How do chance and coincidence enter our world? And why are so many things unpredictable?

Through an accessible, exciting and amusing narrative, the author takes us into the world of chemistry, quantum physics and biology. Touching on astronomy and philosophy, we witness a rewarding journey of discovery. In the process, he develops a completely new view on chance, coincidence and randomness based on the laws of nature. Here, the omnipresent nonequilibrium plays an extremely decisive role, because it generates the complex structures in our world. Finally, on this basis, he presents an equally simple and captivating hypothesis about the nature of time.

This nonfiction book provides deep insight into the fascination of research, the painful search for fundamental understanding, and the struggle for scientific knowledge.

The Author

Dr. Bernhard Wessling is a chemist and entrepreneur. His main occupation has been chemical product and process development, including basic innovations. In addition, he conducted basic research in colloid chemistry and physics, as well as non-equilibrium thermodynamics. As a sideline, he is one of two managing partners of a large organic farm. For decades, he has been actively involved in environmental, nature and species protection on a voluntary basis and has conducted behavioral research on wild cranes for many years.

The translation was done with the help of artificial intelligence. The text has subsequently been revised further by the author to ensure content correctness and by a professional english native speaker copy editor, Marc Beschler, in order to refine the translation linguistically.

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Wessling

What a Coincidence!

Bernhard Wessling

What a Coincidence!

On Unpredictability, Complexity and the Nature of Time

I dedicate this book to my grandchildren and those of my life partner, on behalf of all young people today. I hope it will help them in understanding our dynamic and sometimes chaotic world.

Preface

"How could this have happened again? That's impossible!" We've all uttered, heard, and read such exclamations many times. We consider unlikely events to be practically impossible. Experts calculate probabilities of disasters that we and, above all, the relevant politicians trust. There was theoretically nothing worse than a DBA (=design-basis accident) or "maximum credible accident" for nuclear power plants, but in practice, much more happened in Fukushima than was previously considered the worst case scenario. That was "coincidence" ("there were just too many unpredictable things coming together").

Successful people like to claim that they have planned everything, that they have stuck to their strategy. And yet, they forget how often they have met exactly the right people (whom they didn't previously know) by chance or appeared on the market in exactly the right market situation (which they could not influence at all) with a product (which was not intended for this exact market situation at all). Those who have worked just as hard but without success (if they are self-critical) accuse themselves of all kinds of mistakes, but often fail to notice that they have not met the right people by chance, or that they have appeared on the market too early (when the market situation was not yet suitable) with practically the same product, and therefore failed by accident.

August 2021 marked the thirtieth anniversary of the launch of the *World Wide Web*. Nobody could foresee, nobody could predict how much the WWW would turn the world upside down only a few years later. Not even its inventor Tim Berners-Lee, who only wanted to develop it for the easier exchange of scientific documents. Even the way to this start was a chain of coincidences and chances, as he has described.

Rather, we all experienced even more coincidences in 2020: Most likely, a new coronavirus jumped from animals to humans at a wild animal market in Wuhan (China) in December 2019. Perhaps this happened without anyone noticing it before, somewhere else, because according to current knowledge, the first infection occurred in Italy in November 2019, as was subsequently found out. In January 2020, the founder of the biotechnology company BioNTech learned of this virus. He decided to radically shift the focus of the company from cancer therapy research to the development of a vaccine against Covid-19. In December 2020, that is, after less than a year of work, the vaccine was approved. This research was only possible because the founding couple had come

across first indications from basic research more than twelve years earlier that *maybe* novel cancer therapies could be made possible using mRNA—we will go into this in more detail. Because, as oncologists, they had founded a company (BioNTech) for this purpose, happened to find two investors by chance—a pair of brothers—who were willing to take risks and be patient; and because they had developed the mRNA technology almost ready for use by the end of 2019, only still with no approved product. The vaccine was possible, even though the research was actually aimed at a completely different application area. But by chance they recognized this possibility of their technology platform and developed a vaccine in an incredibly short time.

We are at least annoyed by very many coincidences. There may be sudden rain, which was not forecast, and the picnic outside falls into the water. Some coincidences are dangerous, such as a car that suddenly takes us the right of way. Some are even life-threatening, such as the accidental spread of the coronavirus to humans. Other coincidences, however, are welcome: We are often happy about small ones. So the sudden reappearance of the sun, after we had packed the picnic quickly and could now unpack it again after all. We marvel smilingly at the bigger one, such as the coincidence that made it possible for me to get to know my life partner for the first time, with whom I live happily together. We shake our heads in joyful disbelief that our favorite soccer club was able to equalize in the very last second, and that only because an opposing defender's leg by chance sent the ball careening in the right direction. The development of stock prices is unpredictable, and this is by far not the only thing that is unpredictable in economic life. Inventions and discoveries are very often, if not predominantly, the result of chance, coincidence and accidents.

Other coincidences are even decisive for all of our lives: The extinction of the dinosaurs, which made the development of mammals possible. And even more decisive was the formation of the moon several billion years earlier, which stabilizes our Earth's axis and thus makes the world we live in possible. A world that we humans could not write about if, by chance, some decisive mutations had not occurred millions of years ago that shaped our brains the way we find them today.

If we're honest, more accidents and coincidence cases happen, more actually rather improbable events than those that we can plan, predict, forecast or influence. All kinds of things go wrong, although we haven't done anything wrong! And just as many events that please us or advance us happen unexpectedly, or at least at a time when we did not expect them. The newspapers and all other media are full of it.

So let's now assume that accidents, coincidences and chances are *normal*, i. e. nothing unusual, but rather completely typical phenomena with us on earth and thus throughout the entire universe; if that is the case—then we also want to know: Where does this come from, how does it come into our world, why is it normal? To answer this question, I will not argue with probability calculations, statistics or chaos theory, as mathematicians, philosophers or psychologists do. Nor will I work with philosophical considerations or psychological analyses that are to make us understand how we can enjoy, endure or cope with coincidence, chance and accidents. First of all—after a more detailed consideration

of coincidences and chances that surround us—, we will look at how it comes about that our world consists of nothing but complex structures. If all the substances in the universe were evenly distributed and nicely homogeneously distributed and mixed, there would be no us, with our complexly structured brain, the nervous and circulatory system, muscles, bones, our complex skin, the sense organs and all our fantastically finely built internal organs. How do such complex structures arise? How does complexity that we observe everywhere in the world, everywhere in the universe, arise?

If all substances in the universe were statistically evenly distributed and did not form highly complex structures, we could not admire the beauty of the cirrus nebula. Here is a new picture of the Hubble telescope.[1] *The nebula looks like a turbulent whirling smoke trail, but with a diameter of over one hundred light years. We will look at such and similar phenomena in the book and come to understand the reasons of their formation.*

To avoid making things too complicated, we will also turn to seemingly simpler structures and questions: Why is mayonnaise so stiff, even though the main ingredients—raw egg yolk, water and oil—are each nowhere near as viscous? Why do you have to follow certain steps when making mayonnaise or sauce Béarnaise and can't just pour all the ingredients together into a bowl and stir? Why isn't it easy at all using raw cocoa powder, as used for tiramisu, and milk to make a nice, rich brown cocoa, where cocoa clumps don't sink to the bottom of the cup after a few seconds? How do such complex and constantly changing structures arise as the mouth of a river delta, for example the Lena, as shown on the cover of this book?

[1]Cirrus nebula, latest picture of the Hubble telescope; source: https://esahubble.org/images/potw2113a/, Credit: ESA/Hubble & NASA, Z. Levay.

I will try to answer some of these questions based on my own research. For I discovered complex structures in material compositions that could not have existed according to generally accepted ideas. In my research as a chemist, I found a common denominator and therein the cause: All of these products are non-equilibrium systems. It was necessary for me to break away from the idea that I had developed as a chemistry student based on lectures and textbooks, just as all my fellow students had: For us, the world consisted of equilibrium systems, *non-equilibrium* was something rare and unwanted, and thus we described such systems only approximately again as equilibrium systems, ones that were *only somewhat* outside of equilibrium.

In my further research, I learned through the study of the work of many other researchers that non-equilibrium systems are structured. I started to wonder: Why is that so? Or, thinking the other way around: Why are complexly structured systems not in equilibrium? Professor Ilya Prigogine received the Nobel Prize for explaining this with a new theory of thermodynamics. It is simply and solely a matter of entropy, which is very decisive for what determines the course of the world. You may have already heard the word *entropy* before, but either didn't consider it important or possibly not understood it in the first place. I will try to make you understand it. Because anyone who wants to understand the world at least a little from the bottom up should have a reasonably accurate idea of entropy. But don't worry, I will explain it in a way that is really easy and practical to grasp.

Then we will also deal with fundamental questions: If everything was chaotic at the Big Bang, why can order arise in the universe, for example the diversely structured galaxies with countless sun/planet systems? And why can a glowing hot earth become a life-friendly blue planet? How did the Big Bang come about in the first place, wasn't that also a matter of chance or coincidence?

The phenomenon of *chance and coincidence* has always fascinated me. When I was working on non-equilibrium thermodynamics, I eventually came across a connection between chance/coincidence and non-equilibrium at some point. But how can that be? Well, that's exactly what this book is about, and I'll explain it step by step in the course of this book. Suffice it to say for now that both phenomena are inextricably linked to each other. And both phenomena are just as inextricably linked to entropy. My only surprise came, during even deeper research for this book, at the fact that apparently no one had come up with similar ideas before. Or, if someone had had similar thoughts, they had not been written down in a publicly (or at least easily) accessible way. In any case, all I kept reading and hearing was: It is the quanta, the unpredictably behaving elementary particles, that should cause chance, coincidental and accidental events in our macroscopic world. I will explain why this cannot be the case. Quite apart from the fact that there is no verifiable evidence to.

And *time*? We're not going to link entropy to *time* as well, are we? Yes, *we* are not going to link *time* to entropy and non-equilibrium, *we* don't have to and couldn't anyway. Because *time* is already linked with entropy.

But isn't time just an illusion, as Einstein said? And as some other very serious physicists and philosophers also think? But if it is not an illusion, what is the nature of time? We will approach the answer to this question, which has so far been clarified neither by philosophy nor the natural sciences, step by step, just as I have done in the course of my research.

And finally, the older ones among us may also expect an answer to the question (which the younger ones can put it aside for later): Why does time go by faster as we age? Is that really the case, or do we just feel that way? Why does time sometimes seem to go slow for the younger among us, like when we're waiting for something urgent, and sometimes seem to go fast, like when vacation is over sooner than we thought?

If you've ever asked yourself these or similar questions, I invite you on an expedition into landscapes of science that you have probably not visited before. We span wide arcs from simple mayonnaise to complex galaxy clusters, from mundane traffic jams on the highway to the fascinating subject of evolution, from the misunderstood Big Bang to the amazing self-organization of order out of chaos, from surprising goals in overtime to unimaginably oversized black holes. And we thus encompass the becoming and passing in our world, entropy, chance, coincidence and time.

We will also occasionally reflect on how our own thinking might work. How open are we to questioning widely accepted explanations, which we ourselves find pleasant and plausible, about the interconnections in our world? If we are all honest: Most of the time we are not very open. But we should try it more often. In the words of Nobel laureate Daniel Kahneman: "Our mind usually works so that we have intuitive feelings and opinions about almost everything we encounter. […] Regardless of whether we formulate them explicitly or not, we often have answers to questions that we do not fully understand, and we rely on clues that we can neither explain nor defend." [2] In this book you will encounter some thoughts that you may never have heard or read before. This will make you sceptical, because, as Daniel Kahneman explains in his profound book *Thinking, Fast and Slow* among many other aspects of our thinking, we hold statements that we have read or heard many times before as being far more likely to be true than those that we encounter for the first time. It then requires considerably more mental effort, and

[2]Daniel Kahneman (Nobel laureate 2002), "Schnelles Denken, langsames Denken", German edition Siedler-Verlag (Penguin Randomhouse) 2012, p. 127, retranslated from the German text by B. Wessling. (Original English edition: "Thinking, Fast and Slow", Penguin Books 2022). It is particularly interesting to consider his description of two different thinking systems and the experimental evidence for this: System 1 is fast and superficial, constantly trying to construct explanations from all sensory impressions that correspond to previous experiences; it is only, if this does not succeed, that System 2 becomes active, a system that represents our conscious (after-) thinking, but it is "lazy" because it uses a lot of energy. System 1 invents obvious explanations that we then accept. It is happy to answer questions that replace the actual questions, because they are much easier. Then, it seems to us as if the acute question has been answered, which is not the case.

thus more energy (!), to deal with new thoughts and phenomena than to read and hear things that we already know and have long considered to be correct.

With this book, I would like to motivate you to subject your previous world view to a critical examination in part: Is everything really *in equilibrium,* should the climate, the ecosystem, our economy really be *in equilibrium* at best? I do not expect you to change or even overturn your previous ideas; but I would like to encourage you to allow for some unusual thoughts and to think them through calmly. Because only in this way we will be able not only to answer the question of how chance, coincidence and accidents come into our world. We will understand the world as a whole a little better.

Jersbek Bernhard Wessling

For this English edition, readers should be aware the original German edition is using the German word “Zufall”. In English, there are several different words for what Germans are all calling “Zufall”: coincidence, chance, accident, randomness. I have tried to use the appropriate term in each given circumstance.

I Thank this World for its Non-Equilibria with the Coincidences and Chances

The origin of this book lies in my unbridled amazement at this world. And about what I found out in my research. I started writing in 2016, having, at the time, just been together with my new life partner for a year. How wonderfully unpredictable my life has been: A big thank you to non-equilibrium of the world I live in, and the coincidences and chances that brought me together with her! She viewed me indulgently when I hacked away at my laptop for hours at the table in our living room-kitchen in our first small flat together in Germany or at the sofa table in China. And not only there, but also on the plane to or during our trips within China. For two years. I am very grateful to her, above all for tolerating and supporting my work on this book—in parallel to my other books[3]. But even more than that: She had read the pre-pre-pre-version during its creation in 2016/17. But then stated: "I won't read the book again until it's really finished." So, she knew, even before I did, that it would take many years and many revisions and fundamental changes until the book was *really finished*, assuming it ever really was. It indeed got finished. She was surprised how much had changed when she read the original German edition.

Of course, not all the people to whom I am or should be grateful can be found here—the list would be too long for this book. But those not named can be sure of my gratitude! Nevertheless, I would like to mention a few key people.

Without Professor Ilya Prigogine and his scientific life's work, I would never have found the solution to the puzzles that troubled me so much for years, if not decades. Professors Werner Ebeling and Grégoire Nicolis specifically pushed me towards an essential question that I had to work on and could solve. The theoretical physicist Dr. Helmut Baumert let me lure him into a question that was initially uninteresting to him, until we were able to jointly develop a new theory of turbulence in non-Newtonian fluids. The non-equilibrium thermodynamicist Dr. Rainer Feistel,[4] the physicist Prof. Serdar Sariciftci

[3]"Der Sprung ins kalte Wasser", Verlagsgruppe Eulenspiegel 2023 sowie "Der Ruf der Kraniche", Goldmann 2020/"The Call of the Cranes", Springer Nature 2022.

