SOCIAL SUSTAINABILITY, PAST AND FUTURE

Undoing Unintended Consequences for the Earth's Survival

Sander van der Leeuw

Social Sustainability, Past and Future

In this Open Access book, Sander van der Leeuw examines how the modern world has been caught in a socioeconomic dynamic that has generated the conundrum of sustainability. Combining the methods of social science and complex systems science, he explores how western, developed nations have globalized their world view and how that view has led to the sustainability challenges we are now facing. Its central theme is the coevolution of cognition, demography, social organization, technology, and environmental impact. Beginning with the earliest human societies, van der Leeuw links the distant past with the present in order to demonstrate how the information and communications technology revolution is undermining many of the institutional pillars on which contemporary societies have been constructed. An original view of social evolution as the history of human information-processing, his book shows how the past offers insight into the present and can help us deal with the future.

Sander van der Leeuw is Foundation Professor in the Schools of Sustainability and Human Evolution and Social Change at Arizona State University. Trained as an archaeologist and historian, he specializes in long-term interactions between humans and their environments and pioneers the application of the complex adaptive systems approach to socioenvironmental challenges, technology, and innovation. Van der Leeuw is the author and editor of eighteen books. In 2012, he was awarded the "Champion of the Earth for Science and Innovation" prize by the United Nations Environment Program.

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Social Sustainability, Past and Future

Undoing Unintended Consequences for the Earth's Survival

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Preface

This book condenses some thirty years of working in archaeology, complex systems theory, sustainability, and the wider social sciences. It is therefore simply impossible to thank all those people who have contributed, directly or indirectly, to the ideas it presents. I will have to limit myself to the most salient ones, colleagues and friends in many countries and working on many disciplines.

I will begin with some close friends who are no longer among us, but from whom I have learned lots and lots, and with whom I have collaborated closely over many years in different parts of the world: Roel Brandt and Willem Willems in the Netherlands were there at the beginning; Serge Cleuziou and Jean-Luc Fiches not much later in France. I miss them very much.

Normally, one mentions one's life-long wife, friend, and companion last in prefaces such as this, but I want to mention Anick Coudart next – she enabled me to do whatever I have been able to do over the last thirty years by always being there, always listening, supporting, helping, but also commenting, critiquing, and so much more. From my time in Holland, after my studies, I want to mention and thank in particular some of my PhD students in Amsterdam, such as Ineke Abbink, Roswitha Manning, Nico Roymans, Linda Therkorn, Frans Theuws, as well as colleagues there such as Jan-Albert Bakker, Anthonie Heidinga, Jan Slofstra, Bert Voorrips. In Leiden I worked closely with potter Jan Kalsbeek, and profited from the wide-ranging interests of Henri Claessen.

I came to Cambridge as a result of a long-standing relationship with UK archaeologists. From that British period, Robert Chapman, John

Cherry, John Coles, Robert Foley, Colin Shell, Marie-Louise Sørensen, Robin Torrence, and Todd Whitelaw stand out in one way or another.

Then there are the many, many colleagues of the ARCHAEOMEDES project in the 1990s. Altogether we were a team of sixty-five people from eleven countries, and I cannot mention them all. But I owe a particular intellectual and social debt to Peter Allen, Geoff Bailey, Sarah Green, Mark Lemon, James McGlade, Laurent Olivier, Roger Seaton, Nick Winder in Britain, Françoise Audouze, François Favory, Jean-Jacques Girardot, Helene Mathian, Denise Pumain, Lena Sanders in France, Einar Holm, Sture Oberg in Sweden, Marina Picazo in Spain, Paola Filippucci in Italy. Together we created a unique project, a unique team, and a unique atmosphere.

During my time on the faculty of the University of Paris, I was received with open arms by another group of long-term friends, among whom Jean-Paul Demoule, Thierry Berthoud, and Alan Schnapp played, and still play, very important roles.

At the Santa Fe Institute (SFI), Henry Wright, Tim Kohler, and Geoffrey West introduced me to that community and opened new perspectives. Out of the collaboration with SFI colleagues emerged the ISCOM project, with particular contributions by Luis Bettencourt, Davide Ferrari, David Lane, Jose Lobo, Irene Poli, Denise Pumain (again!), Roberto Serra, Geoff West, and numerous others. I think back to those lovely meetings in Italy, especially on San Servolo in the lagoon of Venice, with great pleasure.

At Arizona State University (ASU), among the hundreds of colleagues with whom I worked in one capacity or another, I want to express my thanks first of all to Charles Redman who introduced me there, then to Jim Buizer, the friend who helped me navigate the institution successfully to create the School of Human Evolution and Social Change, as well as Dean Alan Artibise. Bill Kimbel, Ben Nelson, Keith Kintigh, and many others in the faculty supported me in making drastic changes in that School. Somewhat later I linked up with Gary Dirks, Chris Boone, and other faculty members at the Julie Wrigley Global Institute of Sustainability, and with Manfred Laubichler of the Global Biosocial Complexity Initiative.

In recent years, friends and colleagues in Japan, China, Germany, France, and Sweden have enriched me with different ways of thinking. Among those, I'd like to mention Kenichi Abe, Carl Folke, Zhangang Han, Carlo Jaeger, Hein Mallee, Daniel Niles, Ortwin Renn, Johan Rockström, Qian Ye, and Yongsheng Zhang. They have been a huge stimulus in writing this book.

I also want to acknowledge the support I have received in various stages of my trajectory from my "bosses": Willem Glasbergen and Hans "Carlos" van Regteren Altena in Amsterdam, Colin Renfrew in Cambridge, and Michael Crow at ASU. Their patronage allowed me to go my way, protected me at difficult moments and, in one way or other showed their belief in me. That was a very important contribution.

Last of all, I owe a huge debt to those friends and colleagues who have read this manuscript, in whole or in part, and have enriched it by their critical examination from very different points of view: Vernon Scarborough, Gary Dirks, Yongsheng Zhang, and above all Thierry Berthoud, Alan AtKisson, and two anonymous reviewers.

I am immensely grateful to all these people for the many ways they have helped me throughout my life, and thus have contributed to the realization of the intellectual voyage that led to the pages you now have in front of you.

But I want also to express my deep gratitude to the institutions that have supported me during the writing of this book. First of all Arizona State University which granted me leave to work away for most of the spring and summer of 2016 and then gave me a full year's sabbatical from August 2016 to August 2017. That first spring and summer of 2016 were spent at the Institut Méditerranéen de Recherches Avancées (IMÉRA) of Aix-Marseille University in France, where the staff not only housed us magnificently, with a view over the whole old city of Marseille, but created the ideal atmosphere in which to write and work in a relaxed and productive manner. I also owe much to colleagues at that University, in particular Joel Guiot, Wolfgang Cramer, Alan Kirman, and Daniel Contreras, who made sure we also had a pleasant social life and inspiring discussions at OT-Med, one of the very prestigious Laboratoires d'Excellence funded by the French central government.

After an intermezzo in Beijing and other parts of China, we took up residency among our old friends at the Research Institute for Humanity and Nature (RIHN) in Kyoto, Japan who very graciously (and exceptionally) granted us a second fellowship of four and a half months from September 2016 to mid-January 2017. Those who know RIHN and Kyoto will not be surprised that that was another ideal place to be writing, unconstrained by obligations, with interesting colleagues and a very effective and pleasant staff. Here, I particularly want to thank the Director-General, Tetsuzo Yasunari, his two Deputy DG's, Jumpei Kubota and Makoto Taniguchi, and several of their many colleagues with whom we created strong bonds: Kenichi Abe, Junko Habu, Hein Mallee, Steven McGreevy, Hisei Nakanishi, Daniel Niles, and Tatsuyoshi Saijo. Moreover, RIHN graciously allowed me to organize two workshops during our stay, and we enjoyed some particularly instructive and pleasant trips with Kenichi Abe.

After a brief intermezzo at ASU we then moved to the Institute of Advanced Sustainability Studies in Potsdam, Germany, where our welcome was as wonderfully warm as in the first two places. Ortwin Renn, one of its directors, graciously mediated for me a two-year senior fellowship that strengthened contacts with a number of colleagues working in Berlin and Potsdam. Unfortunately, obligations at ASU did not allow me to profit from our stay at Potsdam for more than five months, but we came back in the fall of 2018. Apart from Ortwin, we found old friends there, in particular Ilan Chabay, Armin Haas, Carlo Jaeger, Falk Schmidt, and made new friendships with Mark Lawrence and Patrizia Nanz (the two other members of the directorate), Jörg Mayer-Ries, Tim Butler, Pia-Johanna Schweitzer, and others.

Our stay at these institutions enabled me to write unrestrained by appointments, meetings, and other obligations, and that meant I could write when I was really in the mood, and not squeezed between other events as I had been doing for a long time. In so far as this book is understandable, it is entirely due to the largesse of these institutions and the colleagues peopling them. Bliss!

PART I

1

How This Book Came About, What It Is, and What It Is Not

Introduction

To date, I have only twice in my life tried to write a book-length manuscript, and this third attempt is undertaken at a time, and in a discipline, in which journal papers are more highly valued, careerwise, than books. Why would I now write a book? I am close to retirement, so I do not need it for my career. I have published a substantial number of papers, which is certainly easier than writing a book. But I have the urge, no doubt because of my age, to start bringing the various strands of my thinking together. I am, in many ways, writing this book for myself – using the occasion to rethink ideas, to combine themes, and show the relationship between some parts of my academic thinking. But I also would like to give back, to share that effort with the many people who have contributed to these ideas, and, if they are of interest to them, with others.

To lay the groundwork for this endeavor, I will begin this chapter with a (very short) summary of some of the stretches and turning points in what has become a true slalom of a career, spanning four countries in which I resided for a decade or more, and many others in which I had the privilege of doing fieldwork, experiencing the hospitality and collaboration of many colleagues, and sharing ideas and experiences with many more.

Trained in the Netherlands as a cultural and environmental prehistorian and archaeologist, and as a medieval European historian, I began my active career with a stint of excavations in the Euphrates Valley in Syria, as part of the Tabqa dam project (1972–1974). One purpose of the project there was to get a sense of the long-term development of human–environment dynamic relations, and another to study the evolution of pottery making from a technological perspective. I did my PhD thesis on that last topic, and will come back to that later in these pages (Chapters 12 and 13).

But the dominant experience in Syria for me was living in a Beduin village for about fifteen months, among people who had at that point never been visited by Europeans and had only very rarely had contact with urban Syrians. What an eye-opener!

We lived among people of a different culture, creed, and religion, saw how they managed to make a living based on agriculture and animal husbandry in a very dry area, using a hoe to till the soil, yet undergoing a technological transition due to the availability of cars, water pumps, and various other *accoutrements* of western material culture. All of us were, I think, changed by that experience for the rest of our lives. We shared in the ups and downs of village life – marital troubles, illnesses and how they were treated in the absence of western medicines, neighborhood conflicts, weeks of rain so that everything we owned was permanently wet, the arrival of the first pairs of sunglasses and portable radios bought with money earned on our excavations, etc.

During breaks in the excavation schedule, and after the excavations, I was able to travel relatively widely in the (then still peaceful) Near East, visiting many sites and urban contexts, in Syria, Jordan, and Lebanon. I deeply appreciated the cosmopolitan culture of the area, as well as the amazing landscapes and antiquities (e.g., Palmyra, Petra, Wadi Ram), and everywhere found friendly, open people, such as in one of the Palestinian refugee camps near Amman.

This book is not about that wonderful period of my life, but I think it is through that experience that my interest in the topic of this book was raised: the long-term evolution of how people dealt with their natural environment. When university politics made it difficult for me to continue in the Near East, I was asked to participate in an archaeological project in the Netherlands, which turned out (you never know in archaeology!) to enable us to develop a vision of the emergence of the Western Netherlands from the sea – that unique part of the country that lies below sea level and was literally wrested from the sea over a period of some 2,000 years. Again, the theme was the evolution of the ways people dealt with their environment. One of the results of that work is Chapter 10.

After moving from the University of Amsterdam to Cambridge University in 1985, I was invited by French colleagues at the CNRS to participate in a third regional man–land focused project, this time in the Massif des Maures in southern France. In 1990 that area was ravaged by a huge wildfire that destroyed all vegetation over a wide area around our principal excavation site. Fortunately, that happened on a Friday – the day that I had given our students and fellow archaeologists a day off, following the Near Eastern tradition, with the result that nobody was hurt even though I still have metal tools in my study that melted while the fire passed over our site. Suddenly, we saw the landscape as it had been before many years of *garrigue* growth had covered it, and we were able to walk everywhere and identify many remains of human activity. We changed the strategy of our project and developed an intensive survey campaign that localized human impact on the landscape going back to pre-Roman times, and we were able to reconstruct yet another instance of human–environment evolution over a couple of thousand years.

But in the midst of that project, my career was definitively sent on a different trajectory – by what was in those days a very large grant from the European Commission's Research Directorate – to study modern human–environment relationships in all the countries of the northern Mediterranean rim, under the umbrella of "Desertification in Europe."[1] The funding enabled me to bring a team together of some sixty-five scientists covering every conceivable discipline from theoretical physics and complex systems through mathematics, the natural, earth and geographic sciences to the social sciences, including history, rural sociology, and archaeology. And importantly, I was given the freedom to choose scientists from all over Europe without any institutional constraint so that I was able to assemble a team of people I liked to work with. It was a unique opportunity for me to get a third university education, this time completely transdisciplinary. In various forms the core of the team stayed together for a decade (1991–2000), so that we had ample time to learn from each other and develop a group identity to replace the disciplinary identities of the individuals concerned. Quickly, our research focus moved from desertification to environmental degradation and from studying principally the environment to studying the people in their environments, and ultimately how they made decisions about their environment. I will refer in certain places in this book to that project, the ARCHAEOMEDES project, so I will be short here. We investigated areas in Greece (2), in Dalmatia (1), in Italy (1), in France (several, depending on how you counted them), in Spain (3), and in Portugal (1). In some areas, the research spanned 12,500 years, in others a few decades. The areas varied from a couple of hundred to more than 10,000 square kilometers, as did the intensity of the research with them. An important innovation was that much of our thinking was based on a complex adaptive systems (CAS) approach. Though I did not realize that fully at the time, in that sense the ARCHAEOMEDES project was far ahead of its time. And again, that laid the foundation for a very important aspect of this book.

In the mid-1990s I moved from the United Kingdom to France for personal reasons and decided that, while retaining the long-term perspective that is also at the core of this book, I would focus on its impact on contemporary people and their environments. I relinquished my responsibilities in various archaeological activities that I had maintained thus far, and became, in essence, a sustainability scientist *avant la lettre*.

In 1999–2000, somewhat tired of project management, I was offered a year's sabbatical at the Santa Fe Institute and Arizona State University, which – again – ended up being a life-changer. It reconnected me with North American colleagues in archaeology, some of whom I had known since the mid-1970s, but the post also gave me the opportunity to gain deeper insights into CAS, and in particular to further develop my CAS thinking in the social sciences, grounded in the ARCHAEOMEDES experience.

In that process, I reconnected with two very early interests, one in the evolution of technology (as embodied in ceramic technology) on which I had done my thesis in the 1970s, and the other in the role of information processing in human evolution that began in the early 1980s, and I combined them. The ceramic interest was due to my early love of pottery making, in high school, and working together for my thesis with Jan Kalsbeek, a professional potter who instilled in me the potter's way of looking at archaeological potsherds. It taught me a lot about the contrast between creative thinking and scientific thinking and led to ethnographic fieldwork on pottery making in the Near East and the Philippines in the 1980s. But above all, it gave me a completely novel 'inside' perspective on techniques and technologies and their coevolution. In the very early 1990s, at the invitation of colleagues at the National Autonomous University of Mexico, my interests in this topic found their culmination in ethnographic fieldwork on innovation in pottery making in Michoacán with my wife Anick Coudart and Dick Papousek.

Stimulated by the SFI experience, I combined this interest with my early foray into the role of information processing as a major driver of societal evolution, and this led a couple of years later, again funded by the European Commission but now through its Information Technology Directorate, to the "Information Society as a Complex System" (ISCOM, 2003–2007) project, which aimed in particular at the relationship between innovation and urban dynamics, an interest that I have actively pursued until this day, and which has contributed a lot to the thinking that I will elaborate in this book. It is this project, which I initiated while at the Santa Fe Institute and conceived and codirected with David Lane, Denise Pumain, and Geoffrey West, that a few years later gave birth to the "allometric scaling" approach to urban systems codeveloped at the Santa Fe Institute and Arizona State University (Bettencourt et al. 2007), as well as to a series of projects dealing with the dynamics of invention and innovation.[2] One of the results of the project is the approach to the coevolution of cognition, societal organization and environment that is reflected in Chapter 8 in this book, and which was first published in a volume that gave birth to yet another lively project: IHOPE (Costanza et al. 2007) as well as in the ISCOM book (Lane et al. 2009a).[3]

But in 2003–2004 I moved to Arizona State University (ASU), attracted by its president's very innovative vision about universities as well as by the very collegial atmosphere I had experienced in its anthropology department in 2000. I accepted the directorship of that department, with the charge to develop it into a transdisciplinary school, for which the name "School of Human Evolution and Social Change" was chosen. A few years later, in 2010, that was followed by the deanship of the School of Sustainability that ASU created in 2005, and a little later by the directorship of ASU's Complex Adaptive Systems Initiative. Much of this last decade, therefore, I devoted with much pleasure to institution building in the very exciting and rewarding atmosphere of ASU. I published a number of papers on aspects of my thinking about the long-term coevolution of societies and their environments, but this left me too little time to undertake writing a book like this. So here we are.

Stepping Stones

While writing the chapters that follow, I was often reminded of Deng Xiao-Ping's famous dictum when he wanted to change the course of Chinese history: "Cross the river by feeling for stones." For much of my life, I have wondered and marveled at where I was going. Here and there, reading in very different corners of the intellectual world, discussing with many friends in different places, I have found things that appealed to me because "they fitted." But what did they fit? I was often not aware of the pattern in which they might fit, but followed a kind of hunch that "this was interesting." It is only with the benefit of hindsight, over the last ten years or so, that I began to see a pattern. Each of the following chapters is thus a kind of stone in the river that allowed me make another step in crossing my stream both literally (to a comfortable senior citizenship) and intellectually (from study of ancient techniques and societies, to a preoccupation with the impact of information technology on our modern societies).

