by humans, may provoke many of these tipping points in turn, causing ever stronger, sudden changes, and ultimately moving the entire climate system into an altered state. This could be fundamentally different to everything we currently know.

The dramatic effects that can occur after such climate tipping points are toppled can be seen clearly throughout the Earth’s history. From researching the ocean’s sediment layers, we know that, at different points in time, what are known as ‘anoxic events’ occurred in our oceans. Within comparatively short timeframes, the oxygen concentration in the oceans plummeted dramatically. In these phases, weathering products made their way into the oceans as a result of strong erosion and increased volcanic eruptions. They became over-fertilised. At the same time, the vital thermohaline circulation was disrupted. Just like the small and large seas, the oceans then fell out of balance. Experts believe that this global marine tipping point has already been passed many times and is partly to blame for mass extinctions of sea creatures, from which the oceans would not be able to recover again for hundreds of thousands of years.

How can we tell, though, whether a system is standing on the precipice of a tipping point? Can we calculate how serious the situation is? In the chapter ‘Criticality’, we saw that critical phenomena in fact send out dynamic signals if they are approaching such a point. Tipping points behave in just the same way. The gradual nearing of a tipping point leads to coincidental fluctuations in the systems. Every natural system is always exposed to some coincidental environmental influences which knock it slightly off-balance, so that it then rights itself again. To return once more to the image of the marbles: from time to time, the marble is pushed off-balance and then rolls back again. But if you near a tipping point, the stable ‘dip’ in which the system ‘pauses’ becomes flatter and flatter. This means that little disturbances which move the marble left or right have bigger, more serious effects than they would have had if the dip was deeper. The system finds it harder to bring itself back to a stable equilibrium. In the marble example, we also see another characteristic which goes hand in hand with the approach to a tipping point, known in the scientific community as ‘critical slowing down’. Because this dip becomes almost flat before the tipping point is breached, it takes much longer for the marble to arrive back in the stable ‘base’ of the dip.

We have been able to measure these two exact effects, both stronger fluctuations and a slowed return to equilibrium, in very different systems.

A classic tipping point system can be found in fishing. Without fishing, the cod population in the Baltic, for example, would increase to a critical point at which reproduction and a limited food supply would invariably bring the population to a standstill. If a certain proportion of the population was overfished, competition would decrease within the population that was left and this would regulate itself back to a balancing point, in spite of fishing. If, however, there is too much fishing and a tipping point is reached, the cod population would collapse, only reviving again if fishing levels dropped dramatically, such as before the tipping point had been passed. In real situations like this, we have observed that variations in populations increase dramatically as the rate of fishing increases only slowly, and that the effects are particularly strong before a collapse occurs.

In terms of large-scale, geological climate change too, for example in transitions from ice ages to warm, interglacial periods, we have been able to detect this combination of heightened fluctuation and critical slowing down. Around 34 million years ago, the Earth moved from a very warm, tropical climate with no polar ice caps, which had lasted for several hundred million years, into a colder cycle phase, with polar ice caps. A finger print of this move from greenhouse to icehouse can be measured clearly in the layers of calcium sediment in the South Pacific, where there was a more apparent increase of calcium concentration. But even several million years before the abrupt transition, it was apparent in fluctuations the calcium sediment. In the meantime, countless examples in ecology and climate research prove that the majority of tipping points transmit these universal signals.

Tipping points and rapid transitions from one type of system to the next via gradual changes in external influences do not only exist in ecosystems or climate models. In social systems, too, these processes play an important role. Tipping points are most easily observed in rapid changes of social norms. Often it is an active minority which reaches a critical size and then causes a social norm to change quickly. Examples of social norms which were originally stable and then suddenly tipped can be seen in the intolerance towards smoking in public places, the legalisation of cannabis in many countries, and changes in other social norms and conventions. The easiest model for describing the dynamic of these social norms and conventions works in a very similar mathematical way to the marble-in-the-dip models which helped us to understand ecological systems. We'll explore this topic at closer quarters and discuss examples in the chapter 'Collective Behaviour'. The most important element in an abrupt change of social norms is also the network of dynamic elements; in this case it's the people within a society or a group who are in dialogue with one another within a network.