[4]https://www.io-warnemuende.de/rainer-feistel.html

(Johannes Kepler Universität Linz, Austria)[5] as well as two other scientists read an earlier version of the manuscript and made a lot of critical comments. These have prompted me to do additional research and to think even more deeply, which is reflected in the book. My younger brother gave me numerous hints for passages that, despite my best efforts, had not been written in a manner that would be understandable to everyone. But, in particular, without the work of my many employees, especially in the laboratories of my company, there would have been nothing for me to discuss with these outstanding scientists. I have worked very closely with many of my employees, some for more than twenty to thirty years. The extremely intense thirteen years I spent in China also fill me with gratitude. I cultivated friendships there, that are still alive today. Our common active time was full to bursting coincidences, chances, accidents and exciting scientific discoveries …[6]

The freelance editors Obst & Ohlerich criticized an early version of this book to the ground in 2017, but they found the final version convincing. I learned a lot from the final round of editing carried out by Rouven Obst of the original German edition. Now, this English edition was reviewed by Marc Beschler (who already had reviewed the translation of my previous book about my sideline crane behaviour research, "The Call of the Cranes" (SpringerNature 2022), and I am again so grateful to him. The German poem in the Final Remarks (at the end of the book) was translated by Timothy Adès, a "rhyming translator-poet", whom I found "by chance" (sure! how else could it be!) and with whom I exchanged a few emails until the final version was approved by both of us, we both had fun. Let is be known that I am solely responsible or all remaining errors. In his editing of the original German edition, Eric Blaschke (editor at Springer Vieweg) pointed out numerous minor and major deficiencies, which prompted further research and improvements to the text. The publisher Springer Nature, here in particular the responsible editor Eric Blaschke and his boss Dr. Garbers, took the risk of publishing this book project, and now also this English edition—for this I am particularly grateful. Especially because Springer found my book project interesting and worth publishing, after I had already collected rejections from countless publishers and literature agencies before. Actually, I had already given up hope that a publisher would take it and want to bring it out. What a coincidence that I finally asked at the editorial team of Springer Vieweg!

But that is exactly how our world is, constantly things are happening that one cannot imagine, that cannot be foreseen, and for that I am grateful to the world for it! How boring my life would have been, if everything had been predictable and everything that I was to experience in my life had been documented in the appendix to my birth certificate. Fortunately for all of us, however, the world is made up of nothing but non-equilibrium systems—full of grace, beauty and surprises.

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[5] https://www.jku.at/en/institute-of-physical-chemistry-and-linz-institute-for-organic-solar-cells/team/sariciftci/

[6] https://www.researchgate.net/publication/260427241_Milestones_highlights_of_the_Organic_Metal_Polyaniline_Science_Technology, see Appendix 15.

Contents

Vita

Dr. Bernhard Wessling, born 1951, raised in Herne, studied chemistry in Bochum. From January 1978 to the end of 1980, he worked for an engineering company in Düsseldorf. After that, he moved with his then wife and two small children to Bargteheide and took over the management of the development laboratory of Zipperling Kessler & Co., a company with fewer than fifty employees, but a 170-year history. A few years later, he took over the management, and soon he became a shareholder of the company (with a very risky buy-out of a previous shareholder). It subsequently developed into a successful company with three hundred employees. At the end of 1995, Wessling founded the daughter company Ormecon, selling all of Zipperling's business to Clariant AG mid-1996. Wessling, having relocated in 2005 to China, sold Ormecon at the end of 2008, founded his one-man technology consulting company in ShenZhen and remained in China until the end of 2017. Throughout his career, despite holding such positions as managing director, he continued to be directly responsible for research and development. Thus, even as he fashioned himself as an author and entrepreneur, he remained committed to pursuing basic research.

Chance and Coincidence Take their Course

1

Abstract

The author describes numerous instances of chance and coincidence that opened his way into science, into basic research, in a small company that he has been responsible for as managing director and shareholder at a very early stage. These coincidences led him deeper and deeper into areas that have previously received little scientific attention and where surprising phenomena waited to be discovered.

About 30 years ago, on August 6, 1991, the world's first website went online.[1] The initial ignition of the *World Wide Web* was a product of the European research center CERN—created by accident and as the result of many coincidental events—, albeit initially only an internal one. Two years later, on April 30, 1993, the WWW was activated for the general public. Access was free of charge, but there was considerable cost around the technical requirements and the high telephone charges at that time. And still hardly anyone noticed it, certainly, no one predicted at that time that the WWW would have an impact on practically all areas of our lives. It was intended as a platform for the documentation and international exchange of documents within CERN, and even that came about unplanned.

Only two years later, on October 5, 1995, my company became the second chemical company in the world to go online, the next coincidence. I was and am anything but a

[1] Here is a copy of the original website: https://www.w3.org/History/19921103-hypertext/hypertext/WWW/TheProject.html; or here: http://info.cern.ch/hypertext/WWW/TheProject.html.

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computer nerd, yet I almost landed on pole position. Only the then-chemical giant Hoechst AG had beaten us by just a few days. But our site was much more informative: I had ensured that *all* our technical information and my scientific publications (together, over four hundred documents) were available, while Hoechst offered only the homepage.[2] In1995, in the Internet, which was intolerably slow from today's point of view, housed only 23,500 web addresses.[3] Today (as of Sep 12, 2022) there are two billion,[4] that is, over 80,000 times as many. As to our own site, I had no further ambition back then but to make our technical and scientific information more easily available to our international customers and research partners worldwide back then. There was no notion at all as to what the WWW would become in just a few years to come.

I was only reminded of the fact that the WWW would celebrate its 30th anniversary in 2021 or its actual anniversary as a public Internet in 2023 thanks to the article *How the Web Came Into the World?* at the end of 2020 from the weekly magazine DIE ZEIT.[5] And although the platform is therefore, strictly speaking, still very young, it seems to me as if the Internet has always existed. My memories of the telex, which I myself used actively for many years, as well as the fax machine that followed, strike even me now as being akin to stories from the time of early industrialization.

How many coincidences led to the existence of the WWW? Above all, there was never a plan to build something that even remotely resembles the Internet as we know and use it today. Tim Berners-Lee, who is considered the inventor of the WWW, once said that there was never *the one* decisive idea that initiated the Web: "I wrote the first programs. But many other people have contributed important ingredients, just as randomly as I did." Bernd Pollermann, who also worked on this chaotic team, said: "Why did I join in? So that my colleagues would no longer annoy me with their never-ending requests for internal telephone numbers." So, he just wanted to create a telephone directory that was accessible to everyone and could be edited easily, nothing more. Neither was the project an official project of CERN, where the developers were employed, nor was anything more planned than easier availability of scientific documents and telephone numbers of this huge European research institution; such information was previously almost impossible to find, even for insiders. The Englishman Berners-Lee had already completed an internship at CERN in 1980, after which worked for four years at

[2] In this web archive, you will find a copy of the websites from back then, not directly from October 1995, but from November 1996, because in 1995, there were also no web archivists: https://web.archive.org/web/19961125121325/http://www.zipperling.de/ZKC/About (with the hyperlinks that also work in this web archive, the reader can call up other websites from my company from that time); however, only the very few initial Hoechst websites from January 1998 can be found there.

[3] "unique hostnames"

[4] http://bit.ly/3HXSli1 "How many Web Sites are there?" (Sep 2022)

[5] https://www.zeit.de/2021/01/word-wide-web-erfindung-internet-cern-genf-physiker-forschungszentrum.

zipperling

My then-still small children, whom I often took with me to the laboratory when I had something to do there on weekends, said: "Dad, that's you!" Well, the only similarity was actually the lab coat.

And 14 years later, at the international plastics trade fair K'95, we presented the world's first truly informative website of a chemical company. Thus a chain of accidents and coincidences and all kinds of forks in the road completed the circle. They opened up deeper and deeper paths into the unknown landscapes of science, which we will look at step by step in the following chapters.

A few weeks later, I founded a new company as a subsidiary of Zipperling: Ormecon. I wanted to try to market my now almost market-ready *electrically conductive polymer*, which I will tell you more about in Chap. 3. I had long since become managing director and shareholder. Zipperling had meanwhile grown to three hundred employees, producing one and a half thousand different special products for hundreds of customers every year, representing around 25,000 metric tons per year. We were experiencing an enormous growth. I was aware that we would not be able to successfully plough two such different, non-overlapping business areas as a small company. We also lacked the capital for this. So, I looked for venture capital investors.

Again, help arrived by chance: Only a few months after the fair, I received a call from a member of the board of Clariant AG, a world-leading and very important specialty chemicals company. Clariant was also one of our competitors. The board member, whom

I had previously met at a meeting, had got wind of my search and, without much preamble, came bluntly to the point: "We can provide the capital if you sell the Zipperling business to us." We agreed on a meeting, which took place only a few days after the phone call, and three months later, we signed the purchase agreement. This had all come about despite the fact that I had already rejected a takeover offer five years earlier. Yes, what a lucky coincidence!

More details on this chapter in appendices 1 to 4.

Essential Uncertainty is Everywhere

2

Abstract

Based on numerous examples from recent times (including the Corona pandemic), scientific research, technology, economy, history and politics, one can clearly see: It is the so-called *essential chance* that determines the course of history, and *essential uncertainty* can be found in all aspects of life and nature, especially evolution that our uncertainty about future events is essential. We will also deal with explanations of the causes of chance, coincidence, accidental events and randomness that have been presented so far by other authors from physics and philosophy. The *essential chance* (or: *essential coincidence*) is to be distinguished from this.

It could be that part of my readership may come to think that now really too many coincidences had been mentioned for them all to have really happened. That this might clearly be a case of a failed, as well as dilettantish, novelist going gaga. No, I guarantee that none of this is made up. I would simply like to encourage you to ask yourself attentively and critically whether it doesn't work out similarly for all of us in life. Some could now object that some people have a lot of good luck and others have a lot of bad luck (both of which are chance, coincidences or accidental events). For me, as is probably the case for many other people today, the range of possibilities for events in life has increased enormously, and we are also now capable of learning more about the whole world through all kinds of media. That's probably why we experience more coincidences and hear or read about many others.

But there is one statement that most Germans (with the exception of a large faction located mainly in the south of our country) would likely agree with: Bayern Munich as a Bundesliga soccer club has more luck than other teams, with coincidence most often channeling its good luck into the feet of the Bavarians. For example, on May 19, 2001, in Schalke stadium, when Schalke 04 was already feeling having become the German soccer champion after the last minute of the last game of the season 2000/2001. But then,

B. Wessling, *What a Coincidence!*, https://doi.org/10.1007/978-3-658-40671-4_2

everything changed in the game in Hamburg that was running at the same time but had not yet finished, a game that Bayern Munich would have to lose in order for Schalke to receive the championship trophy, and when the game in Schalke had finished, Hamburg's soccer club was leading: But in the very last minute, something went wrong, Bayern tied the score—the final whistle blew, and Bayern were champions, while Schalke were only "champions at heart".[1]

But whether Bayern Munich experiences more coincidences that lead them down the winner's or the loser's road is probably more a question of perspective. For example, in the final of the Champions League 1999 against Manchester United in Barcelona. There, the Bavarians led 1–0 until the 90th minute, when in overtime the Englishmen scored twice, bringing the score first to 1–1 and then to 1–2. The tying goal was definitely a product of luck, because the long pass forward was a blind shot of desperation.[2]

In soccer, most people would probably admit: it is perhaps normal that coincidence and accidental events so often prevent or produce a goal. But not otherwise in life! However, let's be honest: If you think intensively, talk to parents, siblings, other relatives and close friends, you will also find that such chains of coincidences have also affected you yourself, as they have significantly influenced the fate of each of us.

An older acquaintance recently told me about her marriage: In the first year, it crashed so often that she filed for divorce at the end of the year. However, then the lawyer's letter was subsequently lost, and thus the matter came to nothing. And lo and behold, the marriage became a happy one. As I write this paragraph, the couple has been married for 48 years and is happy that the letter got lost.

Sometimes, it was a teacher who gave a special advice or encouragement, which then led to the choice of a fulfilling profession or an important hobby. Maybe it was just the decision by childs' parents to move to another town, which led to the childs losing friends, but allowed them to enroll a school that promoted their talents and aroused their interests like never before. An accidental bout with a serious illness can, in some cases, lead to a completely different view of one's own life, turning it upside down. Everyone can find plenty of examples of more or less serious coincidences and accidents that caused either a negative or a positive change.

The Accidental Corona Pandemic

We all became witnesses to the consequences of a drastic accidental event at the beginning of 2020, which still has far-reaching consequences. As I became more and more involved with this book in 2019, based on work done in previous years, a virus jumped

[1] https://www.sport.de/news/ne2229064/fc-schalke-04-die-schwaerzeste-stunde-der-vereinsgeschichte---fc-bayern-schnappt-titel-2001-weg/

[2] https://www.spiegel.de/geschichte/fc-bayern-muenchen-vs-manchester-united-finale-1999-mutter-aller-niederlagen-a-1269035.html

Mankind, an Ecosystem for Viruses

There are billions of viruses on us and in us, about ten times as many as there are bacteria,[7] which, as single cells, are true living beings. According to everything we or the relevant scientists know, each one of us consists of about 100 trillion (i.e. 10^{14}) cells,[8] and, depending on the source, we also host 10 to 100 times more bacteria cells[9,10] or possibly "only" 1.3 times more.[11] That doesn't even include the ten times as many viruses, or the insanely high number of fungi that colonize us. We might well ask ourselves what we humans actually are. Maybe we're mainly an ecosystem that functions optimally by chance, one that happens to be perfectly suited for the real rulers of the world: microorganisms and viruses? But that's not a question for this book; we're thinking about chance and coincidence here. So, let me ask it another way: Maybe it's to be seen as an essential coincidence that we live, *despite* being inhabited by so many microorganisms and viruses. And maybe it's not by accident, but perfectly normal, that humans are threatened by influenza, Ebola, measles, and, since the end of 2019, SARS-CoV-2 viruses? However we want to look at it, accidental events and coincidence are definitely at work here, and not just a single one!

There are ten million viruses in every cubic centimeter of seawater, and it is estimated that there are a total of 10^{31} viruses in the world's oceans. These are estimated to be the representatives of about one hundred million virus types.[12] Viruses contributed almost ten percent of our genetic heritage during evolution.[13] As far as is known, the corresponding genes are mostly inactive. But we also know that a *retrovirus* that has been introduced into the genome releases proteins in only a few days old embryos, that is, shortly after fertilization, that prevent the entry of other viruses into the embryo, which, at this time, is still a cell mass. In addition, this former virus gene is involved in supporting the establishment of protein production in the cells of the embryo. Other former virus genes are active in placental cells and produce two proteins that "glue" the cells together.[14] Even parts of our genome that have been shown to come from bacteria probably came into our genome with the help of viruses.

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[7] https://www.scientificamerican.com/article/viruses-can-help-us-as-well-as-harm-us/

[8] https://www.smithsonianmag.com/smart-news/there-are-372-trillion-cells-in-your-body-4941473/

[9] https://www.sciencefocus.com/the-human-body/human-microbiome/

[10] https://en.wikipedia.org/wiki/Microorganism

[11] https://www.scientificamerican.com/article/strange-but-true-humans-carry-more-bacterial-cells-than-human-ones/

[12] https://www.scientificamerican.com/article/viruses-can-help-us-as-well-as-harm-us/

[13] https://www.nature.com/articles/nature14308/

[14] https://www.spektrum.de/news/die-gute-seite-der-viren/1722318/

In our digestive system, not only can bacteria be found, but also countless viruses.[15] Their role is largely unexplored. Bacteriophages—a special family of viruses—are active in the intestine, mainly acting as our helpers by attacking pathogenic bacteria. However, viruses that can cause infections of the digestive system apparently also have a positive effect on the healing of damaged tissue in the gastrointestinal tract. Herpes viruses seem to be able to hinder bacterial infections. It is by no means clear what viruses, which are simply everywhere in the world, can do. But it is obvious that proteins enveloped in RNA—that is, viruses—have played a decisive role in the development of life. Indeed, it is not at all excluded that viruses or precursors of viruses are older than life itself, and thus were involved in the beginning of life.

In view of the incredible abundance of viruses of numerous types, of which the vast majority does not harm us humans and other living beings, but rather offers benefits or is neutral, it is certainly understandable what a truly unpredictable coincidence it was when the SARS-CoV-2 virus from the Corona virus family, together with its variants, became so virulent and dangerous for us. There are many experts and several previous studies that say that such a pandemic was to be expected. The close contact of people with wild animals, through hunting, wild animal markets, and our civil infrastructure penetrating deeper and deeper into formerly wild landscapes, is seen as conducive to this. Therefore, the probability increases that one of the trillion viruses surrounding us could become threatening again. Whether, when and how, and what kind of virus—that is all by accident. And to put it bluntly: This type of accidental event or coincidence, which happened at the beginning of the pandemic, is an essential characteristic and tool of evolution. This concatenation of coincidences, at the beginning of each of which are mutations, over millennia and millions of years, we call *evolution*.