I am emphasizing this for a number of reasons. First, because the book is not a tightly knit piece of work that holds together, examining a specific set of issues from every possible angle, profoundly digesting a complete literature. Instead, it resembles a network of stepping stones, in themselves coherent and that deal with different, loosely connected issues. To link them into the kind of direction where I found myself going I have made some large, only feebly documented jumps, in particular when discussing the impact the ICT revolution might have on our future.

Second, the domain that I propose to explore is not clearly defined, and there is no coherent community in existence to reconnoiter it. I have thus used my intuition as a compass to point in a new direction for sustainability research, rather than design a map in order to answer specific questions. It is too early for that. The interactive dynamic between the domain of research and the community interested in it has not had sufficient time to mature.

Third, the reader is reminded that the book represents about forty years of intellectual and physical wandering. Hence, some of the stepping stones are much older than others. That is particularly reflected in the literatures on which my arguments are built. I have not tried to update those references, as this is beyond my reading capacity. Moreover, as a historian designing an approach that is fundamentally processual, historical, and focused on the emergence of novelty, I feel a certain pride in showing the reader how I traveled, which stones I stepped on and how they relate, rather than – like Thucydides – hide that process by overlaying it with multiple rewrites. After all, I cannot – and cannot be expected to – master the many very different topics that I have touched on. The stones, therefore, are very different in nature and quality. Many topics I refer to have been the subject of decades, if not centuries, of discussion and I have therefore had to rely on relatively general summaries to include them in the discussion.

As Anick observed, the result is that I have done not much more than open a window and describe, in vague terms, the vista that one sees when looking out through that window. I can only hope that there are people out there who feel challenged by that vista. If there are none, my consolation is that writing this book has been a very satisfying voyage of personal discovery. I do not believe in convincing people – people convince themselves.

The Book: What It Is and What It Is Not

So, what is this book about, and what is it not about? To whom am I addressing myself? What is the core message? To introduce that first question, I will begin with an anecdote. One that occurred in the very first days of the ARCHAEOMEDES project. We were in northern Greece, in Epirus, close to the Albanian border, initiating our research on environmental degradation as was part of our brief for that project. The anthropologist of our team, Sarah Green,[4] who was born and raised in Greece, started walking around the landscape in an attempt to find out what people considered degradation. After a couple of weeks, in despair, she took a local family into their own backyard where there was a very large hole of (I seem to recall) 20 meters across and about a meter deep, caused by underground solifluction. She pointed to that hole and asked "Is that not degradation?" The family shook their heads and said something to the effect of "No – we have had that hole in the ground forever, and we live with (and around) it." So, asked Sarah, "What is degradation?" They laughed a bit, pointed to a nearby mountain called Kasidiares (which means "the bald one" in Greek) and said: "The fact that the bald one is growing hair." What they meant was that for them, degradation was the fact that there were now trees growing on a mountain that had always been bald before!

That idea certainly relativized our concept of environmental degradation – here people considered the growing of trees to be degradation. How was that possible? This apparent contradiction initiated a highly interesting strand in our research, which led us ultimately to accept that environmental degradation as a concept is culturally defined and directly related to the experience of the inhabitants/observers. In this precise case, we drilled down quite deep and became convinced that the growing of the trees, for the Epirotes of the region, symbolized the fact that their experience of their own society's evolution since World War II was essentially negative. That determined in many ways the direction this book takes.

Sustainability is a word that has many different meanings, uses, (mis-) interpretations, emotions, and rationales associated with it. At a later stage, I will discuss how one might define "sustainability," its content, its temporal dimension, its relations with other concepts currently used in the domain explored in this book. This book is about a particular vision of sustainability, climate change, and a whole range of related phenomena as primarily social and societal rather than environmental.[5] Indeed, it has been recognized for some time in our community that we are dealing with socioenvironmental dynamics, and I subscribe to that. The Resilience Alliance, Elinor Ostrom and many others have cogently argued for that. But I want to go a step further, and argue that the *second order socio-environmental dynamics* (the ways the socioenvironmental dynamics have changed over long timeframes) *are essentially driven by societies and the societal dynamics within them*. After all, humans do not only define what they consider their environments, but they also define what they consider to be environmental challenges (essentially challenges to the environment as they see it). And finally, societies devise what they consider solutions to these challenges. Those solutions, as I will argue in Chapter 10, have unintended consequences, and these in turn cause challenges and ask for solutions.

This position – that societies define their environments, environmental challenges, and potential solutions depending on their culture – goes to some extent against the prevailing conclusion in the western world that nature and culture are two opposites. That conclusion therefore needs consideration. A more detailed examination of the concepts "nature" and "culture," for example by examining how the contrast between "natural history" and (social or cultural) "history" emerged in the eighteenth and nineteenth centuries makes very clear that nature and natural history are in effect cultural constructs. Nature as we know it has been defined within the western cultural tradition as distinct from culture. It is therefore not surprising that when we look around at other cultures, whether in Amazonia, in Japan, in India, or in traditional China, the relationship between human societies and their environments has been viewed very differently.

To summarize, *sustainability is a social and societal issue, rather than an environmental one*. It involves all the different fields and dynamics of our human behavior in societies: politics and governance, institutions, the economy, our collective perceptions and decisions, our social interactions, etc. It is not just about the emission of CO_2 and other greenhouse gases, however much these may impact on our climate. I will argue in this book that those emissions are only one aspect of a much more fundamental threat to the continuity of our current ways of living on Earth. What I call "the crisis of unintended consequences" is hitting our way of life in many other ways, some of which (regional water shortages, food security, global societal instability) may well become dramatic before climate change or sea level rise do.

One core message of this book is that one can only begin to deal with these issues if one stops defining them as a potential crisis that needs to be avoided. Though fear has over the last thirty years alerted people to an emerging challenge, it does not, in the long term, mobilize societies to change – hope on the other hand does. The fact that our societies are waking up to the fact that they may be getting close to a tipping point in their relationships with their environments also offers an amazing occasion to think through and to implement a very different way forward, which some have called green growth – a way to reduce poverty by deliberately aiming for a very different kind of economy and lifestyle, based on partial dematerialization of our value systems. After all, if you want to get out of the hole you have dug for yourself, the first thing to do is to stop digging!

One must remember that many societies, at different times in history and in different places, have been faced with the kind of tipping point that we currently see emerging on the horizon. *Sustainability has always been a challenge.* And in many such instances, there is no substantive evidence to argue that such a tipping point was directly related to climate change. Indeed, one could justifiably argue that focusing on such emissions is a form of escapism – an escape from meeting the underlying issues head-on.

It is one of the other important tenets of this book that thinking about the future must be developed into a coherent approach, moving from a science that explains the present by studying the past toward an approach that uses the study of the past to learn about the present, and aims to use that knowledge to improve our perspective on the future, even though we may at present not quite see what that approach would look like. I will elaborate on that in Chapter 6, developing some tentative pathways to do so.

Yet another emphasis in this book is on the role played by the *organization of information processing and its evolution throughout human history*. This focus finds its origin in the fact that for the first time in the history of our species we are faced with a major transition in that domain, from human to electronic information processing. In my opinion, it is not coincidental that that transition occurs in parallel with the approaching sustainability tipping point. Moreover, the information and communication technology (ICT) revolution that embodies this transition will profoundly influence what the future will look like, and how people may be able to deal with the challenges facing us.[6] Treatment of the massive data on the environment and sustainability at large that is available today as part of the "Big Data" revolution is helping us to better understand the processes involved, both in the environment and in society, but the ICT revolution has many other consequences for society that have generally not been taken into account in this context, and I will devote substantive attention to them.

To whom am I addressing myself? I am trying to get my core message across to as wide an audience as possible. That potential audience concerns scientists in all disciplines as well as the wider educated public. Part of the message is directly aimed at science and scientists, as it is my opinion that the last two and a half or three centuries of scientific activity have contributed to the challenge that we are facing. Much of the science until recently has been reductionist – gaining clarity about phenomena by reducing the size and scope of what was being studied, as well as reducing the number of dimensions taken into account. Moreover, it has focused on explaining the present by relating it to the past, and as a result has not really dealt with the need to scientifically look toward the future to anticipate future challenges. But some sciences have evolved in the last thirty or forty years, and I see considerable need and opportunity to further develop the sciences of complex systems – which focus on emergence of novelty rather than explaining origins – to help us develop new approaches to deal with the challenges at hand.

But more needs to be done by the scientific community – over the past forty years it has slowly but surely, in many ways unconsciously, lost some of the trust that allowed scientists in earlier decades to help society find solutions to emerging challenges. Another main message of this book is that science has in my opinion promised too much in some domains, while in others it has implemented solutions with unintended, and negatively perceived, consequences. But above all, science has progressively lost the independence it had when it was mostly practiced by amateurs, as was the case in the seventeenth to nineteenth centuries. On the one hand, it has become encapsulated by business as a way to innovate and make money while on the other it has been used by governments everywhere – and at all levels – to justify decisions that society was not always ready to take. If science is to help us again to change course, that trust needs to be regained. But it remains to be seen how scientists will make their community evolve and how this community and the scientific process will be restructured, improving transparency and independence as well as diversity and transdisciplinarity.

Although both the above messages are directed at the scientific community, they are also directed at all those people who actually impact on scientific institutions, practices, and directions, as well as all those who are active in ways that are influenced by science and scientists. Hence, I am aiming this book at a wider audience than the scientific community alone. I will not try to argue my position in contrast to existing scientific positions, thus engaging in a series of narrow debates. Instead, I think my cause is best served by a 30,000 feet perspective that is written in a language that can be understood by anyone with an education. This will therefore not be a scientific monograph that reviews existing theories and documents additions or changes. It will follow an out-of-the-box approach, outlining its principal theses in bold traits, illustrated with examples.

The book is organized in three parts. The first, comprising Chapters 1–7, presents my perspective on a scientific context within which one can profitably view sustainability issues. The second part, Chapters 8–14, describe from the perspective of information processing the way in which I think we have come to the present sustainability challenge. The third part, Chapters 15–21 discusses various aspects of the way I think we might, as scientists, contribute to smoothing the transition from the present to the future, taking into account the simultaneous acceleration of environmental challenges, the challenges of the ICT revolution, and those of the fundamental global socioeconomic and political system.

NOTES

1 The project was funded by Directorate General XII (Research) of the European Commission under contracts EV5V-91-0021 (ARCHAEOMEDES I), EV5V-0486 (Environmental perception and policy making), ENV 4 CT 950159 (ARCHAEOMEDES II), and ENV5-CT97-0684 (Environmental Communication).

2 The project was proposed under number IST-2001-35006 on November 20, 2001 as an RTD Project under call IST-01-07-2A, Program 1.1.2 (IST), Priority VI.1.1 (FET Open) to the ICT directorate of the European Union, and funded from 2003 under contract IST-2001-35505. It proposed, in its introduction "to achieve a deeper understanding of what 'information society' means by developing a theory and a methodology to investigate how socio-politico-economic structure is related to the ways in which new information, communication and control technologies are generated and used. Our approach will focus on the relationship between information processing and the organization of society. We will focus on the dynamics of invention and innovation in multilevel heterarchical organizations, and on the structures that emerge as a result of these dynamics."

3 It is for the ARCHAEOMEDES and ISCOM research that I later received the UNEP's "Champion of the Earth for Science and Innovation" award (in 2012).

4 Now a professor of anthropology at the University of Manchester in the United Kingdom.

5 Throughout the book, I will use "social" for the dynamics of individuals' interactions and "societal" for society-wide dynamics that affect the structure of the society.

6 Throughout the book, I will use the term ICT revolution, including under this term the "digital revolution" and the "4th industrial (or technological) revolution," as all these are in my opinion part of one and the same longer-term process.

2

Defining the Challenge

Background

In the early years of the current century, Will Steffen and colleagues (2004, 2005) published a couple of illustrations that summarized our understanding of global change in a very effective way, showing how, since 1750, changes in the Earth system had accelerated very rapidly. To do so, he combined in two figures measured changes in environmental and societal parameters, ranging from CO_2 and NO_2 emissions, loss of biodiversity, and increases in Earth surface temperature to the number of people worldwide, gross domestic product (GDP), and water use (see Figure 2.1). These figures were reproduced in many publications and became extremely well known and popular at a time when the scientific world was principally looking at global change in the context of different scientific disciplines.

A few years later, in a paper in *Nature* that has also been frequently cited, in a team led by Johan Rockström of the Stockholm Resilience Center (Rockström et al. 2009a), we made for the first time a strong case for the fact that our worldwide management of the environment was exceeding what was called the "safe operating space" of the Earth's environmental dynamics. Much of the debate that followed focused on the question whether it was possible to a priori set global limits to such a space, or even whether such an approach was conceptually sound. Another part of the debate questioned the boundaries themselves. But relatively little attention was paid to an important message: the fact that if human activities pushed the Earth system dynamics beyond certain limits *in more than one dimension* (e.g. CO_2 emissions, biodiversity loss,

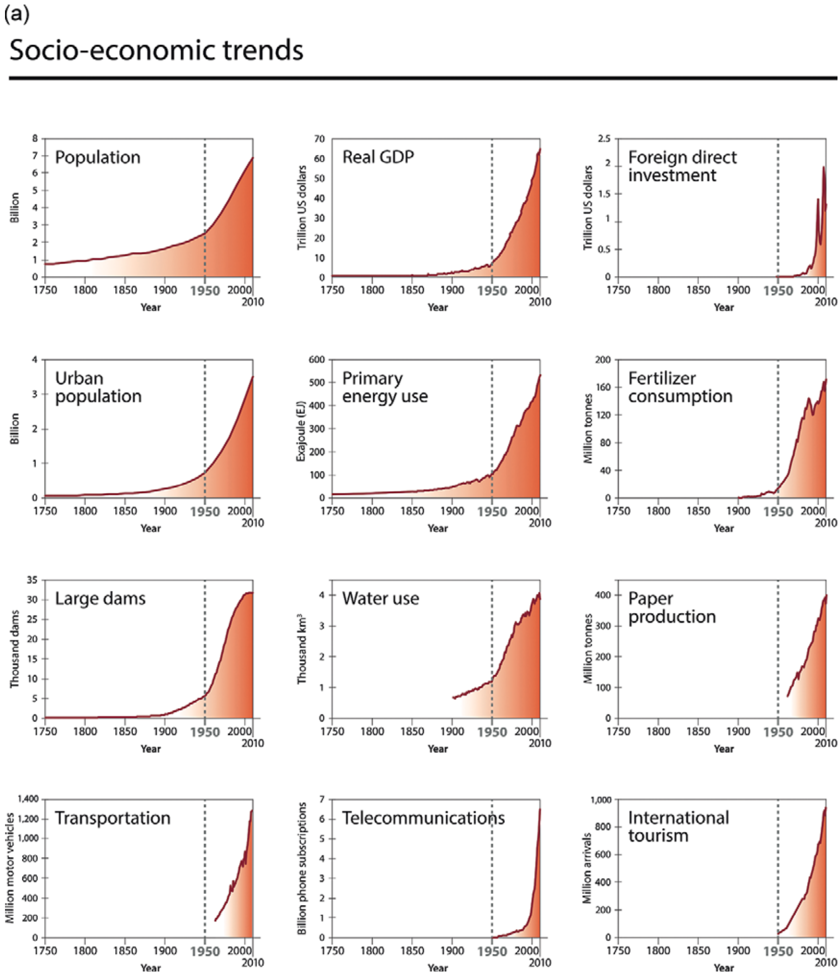

FIGURE 2.1a,b The rapid acceleration of change over the last 2½ centuries viewed through the eyes of many dimensions, both natural and societal. (Source: Steffen et al. 2015, *The Anthropocene Review*, by permission SAGE)

ocean acidification, etc.), the system as a whole could easily move into completely unpredictable, (near-) chaotic behavior, rapidly undermining the environmental bases of our various societies.

The paper, and a subsequent one headed again by Will Steffen (2015), thus not only drew attention to the fact that our Earth system was undergoing rapidly accelerating change in many environmental as well

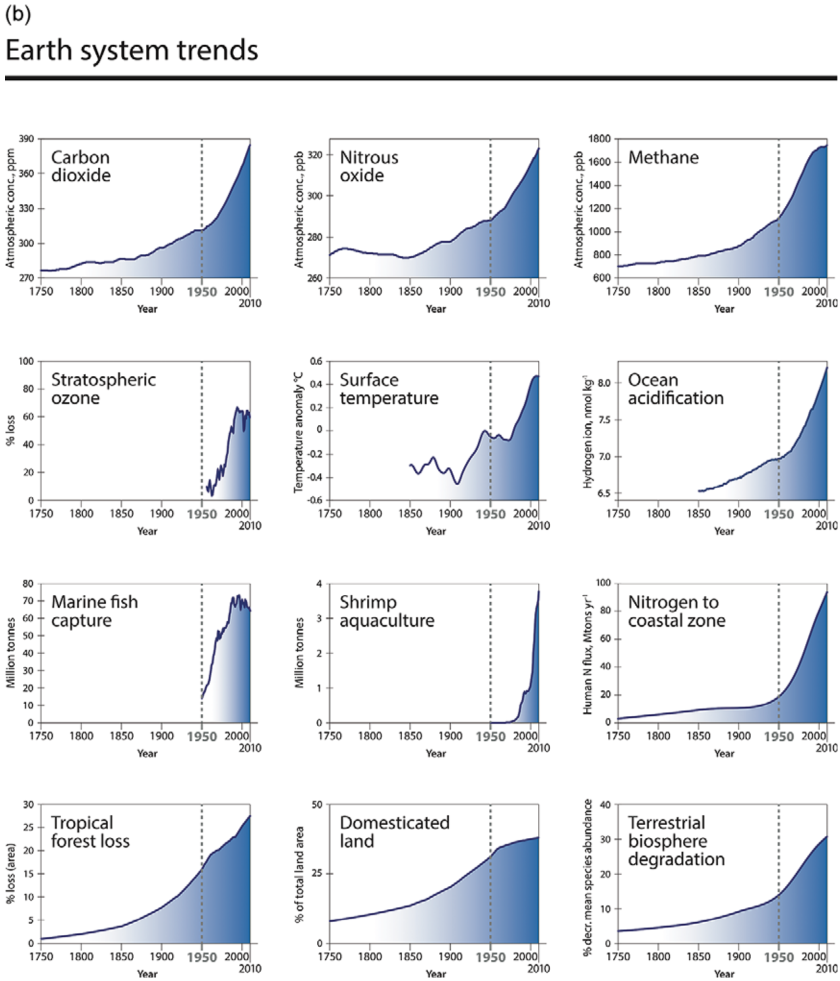

FIGURE 2.1a,b (*cont.*)

as societal dimensions, but that there might come a point where these many changes would themselves generate second-order changes (that is, changes in the nature of the dynamics themselves, dynamics which during most of the Holocene have remained within narrow boundaries) that could rapidly and unpredictably transform the natural as well as the societal sphere in which human groups have functioned for centuries. By implication, these papers argued for a transdisciplinary approach that involved the atmospheric sciences, chemistry, oceanography, geology,

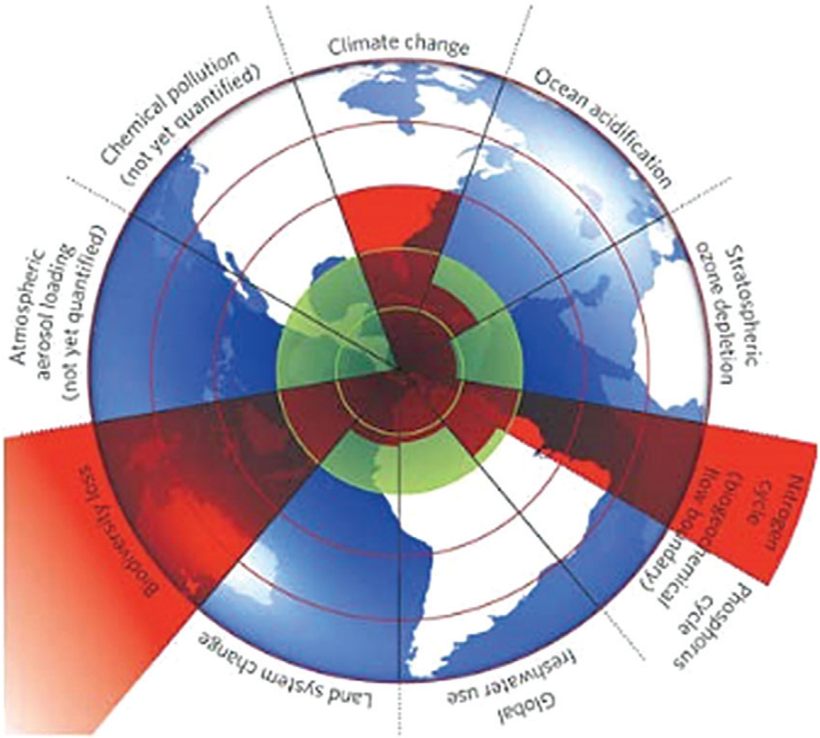

FIGURE 2.2 The Earth system is close to exceeding its "safe operating space." (Source: Rockström et al. 2009a, *Nature* by permission)

biology, and other disciplines. But they did not include the social sciences in equal measure.