Meanwhile, ecological network models are also used, as I explained at the start, in order to better understand economic systems, particularly the dynamics of global financial systems. In financial markets, systemic risk is also an important factor. This risk describes the probability that the entire, interconnected finance system or another branch of the economy may collapse, because self-reinforcing negative cascades destabilise the overall system due to the complex processes on the market, for example, individual banks going bankrupt. Since the financial crisis in 2008, it has been clear that the traditional economic models neither predict nor adequately explain these crises and that they can only poorly quantify system risks with conventional approaches. Any signs of a collapse were also only 'moderately' recognised. The financial crisis prompted a wide array of research projects and scientific studies, into which concepts from ecology and network theory were introduced, terms such as 'tipping points', 'multistability' and 'robustness against outages'. In a study commissioned by the US Federal Reserve, scientists examined a network of 5000 individual banks. The network's links symbolise the transfer of funds between these individual banks. Scientists found that this network was highly disassortative, meaning that banks with connections (higher node grade) were typically linked with smaller banks (low node grade), and vice versa. We can also see very similar network structures in real ecological networks, such as in symbiotic networks comprising flowering plants and pollinating insects, for example. Flowering plants which work together with many insects favour ones which are specialised. Insects who are not choosy about flowers often pollinate many flowering plants which are exclusively served by this kind. Theoretical analysis shows that exactly this kind of network structure is robust in withstanding disturbances, but only in a certain area. If networks are overburdened, they will reach a tipping point and collapse irreversibly. From this point of view, we can conclude that, though financial markets principally have a structure which keeps systemic risk low, nevertheless they still reach tipping points through gradual changes, such as continuous growth, they still collapse and cause worldwide financial crises. Because just here there is a fundamental difference. The ecological networks are not growth-orientated, but are centred around dynamic balances. A sustainable design of societal economies could serve this kind of structure, which has existed for hundreds of millions of years, are spare us grave crises, high costs, and serious consequences, both in terms of economic and personal consequences.

Epilogue The ‘Header Monster’: what we can learn from Neanderthals and cyanobacteria. (p. 211 – 215)

The Neanderthals died out 40000 years ago. As a child, I learnt that they were a precursor to modern humans, a kind of ‘ape men’ that had developed from the great apes themselves. Muscular, a bit dim. Gross motor skills but no language, covered in thick hair (we’ve already discussed the racist bias in the theories of old, white men), naked or clothed in a loincloth at most. Yes, ape men.

Today, we know that Neanderthals were another type of the *Homo* species to modern humans, although equal to us in all human aspects. They lived long before us in Europe and Asia. They could speak. They buried their dead. They hunted astutely as a team, produced tools, weapons for hunting, and art. They used fire, wore clothes they made themselves. Their brains had a larger volume than those of modern humans. Even their characteristic, distinctive browbone was more likely a trend of the time, since the then ‘modern’ humans had this too. Only later were they cosmetically evolved away. Furthermore, Neanderthals were also probably lighter pigmented than the Early European modern humans, or Cro-Magnon, who came from Africa to Europe, were probably the first modern humans to form settlements, and would become our forebears.

For around 4000 years, Neanderthals and modern humans lived side by side in Europe. And not only that. It’s clear that *Homo neanderthalensis* and *Homo sapiens* also occasionally had interspecies relations, because there are clear traces of Neanderthal preserved in the genes of Europeans and Asians who live today. Some 2.5% of their genetic make-up still lives in us – perhaps a small comfort to the *Homo neanderthalensis* species, who, after walking the Earth for approximately 100 000 years, more or less disappeared without so much as a whimper. It is not clear whether Neanderthals were actively ousted by modern humans. It’s more likely that they simply bred too slowly and moved around too frequently. Today, we still have no clear evidence of any direct conflict with modern humans. From the species’ point of view, Neanderthals’ disappearance is of course a tragedy. And from the point of view of the entire *Homo* species, whose last representatives are humans, too. *Homo floresiensis*, *Homo heidelbergensis*, *Homo ergaster* and a handful of other types of our species had only brief cameos until *Homo erectus* came along. For our planet, it’s surely no tragedy at all.

The Earth is around 4.54 billion years old. It’s been alive for the last 3.7 billion of them. Some scientists assume that even since before 4.2 billion years ago, there was life on our planet. If we were to condense the Earth’s history into a 90-minute feature film, Neanderthals’ appearance would last around 1/10 second, shorter than the blink of an eye. In the last 4 billion years, the biosphere has burst forth with an almost unimaginable richness of life. At least 99.9% of all species in the Earth’s history have become extinct. In the last 500 million years alone, the Earth has seen five mass extinction events. It has survived alternating ice ages and extreme heat; some scientists think that, 600 million years ago, the Earth was almost completely covered by an ice sheet for around 200 million years, a phenomenon known as ‘Snowball Earth’. In spite of all this, life carried on.