Coincidental Inventions and Disasters

This is also the case with events that change technology, science or history. Actually, most things are set in motion by chance, by accident. This is the case with all inventions. But what exactly is an invention? It is a new idea that is then implemented worldwide for the first time by means of work—often very systematic, very time-consuming, rarely very quick and easy—in industrial practice, in the market, in our households. Ideas form purely by chance (I will come back to this in Chap. 3). Anyway, something happens in the brain while inventing: Suddenly, you see how a problem can be solved in a new, previously unthinkable, often even inconceivable way. Nobody can plan or even force an idea, no, it's not that simple. Such ideas come to you, or they don't.

I have made several dozen inventions of different kinds myself. And I've had even more ideas. The ideas all came to me unannounced and mostly in situations where I

[15] https://www.frontiersin.org/articles/10.3389/fmicb.2015.00918/full

dispelled so many points of contention, found so many compromises —now it had to be over. We agreed to threaten our boards: "If we don't sign very quickly now, the other side will shut down." There was absolutely no talk of this on the other side, but we took this risk of the alleged ultimatum on the other side. It worked as hoped. The groundless concerns were dropped.

At the beginning of September, we met with a Hamburg notary public for the signing. Exactly ten days later, the US bank Lehman Brothers collapsed. My negotiating partner and I met again in China the day after the bank disaster, and he candidly admitted: "If we hadn't signed a few days ago, the deal would never have come about. Corporate management is now in sheer panic mode." We had simply been lucky that we could sweep the pusillanimous concerns of the approval committees off the table. Sai Weng was right with his philosophy of life.

2009 was an economically terrible year. But already towards the end of this catastrophic year, and even more so later, it became clear that the contract with the US company was a stroke of luck, because, within a very short time, we developed my process into the company's most sales- and profit-strong product. Only a few years later, we were market leader with my product. *We* then meant, however, the buyer of my company, while I was working in a completely independent position (not subject to any instructions) as a technology consultant for the group, although I was actually leading all the technical marketing and laboratory work for my product, together with my former employees in Germany and China. Above all, I advised the customers and their customers, the international large corporations of the electronics industry, in terms of application technology. If we had delayed the signing of the contract by a mere ten days, the sale would have collapsed. In the following years, the US group would probably have encountered enormous problems without our product, because all other product groups shrank or, at best, stagnated in the course of the next years. And whether I would have survived the years 2009/2010 in China with my small company is definitely not written in the stars.

The *Financial Crisis Inquiry Commission* legally installed in 2009 took two years to uncover the causes of the financial crisis. It turned out that there were numerous, long-term developing and mutually interacting causes that eventually brought about the collapse. It is the classic toolbox for the generation of coincidences: The individual reasons would never have caused such a world financial crisis on their own. And because no one was able to foresee that this and that and further reasons would cause such a fundamental crisis of the entire world financial system several years later, we also see here the very typical composition of the type of coincidence that we want to examine in this book.

Accidental Events and Coincidences in Scientific Research

It is no different in natural scientific research, even if researchers themselves like to tell their story differently in cases of success—namely, that everything actually followed a great long-term plan that was systematically implemented by oneself or the department

or company. Of course there had been failures, that's normal, but after patient systematic work, success finally set in. You may believe this or not; I don't believe it: The vast majority of research results have been highly dependent on chance and coincidence. On the fact that the researchers met people important to their work, that they were lucky enough to find good employees, that they were able to prevail with a research application, not least because they *accidentally* heard or read or observed something that helped them decisively. Only very rarely does one read anything from researchers themselves about how much their research results depended on chance and coincidental events.

James Watson, on the other hand, very illustratively described in his book *The Double Helix,*[27] how convoluted the path to the discovery of the DNA structure was. I devoured the book as an 18-year-old aspiring student who wanted to become a biochemist. It still sits on one of my bookshelves today. Watson and Crick were already my idols during my high school years. I know that, in recent years, Watson has maneuvered himself onto the sidelines with various controversial (racist and homophobic) remarks. Researchers who would express similar views today would certainly not be given a leg to stand on. But Watson's later unquestionably rejectable and reactionary views do not change the significance of his and Crick's pioneering achievement.

His book is extremely enjoyable to read. Watson was born in the USA, grew up there and went to university at the age of fifteen. He is highly intelligent. At first, he wanted to specialize in ornithology, but then switched to zoology because of his interest in genetics. He began his first research project in a group at Indiana University that was determined to clarify the chemical basis of genes. Many coincidences eventually led him from Copenhagen (where he was a postdoc and was actually supposed to be working on another topic) to Cambridge, bringing him into contact with Francis Crick. Thus, two congenial scientists, who were also unconventional in every respect and liked to stray from the usual paths, met by chance. They did their mostly mental and modelling research work not with the blessing of their bosses, but outside of their actual tasks. Not least, they did not like to deal with chemistry at all, although they had set themselves a structural-chemical question. At that time, there was one hypothesis, or let's call it a *paradigm* (more on this in Chap. 5), that enjoyed the greatest popularity, according to which the genes in the chromosomes consist of proteins. Deoxyribonucleic acid (DNA) was considered an unimportant interfering by-product. But there were also first signs and individual researchers who suspected that genetic information was housed in the DNA. Watson's and Crick's chaotic, playful and creative approach is clearly visible in Watson's book. And one of their main motives—in addition to the acquisition of knowledge—was to be faster in the elucidation of the DNA structure than the already famous Linus Pauling (he received the Nobel Prize in 1954). Pauling had recognised the

[27] J. D. Watson, The Double Helix, Atheneum Press (US) and Weidenfeld & Nicolson (UK) 1968.

The Essential Coincidence—an Attempt at Description

"The physical research of the last 4–5 decades has shown, clear as daylight, that, at the very least, for the overwhelming majority of events whose regularity and constancy have led to the postulate of general causality, the common root of the observed strict regularity—is chance."

Erwin Schrödinger: *What is a natural law?*[38]

This sentence comes from Erwin Schrödinger's inaugural speech at the University of Zurich in 1922. Even if Schrödinger probably meant other types of chances and coincidences than the ones we are examining in this book, the sentence, if we take it literally, is completely correct. In the hundred years since he spoke it, we have only learned much more about chance and coincidence.

We should now try, after reading several examples and Schrödinger's statement, to find a general definition for the type of coincidence that I want to limit myself to in this book.[39] There are several types of chances/coincidences. For example, there are those for which we—who experience them—do not recognize a direct cause ourselves, but only because we have overlooked them. So, we do not have to complain about the alleged coincidence that we have not changed our bicycle tire for years, now that it has gotten a flat tire on a gravel road. It may be a coincidence that it happened *today*, but it was basically foreseeable.

The eminent biochemist and Nobel laureate Jacques Monod examines the concept of chance and coincidence somewhat systematically in his book *Chance and Necessity*.[40]

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[38] From: "The Natural Sciences" Issue 1, 04.01.1929, p. 9–11; the pdf of this speech can be downloaded here: http://www.psiquadrat.de/downloads/schroedinger22_29_naturgesetz.pdf. The phrase was translated from German by B. Wessling.

[39] In this book, we will **not** deal with the question of how people in general perceive chance and coincidence or accidental events, or the fact that that we humans also like and (pre)tend to see connections and supposed causes where there are no connections and no objective causes (belief in supernatural powers and forces, superstition, esoteric beliefs, conspiracy theories).

[40] Jacques Monod, "Chance and Necessity—An Essay on the Natural Philosophy of Modern Biology"; (German edition "Zufall und Notwendigkeit": Piper-Verlag p. 107, page numbers corresponding to the edition of 1996; I had already bought and read the original edition from 1971 at the beginning of the 1980s, but after 10 more moves, I could not find it again in my bookshelves, so I bought the antiquarian edition of 1996 for the work on this book). The original wording in French is "hasard essentiel", cf. Jacques Monod, "Le Hasard et La Nécessité—essai sur la philosophie naturelle de la biologie moderne", Éditions du Seuil, Paris, 1970, p. 128, here also the term "incertitude essentielle" is used and explained. In the following English edition ("Chance & Necessity"—An Essay on the Natural Philosophy of Modern Biology", Vintage Books, 1972), the terms "essential uncertainty" and "essential chance" is used and explained, p. 113 and 115, resp. Instead of "chance", I mainly prefer to use "coincidence", in addition to "chance" and "accidental events".

He starts from a quote by Democritus: "Everything that exists in the world is the fruit of chance and necessity."[41] But then he differentiates between chances in contexts that can be investigated using probability theory and those phenomena to which chance or coincidence is "essentially" inherent.

The first case we encounter, for example, is with roulette, the unpredictability of which, according to Monod, has a purely operational, technical cause. It is rather impractical for us to predict where the ball will land. There have been attempts to outsmart the ball's random behaviour in the roulette wheel. J. Doyne Farmer developed an appropriate procedure in the 1970s.[42] A computer with suitable software must be told a) how quickly the ball can traverse the circumference of the wheel one time, and b) how long the wheel takes for one rotation. The inventor secretly measured this with a stopwatch and transmitted it by radio to a partner outside the casino. This allowed the computer to calculate quickly before "rien ne va plus". With this approach, the chance of winning by placing a bet on, for example, "red" increased from 48.6% (which means that you lose in the long run) to 51.6% (so that you win in the long run if there are enough attempts). In theory, of course, an (undesirable) apparatus is also conceivable, one that uses laser beams to carry out the measurements much more accurately and quickly. The calculation would be carried out today with a modern fast laptop instead of a slow 1970s computer, a change that would increase the chances of winning even more. Of course, this could never be practiced, but J. Doyne Farmer showed that roulette does *not* generate *essential chance*. What we observe with roulette, is *randomness*.

The situation is similar with dice or other games, and, in principle, also with the lottery: randomness. With *6 out of 49,* it is *not* fundamentally impossible to predict which ball will fall next by means of a super-exact observation of the flight paths of all the balls. Only, it would not help anyone to win, because you have to submit your lottery ticket the day before. But the probability of winning is exactly known.

It is just as apparent that my followers on Instagram have, on average, more subscribers than I do; the same is true of most of the photographers I am connected to: If they checked, they would observe that their contacts, on average, have more contacts than they do. In the case of Facebook, it was calculated in 2011: At the time, Facebook users had, on average, 190 friends; but the friends of this average user had, on average, 635 friends. For 93% of the people on Facebook, their own list of friends is shorter than the list of friends of their friends. This appears illogical, but it is so. Scott Feld has mathematically examined it using statistics and analysis of the "sample bias" principle in his paper *Why your friends have more friends than you*.[43]

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[41] J. Monod, loc. cit (German edition), p. 17.

[42] https://www.sciencealert.com/a-physicist-has-built-a-machine-that-can-beat-the-odds-at-roulette

[43] Scott L. Feld, "Why Your Friends Have More Friends Than You Do", American Journal of Sociology, Volume 96, Number 6, May, 1991, pp. 1464−1477. Numbers of the Facebook study cited after Christian Hesse, Warum deine Freunde mehr Freunde haben als du, Springer Nature 2017

For example, one base could be "missed" when copying; then, the triplet is read completely differently, a *completely* new protein is created. This might be simply useless or it might be harmful, or it could cause a new property of the organism. On the other hand, if only one base is read incorrectly, this might have no effect at all, or it could lead to a completely different folding of the protein. What this, in turn, does to the organism is also unpredictable. Apart from that, a new species is not created by a single mutation, but only over the course of many generations, with many equally accidental mutations and the coincidentally resulting changes.

So, we are dealing with a chain of coincidences in evolution that are initially unrelated to each other: The accidental—and extremely rare!—occurrence of a copying or reading error; the resulting coincidental change in the now differently composed protein; the then also resulting unpredictable change of a property, unless it leads to a disease or the death of the organism, which, in turn, influences the ability of the organism to survive and reproduce in the ever-changing environment.

It is this type of intrinsic or *essential* coincidences based on "essential uncertainty" (as Monod worded it) that I want to examine in more detail in this book. We will not limit ourselves to mutations and evolution. Therefore, we want to rethink the term *coincidence, or chance,* again. Of course, it is worth taking a closer look at philosophical definitions of coincidence (chance) at the beginning.[46, 47] However, I don't want to adopt such formulations, but rather describe it with my own words as follows. That is, I *do not define* it, because there are certainly people who would be more competent at this sort of lexical definition, but formulate it for our purposes in this book so that we can understand it better:

> *Essential coincidence is characterized by the fact that two or more causal chains, which are completely independent of each other, coincide. Such a coincidental or accidental event therefore has more than one cause. Just before such an event occurs, when the independent causal chains coincide,* "chance" *turns into* "necessity", using Jacques Monod's words. *Essential coincidence is an event that actually occurred under given conditions, but, in comparison to other possible event chains, had an extremely low or even incalculable probability of occurring. It is a sudden change in the real world that can, in principle, be ascertained by observation or measurement, subsequent analysis of documents, traces, long-term consequences or the like. It can happen just like many other possible events, but is inherently unpredictable, was not predictable or, at least, not foreseen. Not least because the probability of such an accidental happening is close to zero. In retrospect, the causes of*

[46] For comparison or for pleasure, you can look at various websites: https://plato.stanford.edu/entries/chance-randomness/ or https://link.springer.com/chapter/10.1007/978-3-319-26300-7_2.

[47] Cf. the following definition: "An event is referred to as happening by chance if it does not follow from a given set of conditions with inner necessity, if it could have happened this way, but also differently. This does not mean that a coincidental event is not causally determined. The universal validity of the causal principle also extends to accidental events." (translated by B. Wessling, originally in: Günter Kröber in Klaus, G., Buhr, M. (1969), Philosophical Dictionary. Bibliographisches Institut Leipzig. I would like to thank Dr. Rainer Feistel for this hint).

such unexpected or even unpredictable events can be understood and objectively analyzed, even if sometimes not all causes are or can be recognized.

Many, if not most, processes in the world have several optional ways they can develop over time. We can often estimate the probability of different possibilities A, B, or C occurring; perhaps based on experience, or perhaps from theoretical considerations. But if a completely different possibility X occurs, which is extremely unlikely, and therefore no one will have considered it, we call that coincidence or accidental event, or: it happened by chance.

Let's take an everyday's example: Maybe we always go to the market on Fridays to do our shopping. With different probabilities, we will meet a neighbor A there (60% probability, we will meet him in 6 out of 10 cases), a sports buddy B (30%), and the mayor of our small town, whom we know (10%). Each meeting with these people at the market is a normal event, even the encounter with the mayor. It is not necessarily the case that we meet these people, but it happens often, which is quite normal, because they are also usually at the market at about the same time as we are on Fridays.

We would not expect to meet a former schoolmate there, someone we haven't seen in decades and have totally lost track of—but it happens one Friday anyway. Maybe because he was on a trip, his car broke down, he had the car quickly repaired at a nearby garage, and he took the opportunity for a walk into town. When he noticed the market, he wanted to stroll around there and maybe eat a bratwurst. He had no idea at all that we had ended up in this small town. It was purely by chance that we met again here, unpredictable, impossible to calculate a probability for this happening, and still, it happened: an essential coincidence. In retrospect, it can be understood, but not foreseen: We observe essential uncertainty.

Next, we look at the growth of a tree: It is 100% likely that the tree will form branches. But when exactly and where this happens, we can neither calculate nor predict. Branches can grow in completely different places, in completely different directions, the branching can begin at completely different times. These are simply essential coincidences. This results in impressive, unique structures of a tree crown, as we can in the photos below showing an Australian fig species (left) or this tree crown landscape in an Australian national park (right, photos by the author).

A small, but beautiful and unforgettable meeting by chance: I was walking along a narrow, densely overgrown path from which I had never been able to observe cranes (I am a crane researcher in my spare time). On this day, I happened to have my large camera, which I rarely take with me, and encountered this crane only twelve meters away from me. It was just three months old. I had never been so close to a wild young crane before. Cranes usually have a flight distance of at least 200 meters from humans. We looked at each other quietly for almost two minutes, me with the camera at my eye. (Photo by the author, July 2021).