This intellectual shift occurred in parallel to an organizational shift in the global scientific community's institutional context. In the 1980s and 1990s, a number of Global Environmental Change communities had been created and funded that grouped certain disciplines together: the World Climate Research Program (1980; climate sciences, meteorology), the International Geosphere-Biosphere Program (1986; Earth sciences, life sciences), the International Human Dimensions of Global Environmental Change Program (1990; social sciences), DIVERSITAS (1991; biodiversity-related disciplines such as ecology), etc.

An important aspect of this situation was that this movement involved the upstream part of the Earth science community alone, while in other scientific fields (physics, chemistry, biology, etc.) there usually are large "intermediate" scientific communities dealing with "applied sciences" before the scientifically acquired knowledge can be adopted for technological, industrial, agricultural, medical, and other applications. This shortcut created a wide disconnect between the Earth science and sustainability communities on the one hand and the general public as well as all people involved in doing things (engineers, politicians, professional organizations, etc.) on the other. In the latter sphere, because knowledge is immediately related to "needed actions" and their consequences, scientific knowledge is mainly approached as emotion (how many images have we not seen of polar bears deriving on melting icebergs?), rather than rationally with reference to the means to act. Action is all too often caricatured as being in the hands of a business community that is only interested in short-term profit.

In 2006, at a meeting in Beijing, a new organization was created, the Earth System Science Partnership, which was conceived as an organization to start building the links between these different communities. This proved difficult, and was quickly abandoned as an effort, to be replaced by a complete reorganization of the whole Global Environmental Change community into a single organization, called Future Earth. This was initiated in 2012 and is nearing its cruising altitude and speed as I write. As part of that transition, an explicit focus on learning for the future, transdisciplinarity, co-design and the development of applications is included in Future Earth's vision, but in practice the organization is still very much driven by the academic community and its longer-standing approaches.

Both intellectually and organizationally, the first decade of the twenty-first century thus saw a clear move toward investigating global change in an integrated, transdisciplinary manner. It seems to reflect a fundamental conceptual change that began a couple of decades earlier, in the 1980s, which changed our conception of the relationship between people and their environment, as summarized in Table 2.1.

The last few decades have seen a shift in our understanding of the relationship between societies and their environments. Up to the 1980s humans were predominantly seen as (reactively) adapting to nature. Under the impact of the environmentalist movement, the late 1980s and 1990s saw the emergence of the opposite perspective: humans as pro-active, with (mostly negative) consequences for the environment. That led to the emergence of sustainability as an ideal. In the late 1990s and 2000s a more balanced perspective emerged, which views the relationship between societies and their environments as interactive. The core concept

Table 2.1 Shifts in the conceptualization of society's relationship to nature

Pre-1980s	*1980s–1990s*	*2000s*
Culture is natural	Nature is cultural	Nature and culture have a reciprocal relationship
Humans are re-active to the environment	Humans are pro-active in the environment	Humans are interactive with the environment
Environment is dangerous to humans	Humans are dangerous for the environment	Neither are dangerous if handled carefully; both if that is not the case
Environmental crises hit humans	Humans cause environmental crises	Environmental crises are caused by socioenvironmental interaction
Adaptation	***Sustainability***	***Resilience***
Apply technofixes	No new technology	Minimalist, balanced use of technology
Milieu perspective dominates	Environment perspective dominates	Attempts to balance both perspectives

Source: van der Leeuw.

shifted again, this time to resilience – the capacity to respond to change without losing continuity or identity.

But in many relevant scientific communities, this shift is not yet complete. In the climate, Earth and life sciences in particular, the role of societies is acknowledged, but many in these disciplines still see that role as defined by, and often ancillary to, the role of atmospheric dynamics, geological or geomorphological processes, ecosystems, etc. Thus, when practitioners of those disciplines formulate questions that they hope can be answered by social scientists, they (understandably) do so in ways that derive from their discipline of origin.

A central theme of this book is the fact that our so-called environmental challenges are in fact *societal* ones, involving all aspects of our societies, including governance, economics, culture, technology, institutions, environment, resources, etc. I use this term throughout the book to distinguish the dynamics involved from purely social ones. At the most fundamental level the distinction between society and nature is a societal one. As I will explain in Chapter 3, the concept "nature" emerges in its current position as a counterpart to "culture" in the eighteenth and nineteenth centuries in western Europe in an attempt to define natural history (biology) by contrasting it with history (the history of societies and human individuals) (van der Leeuw 1998).

The questions asked by the natural and life sciences often do not hit the sweet spot among social scientists, and do not trigger the kind of research effort that, fundamentally, they merit in view of the urgency of dealing with the socioenvironmental issues involved. It is often as if there is a glass wall between the disciplines involved: they see each other, but they cannot touch. I will discuss the historical reasons for this in Chapter 3.

What concerns me here is rather to present a first outline of the task of reaching out across that barrier, to achieve the kind of intellectual fusion that is necessary to deal with the issues concerned. As a starting point, I think we have to acknowledge that most of the kinds of scientific challenges that the social sciences deal with are very different from those tackled by the natural, life and Earth sciences. One way this difference has been formulated is by Cristelli et al. (2012), who show an image of one of the US astronauts on the moon, alongside an image of a huge traffic jam in London and ask "Why can we reach the moon but not the airport?"

The answer is that these are two very different kinds of problems. Reaching the moon is not easy, but at least the goal is well defined, and the number of dimensions involved is limited and knowable, so that the challenges to be met and the dynamics affecting them can be isolated, the overall challenge disaggregated into subsets and solutions found for these subsets. Once such solutions have been found, one can then bring the subset solutions together to meet the overall challenge. Many of the problems in the natural, earth, and engineering sciences are of this nature. Once they have been solved, they will not recur as problems. They are considered "tame" in comparison with "wicked" problems.

In their image, the way to the airport is blocked by a traffic jam. Traffic jams are examples of such wicked problems, problems that cannot be solved definitively. The number of dimensions involved is so large that it is unknowable, and the challenges can therefore not be disaggregated. Such problems are characterized by indeterminacy in problem formulation – the precise formulation of a wicked problem as a problem with unique and determinate conditions to be satisfied is virtually impossible – and by the fact that there is no definite and rigorous ultimate solution with definitive results. Such problems can at best be suppressed, managed, or solved over and over again (Rittel and Webber 1973). Most challenges involving society are of this kind – if only because the behavior of so many individuals is involved. Other examples of such wicked problems are the "Not In My Back Yard" (NIMBY) problem, the recurrence of financial crises, and terrorism.

Such differences in the nature of the issues investigated, as well as the (related) differences in disciplinary history, research goals, paradigms, methods, and training have led to (groups of) disciplines that collect their data under the impact of different epistemologies, using different methods and techniques, and set different standards for the validation of research results. Hence the data and information collected and used by these disciplines cannot be treated in the same manner, and that constitutes another fundamental barrier to developing an integrated perspective on socioenvironmental dynamics. This is aggravated by the fact that many scientists in both the disciplines related to the Earth sciences and the social sciences and humanities disciplines, as well as politicians, business (wo) men, journalists, and others are only partly aware of the fundamental epistemological and conceptual differences behind their disciplines, which in many instances leads to confusion, and therefore to ambiguity concerning the nature and value of the data collected.

One reason for this semi-awareness is the nature of our education systems, which are so strongly discipline-based and discipline-focused that they develop their own communities of practitioner-experts, their own education curricula, their own specialist languages, their own funding sources, and above all their own criteria for admission into a particular field of study. These different fields of study focus on particular issues, questions, methods, and techniques, and relegate to other communities of scholars and scientists the task of answering questions that they themselves cannot. In this process of – for want of a better term – educational and social alignment, many academic – disciplinary – communities have increasingly closed themselves off from scientists and scholars in other disciplines because it became increasingly difficult for those who had not followed the anointed *cursus honorum* of a discipline to achieve the full depth of understanding of its expert practitioners. As a result, the scientific worldview that was once the pride of the Enlightenment has fractured into many disciplinary academic ones, and that state of affairs has been cast into administrative structures in (almost) all universities and research organizations. But it should be pointed out that this is not the case, or at least not to the same extent, among the applied science-, technology-, engineering- and related communities that have to an important extent been industry or business -driven.

Once a sufficient number of scholars and scientists became aware of this issue, they initiated a swing in the opposite direction, emphasizing consecutively "multi-," "inter-," "trans-" and most recently "un-" disciplinarity. That battle-cry is now resounding everywhere, but in practice, for reasons to be discussed later, it is personally and institutionally still very difficult to achieve the kind of intellectual fusion that is needed to deal with complex questions such as sustainability. I would like this book to contribute a vision of the challenges facing us that enables an improved intellectual fusion between the disciplines involved by providing the necessary scaffolding structure.

In order to do so, I have adopted a starting point that is very different from most of those involved in the sustainability debate. Rather than view our current socioenvironmental dilemma from the perspective of the natural and Earth sciences as is done, for example, by the Intergovernmental Panel on Climate Change (IPCC) I will do so from a societal perspective, in keeping with the thesis expressed in Chapter 1, that the second order drivers that are increasingly pushing the socioenvironmental dynamics of our Earth system to transgress the boundaries of our "safe operating space" are essentially societal, not environmental.

The argument for that is quite simple. Everything humans observe and do passes through the filter of their cognition. That filter defines all the categories humans simultaneously observe and create. Hence, both "nature" and "culture" are in effect cultural categories, defined by humans who have adopted different perspectives on the world around them. Environment is another such culturally defined category. Humans define what they consider their cultural and natural environments. They also define what they consider the challenges they observe in these environments, and finally they determine what they consider to be the "solutions" for such challenges. Other cultures than our own, western one define their environments differently. In some instances they do not in any way distinguish the cultural or social sphere from the natural and environmental one (as in the case of the Achuar, see Descola 1994), while in other cases they acknowledge a difference between these spheres but conceive the relationship between them in ways very different from our own, as for example in Japan (Berque 1986). But even when a group does not distinguish between "culture" and "nature," that in itself is a sociocultural choice. It is thus not only appropriate but essential that we view socioenvironmental dynamics as being societally driven. This will be of fundamental importance in the sustainability debate in the current century, in which major societal changes are likely to occur.

The choice to try to develop an integrative (transdisciplinary) perspective on socioenvironmental dynamics from the societal point of view brings a novel, daunting challenge: to introduce a perspective on societal dynamics that engages natural, life, Earth, economic, and social scientists, so that they can all contribute to its development. Moreover, that approach should not only be able to provide proximate explanations for observed phenomena, but also ultimate explanations for both the first- and the second-order socioenvironmental dynamics we observe in all three so-called pillars of sustainability: society, economy, and environment.

To find a starting point, I have argued as follows: if we consider for a moment human beings as "just another unique species" (the title of Foley's 1987 book), I think we can agree that, like all other living beings, humans process energy, matter, and information. They use energy and matter to physically live and survive – to feed themselves, to grow, and to reproduce. Some of that energy is processed in the form of raw energy – heat from sunshine, for example, which is transformed into vitamins and absorbed to help maintain the necessary body temperature. The remainder of the energy needed to maintain body temperature, as well as the energy expended in movement and other muscular activity is processed in the form of matter – food. Other forms of matter, and this distinguishes humans from many other animals, are processed to provide protection, tools, shelter, and the like. In all these cases, the processing involves the transformation of the information content of the matter, either through digestion (increase of entropy) or creation of functional objects (decrease of entropy).

Humans, like all other animals, therefore also process information. But what is specific about human beings is that they not only learn (and learn how to learn, see Bateson 1972), but they can (and do) organize (Lane et al. 2009b). In organizing, they add information to matter and energy when they transform either or both for a specific human purpose. They organize their thoughts, their needs, their actions, their tools, and they also organize themselves – into communities and societies. In doing the latter, they put to use a particular aspect of information – the fact that it is not subject to the law of conservation. Energy and matter, because they are subject to this law, *cannot be shared*, but information *can be*, and is, *shared*. A society functions as such because its members communicate and share ideas, expectations, ways of doing things, knowledge about certain resources, etc. It is the sharing of information that holds a society together and constitutes its culture. The fact that information is processed both individually and (in later human prehistory) collectively is responsible for the fact that each culture has its language, its customs, its technology, and material culture, its myths and legends, its art, etc. All of these are shared and communicated ways of doing things.

One could in effect say that each and every individual and society processes energy and matter, but what distinguishes individuals and societies is the *form* that such processing takes, and that in turn is dependent on the information processing of both the group and the individuals that are its members. André Leroi-Gourhan was as far as I know the first to point in this direction in the mid-1940s in his *Technique et Langage* (Technique and Language), part of a magnificent set of two volumes on many of the contextual dimensions that impact on techniques and technology, including long-term history, materials, cognition, economy, and tradition.

Taking the above argument as the starting point of my search for a perspective on societal dynamics that can engage scientists on both sides of the social–natural sciences divide, I have looked at a number of aspects of human dynamics from the information-processing perspective, and will introduce these explorations in later chapters (Chapters 8 ff.) of this book.

Six Fundamental Points

In order to give the reader a synthetic preview of some of the main points that have shaped my perspective on sustainability issues and that underpin much of this book I want to present six major points in a nutshell.[1] The reader will see them recur as part of the weft of the book.

The **first** of these, that *we are facing a societal rather than an environmental crisis* has already been referred to: societies define what they consider their environment, what they consider its problems, and what they see as the potential remedies for the latter. Or, as Luhmann (1989) emphasized, society does not communicate with its environment, it communicates within itself about the environment, and such communication is self-referential in each culture. We cannot escape the fact that our societies are responsible for the environmental phenomena that cause us to worry, and only by changing our collective behavior can we do something fundamental about these worries.

A first step in that process is to understand the societal dynamics behind the environmental crisis, including the role of science itself – its overpromising, its unintended consequences and their negative effects, as well as its numerous positive contributions to many aspects of human life and society. We need to ask, for example, what is the role of science in the fact that there is such a protest against Genetically Modified Organisms

(GMO's) in Europe and there was much less on nuclear issues? This also touches on the role of scientific communication – which five or ten years ago was not on the agenda.

The **second** point I emphasize is *the importance of looking at dynamic systems over the long term*, sometimes up to several millennia. This allows me to discern aspects of systems dynamics that are not usually included in shorter-term visions:

- Slow changes that do impact on the environment and society, but are barely discernible at secular timescales;
- A wider range of system states than the ones that the system has encountered over the last few centuries;
- Second order changes ("changes in the way change proceeds") that reveal important dynamics that often play out very slowly.

Moreover, looking only at the last two centuries or so, we observe a socio-natural system that has already been heavily impacted by anthropogenic dynamics. It is like looking at a very ill patient without knowing what a healthy person looks like. Taking a long-term perspective enables one to distinguish the natural dynamics better from the anthropogenic ones.

My **third** point is that we have to look at *the limitations of human cognition*. Human cognition, whether individual or collective, is limited to a relatively small number of the dimensions of processes occurring in nature. Our actions, which are thus based on partial – and biased – perceptions of the dynamics going on around us, affect our environments more profoundly than we can possibly know. At the 2016 Royal Colloquium in Stockholm Taleb (2017) has called this "the curse of dimensionality." Over time, the net effect of continued learning about, and intervention in, the environment is that the more we think we know, the less we know because we have wrought changes in the environment that far exceed our knowledge. This results in unanticipated, unintended consequences of our actions. Moreover, whereas we "do something about" known frequent risks, these actions engender unknown risks that accumulate over time so that the risk spectrum shifts over the long term toward a dominance of unknown, long-term risks.

This second-order dynamic is reinforced by the fact that our thinking is underdetermined by current observations (Atlan 1992) and thus over-determined by known reactions to prior events Hence, our thinking is path-dependent and difficult to change. The actions we conceive and implement fall within a range determined in the past, and they are therefore very often not optimal to deal with the changed circumstances.