Around 2.5 billion years ago, the Earth had been alive for around 1 billion of those years, but none of its life forms required oxygen. It was then, in fact, that the predecessors of cyanobacteria – tiny, single-cell life forms – began producing oxygen in enormous quantities as a by-product of photosynthesis, until there was more oxygen in the atmosphere than there is today. Because oxygen was toxic for most life forms at that time, this led to a mass extinction event, known as the Great Oxidation Event. Cyanobacteria still exist today, and are not uncommon. The cyanobacteria *Prochlorococcus marinus* is the most abundant life form of all and coincidentally produces a substantial amount of the oxygen in our atmosphere – according to estimates, between 13 and 50 per cent. Every second breath you take delivers oxygen to your lungs that *Prochlorococcus marinus* produced. The world’s oceans are home to octillions of these unicellular organisms. In spite of this, they were only discovered and documented in 1992 (individual cells of this kind are very, very small).

What can we learn from Neanderthals and cyanobacteria? First of all, we can recognise that, as members of the *Homo* species, we are not suited to exist as part of this planet for a particularly long period of time. The *Homo* species is an evolutionary footnote, on the fringes, and its kind only tends to make brief, cameo appearances. Secondly, we have to recognise that *Homo sapiens* are not the only life form to enduringly and irreversibly change the planet’s environment. We have just managed it in a comparatively short time, although, unlike the cyanobacteria, there is a high probability that we will not be able to survive this ourselves. If we acknowledge the fact that our existence on Earth is meaningless, we can more clearly recognise what it means to come to terms with current crises – the climate crisis, consequences of digitisation, globalisation, loss of biodiversity, financial and economic crises, overpopulation and famine – about rescuing our own laughable species.

At the moment, viewed soberly, it doesn't seem like we'll be able to do it. If you are a football fan, you'll know the feeling when your team is 3-0 down in extra time, and you yourself are powerless. You can do nothing but watch. Actually, you could go home, or turn off the TV. But there is still a glimmer of hope that flickers inside you. As a child, I enjoyed watching football. I remember the final of the 1980 European Championships, Germany against Belgium. And I remember Horst Hrubesch. It was 1-1 after 88 minutes. I was 10 years old and couldn't stand it any longer. I ran into my room and lay on my bunkbed, hands balled up into fists and eyes screwed tightly shut. Then I heard my parents cheering from the living room. Horst Hrubesch had scored a header to secure a 2-1 win for Germany. "Manni banana, I head – goal!"[1] is his best-known quote. I can remember only very few moments from my childhood of pure joy. This was one of them. It totally eclipsed my scouting experiences in Norway and Klaus Kleinwächter's pond-crossing escapade. Interestingly, at that time, my hopes were always pinned on Horst Hrubesch. He never disappointed me.

Despite humanity's rather desperate situation, the grave and overwhelming facts, political lethargy, the distortion of descriptions of many people's lived experiences into the grotesque, mass hysteria, autocrats and the dwindling possibility that we might come out of this mess the other side, I do have a tiny fleck of hope. Just like back then. Neither complexity studies nor this book is an instruction manual for saving humankind. But perhaps they are a toolkit which may help us to find a pattern in the misery, to consider the principles of these crises, to think about others' perspectives and to understand that everything is connected: antidisciplinary thinking, identifying essential mechanisms without getting bogged down in the details, recognising connections between phenomena, learning from similarities. Because similarities are the only definite. Nothing can be derived from differences, you can only observe them and count them.

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[1] Wording for this quote, as well as the nickname 'Header Monster', taken from Fifa press release. https://www.fifa.com/news/hrubesch-from-roofer-to-header-monster

Maybe we do have a chance, if we dare to be more Horst Hrubesch. Hrubesch was an unselfish team player. His success grew through working together with others. On the pitch, he was part of a team, of a *complex network* of players, and he was particularly efficient when it came to *collective behaviour*. Unpretentious, modest, low-key, but great. If anyone could handle *critical* situations, it was Horst Hrubesch. He could *tip* a game which many might have thought already lost. Hrubesch always threw himself forwards with all his might and, so to speak, defied the backlash, and he almost always used his head. Now we must also, metaphorically speaking, confront our problems and crises, like Horst Hrubesch, throw ourselves in and use our heads, even if it gives us something of a headache. And just as his teammate Manni Kaltz could put in a cross at an odd angle, so too must we think outside the box and see connections where we perhaps didn’t expect to. We have to run down the wing and finally turn this game around.