Creativity is Coincidence in the Brain

3

Abstract

Coincidental events are constantly taking place in our brains as well. There are serious scientific findings that suggest "chance generators in the brain". Many people, some of them famous, achieved basic findings, discoveries and inventions as a result of a dream or situations in which they did not think consciously about the problem to be solved. The author was also able to solve the mystery of a previously unknown phenomenon in a situation in which systematic logical thinking was not possible. The phenomenon of improvisation, known especially from jazz music, is verifiably possible only if and when brain control mechanisms are turned off like while dreaming, so that chance has free rein.

Actually, I wanted to become a biochemist, but instead, I went to a small engineering company after university, and then I ended up working for an almost insolvent company that mixed plastics with other polymers and with additives. But why didn't I go to the USA or to Great Britain after my Ph.D., countries where biotechnology was slowly developing, where startups were setting out to revolutionize the pharmaceutical market scientifically, technologically and from a business perspective? Well, quite simply: I knew nothing about it. I was very provincial, my horizon didn't extend further than the borders of the Ruhr region, maybe it reached as far as the Münsterland in the north and the Sauerland in the south. About twenty years later, I briefly regretted not having changed to another city during my studies, let alone going abroad. Of course, I am responsible for that myself, but neither my parents nor my professors nor my doctoral supervisor asked me even once: "Why don't you go overseas for a while?" Because that's where the center of biochemistry and biotechnology was.

But over the years, I gradually learned that I had not missed anything. A series of coincidental events and my decisions at the forks in the road have ensured that I have

B. Wessling, *What a Coincidence!*, https://doi.org/10.1007/978-3-658-40671-4_3

Since research had its origins in the search for *one-dimensional conductors*, it was hoped and assumed that polyacetylene would have a long and straight linear chain structure. Based on transmission electron microscopy, it was thought to have a fibrillar, i.e., fibrous morphology. The chains could be arranged nicely in the fibrils—thus the assumption that had crystallized into certainty, which had its origins in a hope—lengthwise and parallel, the ideal one-dimensional conductor was supposedly found.[12] The graphic reproduced here from the justification of the Nobel Prize [sketches (c) and (d) in comparison to diamond and graphite in (a) and (b)] was supposed to show this.

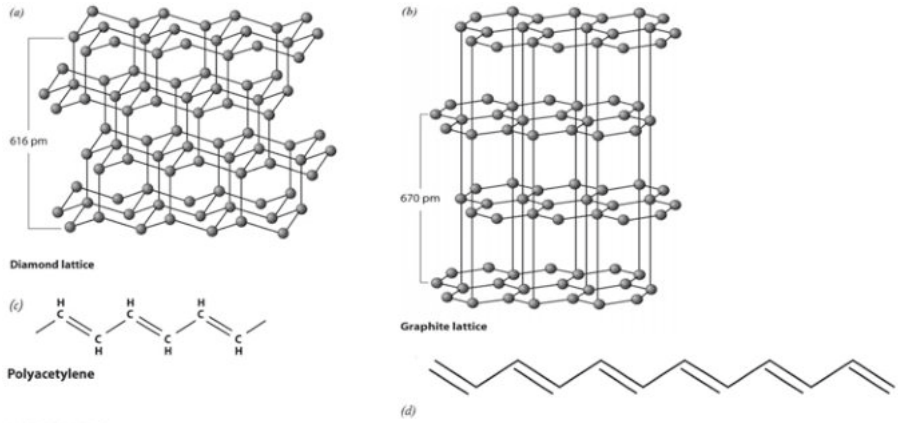
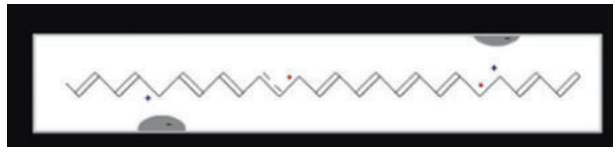


FIGURE 3
Three-, two- and one-dimensional carbon materials: diamond (a) and graphite (b) crystal lattices, and polyacetylene chain (c). An alternative way of writing polyacetylene is also shown (d).

This was identical to the assumption that the electron flow runs along the chain. The Nobel Committee published an animated representation of this (the following is a non-animated screenshot; in the link in the footnote, electrons shown in red jump along the chain).[13] In the text, it says that the electrons move along the chain.

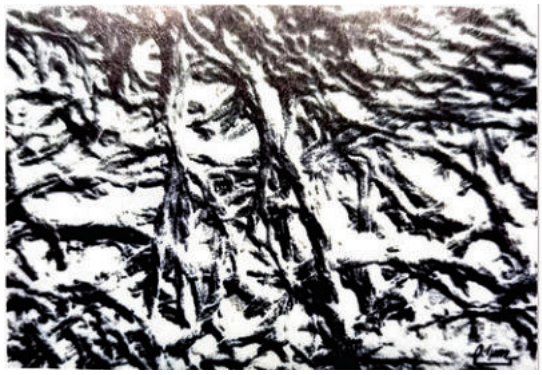


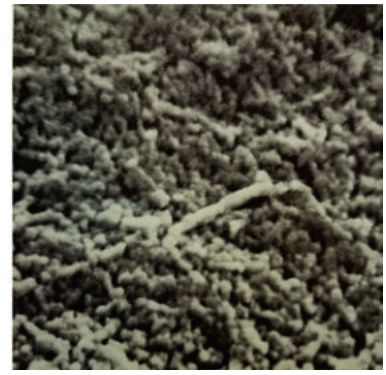
[12] Fig. 3 has been taken from the scientific background material that the Nobel Committee published: https://www.nobelprize.org/uploads/2018/06/advanced-chemistryprize2000-5.pdf, shown here with kind permission of the Royal Academy of Sciences "©Typoform/The Royal Swedish Academy of Sciences".

[13] https://www.nobelprize.org/prizes/chemistry/2000/popular-information/, with kind permission of the Royal Academy of Sciences "©Typoform/The Royal Swedish Academy of Sciences".

My idea was obviously quite naive and also contradicted all generally accepted scientific opinions. I must confess, to my shame, that I didn't think much about it, but above all, I wasn't worried. Because, first of all, I wanted to find out what polyacetylene looked like exactly.

To my surprise, I saw in the scanning electron microscope that the polyacetylene powder I had produced consisted of small spheres, really small, namely, only 100 nanometers in size. My powder contained no fibrils. Now, a suspicion began to dawn on me. I asked the Max Planck Institute for Polymer Research in Mainz, which was also researching in this area, to produce this substance for me exactly according to the usual method, which should lead to fibrils (see Appendix 5). The researcher there cut the resulting film and sent me half of it. We had agreed that he would conduct a *transmission* electron microscopic (TEM) examination there on site with his half, while I would look at my half with the *scanning* electron microscope (SEM). Now, the surprise was complete: In the Mainz TEM (i.e., in the *transmission*), a fibrillar structure was to be seen (picture on the left). With me, in the SEM (in *scanning* mode) a spherical structure was revealed (picture on the right): The fibrils therefore consisted of small spheres closely nestled together, strung together like beads on a string.





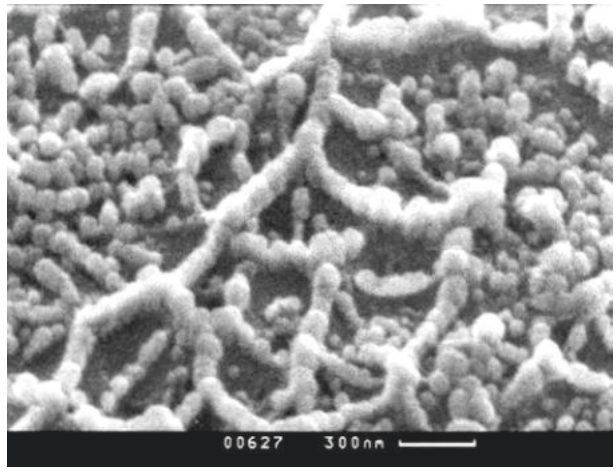
I published this finding, which I considered to be sensational.[17] It had to raise doubts everywhere about the assumed conductivity mechanism "electrons flow along the chain", because, if the smallest structures are not fibrils, but even smaller spheres, how are the chains arranged in the nano-spheres? And how do the electrons get from one sphere to

[17] https://www.researchgate.net/publication/230304769_Beitrag_zur_Diskussion_um_die_Morphologie_von_polyacetylen, Original source: Makromol. Chem. 185, 1265 (1984); an examination of the films in the TEM therefore tempts one to regard "fibrils" as morphological structural elements, because a shadow projection conceals the boundaries of the spheres.

carbon black: below, directly at, and above the critical concentrations.[23] I also looked at the first samples with a low concentration of polyacetylene.

At low concentrations, both substances, carbon black and polyacetylene, are present in the form of isolated spheres about 100 nanometers in size or smaller (see photos in Appendix 7). What? I thought the carbon black particles were highly structured and had lots of "little arms"? Then, it struck me that I saw a great deal many more particles in the samples, on the fracture surfaces, many more particles than the low concentration—only 0.5%—would suggest. This could only mean one thing: The carbon black dispersed into individual spheres or the polyacetylene also present in very small isolated spheres was concentrating in certain areas, so there had to be areas completely void of such particles! Where was the "homogeneous distribution" as claimed everywhere (and required by percolation theory!)?

But what was particularly surprising was that the loos (at low concentration) distribution of dispersed nanoscopic spherical particles in compositions with a concentration directly at or just above the critical volume concentration showed highly complex structures! There, I saw *strings of pearls* that branch off, and these again in a much higher concentration than just the 6% we had worked into it. How could this be?



In Appendix 7, I describe in a little more detail how, for months, I tried to solve this puzzle. It was a tormenting time for me, because I felt that I was close to finding something new and very important, but I couldn't find it. Again and again, I literally had stomach pains, so strenuously and sometimes desperately did I work mentally on the clarification of the question. I developed mental image after mental image, nothing fit together… Finally, I solved the complex puzzle during a twelve-hour wait at Newark Airport (New

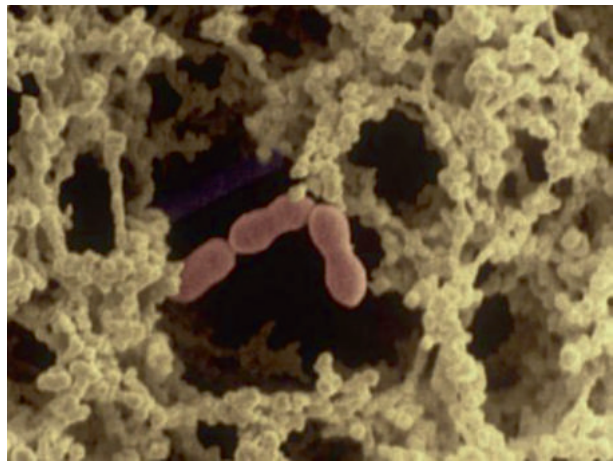
[23] Fig. 5, 6 from B. Wessling, preceding footnote.

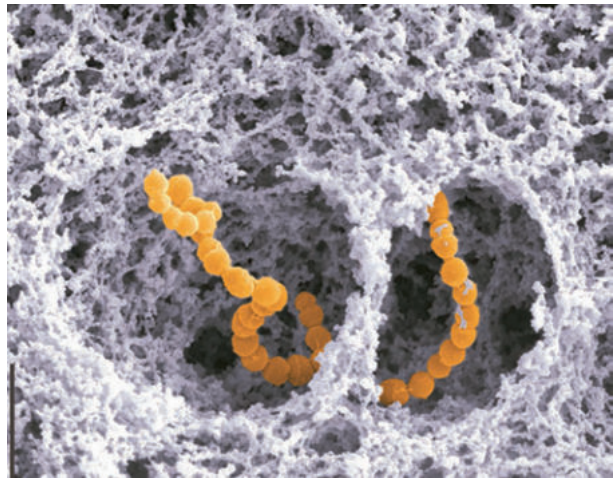
Jersey, USA) due to a snow disaster (see Appendix 7). While it was incredibly chaotic at the airport because all of the passengers, like me, had already been delayed for days, with only a few getting a flight and many becoming hysterical, I was calm as a cucumber. For hours, I sat on the floor leaning at the wall, didn't move, didn't care about whether I got a flight or not; I hardly noticed the constant loud and meaningless announcements through the loudspeakers, nor the yelling and the hectic back and forth of the thousands of passengers around me, but I scribbled sheet after sheet with new drawings, crumpling up 99% of them and throwing them into an already overflowing wastebasket. One sheet remained (sketch diagrams in Appendix 7):

Below the critical concentration, the carbon black and the conductive polymer nanoparticles are completely dispersed as nanospheres. This means that a very thin, very firmly adsorbed shell of molecules of the matrix polymer has formed around the carbon black or conductive polymer particles. The conclusion that it is a firmly adsorbed shell results from the pyrolysis measurements. The dispersed particles are closely packed together in layers, which—as someone from the Ruhr region—I called "seams" (i. e., like "coal seams"). At the critical concentration, the shells of adjacent particles unite, a long tube is formed, the spheres bump against each other, and electrons can now jump from sphere to sphere. These chains look, as I often described it to make it more understandable, like a snake that has swallowed several golf balls. This creates cavities that cause the kink in the density curve. Gradually, it became clear to me that it must be a non-equilibrium system.

In this picture, you cannot see "seams" like the coal seams in the Ruhr region, but rather the result of deposits that took place over millions of years during the cretacious period and also formed layers. Later, when the Himalayas were formed, these layers were uplifted by the same shifts of continental plates. After that, they underwent changes due to erosion and oxidation, so that these beautiful landscape forms and colors were created. These are also results of non-equilibrium processes that continue to take place. Equilibrium processes cannot create something like this. (Photo by the author in the Danxia Shan National Park, China, a UNESCO Global Geopark)

of the milk: They have formed a three-dimensional network structure that causes the typical viscosity of the yogurt.

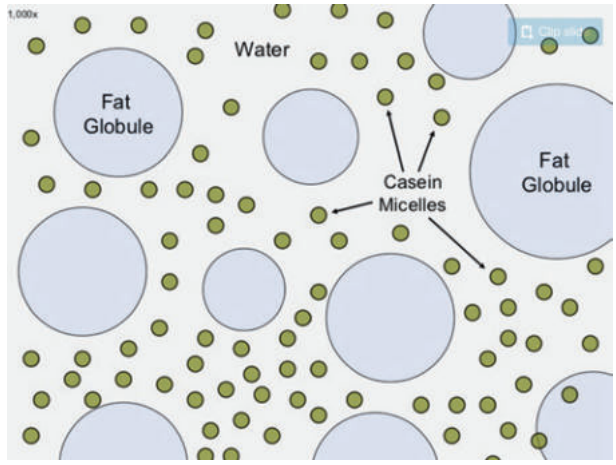


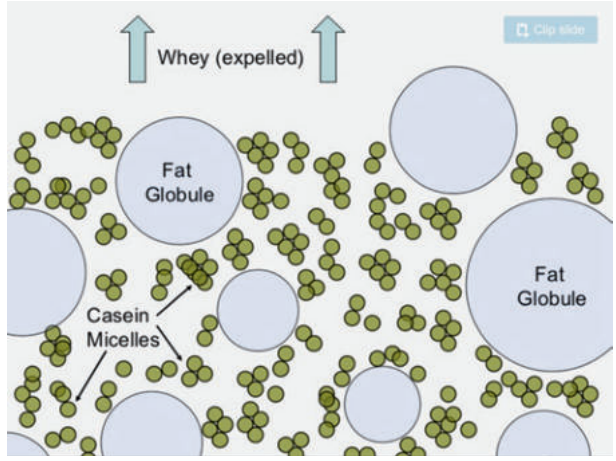


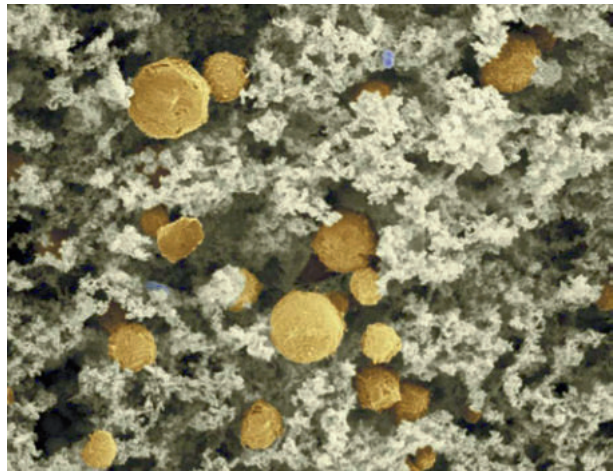
The difference between milk and mozzarella, more precisely said: the process of milk becoming mozzarella, which corresponds to the transition from a liquid to a relatively solid emulsion, can be illustrated as shown below.[35] In milk, the casein protein droplets

[35] https://www.slideshare.net/nsutaria/the-food-science-behind-mozzarella-cheese, see also http://stsimondicroce.blogspot.com/2015/10/di-croce-gr.html (Science 1.4), reproduced with kind permission from slidedoc.com according to their terms of use.