Due to the shift in risk spectrum and the introduction of unknown longer-term unintended consequences, over time the latter accumulate to the point that a society may no longer know how to deal with all of them simultaneously. This is in my opinion what triggers a crisis or (in more scientific terms) a tipping point, a temporary incapacity of a society to do the information processing required to keep it in tune with the changes it has caused. It follows that we must look closely at these unintended consequences of all our individual and collective decisions and actions.

My **fourth** point, following directly from this argument, is that we *have to also invert the way we look at stability and change*, by assuming that change is permanent and humans try and create stability, so that we should be explaining stability rather than change. This is a very fundamental move away from our core Aristotelian scientific perspective toward the perspective of Heraclitus of Ephesus. It implies among other things that we should start to design for change, rather than for stability, such as is timidly being proposed by the protagonists of the circular economy. Another implication is that wherever possible we should follow the precautionary principle, making "do not harm" the core of our interactions with our environment.

The **fifth** point is that the current emphasis in the sustainability community on "innovating our way out of trouble" ignores that 250 years of randomly exploding innovation in every domain is what got us into trouble with the environment, as has wonderfully been illustrated by Klimek and AtKisson's *Parachuting cats into Borneo* (2016). To have any chance of dealing with our present global predicament, we must ultimately find ways to focus innovation in positive, helpful directions. But currently we do not even know scientifically how invention works, and we only partly understand how the introduction of inventions in society works (Lane et al., 1997, 2005). We need urgently to understand this better, in order to focus our innovative capacity on sustainability issues.

My **sixth** point is to ask *why do we forever push against the environment*, trying to transform it, at least in our western societies? Our relationship with the environment can be seen from two points of view – that of the society and that of the environment, which I am here referring to as *environment* (the natural state surrounding society) and *milieu* (society in the center of nature) respectively. Those perceptions interact, according to an interesting perspective on category formation (Tversky & Gati 1978; van der Leeuw 1990), in which the direction of comparison between a subject and a referent with which it is compared

Table 2.2 Different perspectives on the relationship between humanity and the environment

Milieu	*Environment*
Humanity is compared to nature;	Nature is compared to humanity;
The cohesion of nature, its unknown aspects, its strangeness and force are amplified;	The cohesion and strength of nature is diminished, its known aspects are emphasized;
The confusion and the handicaps of humanity are accentuated;	Cohesion and strength are accentuated in humanity;
Humanity is *passive* in a natural environment which is *active* and aggressive;	Humanity is active and aggressive in a natural environment that is *passive;*
Change is attributed to nature, and people have no other choice but to adapt to nature;	Humanity is the source of all change; people create their environment; often with negative effects for nature
Natural changes tend to be viewed as dangerous, because they are beyond human control.	Natural changes seem more controllable and lose their dangerous appearance.

Source: van der Leeuw (2017).

determines whether the comparison emphasizes similarities or differences. Thus, when in the *milieu* perspective humanity (subject) is compared to nature (referent), the cohesion and strength of nature and the confusion and handicaps of humanity are emphasized, whereas in the *environment* perspective, when nature is the subject and humanity the referent, the opposite happens. This leads to the opposition illustrated in Table 2.2.

If we then look at how these two perspectives interact, one sees that taking them together, they exaggerate the unknown dangers of the environment, and downplay the dangers of human intervention in it, explaining in my opinion the opposition between society and environment and the continued intervention of the former in the latter.

This raises an interesting question: where does one focus first – on the context or on the subject, on the ideal or on the reality? What does one consider the subject, and what is seen as the referent?

In this context, there are two interesting differences between a western and an eastern (Daoist) perspective (Sim & Vasbinder, in press). Firstly, in the latter one seems to focus first on the context, and then on the subject, whereas in the West it seems to be the other way around. If that is indeed the case – and I am not at all a specialist in these matters – that would imply that in the Daoist approach the similarities between society and the environment are emphasized, whereas the differences are emphasized in our western approach.

Could it be that this difference is also related to the fact that in our western approach, at least since the Enlightenment, one projects an ideal and strives to get as close to that ideal as possible whereas in a Daoist approach, on the other hand, one tries to act in the best way possible given the context of the moment, rather than strive toward an ideal?

NOTE

1 The final section of this chapter closely aligns with van der Leeuw (2017).

3

Science and Society

Introduction

Now let me start outlining my argument in earnest, beginning with a 30,000 ft historical perspective that illuminates some of the intellectual reasons for the current dilemma and places them in the context of wider societal and intellectual changes over the last few centuries, and particularly the last century or so. This historical perspective may seem at first sight to be a diversion, and not necessarily an easy one to read for others than historians of science, but it is fundamental to understand the origins of many aspects of the current western perspective on sustainability that is the main topic of the book.

Beginning with the transition from the early medieval "vitalist" to the dual Renaissance perspective, I will here show how over the last six centuries a perspective linked to what was originally a human cultural category, "nature," has come to dominate our scientific world view to the point that we are now investigating human functioning (for example of the brain) as a "natural" phenomenon, and have to an important extent lost sight of human behavior as something intrinsically human. That process has also permeated much of our western thinking beyond the realms of science, scholarship, and academia, and anchors our perspective on climate and environmental change.

In doing so, I have focused on the traditional, academic sciences as that is the domain in which I work and to which I hope this book may contribute. As already mentioned in Chapter 2, over and beyond these sciences, there is a wide range of applied sciences where much of what I am arguing here is already current practice, in the sense that their role is to relate "pure" science to the practicalities of everyday life, and that they combine the input of many disciplines.

The last sixty to a hundred years have seen very important and rapid advances in many scientific disciplines. In the natural sciences, we have seen increases in our knowledge about subatomic particles by means of larger and larger accelerators, but also the development of nuclear energy. Astronomy and planetary science have rapidly advanced thanks to the construction of large numbers of (radio-) telescopes and satellites, in the process giving us Geographical Positioning Systems. The discoveries of the double helix and the subsequent mapping of genetic structures have transformed biology, medicine, and our ideas about biological evolution. In materials science, the discovery of unprecedented properties of silicon, and more recently graphene and the nanomaterials, has opened up huge new areas of research. All these discoveries, and many more, have together completely changed our lives, changing what we eat (agro-industry; packaged and frozen foods; the hamburger), how we move around and how far we can go (the jet airplane), what we do in our spare time (the television, computer games); who we consider our friends (Facebook, Twitter) and so forth. But no scientific discoveries have transformed society as much as those that have led to the computer, informatics, the Internet, and – in general – the information sciences.

In the process, science itself has changed. What began in the 1700s as a voluntary, unregulated, and individual inquiry into natural phenomena practiced by the upper middle classes and nobility, funded by their own resources, has developed over the last two and a half centuries into a worldwide community of millions of scientists who are subject to stringent rules (peer review; university administrative structures; promotion and tenure proceedings), and are paid by governments and industries on the premisse [*sic*!] that their activities will lead to inventions and discoveries that improve our lives, satisfy our curiosities, and keep our economies humming. In particular, after the discovery of many novel tools during World War II (e.g., radar, nuclear energy, jet engines), for some thirty years (1950–1980) the general population's respect for scientists was at its zenith. Scientists (natural scientists in particular) were counted upon to perform miracles, guide governments, provide industry with the tools to be ever more performing, and invent more and more ways to make life more comfortable and less wearing. But somewhere in the 1980s and 1990s that trust in science began to wane, and an increasing proportion of the population in western countries became more critical of science.

That shift in the perception of the role of science is of direct relevance to us, and to the topic of this book, because the sustainability challenges facing us now will require an all-out scientific effort to find and to apply solutions, and for that effort to succeed scientists need to regain the trust of society at large. Hence, I want to use this chapter to delve a little deeper into the history of the sciences, laying bare some of the dynamics that have shaped the successes, the directions, and the challenges of contemporary scientific research. In doing so, I will of course not introduce novel ideas, but juxtapose ideas from historians of science in a way that suits my main purpose: to put into perspective the ways in which our scientific approaches have been shaped by, and have come to shape, our world, and to point to some of the reasons why a fundamentally different approach is needed.

The Great Wall of Dualism

Let us first consider the word "nature." *Natura* is the Latin equivalent of the classical Greek word φυσισ which we encounter in the words physics, physiology, physician, and many other words in the European languages.[1] Lewis (1964) argues that already in classical Greek the word conveys an ambiguity, as it can mean "that which is real" (as opposed to fictional) and thus "the way things should be" (in accordance with nature), as well as "nonhuman," relating to the world of nonhuman beings. The ambiguity clearly expresses the difficulties in locating human beings on the Greek mental map of earthly phenomena. Human beings must under certain conditions be considered part of nature, while in other circumstances it is preferable to exclude them from nature. The duality is also an essential step in the objectification of nature as it allows one to think of nature as subject to its own dynamics, its own laws, its own behavior, distinct from those that govern the dealings of people. Such objectification is a *conditio sine qua non* for any attempt to reduce perceived natural risks, indeed for the description of any presumed interaction between people and that what surrounds them.

In two very interesting books, which I summarize here much as I did in my ARCHAEOMEDES publication (1998b), Evernden (1992) describes some of the transformations this conception underwent, beginning in the early Middle Ages. At that time, a single "vitalist" worldview pertained to all aspects of the world, whether mineral, vegetal, animal, or human.

All these realms were seen as inhabited by living beings of different kinds which had close links between them and with the realm of the divine and supernatural. In effect, all that is happening in these realms is seen as an expression of a divine configuration and, in this respect, there was no difference between human beings and any other aspect of nature.

The Renaissance, following on the heels of the major plague epidemics of the fourteenth century (which in some urban locations reduced population numbers by 50% or more), is the next major step. Historians and art historians have long linked the Black Death and the Renaissance in their interpretations (e.g., Gombrich 1961, 1971; Hay 1966), focusing for example on the contrast between the *danse macabre* and the subsequent explosion in the arts, but also on the introduction of the concept of the individual (as manifest in the first full-face portrait painting, of King Richard II of England), the emergence of the signature as a means of identification in commerce (see Cassirer 1972), and the first attempts to measure time with mechanical clocks. Evernden cites the groundbreaking work of Jonas (1982) in according fundamental importance to this period in which a shift occurs from a cyclical perspective in which life and death are both part of a never-ending cycle, to a linear one in which death is the rule, life the anomaly. This opened the door to the notion of an inanimate universe, nature as lifeless "behaving matter," a notion that has grown ever since in a movement that is closely related to the emergence of mechanistic physics (the so-called Newtonian paradigm) and the emerging separation between science and religion.

It is Evernden's contention that this growth was made possible by what he calls "the great wall of dualism" (1992, 90), which protected our conception of humanity from the lifelessness of the inanimate world by maintaining that (nonhuman) nature was subject to fundamentally different laws than were human beings, so that one could concern oneself with the study of the former without attacking the human sense of identity, and thus to reposition human beings with respect to their nonhuman surroundings.

Thus, in the centuries following the Renaissance, Copernicus could introduce the idea that humans are not living on the central body of the universe, but on one among a series of more or less identical planets turning around the sun. Human life thus became an epiphenomenon, a mere anomaly on one planet out of (eventually, centuries later) millions assumed to exist in the universe.

Of direct importance for us here is the push for objectivity in the study of nature, linked to the idea that because human beings are outside the natural realm, their observations and actions on nature would essentially distort its dynamics and our perception of them. As expressed by Shapin and Shaffer: "the solidity and permanence of matters of fact reside in the absence of human agency in their coming to be" (1985, 17–18). Evidently, this had consequences for the period's conception of knowledge, which shifted from one in which knowing is achieved through identification with the object of study to one in which knowledge is in the mind, independent of the object, and achieved through the critical observation and study of that object.

Evernden illustrates, by means of examples from Italian and Dutch painting, how the first stage of this slow change occurred differently in different parts of Europe (1992, 78–79). The stereotyping of Italian landscape painting seems to indicate that, here, nature is assumed to be a coherent system, whereas in Dutch landscape painting the attention for detail and realism seems to indicate that nature is made up of details which project oneself on the retina. It is as if in the Italian case the depiction of nature derives as it were top down, from a particular overall conception, whereas in the northern European examples, nature is depicted bottom up, as an ensemble of observed details. In a similar line of argument, Alpers suggests (1983, xxv) that Dutch society was oriented toward the visual and material, Italian society toward the verbal and conceptual. However that may be, it is clear that from this period onwards there emerges a contrast between developments in northwestern and in southern Europe. Its most eminent manifestation is the growth of empiricism (ultimately followed by the Industrial Revolution) in Britain and Holland, in opposition to the Cartesian rationalist position that dominated in France and Italy.

It is of importance to our further discussions to emphasize that from this moment on we also observe a growing separation between the natural sciences and the humanities that is the inevitable corollary of the separation between humanity and nature. Humanity is a sphere in which values, thought, spirituality and novelty dominate the scene – contrasting with the mechanics which are thought to dominate in the natural sphere. Until recently, most educational institutions in continental Europe and the Anglo-Saxon world have seen it as their task to educate students in both spheres, but it is my impression that that goal is now in many institutions suffering under the increased pressure on students to reduce study time, and focus on their future employment.

Rationalism and Empiricism

The next stage in the development of our western intellectual tradition that shaped our present scientific capabilities and challenges is the transition to the eighteenth century, and in particular the emergence of the intellectual movement usually referred to as the Enlightenment, in which the above differences between Rationalism and Empiricism solidified. It is crucial because it shaped the scientific articulation between theory and observation. That articulation between the realm of ideas and that of observations led to two very different approaches to science that persist, *mutatis mutandis*, to this day. The difference is best summarized by contrasting the approach of Descartes in France with that of Bacon in Britain.

Descartes' famous dictum "Cogito ergo sum" ("I think therefore I am") reflects a movement in which the importance of thought and reason is emphasized over that of experience. Cogitation leads one to adopt a conception of one's surroundings, a construct into which experiences can be fitted. If at first sight these experiences do not fit, one has to look at them in different ways until they may confirm, and maybe nuance, the conception one has adopted. Cassirer gives the example of another rationalist, Leonardo da Vinci, for whom "a dualism between the abstract and the concrete, between 'reason' and 'experience' can no longer exist" (Cassirer 1972, 154). Both these cases lead to an approach that makes experiences fit a conception. At the cognitive nexus between humans and the world "out there," what humans perceive is determined by their worldview rather than by the phenomena they observe. This worldview is primarily the result of reflection and cogitation rather than observation.

In Britain and Holland, on the other hand, there seems to be an aversion to attempts to generalize, to build a reasoned worldview. Such a system is deemed to remain hidden from the senses, reasoned and therefore interfering with the direct observation of nature. Hence, Bacon's view predominates, that to resolve nature into abstractions is less relevant than to dissect it into parts. In arguing that reason has to conform to experience, and that experience deals with the manifest details of nature, the empiricists set about building another worldview by deliberately crumbling the existing one into oblivion. We will come back to that theme when discussing the emergence of our intellectual and scientific disciplines.

It is essential to underline that this empiricist disaggregation prepared the way for a slow shift, as northern Europe flourished economically and scientifically over the next couple of centuries, in which "century by century, item after item is transferred from the object's side of the account to the subject's" (Lewis 1964, 214–215). It is as if in the development of the natural sciences an inevitable initial phase of separation between subject (ourselves, people, societies) and object (nature), is followed by an increasing "objectification" of the study of people and societies, so that in the end, we ourselves as humans have become part of the natural sphere of inquiry. It is in this context that the social sciences emerge in the nineteenth and twentieth centuries, and that at present cognition and thought have become subjects of scientific study and explanation in terms of synapses, chemical communication in the human brain, etc. Resulting in the fact that "now [...] the subject himself is discounted as merely subjective; we *only* think that we think" (Lewis 1964, 214–215). Blanckaert (1998) calls this "the naturalization of Man." Via the "detour" of dualism, we thus see a slow return to a monistic worldview, exchanging the monistic vitalist philosophy of the European early Middle Ages for a materialistic monism in which, nowadays, atoms, molecules, hormones, and genes prevail.

This has created a fundamental paradox in our worldview. In the words of Evernden: "We have in effect been consumed by our own creation [e.g., nature], absorbed into our contrasting category. We created an abstraction so powerful that it could even contain – or deny – ourselves. At first, nature was ours, our domesticated category of regulated otherness. Now we are nature's, one kind of object among all the others, awaiting final explanation (1992, 92–93)."

The Royal Society and the Academies

In 1660 the Royal Society was founded in London. Its creation was followed by other academies, such as the French Académie Royale des Sciences founded in 1666, the Swedish Royal Academy of Sciences founded in 1739, and the Hollandse Maatschappij van Wetenschappen founded in 1752 in the Netherlands. These institutions were created by and for scientists, sometimes with funding from private sources, and they selected their members by cooptation based on (informal) peer review. A number of these scientists, not all of course, were socially part of the classes of society (the modernity-oriented aristocracy and the bourgeoisie) that became deeply involved in developing the economy through the applied sciences.

As time progressed, in so far as they were "science" academies – there also emerged, later, academies of art and letters, for example – these contributed substantially to a stricter definition of what was considered (empiricist) science, and in particular to the idea that every step in an argument should be proven or demonstrated to be considered scientific. What this means in different fields of science, and between different intellectual tendencies, is highly variable. But one thing is certain: one cannot "prove" things by invoking the future. Hence, to this day science places a very heavy emphasis on explaining by invoking dynamics that lead to observed phenomena, in effect relating the past and the present without referring to the future. But the sciences and the humanities do this in very different ways.

Newtonian physics (the dominant paradigm until the beginning of the last century) built from empirical observation a worldview in which phenomena could be isolated from one another, and in which processes occurring at the most fundamental scales were considered reversible (e.g., state changes such as between vapor, water, and ice), cyclical (e.g., celestial mechanics), or repeatable (most chemical reactions, if they were not reversible). It is a worldview that is essentially aimed at "dead," ahistorical phenomena – those whose nature does not fundamentally and irreversibly change during their existence, and who therefore do not have any (long-term) history.

In the humanities, on the other hand, invoking history seems to have been the dominant form of explanatory reasoning, at least since the Renaissance (Girard 1990). In historical interpretation, irreversible time was a dominant strand. As a formal discipline (i.e., as a domain isolated from everyday life) History emerged when invoking irreversible time as explanation was challenged by the emergence of the natural sciences in the eighteenth and nineteenth centuries. On the one hand, it is firmly anchored in empiricist thought (cf. the famous words: "interpretations may change, but the facts remain" attributed to the historian von Ranke). But on the other hand, it developed, notably under the impact of Dilthey (1833–1911), into an approach that differed from British empiricism in its epistemological and ontological assumptions.

Dilthey (1883) acknowledged that the kind of positivist universalism that was current in the natural sciences could not be applied to the humanities. According to his school, the central goal of history (and later of the humanities more in general) is *understanding* rather than the *knowledge* that is the central goal of the natural sciences. To gain such understanding, Dilthey proposed the "hermeneutic circle," the recurring movement between the implicit and the explicit, the particular and the whole, the core and the context, the manifestations of human thinking and the thinking itself. Adopting this position enabled the hermeneuticists to (re-) position people in their historical, geographical, cultural, and social context, and by doing so relate individual, often short-term, actions to longer-term trends. In emphasizing, finally, that gaining understanding has to proceed from the study of the manifestations of human actions to the understanding of their significance, it introduces a particular kind of empiricism that is adapted to the study of people and societies.

The Emergence of the Life Sciences and Ecology

The life sciences emerged in the nineteenth and twentieth centuries as a novel area of scientific endeavor, and one that emphasized long-term irreversibility. They were part of a cluster of disciplines that sprang up between the humanities and the natural sciences at a time when the latter two could no longer easily communicate with each other, once the cohabitation of dualism had been replaced by the battle that accompanied the separation of the two spheres. The disciplines concerned cover a continuum between geology, which is essentially mechanistic in its basic attitude to long-term time (similar causes have similar effects, causality does not irreversibly change) via paleontology, evolutionary biology, and archaeology (in all three, long-term irreversible change is acknowledged, but short-term irreversible change is deemed invisible, incremental or irrelevant) to ethology and anthropology (short-term non-recurrence is accepted; the longer term not really considered).

The "new" disciplines delimited a deliberately ambiguous middle ground, a fuzzy no man's land, either because they dealt with phenomena which do fundamentally and irreversibly change qualitatively during the period of observation (geology, paleontology, botany, zoology), or because they concerned another apparent contradiction, that between the behavior of natural beings (ethology) and the nature of (human) behavior (anthropology). Such phenomena did not fit the mechanistic approach of the "core" natural sciences because these excluded the study of qualitative change, but neither did they fit the traditional historical approach, which focused almost exclusively on the human (non-recurrent) aspects of behavior.

How did this come about, and what were its effects? Jonas argues that as soon as the natural sciences are, in seventeenth-century northwestern Europe, sufficiently mature "to emerge from the shelter of deism"

(1982, 39), the explanation of the observed functioning of physical systems in terms of general principles gives way to the reconstruction of the possible generation of such systems' antecedent states, and ultimately from some assumed primordial state of matter. And

> the point in modern physics is that the answer to both these questions (i.e., functioning and genesis of the system) must employ the same principles. [. . .] The only qualitative difference admitted between origins in general and their late consequences (if the former are to be more self-explaining than the latter and thus suitable as a relative starting-point for explanation) is that the origins must, in the absence of an intelligent design at the beginning of things, represent a simpler state of matter such as can plausibly be assumed on random conditions. (ibid., 39)

When the mechanistic Newtonian approach, which was dominant at the time, was extended to living beings the sheer perfection of the construction and functioning of most living beings made it difficult to envisage their simpler and cruder precursors. The odds against a mere chance production of such perfect beings "would seem no less overwhelming than those against the famous monkeys' randomly hammering out world literature" (Jonas 1982, 42). And moreover, these near-perfect beings continually died and were recreated! It would thus have been easier to explain them as the result of some (divine) design, but such a theory was incompatible with empiricist thought. The two centuries of delay between Kant and Laplace's explanation of the origins of the solar system and Darwin's idea of the origins of living species are indicative of the extent to which the study of living beings was caught between the two prongs of a dualistic worldview. "The very concept of *dévelopement* [*sic*] was opposed to that of mechanics and still implied some version or other of classical ontology" (Jonas 1982, 42).

The struggle to free the practitioners of the life sciences from traditional ideas is evident when one looks at the emergence of what was then called Natural History as a process in which two emerging disciplines, [societal or human] History and Natural History offset themselves against each other in the eighteenth and nineteenth centuries (for more detail see van der Leeuw 1998a). They both had to grapple with similar issues, such as the relationship between universal principles and individual manifestations, the challenge of dealing with the long term from the same perspective as was used for shorter-term dynamics, the relationship between subject and object, etc.

The contrast between the Lamarckian and the Darwinian models of the origins of life allows us a glimpse of what was necessary to resolve the problem. Lamarck's explanation of the living world remained thoroughly natural in the sense that he saw reproduction as the identical re-creation of individual generations of complex beings according to a grand design. But at the same time, he introduced a historical element in his point of view by arguing that, though the design remained the same, it had sufficient flexibility to allow changes whenever 'the environment' imposed different conditions. There lingered doubt about whether such changes could be passed on to later generations. Historical explanation over the timespan of a generation was admissible, but not (yet) beyond. First representatives were still called for, and remained unexplained.

The post-Darwinian model, on the other hand, avoids the difficulties around the improbability of chance origins by arguing that the first representatives could have been much simpler than the present ones. Distinguishing ontogenetic from phylogenetic evolution allows biologists to explain the past and the present of living species in different ways. The essential role of a central, mechanistic, theory unifying the explanation of past and present is henceforth played by the mechanism accounting for evolution (i.e., variation and natural selection), introduced at the meta-level of the long-term existence of species, rather than at that of the individual and/or the single generation. And last but not least from our perspective, the theory of evolution introduced the idea that heredity is linked to change, rather than to immutability (Jonas 1982, 44). This broke the iron grip of reversibility and/or replicability of explanation, and heralded the reintroduction of historical (rather than evolutionary) explanation in the realm of nature. In this, it was inextricably tied to both geology and prehistoric archaeology – other children of the nineteenth century, which helped push back the age of the world and everything in and on it (e.g., Schnapp 1993).

In the context of this book, it is also important to look at the early concept of environment which is invoked by Lamarck, and which Darwin reconfigured as the conditions of natural selection. Haeckel developed what he called the new science of ecology which he described as "the science of the relationships of the organism with its environment, including all conditions of existence in the widest sense" (1866, 286). Whereas Darwin included mankind in his "web of life," Haeckel did not. He defined environment in much the same way as nature was defined a millennium or two earlier – as "nonorganism" (ibid., 286). Such negative formulations, of course, do not define anything but they are nevertheless revealing. In this case, there is a change in perspective on time (the opposition past-present) on the one hand, and on the opposition inside-outside on the other. The distant past and the environment become objectifiable and separable around the same time, giving rise to history and ecology as rigorous, "scientific" disciplines.

The next episode begins in about 1910, when the concept of human ecology is introduced to denote the study of the relationship between humankind and its environment. It accelerates with the rise of General Systems Theory (e.g., von Bertalanffy 1968) and the concept of ecosystem in particular. After re-imposing a distinction in the late nineteenth century between humanity and its environment, the two are brought together again in two concepts which, each in their own way, make humanness a little bit more natural. Following a phase of reductionism that was made possible (but not initiated) by Darwin, we see the pendulum swing back toward more complex relationships between different parts of nature, including human beings. Humanity becomes *Just another unique species* (Foley 1987), part of the complex web of inter-species relationships that is the fabric of life.

The Founding of the Modern Universities and the Emergence of Disciplines

Throughout the Middle Ages and the early modern period, universities were relatively unorganized, bottom-up organizations of individuals who saw it as their mission to share their knowledge and experience with others. As communities of scholars and scientists grew, interacting more and more intensively through travel and correspondence, a process was set in motion that led to a degree of convergence of understanding of the phenomena studied. Some perspectives were agreed upon, others rejected. This trend is schematically illustrated in Figure 3.1.

A shared language emerged that linked these elements of understanding, and other signals were rejected as noise. This focused groups of scientists and scholars on the knowledge they shared, and *what was signal in one group or dimension became noise in others*. The overall process is one of aligning some signals by excluding others.

By the middle of the nineteenth century this reached a new stage, when universities were more formally organized, first in Germany under the impact of Wilhelm von Humboldt, and a little later in other countries, including the Americas (the "Harvard model"). This involved the creation of organized disciplines – consisting of groups of professors teaching related topics – and faculties – groups of related disciplines based on the convergence that had been growing for many years. The principal *raisons*

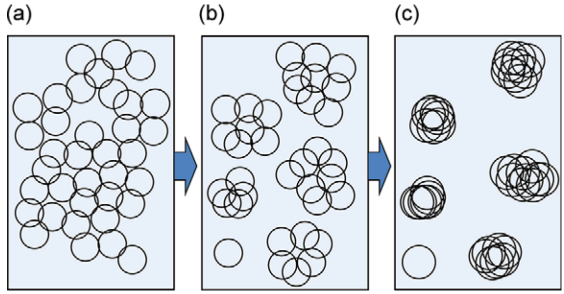

FIGURE 3.1 Convergence of groups of practitioners and their questions and ideas leads to cohesion around certain topics, and the abandonment of others. From left to right: (a) individual researchers all investigate different domains and issues; (b) through interaction they come to focus on certain kinds of information, certain methods and techniques, and certain questions to the detriment of others; (c) ultimately, they form coherent communities focused on more and more narrow domains. (Source: van der Leeuw)

d'être of these nineteenth-century university innovations were the creation of order and education – which gained recognition by the bourgeoisie and authorities as a way to promote innovation in industry and business – and thus to contribute to society at the time of the Industrial Revolution – but also as a way toward personal fulfillment and prestige. The departmental and faculty organization led to discussions among the members of disciplines and faculties about what it was that they all agreed should be jointly taught to their students. As a result, in most disciplines, two important categories of knowledge emerged as fundamental parts of the curricula: knowledge and methods.

Once these had been taught for a while, a major unintended consequence in the conception and practice of science emerged. Up to that time curiosity had driven research. Individuals tackled any problems and questions they thought were interesting, and methods and techniques were a spinoff and a tool (albeit an important one). But once students specialized in certain domains and were taught the "appropriate" questions to ask and the "correct" methods and techniques to tackle them, research became increasingly driven by these questions, methods and techniques rather than by the curiosity that had incited research until then. The result is illustrated in Figure 3.2.

In particular, this shift from a science driven by shared curiosity and the will to better know or understand the natural and social phenomena that we live amongst, to a science driven by an acquired set of questions, premisses,

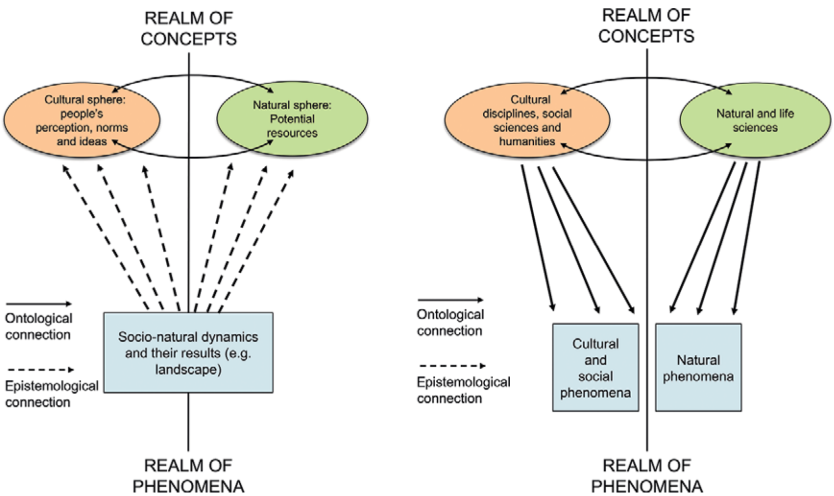

FIGURE 3.2 The emergence of disciplines inverts the logic of science. Whereas initially the link between the realm of phenomena and that of concepts is epistemological, once methods and techniques formed the basis of disciplines, these links became ontological: from that time on, gradually, the methods and techniques learned began to dominate the choice of questions and challenges to investigate. This stimulated increasingly narrow specialization, and led to difficulties of communication between disciplinary communities. (Source: van der Leeuw)

assumptions, hypotheses, methods and techniques, had as a major consequence that the incomplete but holistic views that had characterized much of seventeenth- and eighteenth-century investigation were replaced by numerous, in themselves more coherent, but fragmentary perspectives on our world. And in particular, it solidified the differences between the natural sciences on the one hand and the humanities on the other.

In summary, the past hundred years appear to have witnessed the culmination of the impact of materialistic monism as an explanation and, through the industrial and technological revolutions, as a way of life. One of its crowning achievements thus far is the research on DNA and on the human brain. Between the pincer movements of on the one hand deriving *Mind from Matter* (Delbrück 1986) and on the other having the essence of human individuality evolve from nonliving substances which govern the uniformity and diversity of all living beings, humanness seems inexorably trapped. Is it?

The trap that we are talking about is essentially a tangled hierarchy (see Figure 3.3), a situation of oscillation between two terms which,

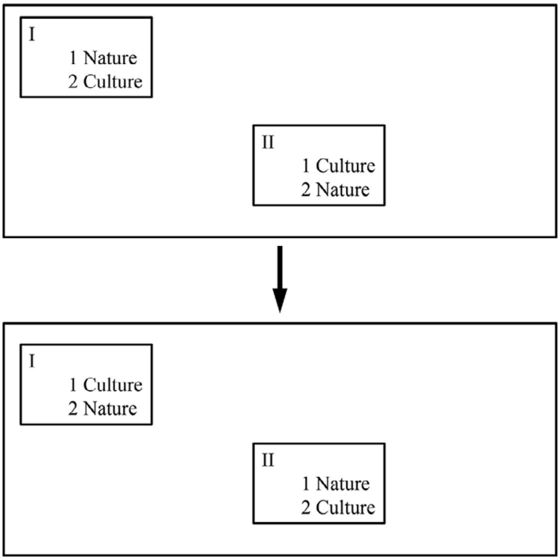

FIGURE 3.3 Two versions of the tangled hierarchy between nature and culture. Inverting the hierarchy (from the top to the bottom version) does nothing to solve the problem of the opposition of the two concepts. (Source: van der Leeuw et al. 1998b, *ARCHAEOMEDES*)

through the complex set of ties which link them, keep each other in a dynamic, approximately stable, equilibrium – not unlike two rivals, each alternately gaining the upper hand for a short time without ever completely defeating the other (Dupuy 1990, 112–113). That which is superior at the superior level becomes inferior at the inferior level – inverting the hierarchical opposition within itself, according to the scheme presented by Dupuy. But, of course, such an inversion is not really a way out of the dilemma because all it does is maintain the same hierarchy and the same barrier, but from the other side.

The only way out is, of course, to negate the opposition and construct a kind of science that does not fall into this trap. In Chapter 4, I will propose that this requires a rethink of our analytical approaches and methodologies from a uniform, holistic perspective.

The Instrumentalization of Science

But before we discuss a possible way out of this dilemma, we must first have a look at how the societal context of science has changed, in particular over the last eighty years. Some of this is due to the evolution of the sciences itself, while other developments are of societal origin. The interaction between the two has had profound effects on both.

These developments have to be seen against the backdrop of two long-term trends. The first of these is the acceleration of innovation since the industrial revolution, and the second the increasing dominance of money as a societal value.

The industrial revolution, and in particular the increasing availability and use of fossil energy has hugely reduced the cost of innovation, which does to a much greater extent consist of the cost of integrating inventions in society than of the cost of producing the inventions themselves. This is an important point that has not usually been taken sufficiently into account in modern innovation studies. In archaeology, it is evident for example in the delay of seven centuries between the invention of iron-working in Asia Minor (c. 1400 BCE) and the transition from the Bronze to the Iron Age in Central and Western Europe (c. 700 BCE). Bronze manufacture is constrained by the availability of the necessary metals (copper and tin). Bronze objects were exchanged all over Europe from a few locations where these materials were found. Iron manufacture is not constrained materially, as iron is found everywhere in streams and marshes. But for some 700 years it was socially constrained because society in Europe was based on power structures related to bronze production. To lift that constraint society had to undergo far-reaching societal changes that broke down the existing power structure, which happened from around 600 BCE. In Scandinavia this proved much more difficult, and the Iron Age did not begin there until the Viking period (c. 700 AD).

An example in the modern period that makes this point with great clarity is the work of Lane and Maxfield (2009) on the effort the Echelon corporation had to expend to get some markets to open up to their major innovation, LonWorks, a distributed information processing package. This involved the creation and maintenance of what Lane and Maxfield (2009) call "scaffolding structures" to maintain the innovative dynamic against very major conservative forces supported by the likes of Honeywell et al. In the United States, they did not succeed and Echelon initially lost the battle for the innovation, but in Italy they did succeed. LonWorks is still current In Italy, and that base allowed the corporation to survive and subsequently build out its presence in the United States with a focus on the Internet of Things.

A second dynamic that has contributed to the acceleration of innovation is the increase in population that has been enabled by developments in sanitation and health as well as education, particularly in cities. It appears that there is a clear positive nonlinearity between population size and the rate of innovation (e.g., Weinberger et al. 2017), and in particular in cities (Bettencourt et al. 2007; Bettencourt 2013) when one applies an allometric scaling approach to this relationship. Although there is a debate about the nature of the relationship and the precise shape of the curves that it generates, in my opinion this relationship expresses the fact that the more people are together, the more ideas are generated. I think one can justifiably generalize this argument to apply to human interaction levels in general, as shown in Chapter 11. If that is so, one can argue that the limited interaction in the form of exchange and commerce since the Middle Ages has contributed to the absence of acceleration in innovation until the Industrial Revolution.

As part of that dynamic, I would argue that over the past several centuries we have also seen an accelerating shift from innovation that principally responded to explicit, conscious, and widely experienced needs, to innovation in which inventions meet demands that have not (yet) been widely articulated, or that future users are unaware of, as in the case of many uses of the smartphone or the vast numbers of newly assembled chemicals.

At the same time, in particular during the last eighty years, the increasing emphasis on productivity and more generally on wealth as the major indicator of wellbeing of people, communities, and nations, which has been one of the results of the take-over of many institutions by economists, has seriously reduced the value space by which we judge our wellbeing. This has led to a more and more short-term and financial valuation of many aspects of our societies.

As a – more or less arbitrary – starting point for sketching the changes in science and its role in society we'll go back to the middle of the nineteenth century. Since the 1850s, major scientific discoveries have enabled new, major industries to emerge (e.g., anilin dyes in the 1850s; Bessemer process for the production of cheap steel in 1883; synthesis of aspirin in 1897; Haber-Bosch process for synthesis of ammonia for munitions and fertilizer in 1915), and this set in motion a trend in which the natural sciences and various industries developed a partnership that was highly profitable to both. In the years since, this has led to the ever-increasing imbrication of the sciences in many, many aspects of the wider economy that is part of our current societies, especially after the wave of innovations that was triggered by World War II: radar, airplanes, television and telecoms, medicine, and so forth.