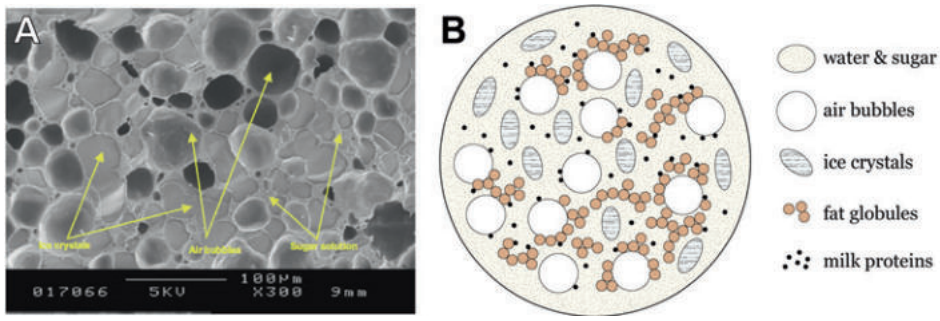
("micelles") are isolated from each other. In cheese, they then form pearl chains, and finally three-dimensional networks:







Electron microscopic photos of the casein network in cheese[36] and tofu[37] show comparable structures.



Finally, I don't want to hide the fact that even much-loved ice cream is a non-equilibrium system with a complex structure, as can be seen in the image above.[38]

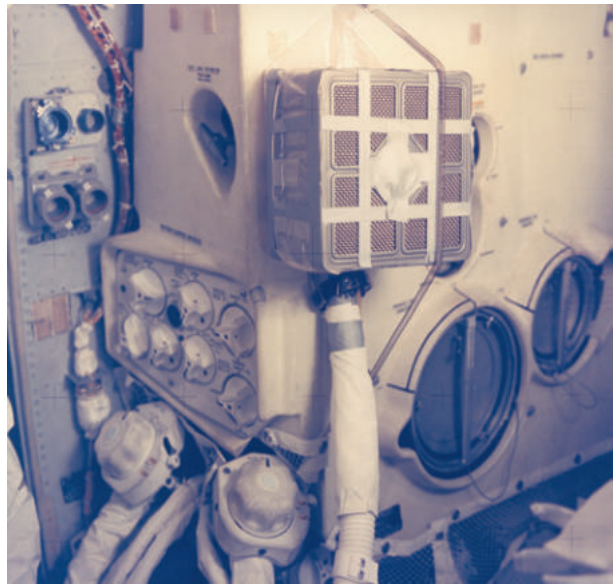
Everywhere, we see structures that are very similar to those that I found in my plastic dispersions. Of course, they are different dispersed or emulsified substances in a different environment. But we can clearly see: The particles or droplets are by no means uniformly, statistically homogeneously distributed, but are forming complex three-

[36] http://www.magma.ca/~pavel/science/Foods&bact.htm, printed with kind permission from Dr. Miloslav Kalab.

[37] https://www.thevetgroup.com.au/more-cheese-gromit/casein-matrix/; casein https://bit.ly/3pQlYGn

[38] https://scienceandfooducla.files.wordpress.com/2013/02/icecreamstructurefull-02.png printed with kind permission from Dr. Liz Roth-Johnson.

Nǚwā (女娃), the daughter of (mythical) Emperor Yàndì (炎帝), played on the beach of the East China Sea and saw the deep blue sea, which tempted her to swim in it. But when she had moved away from the shore a little, the sea became stormy and huge waves piled up. The sea god had allowed himself a joke with Nǚwā, who could not manage to get to the shore and drowned. When Yàndì heard about it, he hurried to the sea and called the name of his youngest daughter, but all he found was a small bird that fluttered around him and called out shrilly. Yàndì was sure that Nǚwā had transformed into this bird and cried bitter tears. Then, the bird suddenly called "jīngwèi"*, flew to the West Mountains, picked up a stone there and threw it into the East China Sea. From then on, the little bird flew back to the West Mountains again and again, picked up stones and threw them into the East China Sea. The sea god understood what the little bird was up to, laughed at it and said: "The sea is so wide and deep that you will never be able to fill it." But the bird replied: "I will never stop, and one day—believe me—I will have filled the sea."*



(Photo credit NASA https://www.nasa.gov/images/content/190026main_filterbox.jpg*).*

*Here is the original photo of the CO_2-filter in Apollo 13 that had to be improvised in a very short time, otherwise, the astronauts would have died. They could only use parts available on board. Here—*https://spacecentre.co.uk/blog-post/story-apollo-13/*- you can find a guide on how to build such a filter yourself based on this example.*

More details on contents in this chapter in Appendix 2, Part 2, Appendix 5, 6, 7, 11 and 12, Part 1.

"Equilibrium is good, Non-Equilibrium is bad"—is that True?

4

Abstract

The widely held views of *equilibrium* are discussed, including the concept of *dynamic equilibrium (steady state).* Entropy is explained in an easily understandable way, as is, despite the 2nd law of thermodynamics ("continuous increase of entropy in the universe"), complex structures can arise. Thus, we learn the basics of non-equilibrium thermodynamics. We understand that we ourselves and everything around us are non-equilibrium systems with dissipative structures. Otherwise, mayonnaise would not be stiff. "For organisms, *equilibrium* means death and decay." (Ludwig von Bertalanffy, founder of the *steady state (or: dynamic equilibrium)* concept).

Do not let the term *thermodynamics* make you uncomfortable in this moment. I will not try to teach you thermodynamics, forget the word, just cross it out in the book if it occurs. Let's just talk about *equilibrium* and *non-equilibrium* and think about both.

We all would like everything to stay nicely in equilibrium. The economy, ecology, climate, even the mutual atomic threat, in German, interestingly called the *balance of terror ("Gleichgewicht des Schreckens")* (no doubt for the purpose of calming our fears). While in the US, it's known as *mutually assured destruction*, an idea also based on the concept of equilibrium, the so-called *Nash equilibrium*…[1] We read the admonishing articles by journalists who express growing concern when, once again, currencies, the stock market, the financial economy, the real estate market have "gone out of balance (or "equilibrium")". And all the more so in regard to the climate. Or we hear about problems with the *ecological equilibrium,* because nature's biggest predators are going missing. In an article

[1] cf. https://en.wikipedia.org/wiki/Mutual_assured_destruction and https://en.wikipedia.org/wiki/Nash_equilibrium

B. Wessling, *What a Coincidence!*, https://doi.org/10.1007/978-3-658-40671-4_4

sound very exciting yet. We can add fine copper or other metal pigment powders to the oil, although just for better visibility, they are unimportant for the principle. Now, we slowly increase the heat input, and we will notice that, at a certain temperature difference, pentagonal and hexagonal honeycomb cells suddenly form, as the photo shows.[12]

What happened there? With a supercritical heat input from the heating plate into the glass dish, the oil can no longer cope with the difference between the temperature at the bottom in contact with the heating plate and the one at the free surface (can not "dissipate" the enormous amount of energy) in any other way than by synchronous rolling, whereby the liquid rises in the center of the cells and falls on the boundaries between adjacent cells: *dissipative structures.* In this way, the excess heat can be dissipated much more efficiently to the outside!

According to what we have discussed earlier, the explanation is clear: While the oil-/pigment suspension was structureless before heating and also at the beginning of our experiment—that is, it contained a lot of entropy, all particles and oil molecules were statistically evenly distributed—suddenly, some complex order was forming: The fluid molecules move in a synchronous rolling motion, along with the pigment powder particles. There is no other interpretation: The entropy has suddenly drastically dropped! How can that be? For our purpose in this book, we understood entropy as a kind of *waste energy* or *energy loss*—the supercritical energy import by the heating plate causes an entropy export, an *energy loss export* by massively increased convection made possible by the dynamic honeycomb structures. Because, otherwise, the system would not be able

[12] https://www.experimente.physik.uni-freiburg.de/Thermodynamik/waermeleitungundkonvektion/konvektion/benardkonvektionszellen; Reproduced with kind permission of the Faculty of Physics of the University of Freiburg.

Johann Heinrich Ludwig Flögel from Ahrensburg, the neighbouring town of my place of residence. This fact was not known until 2010.[31]

A Japanese research group led by Takao Kameda from the *Hokkaido Snow and Ice Research Laboratory* published a classification of snowflakes and similar *solid precipitation* in 2013, based on observations from mid-latitudes to the Arctic and Antarctic polar regions.[32] They defined 121 categories of snowflakes that are fundamentally different in structure, up from 80.

Even under the conditions of a calm frosty night on the ground—approximately constant in comparison to the turbulent conditions during the formation of a snowflake in the air—ice flowers form in shapes that are similar to each other but never identical, and also not symmetrical. (Photo by the author in the Duvenstedt Brook nature reserve in Hamburg, Christmas 2021).

We move from the cold into the heat, albeit only partially. We stand at the geyser *Strokkur* in southern Iceland, where it is cool or even cold, and wait for the next eruption of hot water. Wikipedia says: " It typically erupts every 6–10 minutes."[33] Sometimes, one can also read, it *regularly* erupts every 6–10 minutes or is "periodically spouting".[34]

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[31] https://www.shz.de/regionales/schleswig-holstein/panorama/wem-gehoert-die-erste-foto-flocke-id2018881.html, *all available in German only*, *see also* https://www.shz.de/lokales/stormarner-tageblatt/floegel-jahre-in-stormarn-id18903591.html*and* https://de.wikipedia.org/wiki/Johann_Heinrich_ Ludwig_Fl%C3%B6gel

[32] T. Kameda, K. Kikuchi, K. Higuchi, A. Yamashita, „A global classification of snow crystals …", Atmospheric Research 132–133 (2013), 460–472; the publication contains photos of all different categories.

[33] https://en.wikipedia.org/wiki/Strokkur

[34] https://en.wikipedia.org/wiki/Geysir

were formed. The ecosystems became impoverished in terms of nutrients, evolution stagnated and came to a standstill for a billion years. When the Earth's crust became thicker again, plate tectonics was able to build mountains again, and so, about 300 million years ago, the *Cambrian explosion* occurred: Practically all known animal species originated in this period. May I recommend this to you as a sort of *learning module*? So, the Earth is in a non-equilibrium state. Life, evolution are non-equilibrium processes; they require the flow of solar energy and nutrients to export entropy. If continental drift slows down, the Earth is locally on the way to equilibrium, hardly any further changes take place, and evolution stagnates.

Now, let's also look at two oaks of the same age standing side by side.[38] Are they identical? No, they are not at all. Their size, the trunk diameter, the shape, where the branches branch off, how many there are, how thick they are, the bark pattern, everything is different in detail. Where the next branch and the next branch after that forms is left to chance and coincidence. We will very soon come to understand the causes of the occurrence of chance and coincidence in the next but one chapter.

If we jump to much larger scales, we find that no galaxy looks exactly like another; not only with snowflakes, we do not find two that are identical. In *Monthly Notices of the Royal Astronomical Society,* one could recently learn about the extremely variable structure and properties of galaxies:[39] One can conclude: Every galaxy is unique. The cosmic bodies appear with different bulges, halos, discs and rings. In some, many new stars are born, others hardly develop at all. There are at least $2x10^{18}$ galaxies (2 trillion),[40] and

[38] https://naturfotografen-forum.de/data/o/95/476656/image::dr.karl-heinz_limmer.jpg With kind permission from Dr. Limmer.

[39] https://academic.oup.com/mnras/article/505/1/991/6123881

[40] https://www.nasa.gov/feature/goddard/2016/hubble-reveals-observable-universe-contains-10-times-more-galaxies-than-previously-thought

each one observed so far is like no other! There would be plenty of chance for at least two of them to be identical, but no …

Non-equilibrium is always dynamic, highly interesting, and often very beautiful. When we look at photos (like the one at the end of this chapter) of two galaxies in interaction taken by the *Hubble* space telescope, or the latest photo of the cirrus nebula (in the preface), we see an incredibly beautiful universe. Consider all the different animals, the birds and their feathers, best seen under a microscope! Or coral reefs that I could marvel at as a diver, or the complexity of a river delta like that of the Lena on this book's cover—our non-equilibrium world is beautiful! Now, let's imagine instead what an equilibrium world would look like: All substances—if they ever existed, because how could they have been generated if not in extremely-far-from-equilibrium stars—would be evenly distributed in space. There would be no suns that could produce heavy elements. No planetary systems with suitable planets that could enable the emergence of life. There would be no DNA containing a blueprint of organisms, no proteins that could act as enzymes, no feathers with which birds could hover in the air. There would be no us. Everything would be dead, but in equilibrium. That's not at all what we want. So, let's stop complaining that something has gone out of equilibrium. Fortunately for us, it was never in equilibrium to begin with, because, otherwise, we would not exist.

The photo below[41] *shows two interacting galaxies. There is nothing else like it in the universe. Like any other dissipative structure, these galaxies are unique in their structure, even though the patterns often resemble each other.*

[41] https://esahubble.org/images/heic1107a/Es it is of the object "Arp 273", 300 million light years away from us.

Almost Despairing of Science

5

Abstract

Surprisingly, non-equilibrium thermodynamics is hardly present at universities, rarely in research, and almost not at all in the curriculum, let alone elsewhere in society. This is despite the fact that the justification for awarding the Nobel Prize in 1977 to Ilya Prigogine clearly sets out how important this theory is for the fundamental understanding of our world. Most revolutionary new findings of science had a similar fate: it required a lot of time before they were widely accepted. But Albert Einstein's much more complicated theory of relativity was quickly recognized and has since been at the center of many popular science articles and books. Not at all so for Prigogine's theory. Thomas Kuhn has presented an explanation for the different acceptance of new ideas in his book *The Structure of Scientific Revolutions:* the *paradigm* based on which scientists are doing their work.

Ilya Prigogine received the Nobel Prize in 1977 "for his contributions to non-equilibrium thermodynamics, particularly the theory of dissipative structures".[1] Nevertheless, this actually quite important branch of thermodynamics still leads a *shadow existence.* And that, despite the fact that the world we live in consists essentially of non-equilibrium systems. This is also explained by the Nobel Prize Committee in its press release,[2] in which it says: "Classical thermodynamics has played a dominant role in the development of modern science and technology. It suffers, however, from certain limitations, as it cannot be used for the study of irreversible processes, but only for reversible processes and transitions between different states of equilibrium. Many of the most important and interesting pro-

[1] https://www.nobelprize.org/prizes/chemistry/1977/summary/

[2] https://www.nobelprize.org/prizes/chemistry/1977/press-release/

B. Wessling, *What a Coincidence!*, https://doi.org/10.1007/978-3-658-40671-4_5

cesses in Nature are irreversible. A good example is provided by living organisms which consume chemical energy in the form of nutrients, perform work and excrete waste, as well as give off heat to the surroundings without themselves undergoing changes; […] Dissipative structures display two types of behaviour: close to equilibrium their order tends to be destroyed, but far from equilibrium, order can be maintained and new structures be formed. The probability for order to arise from disorder is infinitesimal according to the laws of chance. The formation of ordered, dissipative systems demonstrates, however, that it is possible to create order from disorder" [if and only if far from equilibrium, author's note].