Among other things due to the Manhattan project (the construction of the first A-bomb) and the victory over Japan that was closely associated with it, belief in the potential of the sciences was at its zenith in the 1950s to 1970s. Then, while the trust in science itself seems to have remained more or less stable (Funk & Kennedy 2017), slowly but surely, a more critical attitude developed toward the contribution of science to wider society, possibly as a consequence of decreased understanding of current science (Royal Society 1985) or as part of a more general decrease of trust in society's institutions (Turchin 2010, 2017; Jones & Saad 2016; Rosenberg 2016) due to increasing instability of our socio-political systems.

In the political arena, the Mertonian scientific ethic (Merton 1973) emphasized that scientists should always give an impartial opinion based on research in order to keep the trust of society. That trust had led to an increasing use of science as an argument in political debates, and ultimately to a close relationship between scientists and many social and political institutions that paid scientists in order to obtain scientific results that could convince the wider public of the advantages of certain proposed measures. But that close bond over time turned into a source of mistrust of the sciences because they were increasingly seen as representatives of the established bureaucratic, top-down, order and thus as a threat to the bottom-up social order that many communities have established for themselves (e.g., Wynne 1993).

Since the 1990s, as the wealth of the developed nations is less and less able to meet the cost of their social and material infrastructure (including education, social security, armies, and bureaucracies), the above developments have had consequences for the funding of science. Such funding has changed character in these countries, shifting from government-funded fundamental research to more and more industry-funded applied research, and from strategic, long-term innovation based on new scientific discoveries to tactical innovation based on recombining existing technologies. This is for example visible in the patents that are accorded by the US Patent office, which increasingly concern the combination and elaboration of existing technologies rather than inventions that can lead to completely new technologies (Brynjolfsson and McAfee 2011; Strumsky and Lobo 2015). This trend set in motion a feedback loop that caused governments to fund less and less research in response to the fact that scientists are seen as not sufficiently responsive to the needs of society, so that funding is increasingly undertaken by industries for their own sake.

Regaining Trust

Given the need for scientific leadership to find ways to respond to the accumulated challenges that humanity is facing in the twenty-first century, how might scientists regain the trust of society? One important, almost self-evident but often ignored element of such a way forward would be the realization that scientific results and opinions, just like all statements, are not evaluated in isolation, on their merits alone, but in the contexts in which they are shaped and received. There is no such thing as scientific objectivity or neutrality. Even if the ways in which answers are obtained to scientific questions may be objective, the questions themselves are subjective, as they are impacted by societal and cultural as well as individual institutions, norms, and values. Similarly, scientific opinions are evaluated against the backdrop of the situation in which they are expressed, but also against the institutional and personal credibility of the person expressing them.

Luhmann (1989, 99) has expressed this with respect to environmental understanding by asserting that "a society cannot communicate with its environment, it can only communicate self-referentially about its environment within itself" (1985, 99). He views society as a self-organizing (social) system of communications, based on complementarity of expectations among individuals. These expectations are guided by values and meanings, which in turn relate exclusively to other values and meanings, and their constitution prepares the way for further communicative alternatives. Communication is therefore not seen as a transfer of information but as the common actualization of meaning. In the process, the complexity inherent in social interaction is reduced by harmonizing or aligning the perspectives of the actors. Everything that functions as an element in the communications system of a group is itself a product of that system. I will return to this fundamental insight; at this point it suffices to point out that it implies that there are no absolute truths or realities.

It follows from this evident statement that we should, as scientists, accord much more importance to our relationships with the contexts in which our ideas function in society. An evident case in point is the idea – inherent in our current tactical thinking – that we have to find solutions for the challenges we are facing. As I have argued elsewhere (van der Leeuw 2012, see also Chapter 10) most, if not all solutions create their own (unintended and unforeseen) challenges. As what we consider to be such solutions are dictated by the values of our society, we are indirectly also responsible for those challenges.

But this reconsideration will necessarily also involve the institutional contexts in which we do research, the ways in which we express our results, and whether or not we take positions on certain issues. If we have solid scientific evidence for a major future train wreck such as climate change, and we have ideas about how to avoid it, do we limit ourselves as scientists to presenting the dilemma to the general public, or do we argue for certain solutions, as opposed to others?

It is not the goal of this chapter or this book to delve into ways to improve the credibility of science. That is better left to colleagues in the Philosophy of Science and Science and Technology Studies. But it will be indispensable to work toward reflexively recognizing that science is conditional, in the hope that this will lead to a critical examination of our fundamental, pre-analytic assumptions that shape the character and content of our visions and scientific knowledge and understanding.

One of the fundamental aspects of any such examination is the fact that our knowledge of the natural phenomena that many of us consider to be independent of human behavior and impact, such as gravitational fields, the speed of light and similar phenomena, is in effect dependent on our observations, and thus on our cognitive capability. This is a relatively novel but highly important realization that is beginning to permeate the natural sciences through the writings of eminent scientists such as Hawking (see his *Brief History of Time* (1998), and Wheeler's introduction of the *Participatory Anthropic Principle* (1990), where recent research into the origin of the laws of nature indicates that conscious observation may play a role. By implication, even physicists might have to pay more attention to the cognitive and social sciences to understand what they are seeing.

In that examination, we must also more closely connect the different scientific and nonscientific communities in order to better take into account the social and societal context of our scientific constructs. Scientific reasoning and understanding are indeed impossible to control scientifically. But, as such a program is contrary to the thrust of modern science, which is directed at imposing a degree of control over the reasoning and the identity of science, we cannot expect that such reflexivity will be easily adopted by the scientific community, nor that the majority of humanity will greatly increase its "scientific knowledge and understanding." But we must try.

NOTE

1 The first part of this chapter originally appeared in chapter 2 of the ARCHAEOMEDES Report (van der Leeuw et al. 1998b); the second part is a novel contribution for this book.

4

Transdisciplinary For and Against

Introduction

While it has been successful for a long time, reductionist, disciplinary, "linear" science is increasingly being confronted with highly complex problems that it cannot usually solve. This is partly because of the increasing fragmentation of the intellectual/scientific landscape into narrower and narrower disciplinary communities, following the institutionalization of science that I referred to in Chapter 3. This has hugely increased our understanding in certain areas, but at the same time it has left large, unmapped, and unexplored gaps in our understanding.

Another important contributing factor to this situation is the accumulation of unintended and unexpected consequences of earlier societal actions, which I will be discussing at length later in this book (Chapter 10; van der Leeuw 2012). Unobserved for a long time, owing to the acceleration of innovation since the Industrial Revolution, these consequences are becoming noticeable in many domains, revealing the underlying complexity of the systems we are dealing with.

Hence a more diverse and multidimensional science is emerging, better at taking contexts into account, and exploring the domains that disciplinary sciences have not.

To place this development in context, I must go back to the emergence of modern universities and the concomitant structuring of academic disciplines into departments and faculties. As previously mentioned, this led to the fragmentation of our scientific worldview and to the tangled hierarchy of the sciences, the social sciences, and the humanities that is still a dominant feature of academia and the global research community.

Tangled hierarchies like this exist in principle between any two disciplines, because once a scientist is brought up within the constraints of a particular discipline, all other disciplines are "others," and therefore themselves subject to the social, organizational, and administrative dynamics that distinguish it from any others. Insiders will thus value "their" discipline higher than outsiders, and outsiders will value theirs higher.

How can we disentangle such hierarchies? There are not many methods (van der Leeuw 1995, 31–32). We have seen that for Dupuy (1990) disentanglement consists of a double reversal of the hierarchies entangled within themselves (Figure 3.3b), so that where nature was first, culture becomes first, and where culture was first, nature becomes first. But as I mentioned in Chapter 3, this would merely twist the tangle the other way around – responding to one of Jonas' points (1982, 17): "if humanity is just a part of nature, then what sense does it make to suppose that nature may not have properties similar to our own?" Jonas's point has led to many developments in ethology, eroding boundaries between humans and nature; dolphins seem to have names, chimpanzees cultures, orang-utans dialects, etc. The fundamental question in all these cases is whether or not – and if so, how far – we project our own human characteristics onto the species concerned. After all, our understanding of the outside world passes through, and is constrained by, our human cognitive system.

One could also try to impose a sort of arbiter, as Aldo Leopold does with his "land ethic" (1949). Central to Leopold's philosophy is the assertion to "quit thinking about decent land use as solely an economic problem." While recognizing the influence economics has on decisions, Leopold understood that, ultimately, our economic wellbeing cannot be separated from the wellbeing of our environment. It was therefore critical for him that people have a close personal connection to the land. "We can be ethical only in relation to something we can see, feel, understand, love, or otherwise have faith in." Such a "land ethic changes the role of *Homo sapiens* from conqueror of the land community to plain member and citizen of it … it implies respect for his [non-human] fellow-members, and also respect for the community as such" (Leopold, 1949, 239).

But the problem with this is that humans cannot (and should not) devise the ethic for other beings, as we cannot experience them other than as "the Other" – i.e. without understanding or feeling or any other form of real contact. Thus, this option would lead to an acceptance of a natural chaos, in which for each living being, each aspect of nature, we

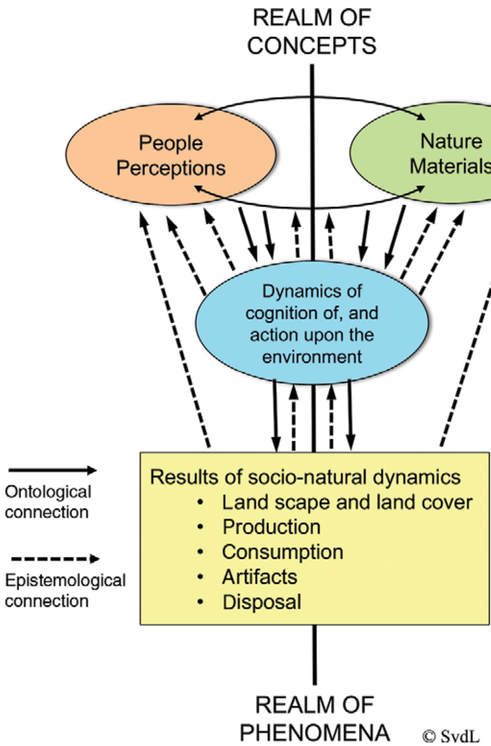

FIGURE 4.1 Doing away with the natural and the societal subsystems. (Source: van der Leeuw)

would impose the same total and absolute freedom as Hinduism allows for cows in India.

Evernden (1992, 94) proposes to radically admit the fictional nature of the opposition (see Figure 4.1). That is, if we want to prevent the realms of humanity or history from becoming subcategories of nature, we will have to admit to ourselves that nature is in fact a subcategory of culture – that we are, after all, the authors of the system we call nature. And moreover, that we are the authors of the dualism that facilitates the existence of humans and nature as separate and qualitatively distinct entities. We will have to admit our own role in the constitution of reality, which in turn means admitting something quite fundamental about the nature of our knowing (see Luhmann 1989; van der Leeuw 1998 for two other lines of argument that come to the same conclusion), i.e. that it is self-referentially construed by society on the basis of its very limited perception of extremely complex phenomena. Then one would bring all disciplines to bear on the study of socioenvironmental dynamics, acknowledging that there is no social subsystem nor an environmental one, but that there are only human perceptions of, and actions on, the social and natural environment that are directed by the human cognitive system (McGlade 1995). This would necessarily mobilize the full range of disciplines and scholarship in an attempt to improve understanding of the complexities involved.

This seems in many ways the cleanest solution, but it raises an important question: "How would one realize such a reintegration of nature within the realm of culture, while acknowledging that we cannot go back to a state of innocence or naiveté in which vitalism is reinstated as the dominant doctrine?" Many scientists in different (combinations of) disciplines have tackled this issue over the last century or so, attempting to get to the point at which the implied integration of many disciplines into a holistic perspective is successfully completed.

Those attempts have gone through a number of phases, from interdisciplinary to multidisciplinary' to transdisciplinary and most recently proposals for undisciplined research. It is the goal of this chapter to discuss some of the challenges that transdisciplinary science has to deal with if it is to live up to its promises. But I will begin with a brief description of how I understand these concepts in order to clarify how they will be used in the remainder of this book.

Interdisciplinarity

The term interdisciplinary implies the use of methods and insights of several established disciplines or traditional fields of study, with a focus on questions that are not raised in the scientific disciplines themselves. Although eclipsed in the last two centuries by the disciplinary organization of scientific research that was brought about by university organization, interdisciplinary research has a long history, according to some going back to the ancient Greek philosophers (Gunn 1992).

Interdisciplinary research is about creating new ideas and approaches by crossing boundaries, thinking across them to connect and combine different academic schools of thought, professions, or technologies in the pursuit of a common task (such as investigating sustainability issues). Interdisciplinary strategies are often applied when a subject seems to have been neglected or even misrepresented in the traditional disciplinary structure of research institutions, creating gaps in our intellectual map. In other instances, interdisciplinary approaches are applied when the topics involved are too complex to be dealt with within single traditional disciplines (among them the so-called wicked or hairy problems mentioned in Chapter 2).

The main intellectual challenge in interdisciplinary research is that the different disciplines involved have their own specific perspectives, questions, methods, epistemologies, and sources of information. Combining these in a fruitful way requires proficiency in, and deep understanding of, the disciplines involved, and is therefore far from easy to attain. As long as the number of disciplines involved is limited, a single individual may be able to achieve this; but as we will see in the next section, it is much more difficult to achieve if it involves teams of scientists trained in different disciplines.

In Table 4.1, I point to some of the differences between the natural and social sciences, and a possible way in which we can look at them in an integrated manner.

Clearly, Table 4.1 covers only a very limited number of the differences, and the solutions proposed are very tentative. It merely aims to give a general idea of the complexity of what is required to truly integrate these two kinds of approaches.

Moreover, in an overwhelming majority of institutions there are numerous administrative and organizational barriers to such interdisciplinary work, but as these also hold for both multidisciplinary and transdisciplinary research they will be dealt with later in this chapter.

Multidisciplinarity Results in a Bee's Eye View

Let us now look at the perspective that is gained by attempting to tightly bundle together the results of a much wider range of disciplines. Wikipedia (April 25, 2016) defines a multidisciplinary approach in much the same way as an interdisciplinary one: "drawing appropriately from multiple disciplines to redefine problems outside normal boundaries and reach solutions based on a new understanding of complex situations." The difference seems to be in the number of disciplines involved and the difficulty of integrating them.

One widely used application of this approach is in health care, where people are often looked after by a multidisciplinary team that aims to address their complex clinical and nursing needs. In such situations, every person involved (except the patient) has expertise and a task of his or her own. The collaboration is effective because all tasks are devoted to getting parts of the patient better, and the patient's body integrates the efforts

Table 4.1 Differences between natural history and human history as an example of the differences between natural and humanistic approaches to environmental research, and suggestions toward creating an encompassing integrated approach to socioenvironmental dynamics.

	Natural history	*Human history*	*Integrated history for the anthropocene*
Domain	Nature	Society	Environment (socioecological interactions)
Time scale	Longer timescales	Shorter timescales	Integrated timescales
Focus	Causality	Human agency and contingency	Causality and agency interacting; envelope of contingency
Goal	Interpreting the past from the present; looking for origins in terms of natural laws	Interpreting the present from the past; looking for origins in terms of causal chains	Looking for emergence (in the systems sense) to understand the present and generate a better future
Process	Observation, description, and experimentation lead to explanation	Description, critique, analysis, and interpretation lead to insight and understanding	Description is the basis for modeling and understanding dynamics of the socioecological system
Tools	Natural science discourse Paleoenvironmental sciences Prehistoric archaeology Conceptual frameworks	Narrative and statistical discourse Classical and historical archaeology Documentary history Case studies as unique trajectories	Multiple discourses Integrated history of people and the environment Use case studies embedded within conceptual frameworks to generalize

Source: van der Leeuw et al. (2011).

into a synthetic one. This is also the case with sustainability, the study of the health of the planet, which involves a very large number of disciplines that each have (at best) a positive effect, while the synergy between the approaches is provided by the socioenvironmental system. In neither case is there intellectual fusion between the expert scientists involved.

Historically, the first practical use of the multidisciplinary approach was during World War II, when the Lockheed Aircraft Company set up its own special projects operation – famously nicknamed the Skunk Works – in 1943 to develop the XP-80 jet fighter in just 143 days. During the 1960s and 1970s, the multidisciplinary approach spread across the academic world, initially among disciplines with a practical purpose, an example being to architects, engineers, and quantity surveyors who worked together on major public-sector construction projects with planners, sociologists, geographers, and economists. Somewhat later, spearheaded by fields such as geography and archaeology that were defined by either space or time rather than by a particular approach or set of questions, multidisciplinary approaches quickly spread to many other scientific domains.

Each of the disciplines involved presents the observer with a (sometimes only slightly) different view of the subject of study because it brings to bear slightly different questions, as well as different methods and techniques. The information gained by each discipline is therefore in itself coherent, valuable, and focused on a specific question or topic, but it is couched in terms designed by the communities that are responsible for the different disciplines and is therefore not easily fused with information gathered by other disciplines. Bringing the results of such efforts together in a single perspective often has difficulty transcending the lowest common denominator, and tends to be more simplistic (and often functionalist) than one could wish for.

This is in part because the practitioners of such multidisciplinary research often have the wrong expectations. They expect "knowledge" and the possibility to seamlessly integrate results from different disciplines as if they were equivalent. In striving for clarity, such an approach loses sight of the fact that most complex phenomena are multifaceted and so rich in information that a single coherent picture of them is at best a very partial representation.

In my opinion all we can hope for is what could be called a "bee's eye view," a multifaceted picture that can provide some insights if one is prepared to accept the fracture lines between the facets and make a number of "leaps of faith" across them (van der Leeuw 1995, 2003).

Although that goes against our (culturally determined) tendency to insist on clarity and simplicity of explanation, such a bee's eye view is not necessarily a disadvantage in dealing with complex information: most insects that have faceted eyes manage very well with them. But it does require that the scholars involved are able to function while holding contrasting or opposing ideas in mind.

To distinguish the results of such an approach from the traditional and interdisciplinary ones, one might perhaps suggest that what we strive for is sufficient understanding (as opposed to knowledge) to be able to begin dealing with complex phenomena. This distinction is introduced to highlight the fact that multidisciplinary investigations do not aim for the same degree of coherence in their explanations as traditional disciplinary ones. Because we believe such coherence can only be achieved for very simple phenomena (if those exist), we hope to compensate for that by gains in the applicability of our understanding to the (inherently complex) real world.

Transdisciplinarity, Intellectual Fusion, and Linking Science and Practice

Transdisciplinary science is for the moment the latest acknowledged stage in this development, explicitly connoting a research strategy that crosses many disciplinary boundaries to create a holistic approach. Crow emphasizes that this requires "intellectual fusion" (2010).

Transdisciplinarity signifies a unity of knowledge beyond disciplines. Jean Piaget introduced the term in 1970, and in 1987 the Centre International pour la Recherche Transdisciplinaire (International Center for Transdisciplinary Research, CIRET) adopted the Charter of Transdisciplinarity at the First World Congress of Transdisciplinarity in Portugal.

As the prefix "trans" indicates, transdisciplinary science concerns that which is at once between the disciplines, across the different disciplines, and beyond each individual discipline. Its goal is the understanding of the present world, of which one of the imperatives is the overarching unity of knowledge. In its approach, transdisciplinary science is thus radically distinct from interdisciplinary and multidisciplinary science. These latter approaches concern the transfer of methods from one discipline to another, allowing research to spill over disciplinary boundaries but remaining within the framework of disciplinary research. Transdisciplinary science explicitly crosses these boundaries and strives for intellectual fusion among the ideas of practitioners of different disciplines and research and practice domains.

But it does more. Transdisciplinary approaches also attempt to cross the boundaries between the realms of ideas and phenomena, and between science and society, by including stakeholders from civil society in defining research objectives and strategies to better incorporate the diffusion of learning produced by the research. Collaboration with and between stakeholders is deemed essential – not merely at an academic or disciplinary level, but through active collaboration with people affected by the research and community-based stakeholders (Thompson-Klein et al. 2012). In this way, transdisciplinary collaboration is expected to become uniquely capable of engaging with different ways of knowing the world, generating new knowledge, and helping stakeholders understand and incorporate the results or lessons learned from the research.

This kind of transdisciplinary approach is the only one of the three that can even attempt to deal with the "hairy" or "wicked" problems introduced in Chapter 2. What are they? The concept was first introduced by Churchman in 1967, to distinguish between those problems that could be solved once and for all and those that could not. As Xiang defines them (pers. comm. 2015), "Wicked problems can be suppressed or even overcome, but cannot be eliminated, and will recur, often in different and more wicked forms. Many, if not most, problems in human activity systems in general, and in socio-ecological systems in particular, are wicked." Such wicked problems are highly multidimensional, and the various contributing dynamics are so unstable that there are no permanent solutions. They recur time and time again and are often the main staple for political decision-makers.

I will discuss the relationship between transdisciplinarity, complex adaptive systems approaches, and wicked problems further in Chapter 5, but for now I will move on to discuss some of the difficulties involved in transdisciplinary research.

Barriers to Practicing Transdisciplinary Science

Apart from the intellectual difficulties of overcoming tangled hierarchies and bringing the contributions of many disciplines together in an intellectual fusion, there are a number of other barriers to the practice of transdisciplinary science, which range from the cognitive to the psychological to the organizational. In the cognitive field, I have already referred to the limits of the human brain's short-term working memory to deal with more than seven or eight sources of information simultaneously (Read & van der Leeuw 2008), which makes it difficult, if not impossible, to deal with challenges that are of a much higher dimensionality. Moreover, our theories are underdetermined by our observations (Atlan 1992), so that our reactions to challenges are usually overdetermined by past experiences. Another issue here is the bias in category formation toward either similarity or dissimilarity that I refer to in Chapter 9, based on the work of Kahnemann, Tversky, and others (Tversky 1977; Tversky & Gati 1978; Kahnemann et al. 1982). At issue in the psychological field, for example, is the important debate about whether choices are primarily determined emotionally or rationally (Elster 2010). From an organizational perspective, one of the important issues is the structure of the team, and in particular the extent to which the structure of the team network is organized along vertical and horizontal lines of communication, and its degree of redundancy. All of these are currently important subjects of research that are aimed at reaching a better understanding of the underlying dynamics in transdisciplinary teams (see Stokols 2006; Gray 2008).

But there are also several issues that do not generally receive much attention. I will briefly point to some of these before moving on to a description of some of the qualities needed for true transdisciplinary research efforts and how we might promote these in higher education. In doing so I will begin with individual challenges, and then move toward organizational and administrative ones.

At the individual level, there are at least two major challenges. The first of these is a lack among many scientists of the skills that are necessary to effectively and efficiently implement transdisciplinarity. Education will help overcome this (van der Leeuw et al. 2012; Wiek et al. 2014; and many others). But there is an underlying problem that is at least as important that is not so often discussed: the challenge of changing identity.

Becoming a scientist is an important investment not only in time and money, but also in one's own human capital. For at least a decade, but often much longer, a scientist will have invested herself or himself in learning the tools of a particular discipline, practicing it, publishing in it, and getting to be known in an increasingly wide community of scholars who are more or less aligned with his or her ideas. In the process, the scientist, if she is competent, will have acquired the respect of that community for the knowledge, understanding, skills, or other talents that constitute the requirements for a scientific career. In effect, the effort has given the person involved a scientific identity that is closely related to the field and the community that is his or hers. Over time, unless the scientist changes careers or disciplines, that identity will become stronger and stronger, in the eyes of the scientist concerned as well as those of the community.

Transitioning to inter-, multi- or transdisciplinary research forces the scientist to give up part of that identity in order to, slowly but surely, assume a new one. This is very difficult for many people; not only because it takes another major investment, but also because until that new identity has solidified, the person does not have a firm and fixed context within which to operate. In such situations, many people are insecure. They do not know the unwritten rules of the new game, have not yet become part of the new like-minded intellectual community, let alone gained the respect that was theirs in the discipline in which they were originally trained. When one adds to this the fact that many of the epistemological differences between disciplines are not clear to their practitioners, because they are buried deep in the core of a discipline's thinking and are not explicitly acknowledged, it becomes easy to understand why many people are not very keen on wholeheartedly making this kind of transition. They will pay lip service to it, even be part of a transdisciplinary team, but have difficulty achieving the kind of intellectual fusion that is the goal of the operation.

All this is not made easier by the fact that over well-nigh two centuries, formal and informal scientific organizations, rules, and institutions have evolved that reinforce and constrain such disciplinary communities. These impose – often rather strict – rules in each discipline on topics that range from "Which questions can be broached and which are out of bounds?," "What is the correct format for reporting scientific experiments and results?," "Which are valid hypotheses, confirmations, or even proofs?," to "Where to publish in order to gain stature in the discipline?" (see for example Ingerson 1994).

One example that is of direct relevance to us, and in which such constraints have until recently confined the discipline very strongly within clear bounds, is (macro-) economics. As expressed by Gowdy et al. (2016, 325–328):

> … its perceived scientific foundations focus generally on narrow concepts of representative agents or average behavior (vs. populations of diverse behaviors in evolutionary approaches), equilibrium (vs. innovation, surprise, and selection dynamics) and markets (neglecting social networks of nonmarket interactions between agents). Economists' research often focuses on efficiency in a static allocation framework, assuming that institutions, norms, and culture are outside the purview of economic analysis. By the middle of the twentieth century the

common definition of economics had become the science of the allocation of scarce resources among alternative ends (Robbins 1935). Issues of formation (i.e., how institutions, norms, and culture develop and how allocative mechanisms feed back onto them) received some consideration, but they were generally to be found at the margins rather than at the center of analysis. Their marginalization led to some quite spectacular shortcomings of economic models, such as their failure to consider, much less predict, the possibility of catastrophic financial crises. (Colander et al. 2009)

But the impact of such constraints is not limited to economics. Economics may be an extreme case, but similar constraints have to varying extents impacted most disciplines, including physics, climate science, ecology, sociology, and anthropology. Indeed, they have helped the alignment of disciplinary scientific communities by creating intellectual constraints around the domains they are involved in, and are thus in a sense tools that have helped create the disciplines and their identities.

Since World War II, and as part of the wave of rapid and huge expansion of scientific investment and effort in the developed countries that followed the war, which went along with a conviction that science could do just about anything, this dynamic has been reinforced by increasingly strict and formal top-down administrative rules, not only concerning the practice of scientific research, but also the funding of research, the career structures, and the evaluation of the scientists themselves. These were made necessary by the rapid upscaling of research effort, and therefore of the size of the research community, but they also strongly reinforced the existing management of disciplines and thus fundamentally changed the practice of science, particularly in many universities but also in research funding organizations.

The core of the structure that has been created is the 'peer review,' about which a great deal has already been written. I will therefore confine myself to a few short paragraphs. This ubiquitous institution on the one hand aims to, and generally does, ensure the quality of scientific work that gets funded or published, and the quality and productivity of scientists at different stages in their careers. However, it also severely constrains, in many cases, the range of scientific topics discussed, the questions raised, and the methods applied. As long as the principal aim of science was the maintenance of quality within disciplines, these constraints were reasonable and acceptable. However, in the development of a wider range of topics and collaborations between disciplines (whether inter- multi- or transdisciplinary), such peer reviews have to some extent hindered the development of novel ideas.

This is in part a generational problem. The people invited onto peer review committees are generally highly respected and senior scientists who do not participate in the scientific culture of the younger generations, the champions of scientific innovation and novelty. Moreover, reduced funding, competition between more and more journals and funders, as well as the increasing call for transparency and responsibility have added stresses to the system.

For many funding institutions, political oversight is limiting the kinds of science that they can fund. Moreover, especially if they fund research with public money, they have a tendency to avoid risk, and therefore to favor research of which they can, at least to some extent, predict the outcome. In the case of journals, the publication of longer papers has become difficult (this is in the process of changing owing to the rise of electronic publishing), while the topics, format, and language of papers have all been narrowed by editorial policies.

From the role of peer review in assessing the quality and productivity of researchers and university faculty, we move into the domain of administrative barriers to transdisciplinary research. I want to begin this section with the statement made by a well-known professor in sustainability science about his home institution. When confronted with a plan to open up such research and to implement new ways of organizing it, he answered: "I'd love to do this, but I cannot – my institution is perfect." Of course, he expressed not so much his own vision, but the image that his institution had of itself.

Such institutional self-images are maintained by rules and regulations, and by quality and performance assessments of junior faculty and students. These involve peer review based on predetermined criteria (number of publications, prestige of the journals involved, amount of research funding raised externally in competitions, patents, teaching performance judged by students, etc.). One difficulty with this system is that because the criteria are predetermined, people are increasingly focusing their activity on them, and a substantive reduction in the diversity of research can be the result. This has been one of the persistent problems with the UK's Research Assessment Exercises, for example (Strathern, 2003, pers. comm.). Once such a dynamic has been set in motion, and an increasing number of people have invested in it, the criteria are very difficult to adapt.

Another problem is that these evaluations are often undertaken by relatively small committees with three- or four-year mandates. Because of their size, there is a substantive possibility that they will be asked to pass judgment on domains or approaches that are at best marginal to their own interests and of which they do not have any intimate knowledge. Moreover, the members of such committees are themselves part of the communities they evaluate, so they have their own agendas. Although I do not in any way want to cast aspersions on the members of such committees, who no doubt make decisions honestly and seriously, I believe that the institutional context in which they work urgently needs review. The current situation is not only hindering the exploration of new research areas and topics, questions and methods, but is also beginning to undermine the value of some of the existing disciplinary research.

Competencies for Transdisciplinary Research

Wiek and colleagues at Arizona State University in the USA and Lange and colleagues at Leuphana University in Germany are among a growing number of leading young scholars in select universities (Maastricht University, Lund University, Stellenbosch University, Technical University of Catalonia, University of Tokyo) that are developing outstanding approaches to transdisciplinary education and training in sustainability. In this section, I will discuss some of their ideas about the qualities that are necessary for effective and creative transdisciplinary work.

Because sustainability problems and challenges have specific characteristics that differ from problems addressed in other fields, analyzing and solving sustainability problems requires a particular set of interlinked and interdependent key competencies. In the case of sustainability these qualities are in fact "functionally linked complex[es] of knowledge, skills, and attitudes that enable successful task performance and problem solving [...] with respect to real-world sustainability problems, challenges, and opportunities" (Wiek et al. 2011, 204). In practice, having these competencies means that people "are able to enact changes in economic, ecological and social behavior without such changes always being merely a reaction to pre-existing problems" (de Haan 2006, 22).

Wiek et al. (2011, 205) distinguish five different competencies (Figure 4.2): (1) systems thinking competency, (2) anticipatory competency, (3) normative competency, (4) strategic competency, and (5) interpersonal competency. Together, these are thought to enable the development of an integrated (transdisciplinary) research and problem-solving framework. The following example, drawn from the same paper, shows how these competencies can interact to create real-world results:

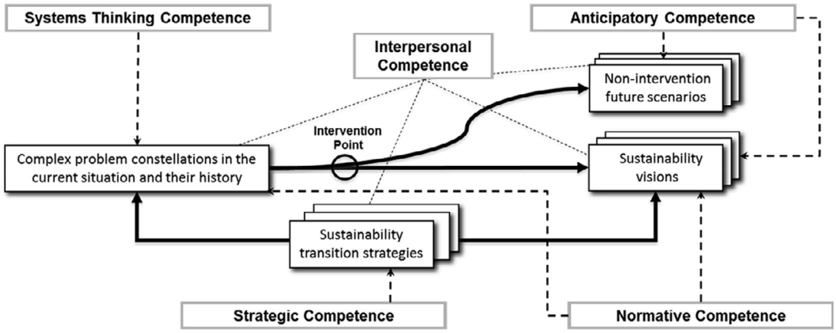

FIGURE 4.2 The five key competencies in sustainability (shaded in gray) as they are linked to a sustainability research and problem-solving framework. The dashed arrows indicate the relevance of individual competencies for one or more components of the research and problem-solving framework (e.g., normative competence is relevant for the sustainability assessment of the current situation as well as for the crafting of sustainability visions). (Source: Wiek et al. 2011, 206 By permission Springer)

Let us assume that the ultimate goal of a sustainability activity would be to develop, test and implement strategies for sustainable urban development. This calls for a well-founded *strategic competence*. These strategies are intended to redirect urban social-ecological systems from unsustainable trajectories toward a sustainable future state. To this end, the current state, past developments, as well as future trajectories of the city are analyzed systemically and key leverage or intervention points in the system are identified. This requires *systems-thinking competence*, and these points are assessed against sustainability criteria (to identify critical trajectories and consider trade-offs), which requires *normative competence*. Based on new knowledge and learning, the strategies are conceptualized as being continuously adapted in order to redirect path dependent future trajectories in the city toward visions of a sustainable future, which requires *anticipatory competence*. The collaboration among a suite of urban stakeholders, including scientists, policy-makers, managers, planners, and citizens is critical for understanding the system's complexity, exploring future alternatives, crafting sustainability visions, and developing robust strategies in ways that are scientifically credible, create shared ownership, and are conducive for action – all of which requires strong *interpersonal competence*. (Wiek et al. 2011, 205–206)

This is not the place to drill down into the ways in which the authors justify each competency in some detail, based on a wide survey of existing literature. For the purposes of this book, the above description must suffice, and the reader who is interested can find details in the paper itself. But there is one other important aspect of achieving transdisciplinary research and problem-solving that has not received enough attention –

how we foster these skills and build sufficient capacity to deal with sustainability challenges across the globe.

For that purpose, based on work done in the medical sciences and in sustainability science in European universities (notably Maastricht and Aalborg), we have at Arizona State University implemented problem- and project-based learning (PPBL) to practice such competencies in real-world situations – dealing with challenges that were encountered in business, and by governments, NGOs, etc. (Brundiers et al. 2013). The key features of this approach are that it promotes student-centered, self-directed, and collaborative learning that focuses on real-world issues and involves stakeholder engagement. It does so by confronting a group of students who have different disciplinary backgrounds with an issue communicated by another organization. The students then unpack the issue and analyze aspects and elements of it, communicate with the stakeholders and among themselves – practicing each of the five competencies outlined above – and ultimately try and find practicable solutions. In the process, faculty will counsel and help, but the work is directed and executed by the students. PPBL thus requires students to actively and self-responsibly develop knowledge, skills, and attitudes, while being supported in reflecting on and deepening their learning experience and strategies. Furthermore, the outcomes expand beyond rich learning experiences by engaging cognitive, procedural, and affective knowledge domains, and also include the writing of policy-relevant reports, intervention manuals, and project proposals for submission to funding organizations (Brundiers et al. 2013).

In this manner, students are also confronted with the fact that they need critical thinking – or, to put it more starkly, that there are accepted immutable facts on which sustainability thinking is based, but that the complex links between them are always part of a particular perspective, and that there are always other perspectives. Once that is understood, they will realize that there are always alternatives to any choice made by the researcher. Such alternatives will have to be evaluated against each other from the perspective of intended and unintended consequences in order to make responsible decisions.

I would expect that once such approaches were commonly taught and practiced, the scientific community could set a further urgent, and in my opinion absolutely fundamental, step – from transdisciplinary to nondisciplinary or undisciplined research. Such research would bring all domains of knowledge and skills, academic, applied, and nonacademic, to bear on the fundamental issues our society is facing, mobilizing all talent available, for example by crowdsourcing answers to vexing questions or solutions to acute problems.

This would further be favored if people who are the best suited for such studies were to be recruited, with commensurate salaries, by businesses and positioned in senior executive functions where nondisciplinarity is practiced every day. In economics, finance, technology, law, trade, markets, industry, and government, issues such as the environment, human resources, strategy, long term vs. short term are among the topics that a senior executive is permanently dealing with. And a business can only be successful over the long term if its senior executives are able to fully integrate these various aspects.

5

The Importance of a Long-Term Perspective

Looking Far Back into the Past

Much sustainability science focuses on a relatively short period of human history, even though it may seem long to us, such as 50, or 100, maybe 200 years. That is justified on the one hand by pointing to the fact that the Earth and everything on it has undergone such drastic anthropogenic changes that the situation in earlier periods seems to be so different that at first sight it appears irrelevant. Another reason often invoked is that for periods beyond the last 100 or 200 years we do not have sufficient quantitative data about such things as the climate, the circulation of oceans, and other natural dynamics, so that in our increasingly quantitative science working on earlier periods is discounted.