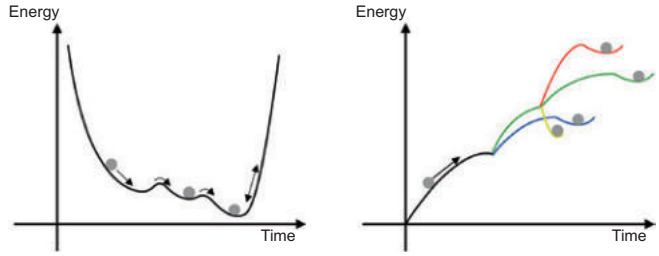
I would like to point out a very important aspect in the the Nobel Prize Committee's justification here: Non-equilibrium processes are *irreversible* processes. This does not mean that one could not reverse certain processes with a lot of effort back to the starting point, but, if it is at all possible, only with *very* high effort. If we have made mayonnaise, we cannot recover the starting materials individually and put them back into the bottles. At least, we would certainly fail to bring the raw eggs back into their shells with the recovered egg yolk. We will not be able to return the egg yolk to its bladder, we cannot repair the shells, let alone the inner membrane of the egg. Please imagine that a sea eagle has flown over your house. I have one that does so occasionally. Could it be conceivable that it could regress back into an egg? The feathers grow back into down, the bones become soft, all organs develop back … and suddenly there is the egg with a hard, unbroken shell back in the nest? No, that is impossible, just as it is impossible for a foal to regress back into the stallion's sperm and the mare's egg cell. I am not asking if time could suddenly reverse direction (that is not possible, a topic that we will discuss in Chap. 7). No, here, I am addressing the question of whether, during the course of the normally progressing time, a development that has once begun, a non-equilibrium process like fertilization, the development of the embryo and the birth, the subsequent growth and maturation, could reverse itself at some point. No, that is not possible; these processes are, in principle, irreversible.

We cannot make a boiled egg raw again by taking away the heat we put into it earlier, nor in any other way. The proteins have been irreversibly converted into another structure. We cannot remove the conductive polymer that we synthesized and then dispersed in a paint base. If we tried to filter it out with an ultrafine filter, we would separate the fine particles—in theory, it is practically impossible—but each nanoparticle would still be surrounded by a monomolecular layer of the matrix, the polymer basis, of which the paint base consists. How can we remove it and bring it back into the paint pot? It just doesn't work, not even with solvents! I tried this once, because I wanted to examine my product after dispersion; I found out: It doesn't work (see Appendix 8).

For what reason are these processes irreversible? It is the entropy: By initiating a process—a dispersion, the boiling of an egg, the fusion of a cell with sperm—entropy has been produced, ultimately exported into space, and we can not, under any circumstances, collect it again and bring it back into the process. This makes non-equilibrium processes irreversible. It looks different in equilibrium or near equilibrium: These processes are reversible. We can dissolve sugar in water and get the sugar back unharmed if we allow the water to evaporate. It happens by itself; it just takes a while.

physics book *Physik Libre.*[40] All three different positions of the ball in the above Figure from the online physics book are referred to as being in *equilibrium,* namely, as stable (a), indifferent (b) and labile (c) equilibrium. But in the end, isn't *labile equilibrium* an oxymoron, that is, a conceptual contradiction in terms, just like *dynamic equilibrium, Fliessgleichgewicht?*

What do scientists' mental pictures of *equilibrium* look like? They are basically not much different from those in the school book mentioned above (see the graphic below left): A ball falls or rolls down from a height, from a state with a lot of potential energy, into equilibrium, i. e., into a minimum of energy. In addition, there are other equilibrium states with similarly low energy. These can be reached due to a slight disturbance. Non-equilibrium, on the other hand, does not exist in the world of imagination of most scientists. At best, they imagine *labile* or *dynamic equilibria,* terms from a world view that is still shaped by the equilibrium paradigm. However, the image of non-equilibrium could look like the graphic below: In this way, one can schematically describe a non-equilibrium process that leads to a *comparatively stable non-equilibrium state over a certain period of time.*

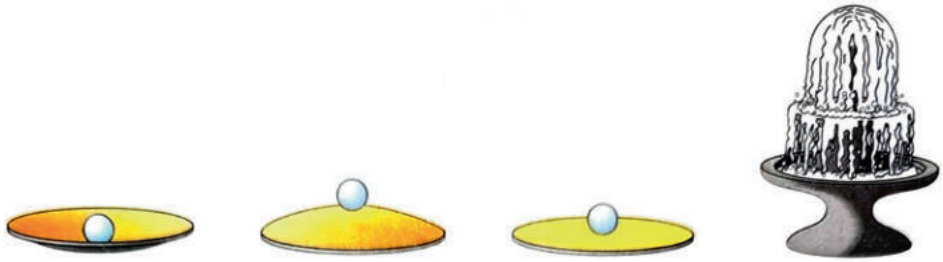


Left graphic: Equilibrium; right graphic: Non-equilibrium.[41] *The y-axis shows the energy of the system, the x-axis the time. In non-equilibrium, the system repeatedly experiences situations (forced by the supercritical amount of energy flowing into the system) in which different paths can be taken: Bifurcations that lead to different relatively stable states (symbolized by different colors) via different paths, each of which occupies a much higher energy level than an equilibrium state.*

[40] https://physikbuch.schule/equilibrum-and-stability.html, Michael Grundel, *Physik Libre,* Freely available physics book for high school level II, graph taken from https://commons.wikimedia.org/wiki/File:Types-of-stability.svg.

[41] Graphic concept adopted (but graphically changed and clarified) from B. Wessling, https://www.researchgate.net/publication/233979584_Dispersion_hypothesis_and_non-equilibrium_thermodynamics_key_elements_for_a_material_science_of_conductive_polymers_A_key_to_understanding_polymer_blends_or_other_multiphase_polymer_systems.

You can imagine this by thinking of throwing a ball with a lot of energy from the street in front of a house onto the roof, watching it roll down the roof tiles and settle in the gutter. You can also imagine a high mountain lake without drainage: it rains, the lake fills up, the water stays in the mountain lake and does not flow into equilibrium, i. e., into the open sea. In addition, over time (x-axis), while energy is constantly flowing through the system, other states suddenly become possible. We will think about this in the next chapter. A non-equilibrium process does not necessarily lead to exactly *one* result, but can cause several or even many different results. These are then to be practically understood in the description of the *energy landscape*, as high mountain valleys in the heights of the potential energy that the respective system has reached.



stable unstable indifferent dynamic

In a book's chapter on *Ecology,* the term *ecological equilibrium* is introduced and often used as if it were self-evident, and it is in general use.[42] First, the term *equilibrium* is illustrated with an image from a physics book (see the figure above). The text then explains that the *labile equlibrium* does not adequately describe biological systems, but that a picture of a flowing fountain (upper right) is more appropriate: dynamic equilibrium.

This is similar to the term Fliessgleichgewicht (*flow equlibrium),* which we discussed in Chap. 4. Then, the authors continue: "When something flows, it does so because it is *not* in equilibrium." How true! And furthermore: "Every biological system uses a complex *texture of imbalances* … " (emphasis by the authors). And yet, the whole thing is entitled *The ecological equilibrium,* and the cycles of the most important nutrients in a pine or oak forest and the phosphate cycle are schematically represented and explained. Both *cycles* seem to move on their own (just like the fountain in the picture, whose

[42] e.g. here: E. Philipp, B. Verbeek,Ökologie, in: Materialien für den Sekundarbereich II, Biologie (= *Ecology,* in: *Materials for Secondary Level II, Biology);* Schroedel-Verlag 1998, p. 72; reprint permission by Westermann-Verlag.

The Birth of Chance and Coincidence in Complex Systems

6

Abstract

Using characteristic examples from biology (biochemistry, evolution), weather, climate change, complex networks and cosmology ("the big bang"), the dynamics and non-linearity of non-equilibrium systems are examined in more detail. It becomes clear that higher levels of organization of matter develop their own, new laws in comparison to lower levels. The *emergence* of new properties and laws is an important aspect. The *non-linear* behavior of these complex systems is the cause of the occurrence of chance and coincidence. Finally, the phenomenon of *decoherence* shows us why the quanta (elementary particles), with their indeterminacy, cannot cause chance or coincidence in the macroscopic world.

In the previous chapters, we learned about many examples of different coincidences, but we focused on the type of coincidence and chance that Monod had called *essential*. We left out those processes that only appear as coincidental to us because it is not possible or too expensive to predict the result for practical reasons; such processes that can also be reliably investigated using probability calculations should be referred to as *random*.

We have dealt somewhat extensively with the principle of *non-equilibrium*, which pervades and shapes our world. And you may have already suspected that the reason why I have talked about it so much, is because chance is somehow related to it. That's right, that is the case, and now, we want to get closer to the solution of the question *How do chance and coincidence enter our world?* so that we can finally answer it.

We had already learned an important criterion of non-equilibrium processes: irreversibility. I had described this using the example of the development of living beings from seeds and eggs, but I can also take a banal example from my favorite sport, soccer: If the ball has entered the goal (in accordance with the rules), then the goal is scored and will not be taken back, even if the ball only landed in the goal because of an unfortunate

B. Wessling, *What a Coincidence!*, https://doi.org/10.1007/978-3-658-40671-4_6

coincidental encounter with the foot of a defender who wanted to prevent a goal shot. This had changed the ball's trajectory so that it landed in the goal, but whereby, without the foot, it would have actually landed outside of it. Let's look at the flight path of the ball: After the striker kicked the ball, it followed a ballistically calculable path, in principle. For good mathematicians or physicists (although not for me), this is calculable from the acceleration and the spinning that the ball experiences, the angle that the path initially forms with the plane of the soccer field, the air resistance that slows down the ball, and the gravity that will eventually force the ball back to the surface of the earth.[1] During the game, even good physicists or mathematicians, if they are also good goalkeepers, would not be able to fall back on such a calculation. But the experienced goalkeeper can, even if he cannot handle formulas well on his laptop, *intuitively calculate* such balls, and knows where they will arrive. But now the defender's leg gets in the way: The beautiful linear movement, which is easy for the goalkeeper to assess, gets a kink in it, the ball continues to fly, although a little slower, but now, unfortunately, in a different direction, namely, into the goal. For a goalkeeper like me, that's extremely annoying, because the reaction then comes too late. For the affected team, a disaster, if this exact goal seals their relegation from the previous league.

This introduces us to another principle that is characteristic of non-equilibrium processes far from equilibrium: non-linearity. Every *event* is the result of a *non-linearity* in the previously linear process. This process exhibits fluctuations that can build up and make the process unstable, and suddenly, we have a new situation: Structures or processes have changed, an event has happened. Over the course of evolution, processes have been established for life that run extremely non-linearly: A chain of independent coincidental events is the cause of a surprise, such as the appearance of a new property in organisms as a result of mutations. A *new* property is the result of an initially linear process, in which (just as an example, a number sequence), after "1 - 2 - 3 - 4 - 5 -", not "6", but non-linearly "17" or "minus 31" follows. We observe this not only in evolution, but in life in general or in the course of the cells of every organism, as well as in inanimate nature and everywhere else in the universe. Such a thing is known as a *phase transition,* or also as an *event*.

Enzymes: Results of Non-Equilibria and Actors Therein

Enzymes are not simply constantly active. There are molecules that cause enzymes to start or stop their task. The function of the molecules controlling the enzymes is not linear. There are threshold values above which the effect reacts like a switch (ON or OFF).[2] This is done by changing the folding of the enzyme so that it can either work or not work.

[1] https://www.researchgate.net/publication/322335277_Study_of_soccer_ball_flight_trajectory.

[2] J. Monod, cit. loc. p. 72/73.

Higher Aggregation Level of Matter: New Properties

We look at another level, into the cell: Here we find complex regulatory systems. Of course, these had not been created on purpose. Rather, out of the *possibilities* offered by the most diverse substances with their interactions, such regulatory systems have emerged in cells over the course of evolution, which finally gave rise to organisms capable of surviving and reproducing. From the *infinite* number of *possibilities*, those cell and organelle functions that are actually valuable or even indispensable for life and reproduction have emerged through *chance*. At the level of the cell, more new properties (= information!) have arisen that are not inherently contained in the single proteins and enzymes as such; they arise only by their interaction with each other.

For example, ribosomes are a product of self-organization, the spontaneous formation of order from disorder. Prigogine calls it *order from chaos:* Ribosomes are the location, the organelle, where proteins are synthesized. There, the translation of the code written on DNA and the amino acid sequence corresponding to the DNA code takes place. Ribosomes are the *protein factory* of the cells. Organisms with a true cell nucleus and a rich division of the cells, that is, subunits separated from each other by membranes, have very complexly built ribosomes. They consist of more than fifty different proteins and, depending on the organism, at least three ribosomal RNAs. If you separate the respective components and bring them together outside a cell, they spontaneously form fully functional ribosomes. The components do not form covalent, that is, real chemical bonds with each other. There are only electrostatic and adsorptive interactions that create a ribosome. Order from chaos, through physical interactions alone. And again, a new complex function arose on a higher level of organization of the substances. This is very much in line with Haken's theory of synergetics, which describes "processes in which the macroscopic state of the system changes qualitatively through self-organization (emergence of new qualities)".[4]

The amino acid sequence results from the DNA code. The DNA code "does not know" what three-dimensional structure results from it in the protein, let alone what function the protein will have. This results from the spontaneous self-organization due to the interactions. How the proteins are arranged together and the cell organelles formed results, again, only from the interactions that can be derived neither directly nor indirectly from the DNA or the amino acid sequence. The cells interact and form organs and bodies. These then form eco- and social systems. From the lower aggregation level *DNA,* we can there-

[4] Already >50 years ago, physicist P. W. Anderson published a groundbreaking article in Science (Vol 177, S. 393–396, 1972) entitled "More is Different". In it, he makes it clear that complexity arises with the appearance of more components in a system and thus new properties ("emergence"). He therefore does not believe it to be appropriate to state that one could understand all phenomena and laws on more complex levels of matter by means of an ever more detailed analysis of the lower levels of their components. See also section "Self-organization" in Chap. 4

fore neither directly nor indirectly derive the properties and behavior of human societies from the intermediate aggregation levels of protein, cell, organism, species, ecosystem. On each higher level of organization of the substances, new interactions occurring there are causing new functions. New laws arise that cannot be reduced to the single components of the respective level. Chance and coincidence shaped life, and continue to do so.

We must keep in mind: The fundamental structure of all organisms is the same. The control of all cell processes is based on the same mixture of substances, DNA and RNA, as well as proteins and other substances, which consist of only a few building blocks, and always the same ones. The components arranged in the DNA and RNA chains, in turn, contain the same purine and pyrimidine bases, each of which also fulfills the same type of function. In the end, it is only variations in detail that distinguish an amoeba from a sea eagle or us humans. But what huge differences in properties these variations cause!

I recently came in for a big surprise[5]: Evolution has developed an actually unimaginable ability in octopus and squid species that no other family of species has at its disposal. They can vary RNA, so that they can adapt by implementing instructions from DNA differently, namely, more advantageously than is normally the case in all other organisms through *copy/paste*. Here, an editing function is also active! 60% of the RNA in the nervous system is modified in this way, which also changes brain physiology itself. This seems to allow for adaptation to different water temperatures and, so it is assumed, is somehow responsible for the high intelligence of this species group. What new, surprising properties arise from the different interactions of the substances DNA/RNA/proteins known to us that allow a brain to be formed!

Let's now look at much simpler systems than the cells of organisms or evolution. Let's look into our everyday lives: Even a simple traffic jam "due to high traffic volume" can not be understood from the properties of the components that form the jam. A traffic jam does not arise on the level of one *car* or even a lower level, like *motor, wheel, transmission.* Not even on the level at which we describe the limbs and other organs of humans (including their brains), who drive the cars or sit in them. We cannot find or develop any regularities for the formation of traffic jams on a sunny Saturday morning on these lower levels of the elements involved in the traffic jam. We cannot even unify the laws that prevail on the elementary levels, which can describe a traffic jam formation. Of course, a traffic jam would not be possible without many people who steer their cars on the same road at about the same time, and not without these cars having engines and wheels and much more. But nevertheless, the laws of traffic congestion build-up cannot be reduced to the laws of the functioning of cars or drivers—and not even of both together. The laws of jam formation arise only when the traffic participants come together in large numbers and influence each other, that is, *interact* with each other and with the environment, the road network—something quite typical of self-organization processes.

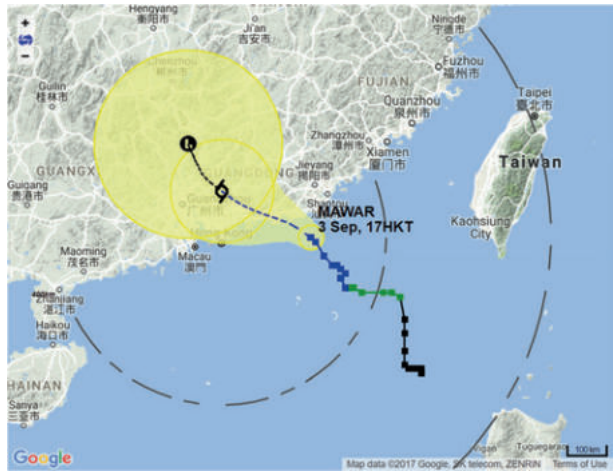
[5] https://www.sciencealert.com/octopus-and-squid-evolution-is-weirder-than-we-could-have-ever-imagined

this impact was the trigger for the development of the Amazon rainforest as we know it today, as it still exists in parts.[38]

Chaotic Typhoon

Normally unpredictable events happen when at least one non-linear process reaches the point of its development curve, at a bifurcation, where it takes a completely different course. This is much more often the case when two or more non-linear processes interact with each other—things become completely messy. Towards the end of my 13 years in China, in September 2017, I continued working on first drafts of this book in my Shen-Zhen apartment.

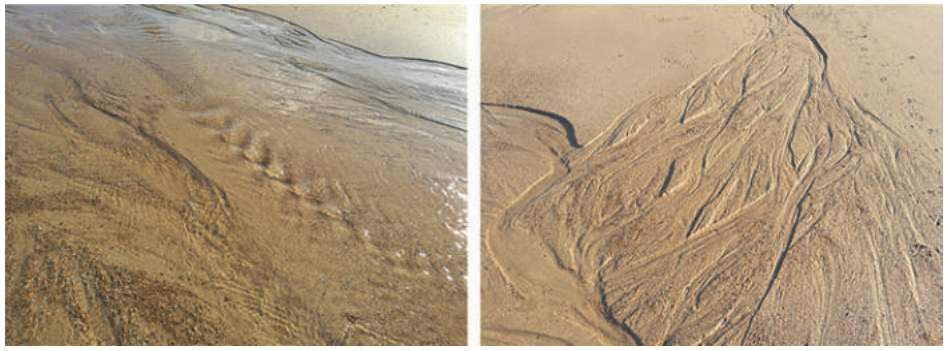
I lived on the coast of this southern Chinese city with a free view onto *ShenZhen Bay;* across the bay, I could see the uninhabited coast of an island belongig to Hong-Kong. In the days when I was working intensively on a predecessor to this chapter, a typhoon threatened to come very close to our coast, directly from the sea opposite my balcony. Since I had already experienced several typhoons there, and had once even had the eye of a typhoon pass directly over my residential area—a literally breathtaking and ear-deafening experience! fortunately without any dramatic damage—I always followed the typhoon forecasts with great interest. Over a period of ten days in September, two typhoons had already occurred, and a third one was predicted to be on its way to HongKong and ShenZhen. While the first two landed at locations on the coast of the province of GuangDong, to which ShenZhen belongs, each within fifty kilometers of the originally predicted locations, the third typhoon behaved in a very unfriendly manner. Its arrival was announced for Sunday, September 3, 2017.



[38] https://www.si.edu/newsdesk/releases/how-chicxulub-impactor-gave-rise-modern-rainforests

to branch off. The technical term for *branching off* is *bifurcate.* That is why Prigogine used the term *bifurcation,* introduced earlier by Poincaré, to describe his observation that, with the constant increase of a critical parameter—for example, temperature or amount of energy—systems often reach points at which they have two or more options for further development.[44] It describes the phenomenon when changes in the qualitative state occur in nonlinear systems. Such branchings—the forks in the roads of our lives—allow chance and coincidence to strike constantly. And so, at one tree, the branch branches off here, at the other tree, the next branch branches off there, becoming another branch that allows other branches to branch off in this or that way, until, finally, a unique tree is created—so it is for us with our own road forks: They branch off until, finally, every life becomes unique, repesenting experiences that, in its many details, are shared with no one else in the world, one that is not repeatable and not predictable.

Just as it is unpredictable how a river will shape the banks between which it flows, and how the ground and the banks will shape the river—because this, too, is something reciprocal, based on intense interactions, with an infinite number of possibilities for coincidental effects—two rivers in the same environment may not even be remotely alike. We will hardly ever have the opportunity to see two real rivers in really comparable environments, but, on a small scale, it is possible: The two photos below show two tiny *rivers* on a beach in northern Brittany (France), only two meters apart, and not even these look the same.[45]



How different each river system is from all others is shown by the fascinating river maps prepared by "Robert", who started *grasshoppersgeography* and, among other things, shows the rivers of the world with their tributaries.[46]

The NASA satellite photo on the cover of this book (the mouth of the Lena river in North Siberia) shows us a very typical non-equilibrium system, a typical dissipative structure. The delta will look different again a little later. The patterns on the wings of

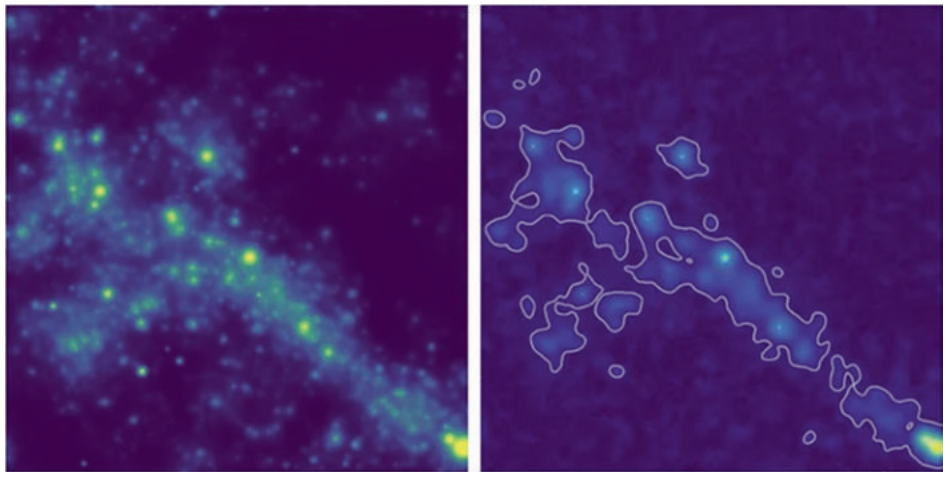
[44] https://en.wikipedia.org/wiki/Bifurcation_theory

[45] Photos by the author.

[46] https://www.grasshoppergeography.com/River-Maps/

the course of events, even if it is to suspect supernatural forces or beings at work, which leads to an esoteric world view or superstition.

However, our ever-deeper understanding of the universe could actually show us that we need neither elementary particles with their indeterminacy, nor fate or supernatural explanations for the emergence of the phenomenon of *chance and coincidence.* Even as we only have diffuse ideas about the beginning of the universe, and these ideas are likely to change in the next decades and centuries, it is clear to careful observers: The highly complex and diverse structures in the universe are not consistent with the assumption of a homogeneous beginning—let's call it *The Big Bang* as usual—and the *cosmological principle* associated with it. This principle states that the universe is homogeneous on large scales and looks *equal* in all directions and from all locations. It is a key pillar of the *Standard Model* of cosmology.[50]

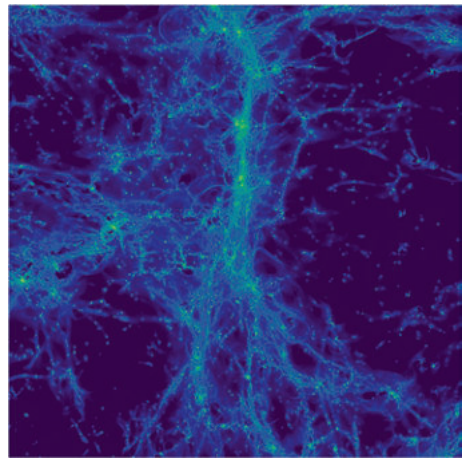


Recently, a worldwide research group collaboration discovered that hundreds of thousands of dwarf galaxies are practically lined up one after the other, as can be seen in the images above and on the next page.[51] The large-scale structure is clearly visible in it: It shows the light emission of hydrogen gas with a diameter of 15 million light-years, with the bright points in the filaments each showing a galaxy in which the first stars are forming.[52]

[50] https://www.intechopen.com/chapters/66783.

[51] *R.* Bacon and many others, "The MUSE Extremely Deep Field: The cosmic web in emission at high redshift", Astronomy and Astrophysics 647 (2021) A 107 (26 pages), accessible here: https://www.aanda.org/articles/aa/full_html/2021/03/aa39887-20/aa39887-20.html

[52] Fig. 4 in the press release of the CNRS: https://www.cnrs.fr/en/first-images-cosmic-web-reveal-myriad-unsuspected-dwarfgalaxies; Reproduced with kind permission of the CNRS, researchers Jeremy Blaizot, Roland Bacon and Thibault Garel



Also currently in the news is the discovery of incredibly large and far-reaching gas filaments in the universe, objects that had been detected earlier but on a much smaller scale.[53] These much larger examples were found by a large international team of researchers led by the *Argelander Institute for Astronomy of the University of Bonn*: the total length of the network is 50 million light-years, and that is only the mapped part.[54] These gas filaments are connecting elements of the "sponge structure" of space created during the expansion of the universe. Huge spaces emerged that contain virtually no galaxies, but these empty spaces are, so to speak, enveloped by so-called *walls* of denser arrangements of galaxies, including the Great *Wall*[55] and the *Sloan Great Wall*[56]. The clusters of galaxies and the agglomerations of these clusters in the *Great Walls* are networked together by these filaments. One can practically see their formation as *dissipative structures* in the non-equilibrium system universe. A similar situation exists with billions of dwarf galaxies that are *connected* to each other.[57]

These structures also arise by chance, that is, it is not known or predetermined from the initial conditions of the universe how they will look now. We can not predict how they will look in a billion years. Recently, something even more surprising and hitherto

[53] https://science.sciencemag.org/content/366/6461/97

[54] https://astro.uni-bonn.de/~reiprich/A3391_95/A3391-95_2020_12_04.pdf (Pre-publication from "Astronomy & Astrophysics"), a German summary can be found here: http://www.raumfahrer.net/news/astronomie/25122020172213.shtml.

[55] https://en.wikipedia.org/wiki/CfA2_Great_Wall

[56] https://en.wikipedia.org/wiki/Sloan_Great_Wall

[57] https://scitechdaily.com/first-images-of-the-cosmic-web-reveal-unsuspected-presence-of-billions-of-dwarf-galaxies/

An unimportant, but simply beautiful event, which is also an example of essential coincidence: Sunrise behind clouds on the horizon, long, quiet waves coming by chance from a suitable direction, to create such impressive splashes on a coincidentally suitable rock ledge, upon which I stand by chance at exactly the right time: Two processes running linearly (sunrise and wave movement) meet in time, while the wave ends non-linearly on the rock and splashes up in part, all of which unexpectedly coincides with my presence on this rock. (a unique photo by the author taken on the coast of Wollongong, Australia, 2004).

What Flows When "Time Flows", and Where Does It Flow to?

7

Abstract

First, we look at what different physicists think about time: Is it an illusion? Does the timelessness of the quanta mean that there is no time at all? Can the arrow of time be reversed? Do we live in one of many universes? We then think about what the formulation "time flows" could mean. It is explained that time cannot *flow* and cannot *pass*. Finally, a new hypothesis is presented that describes time as an emergent phenomenon through the flow of entropy. This new hypothesis is experimentally verifiable.

… *Black holes in which time stands still*—how do I come up with such a formulation at the end of the previous chapter? How can time stand still, is that even possible? What is it, time? What is the nature of time? What is it made of, if you can ask that question, what is it that is flowing when we say "time is flowing"?

These questions are still an unsolved mystery for most of the people, natural scientists, philosophers and many others, who occasionally think about them. John Wheeler (a prominent theoretical physicist)[1] once wrote: "Explain time? Not without explaining existence! Explain existence? Not without explaining time! Reveal the deeper hidden connection between time and existence […] A task for the future."[2] With this book, and especially this chapter, I would like to make an attempt to contribute to the accomplishment of this task.

[1] https://de.wikipedia.org/wiki/John_Archibald_Wheeler.

[2] J. A. Wheeler, American Scientist 74 (1986), pp. 366–375, quoted from Carlo Rovelli, "The Order of Time", Rowohlt 2018, p. 100/101 or the footnote 72 there.

B. Wessling, *What a Coincidence!*, https://doi.org/10.1007/978-3-658-40671-4_7

Many wise people have expressed deep thoughts about the nature of time. For Aristotle (Book IV), time is "a number of motions with respect to 'before' and 'after'."[3] Time points ("nows") are not units of time, but boundaries of time intervals, the length of which is measured by the heavenly bodies.[4] According to Isaac Newton, "absolute time (which is nothing other than duration or the perseverance of the existence of things) remains the same, whether the motions be be swift, slow, or null."—"Absolute, true, and mathematical time, from its own nature, passes equably without relation to anything external, and thus without reference to any change or way of measuring of time (e.g., the hour, day, month, or year)." (cited here as paraphrased in Stanford Encyclopedia of Philosophy)[5]

Let's jump into modern times. Henning Genz suggests choosing the radius of the universe as "the representative of the 'time' parameter."[6] For Genz, time is connected with movement, with the expansion of the cosmos. I have a problem with that, because, as long as the gravitational constant is actually constant, the universe expands, but not the earth—nevertheless, we observe time here on earth as a real phenomenon, the nature of which we want to understand.

In an introductory article *What is time?,* Andreas Müller discusses the concept of time (in German).[7] The author makes it clear that, even after centuries of reflection, there is still no physical explanation of time. Strangely, entropy is misrepresented here, in that it is described as *only and always increasing*. This, as we have discussed in previous chapters, is the case on the scale of the entire universe, but not in all the open subsystems in the world that are far from equilibrium—that is, the current majority of all parts of the universe. Finally, the author sums up: "The physical concept of time must be further explored." I do not share his "deep hope" for enlightenment in "new, higher-level theories, such as quantum gravity" and, in particular, in *Loop Quantum Gravity*. After the author sets his hopes on these theories, he continues sadly (because these concepts are "relatively unenlightening"): "We pay with the clarity and win the price of knowledge." It should be said that *Loop Quantum Gravity* and other theories of this kind have not yet yielded any knowledge, but have already become unenlightening at this point. I would like to start an attempt here to refute this and to make it possible to gain knowledge

[3] https://en.wikipedia.org/wiki/Physics_(Aristotle)

[4] https://ndpr.nd.edu/reviews/time-for-aristotle/

[5] https://plato.stanford.edu/entries/newton-stm/

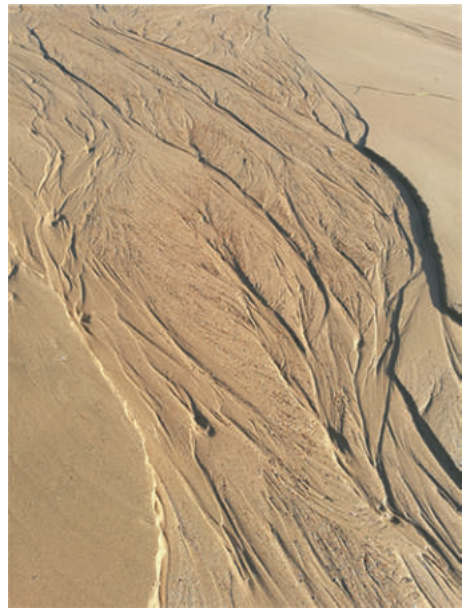
[6] Henning Genz, "Wie die Zeit in die Welt kam—Die Entstehung einer Illusion aus Ordnung und Chaos", Rowohlt Taschenbuch 2002, p. 228 ff. (English introduction into a new German edition: "How time came into the world—The origin of an illusion from order and chaos", https://www.hanser-literaturverlage.de/en/buch/how-time-came-into-the-world/978-3-446-18742-9/)

[7] https://www.spektrum.de/astrowissen/zeit.html. Adam Becker is also promoting the "loop quantum theory" as a tool for better understanding of space and time, which as well does not contribute any deeper understanding but abstract theory, detached from reality, without any tangible (and especially not provable, falsifiable) results, cf "What Is Spacetime Really Made Of?" Scientific American, Febr 1, 2022 (https://www.scientificamerican.com/article/what-is-spacetimereallymade-of/)

an illusion? Or would both mental variants of the time flow rather be arguments that time is constantly being created?

If we stay with the analogy of a *river*, we should be more precise linguistically: It is not the river that flows, but the water. If we say: "The river is flowing particularly quickly today!", it is actually an imprecise formulation. The correct form would be: "The water is flowing particularly quickly today", and that "in the river bed". So, let's for a moment imagine *time* as a *river bed*. Does the river, the river bed, disappear when the water flows past us from the mountain down to the sea? No, the river, again, the river bed, remains; only the water flows past. And it does not disappear either, but ends up in the sea. As long as water flows in the river, the river remains. *River* is our term for what the water causes when it flows down in a stream from higher levels.

The phrase "time has passed" implies that it could disappear, but let me insist for a little longer that it no more disappears than the river, the river bed, in my example. If the river dries up, the river bed remains (as in my photo of the beach). And just as the traces of what flowed through the river bed are preserved, so can we at least partially *read* the past, as what flowed in time, in the past time, left traces in the present and also acts in the future. For the sake of simplicity, let's assume the following: *Time does not flow.*



packages' (that is, before their perception, a physically interpretable loss of information about the temporal ordering takes place). In this respect, the 'real' time continuum is just as fictitious as the (not violet-red) continuous spectrum of light. But it should be emphasized once again that this fictitious character does not mean secondary importance to something more fundamental or (apart from the purely subjective) better justifiable. " We must also be aware that the *perception* of time has nothing to do with the *essence* of time, more on this in the next chapter.

Our Perception of Time

8

Abstract

It is important to understand that our perception of time has nothing to do with what the nature of time is, just as our perception of color has nothing to do with the nature of light or hearing a sound with the nature of sound. We learn how the body organizes rhythms, what *clocks* the cells have and how and where the sense of time is generated in the brain. Finally, it is explained why, for many people in old age, time appears to *pass* more quickly. A close connection to the nature of time (see Chap. 7) becomes clear.

Our intensive occupation with the causes of the emergence of chance and with the nature of time would be incomplete if we did not also turn to the time in ourselves. After we have seen that chance, coincidence and time have entropy in non-equilibrium systems in common, now, only time should interest us, no longer chance or coincidence, nor any accidents. There are 2 topics to which we will turn in this chapter,

- the control of the various rhythms in the cells and organs of the body and their sensory and neurological processing, as well as
- the psychological aspects of time perception.

Of course, I am not asking you that you become an expert in chronobiology[1] or chronopsychology[2] (if you are not already), nor am I an expert in these science fields, but together, we can now gain a small insight into them.

[1] https://www.spektrum.de/lexikon/biologie/chronobiologie/13999 *and also* https://de.wikipedia.org/wiki/Chronobiologie.

[2] https://www.spektrum.de/lexikon/biologie/chronopsychologie/14010 *and also* https://de.wikipedia.org/wiki/Chronopsychologie.

B. Wessling, *What a Coincidence!*, https://doi.org/10.1007/978-3-658-40671-4_8

Let me point out beforehand that what the body does with and in time is quite different from how we perceive it. The phenomenon of time *sensation* must also not be confused with the *essence of time,* just as the sensation of color must not be confused with the essence of light and its frequency spectrum that hits the eyes, nor should our perception of sounds be taken for the nature of sound, i. e., the vibrations of the air that arrive in our ears. Light waves and air vibrations are only processed in the brain into sensations and perception that we call *color* and *sound* via suitable sensory cells and neurological connections. The cognitive researcher Fred Mast writes, among other things, in his fascinating book about "imagination" (translated by the author): "One must be aware that the physical stimulus *causing* it [a sensation of color or sound] is not known to us [the author probably means: "not conscious"; note by the author]. […] We have to decipher the physical stimulus. […] Assumptions [of the brain; note by the author] about the stimuli play an important role in the perception process." [3] We therefore have to distinguish what the body receives in terms of external (or internal) physical stimuli about time, how the body controls times and rhythms, and, on the other hand, how the brain perceives time and makes it experienceable for us, and why we rarely feel time as progressing at a constant speed.

Let's start with what our body does over time and in time. We all feel our inner rhythms, our bio rhythm, every day: We feel particularly vigorous in the morning (if we have slept well). At noon, we are not as productive and would rather take a break (the southern Europeans take a siesta). And whether we are the so-called *larks* or the *owls*, we all have a relatively stable sleep/wakefulness rhythm, although different ones. We go to the toilet at about the same time every day to "drop a packet". And anyone who has flown to America or Asia knows jet lag. We consider it quite normal—but how does my body still know, when I have landed in China, what time it is in Germany? Why does he still feel like he's at home in the middle of the afternoon when it's dark here in China and I should go to bed and sleep so that I'm fully rested the next day? Whatever the reason, I can not, although dog tired, fall asleep until three o'clock in the morning or even later. Three o'clock in the morning in China is only 8 pm in Germany (if we have not switched to summer time). My body claims it is only 8 pm, and still will not let me fall asleep. Only after a few days does my bio rhythm also arrive in China, with my bowel movement even taking a few more days after that.

[3] Cf. Fred Mast, "Black Mamba oder die Macht der Imagination", Herder 2020, pp. 53 and 54 (German).

One further method for preventing feeling that time is passing so quickly in old age is to break out of the routine that has grown during one's life. You leave your comfort zone and do something unusual. My 13 years in China forced me every day to break out of the routine. In the last years of my life in China, we undertook several major trips to areas that are very little developed for tourism. These were not backpacker tours, but we were very far outside our comfort zone. Here is a view from a hill in the Gobi desert. These were unforgettable weeks full of unique impressions that have noticeably "rejuvenated" my feeling of time. (Photo of the author 2016).

Final Remarks

We have undertaken a long mental journey in this book and have now arrived at our destination. I was able to deliver to some of you, I hope, a new or, at least, a deeper understanding of the world we live in. I may have shown some readers some new aspects. Some will have been surprised or even disturbed that our world is not *in equilibrium* at all. We don't have to worry about it, it is nothing new, it has always been like this; it's just that we humans tend to suppress it. This does not change the fact that those who do not know, as well as those who do know, are always confronted with chance and coincidental events. The non-linearity of all the different non-equilibrium processes and interactions is simply unavoidable and unpredictable. Therefore, coincidental events are quite normal. Catastrophes are terrible, many accidental events are existentially dangerous or even deadly. Sai Weng taught me that, as long as I can overcome a "fateful" blow to some extent, something good may develop from it. And he taught me to take lucky coincidences not only with humility, but also with caution: They can also have a negative effect.

The entropy flow in and out of open systems has turned out to be a key element for the causes of chance and coincidence and for the nature, for the essence, of time. Only in non-equilibrium systems far from equilibrium is something in motion, and this is not linearly the case. Entropy flows, structures are built, we can observe changes all the time, and entropy is exported. This results in situations with the possibility of forks in the road (bifurcations), and chance and coincidence surprise us again. Furthermore, the flow of entropy creates time. Without non-equilibrium, there would be no world, and no us either. We have thus also received chance, coincidence and time as a gift. In equilibrium systems, nothing happens any more once equilibrium is reached: Entropy has reached its maximum value, time stands still. This is the case in a black hole, just as it is in a watery sugar solution that we pour into a glass, sealing it so that the water does not evaporate – but that would also be just another way into another equilibrium in which only the sugar crystals would remain, so that time would also stand still in them, if it were not for some bacteria enjoying the sugar.

B. Wessling, *What a Coincidence!,* https://doi.org/10.1007/978-3-658-40671-4

A critical reader[1] of one of the previous versions of my manuscript wrote to me during the course of a longer discussion: "But yes, the world is in approximate equilibrium, just not in *thermodynamic* equilibrium (according to Prigogine)." I asked him what kind of equilibrium then? His answer was an example: "If you go to bed at night, you do so with the certainty that you will wake up in the same bed in the same room in the morning. So, the world is approximately in equilibrium during your night's sleep." I replied to him by email: "I completely disagree, because I myself am already a non-equilibrium system (including in the sense of Bertalanffy!): I have eaten and drunk during the day (so I have taken in energy), while I continue to digest during the night, so that I excrete waste products in the morning (and thus a lot of entropy). And even during my sleep, I export a lot of entropy by radiating body heat. So, I am a typical open system in the sense of Bertalanffy and Prigogine. But the world around me was also not in equilibrium during the night, not even approximately: The temperature had dropped, in the morning, it rises again, the weather has changed, ebb and flow have taken place (definitely no equilibrium processes!), etc." I had not even considered the outbreak of a war like the Russian attack on Ukraine, which happened many months after the email exchange cited above.[2]

So, this critical reader and I had the problem that I had already discussed in Chap. 4 under the keyword *dynamic equilibrium*: We have different ideas of what *equilibrium* means. I hope I was able to convince you that it is necessary to use clear and unambiguous terms. We can not, if we want to understand our world better, use the same word *equilibrium* for two completely opposite phenomena or states. Equilibrium and non-

[1]A mathematician, and theoretical physicist, and emeritus university professor, who has dealt a lot with chance, coincidence and time; due to his critical remarks – for which I am very grateful – I had to carry out quite a bit more further thinking and research, the results of which are reflected in the book.

[2]When we discussed this, we were still a year and a half away from 24.2.2022. When I woke up that morning, Russia had attacked Ukraine on the orders of its President, Vladimir Putin. That showed that the security system that was set up in Europe after the Second World. War was "more wobbly and rotten than the West wanted to admit" (as the German weekly magazine DER SPIEGEL wrote on 25. 2., see https://www.spiegel.de/ausland/wladimir-putin-und-sein-krieg-in-der-ukraine-der-angriff-der-die-welt-veraendert-a-7720502b-38d1-4963-a331-3363242cec18). It seems as if the world has fallen back into a phase of ruthless superpower politics, with a very non-linear step: An attack war against a sovereign state, a brutal violation of the Charter of the United Nations, a violation of international law. I would like to refer once again to Chap. 6, subsection *The Birth of Chance and Coincidence in Non-Equilibrium*. There, I explained that not every event, not every non-linearity is a chance or a coincidence. Not even this war of aggression. But out of a chain of countless coincidences, presumably occurring many years before, this war of aggression emerged in an apparently inevitable way (transition from chance to necessity). Inevitable because Russia's President Putin could not be dissuaded from his decision, a decision that can not be justified by anything. *Necessity* only from the view of the Russian government and its loyalists. For the people in Ukraine, for the country, for peace in Europe and the world, for the fight against hunger, a disaster, a catastrophe.

equilibrium are simply opposites, like minus and plus, like end and beginning. So, we should refer to them with different terms – so, the world becomes clearer.

Time arises, according to my hypothesis, in the non-equilibrium due to the flow of entropy. The thought came to me more than twenty-five years ago. At the time, I did not pursue this thought any further, partly because of lack of *time*, partly because I thought other people, especially non-equilibrium thermodynamicists from the Prigogine school, would have already come to similar thoughts. But that was obviously not the case. I know that I am taking a risk with the publication of my hypothesis about time; the same already with my explanations about the connection between chance, coincidence and non-equilibrium, which some scientists may not agree with. I am happy to take this risk.

Certainly, such readers who have a different idea of the nature of time will find my new hypothesis – if they react neutrally-friendly – strange. I look forward to *constructive* discussions. Let's wait and see if there are any other indirect hints or even direct experimental evidence for my proposal in the coming years, or for the refutation of my thoughts. Both will bring progress in knowledge.

Whatever the outcome of this very exciting question – the deep engagement with chance and coincidence and with the nature of time has enabled me, and hopefully also you, to gain many insights into the properties and behavior of non-equilibrium systems, and thus into our lives and our environment.

This understanding can help us to better understand and experience the world in which we live. This affects the world on the micro, the nano and the molecular scale, in cells and organisms. On a large scale, such as in ecosystems and our human societies. And on the largest scale, in the universe. And at the same time, how strange: The better we understand it, the more we realize how infinitely complex and mysterious our world is. The more questions we can answer, the more new questions open up before us. How beautiful and ever new it is again and again!

A few days before the start of my proofreading of the German edition of this book, I heard on the radio (of course, by chance) the following poem by Marie von Ebner-Eschenbach. In my opinion, it very well describes the complexity and, at the same time, the beauty, but also the reality of becoming and passing away in our world in a poetic form – similar to my photo of the Baltic Sea beach on the next but one page. This German poem was translated by Timothy Andès[3] (in a productive poetic exchange with the author Bernhard Wessling so that the poem's message could become optimally reflected and still sound like a poem).

[3]The German poem was translated here by Timothy Andès, a "rhyming translator-poet": https://www.timothyades.com/. He has translated dozens (if not hundreds) of poems from German, French and Spanish into English. B. Wessling reviewed the translation, and after some very constructive exchange, a final form was found.

Summer Morning (Marie von Ebner-Eschenbach)

On mountain peaks bedecked with snow,
On green hills stretching wide below,
The morning sun is shining.
Young beechwoods raise their dewy boughs
And tremble, tremble with the joys,
The very joys of living.

Down from the darkest rocky height
In total unrestrained delight
The roaring torrent rushes.
Its breath wakes life below, above,
In noble tree and lowly shrub,
And in the yielding mosses.

And over where the meadows lie,
The swarms of bees and midges fly
And hum in floral splendour.
See them in high grass stirring there
In busy movement full of cheer,
Buzzing with voices tender.

The young lark rises up so free,
Soars like a shout of jubilee,
A-whirling and a-singing.
In woods nearby the cuckoo calls,
And through the air the song-thrush sails,
On golden plumage winging.

Bright sunlit world! Delectable
Today; the rousing story;
Replete and lofty treasuries!
And yet, alas – ephemeral,
And doomed to death, for nature is
Sheer anguish, cloaked in glory.

The photo on the next page is a beautiful visualisation of this poem.

Even such small, incidental discoveries on a winter afternoon at the beach by the Baltic Sea, where this bird feather with ice crystals and first drops of molten ice show the complex structures in our world and touch us with their beauty.[4] *At the same time, they point to some secrets: How did it come about that the feather is here, that these diverse and complex ice crystals have grown (and nowhere else in the immediate vicinity), and much more if we delve into the details of this photo. At the same time, we see the transitoriness, disguised in beauty; or, as the poem says in poetic English: "ephemeral, doomed to death, cloaked in glory". (Photo by the author).*

[4]You may have sensed while reading this book that I am constantly looking around, eager to observe and admire the complexity and beauty in the world in which we are allowed to live. That's why I have perceived all of my life to be very rich and meaningful. You can find some more objective confirmation of my subjective experience here: https://www.scientificamerican.com/article/a-new-dimension-to-a-meaningful-life1/