But choices made in the past are the initial conditions of the dynamics of the present. Since their earliest days on this planet, human groups, whether as hunters, farmers, stock raisers, or urban residents, have continuously engaged in activities that alter and restructure the natural and societal order. Part of this process is a slow but fundamental change in the dynamic between man and nature that has occurred over a very long time (van der Leeuw 2007, see also Chapters 8 and 10).

At the beginning of the Holocene – some 10,000 years BCE – for example, we find in the Rhône Valley that there is only perceptible change in the terrestrial environment when both climate and people are pushing for such change in the same direction, such as is the case in the Neolithic (van der Leeuw 1998b; Berger & van der Leeuw 2007). Currently, on the other hand, the overall socioenvironmental system has become so thoroughly integrated ("hyper-coherent"), that the slightest change in either climate or anthropogenic impact can push the terrestrial ecosystem out of balance. This is argued, for example, for the Little Ice Age in the sixteenth to nineteenth centuries CE, with three particularly cold intervals: one beginning about 1650, another about 1770, and the last in 1850, each separated by intervals of slight warming. They may have been due to volcanic eruptions that spewed such masses of various gases and fine dust into the atmosphere that the quantity of solar radiation reaching the Earth was temporarily reduced. The effect of this relative cooling of the Earth is noticeable in a number of economic and social indicators (Le Roy Ladurie 1967; Behringer 1999; Cullen 2010).

Similar long-term changes are noticeable in the spatial patterning of human activity. In the Neolithic (around 10,000 BCE), for example, settlement location in the Alpilles (France) was highly dependent on the environment, but over time the spatial aspects of human communication and information processing began to dominate and settlement patterns changed quite substantially. This is clearly visible in the European Iron Age (around 600 BCE) settlement pattern, when new, essentially trade-based, settlements emerged along rivers and at river crossings to complement the traditional settlements on hilltops that were based on agriculture and herding (Gazenbeek 1995).

Presently, humans are adapting less and less to nature; humanity is controlling the ecological dynamic - a symbiosis in which humans are responsible for the behavior and evolution of the natural environment has now developed in a number of locations. Landscapes have become "disturbance dependent"; that is, they have become dependent on human control to remain within a narrow range of states (Naveh & Lieberman 1984).

But, importantly, the consequences of past dynamics often still affect the present in many places, and we need to include them in our research. Hegmon et al. (2001) show, for example, how the early indigenous agriculture in an area of the southwestern United States transformed patches of the landscape by systematically fertilizing them, creating black soils. Today, centuries later, these patches are still visible, and provide a better environment for agriculture than the areas around them. But in many parts of the world the reverse is also true, for example on northern China's loess soils, which nowadays show spectacular erosion.

In summary, we must above all remember that complex phenomena such as the ones we are dealing with operate simultaneously at many, many different and interacting temporal rhythms and spatial scales, from seconds or minutes to seasons, years, decades, centuries, and millennia (see Allen & Star 1982; Allen & Hoekstra 1992; Steffen et al. 2005), and from microns to thousands of miles. Most research, however, has essentially been looking at a very limited number of interacting scales – most often only three (macro-, meso- and micro-). That has left most of the dynamics involved outside the scope of our investigations. Furthermore, the choice of scalar levels was often arbitrary from the perspective of the processes going on, but determined by the availability of either data or tools to analyze them, biasing the outcome of our researches and thus our understanding of the socioenvironmental dynamics.

As new techniques such as Arctic glacier coring, accelerator mass spectrometry radiocarbon dating, and isotope analysis of speleothems, among many others, begin to facilitate more precise measurement of climatic and environmental conditions going back tens of thousands of years, four major deficiencies of the focus on short-term dynamics are emerging.

The Importance of Slow Dynamics

Focusing mostly on the last couple of centuries overlooks very slow dynamics that may yet be important constraints or even drivers of shorter-term processes. One example is the millennial accumulation of low-level tectonic activity that shapes landscapes, such as in Epirus in Northern Greece. We are all familiar with major earthquakes, but often do not pay attention to the fact that in regions such as Epirus where they occur, there are also thousands of small shocks annually. The cumulative effects of such small shocks over thousands of years may shape the landscape more than heavier, rarer, earthquakes, and therefore constrain human action in and on the environment. Yet they are not noticeable as a major force when one only looks at their effects over years, decades, or one or two centuries.

Similar long-term dynamics impact the course of rivers, including the landscapes at their mouths. Yet another millennial phenomenon that is barely noticeable at an annual, decadal, or even centennial timescale is the rising or lowering of sea levels. Yet over time it too has (had) major consequences, in coastal areas, such as the western Netherlands, Northern Italy, the state of Louisiana in the USA, and most of Bangladesh and other river deltas, and for a number of low-lying islands in the Pacific.

But millennial effects are not limited to the natural environment. Human societies undergo long-term evolutions because of exogenous changes in the environment as well as endogenous changes that are inherent in society itself. Scientists are used to looking at the major changes that have occurred over the last few centuries, for example in technology and urbanization. But earlier periods have seen changes that, though much slower, are driven by fundamentally similar dynamics if one looks at them from a systemic point of view. From beginning to end, the Roman Republic and Empire evolved over 1,200 years, and the Chinese Empire even longer. Within such long periods the societal dynamics changed slowly but surely from expansion to contraction, to fragmentation to reconfiguration, and renewed expansion based on a different kind of organization. One can usefully think of this in terms of the approach proposed by Gunderson & Holling (2002) and the resilience community. They view any societal environmental system as a nested set of dynamic institutions. They see the dynamics that each of these institutions undergoes as constrained by potential and connectedness. In this discussion, potential is the extent to which a system can expand further while maintaining its structure, by increasing the scope of its organization and its energy flow. Connectedness represents, in the framework proposed here, the degree of alignment of the people, external processes, networks, and resources that constitute the information flow.

Much of the focus of the resilience community has been on studying the transitions that dynamic systems go through in their relationship with their environment. While not in the least arguing that history repeats itself, at the most abstract level they conceive of four major stages that the interaction between potential (= energy) and connectedness (= information) can drive any system through. By way of metaphor, they represent these phases as a lemniscate combining the four phases through which systems cycle, according to them. Because this metaphor is indeed a handy tool for thought (see Figure 5.1), I would like to discuss it briefly here, even though I am fully aware such metaphors are oversimplifications.

The first of the phases distinguished, exploitation, is the one in which a community grows based on a particular form of organization that permits an increase in energy flow in exchange for an increasingly coherent institutional organization, which increases its impact on the environment over time. As resources are overabundant, every individual has a chance to make something of his or her situation, and according to Thompson et al. (1990), the culture is one of individualism. The phase of growth of the Roman Republic (until *c.* 200 BCE) and that of Europe between 1400 and 1800 are – to an extent – examples of this dynamic.

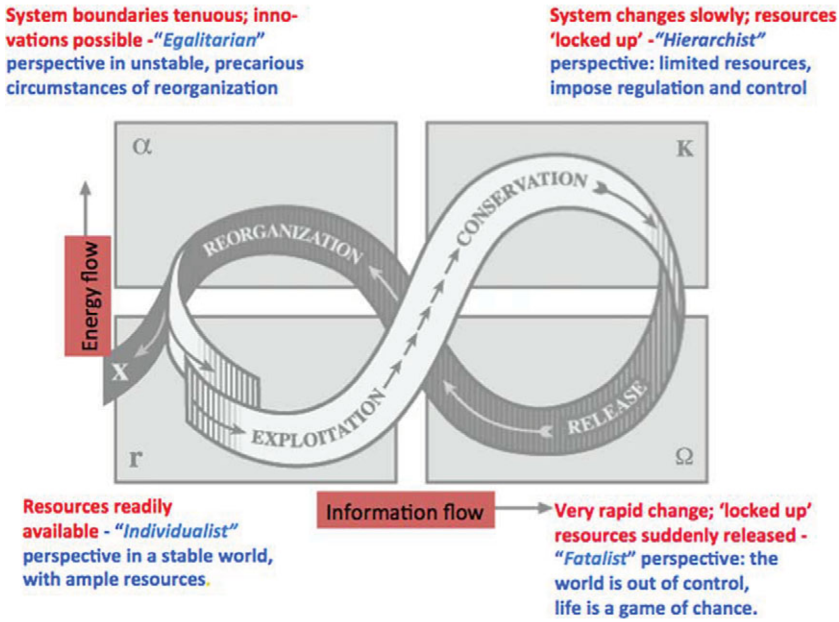

FIGURE 5.1 Schematic illustration of the resilience cycle. The red text describes the state of the ecological component of the system (after Holling 1973, 1976, 1986); the blue text describes the dominant perspective of the society (after Thompson et al. 1990). The interpretation in terms of energy and information flows is mine. (Source: van der Leeuw)

A crucial aspect of this phase is that the system suppresses structural innovation and institutional change because the dominant structure is (and later appears to be) so effective that there seems no reason to innovate. Because any institution is based on the exploitation of a limited set of resources, ultimately the growth curve involved levels off and the system's effectiveness and growth decrease.

The next phase is that of conservation, in which the limits of expansion are appearing on the horizon and the community defends itself by becoming more regulated and hierarchical, as a consequence of the need to deal with increasing levels of conflict over resources (Thompson et al. 1990). Bottom-up power to achieve things is slowly but surely replaced by top-down power over people (see Foucault 1977) to control actions. We see this in Rome after *c*. AD 0, beginning in the political history of modern Europe after 1600, and coming to a head in around 1800. As the limits of the particular mode of organization become clearer, elements in the system may contemplate change. But generally, fundamental change is not implemented because the system as a whole is still aligned on the preexisting dynamics.

In the next phase, release, innovation is freed up once the system reaches a tipping point in which the potential for further growth of the existing structure collapses. The immediate result of that is a complete lack of institutional structure, a true chaos in which the system can transform in many different ways, but none of these profiles itself clearly enough to give a sense of direction. It is this phase that we have characterized as a crisis: the collapse of the existing structure results in the disaffection of people with that structure, and their inability to understand. This in turn leads, in Thompson et al.'s "cultural theory of risk" perspective (1990), to a fatalist attitude. In effect, this is the kind of collapse that we see in Europe after the end of the Roman Empire, between 600 and 1000 CE. The fourth phase distinguished by the resilience community is that of reorganization – a phase of experiments with different forms of organization on a very local scale (Thompson et al. 1990). Once some of these succeed, one sees the slow but unstoppable growth of new forms of institutional organization bottom up, aligning more and more people. As the contours of the organization that will ultimately dominate are profiled, the institution itself will increase its potential, strengthen, and stabilize.

Particularly at the beginning of this part of the trajectory, people will seek local support, forming small and often egalitarian groups. With time, these will align with others, so that the structure can grow and form the basis for a new phase of exploitation – rooted in a different worldview and extracting a different set of resources from the environment.

Clearly, as presented here, this very schematic synthesis of such long-term evolutionary community transitions is insufficiently detailed to apply to any specific instance, but it accentuates the need to think over the very long term if one is to understand any present. One illustrative example of such an instantiation has been the work of the ARCHAEOMEDES team on the last couple of centuries of the history of the Epirus region in Greece (van der Leeuw 1998, 2000, 2012, 2016; van der Leeuw & Green 2004), but other instances abound, and have been studied worldwide (see www.resalliance.org/ and www.stockholmresilience.org/).[1]

We Need to Know the Healthy State of Our Planet

The second major problem with focusing on short-term dynamics is that looking back only one or two centuries limits our insights into the set of potential states of Earth's socio-natural systems to those that have undergone major anthropogenic impacts, to the detriment of the system states that existed before any, or with little, human impact. It is as if a doctor were to look at a seriously ill patient without having any idea what a healthy person looks like. How could one then identify a sustainable future for the patient?

Over the last 300 years or so our planet has been thoroughly transformed by anthropogenic action, to the point that anyone living, for example, 2,000 years ago would not possibly recognize it in the present. Yet the state of the Earth system 2,000 years ago is a stage in the accumulation of initial conditions that have shaped the present. We need to know and understand such past dynamics between societies and their environments if we are to be able to fully appreciate what is going on today, because they enable us to widen our inquiry to a range of states of the Earth system that can no longer be observed today, and thereby change our perspective on the dynamics that have driven the changes involved.

For example, one would need to have a good idea of the state of socioecological interactions before the Industrial Revolution in order to be able to assess how the industrial paradigm that is currently dominant in the western world has changed agriculture by slowly, but surely, isolating the agricultural system from the wider ecology in which it was embedded, substituting artificial fertilizer and pesticides for the ecological processes that nourished crops and dealt with pests – in essence industrializing agriculture. And that process not only concerned what was happening on the ground, but also involved such things as mechanization and the emergence of modern marketing, transport, and other societal aspects of the system.

The Importance of Second-Order Change

Looking only at the short term ignores second order change in socio-environmental systems – changes in the way change occurs and in the dynamics that drive it. This is a point that is of capital importance, yet is rarely discussed or taken into account. Over longer periods, the impact of drivers upon each other very often changes the process of change itself. Such second order change (the change of change) may concern a simple acceleration of certain dynamics or the emergence of one or more new feedback loops, but it may also be more consequential, for example when a conjunction of drivers tips a system's dynamic into a different state altogether, as the crossing of several of our planetary boundaries threatens to do to the overall dynamics of the Earth system (Rockström et al. 2009b). An example from the sociocultural sphere, discussed in Chapter 3, is the way in which the Black Death of the fourteenth century initiated a transformation of the intellectual conception of the world in which people were living, leading to the "great wall of dualism" enabling and ultimately driving the overwhelming development of the natural and life sciences over the past six centuries (Evernden 1992).

Such second order changes are usually taking place over longer periods, and they can only be discerned by detailed study of the first-order dynamics over long time frames. That may be difficult, but this should not deter us from doing it. Understanding second order changes is fundamental to understanding the trajectories of societies and their environments, because such changes often reflect bifurcation points.

In an interesting study, Barton et al. (2015) have mapped the changes in the structure of the dynamics between corn production and urbanization in North America from the precolonial period (up to *c.* 1550), through the colonial (*c.* 1550–*c.* 1850) and the industrial period (*c.* 1850–*c.* 2000) to the present, with an extrapolation toward the future.

In that process, we see how the rapid growth of the urban population, especially in the USA, has both necessitated and been enabled by changes in the agricultural system, involving institutional, technological, legal, health, and ideational changes. What the study accentuates is how, through the whole period of almost five centuries, the feedback loops have evolved, mapping not only the dynamics within each of the three regimes, but also the second order changes between the regimes.

To explain these, and the path dependency that is the result, one has to go back to the precolonial period, in which the initial feedback loops between food production and urbanization were established. Only by doing that, and looking at the pressures and constraints at any particular stage, can one then understand the emergence of the next stage. Between the precolonial and the colonial stages, one aspect of the transition is, for example, the institution of the hacienda system, with concomitant changes leading to the commoditization of corn as a cash crop that is tradable in increasing volumes. It is part of a process in which. owing to a decrease in the indigenous population (and the know-how that it had), Spanish technology takes over, the indigenous population is looked down upon, and its health suffers.

In the next stage, driven by industrialization in North America, the *ejido* system replaces the haciendas; the scale of farming is drastically

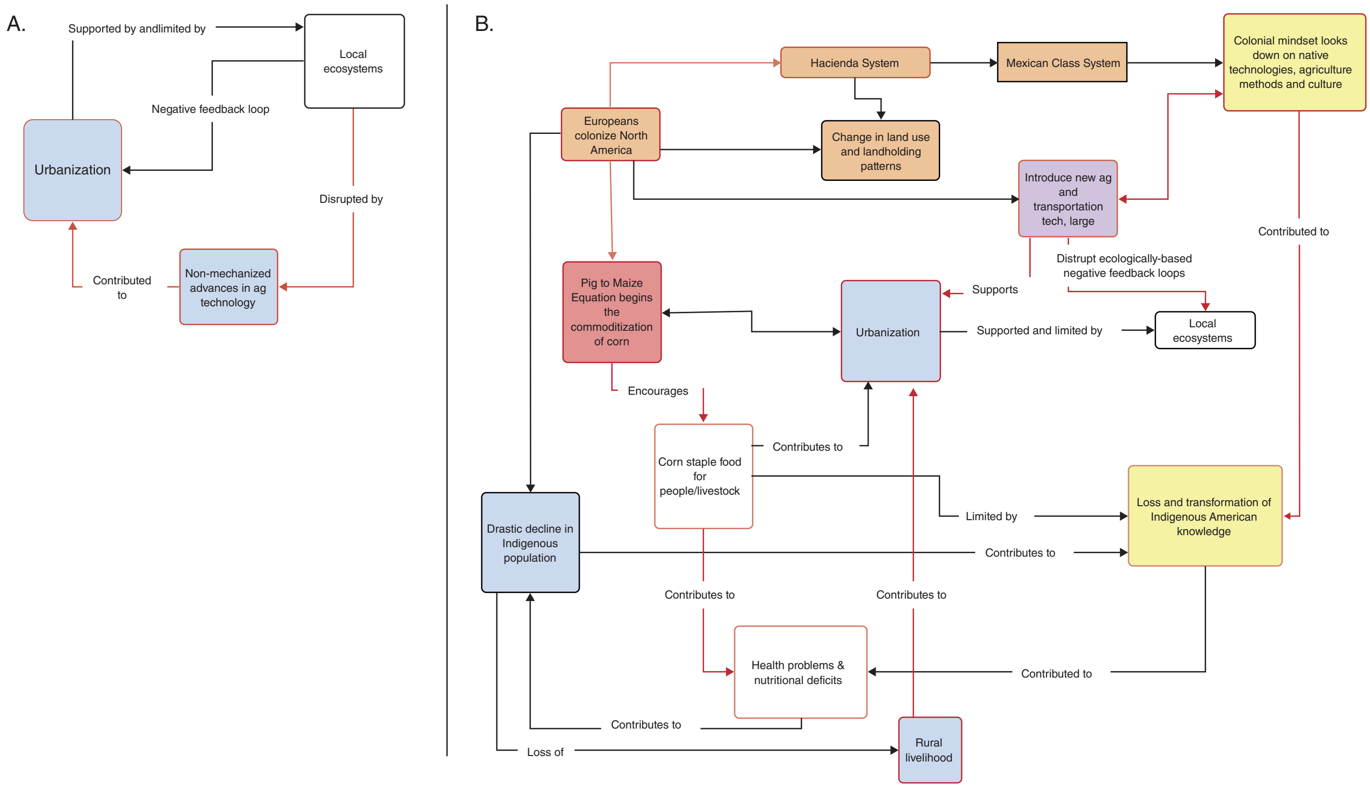

FIGURE 5.2A The relationship between food production and urbanization in precolonial Mexico. The red lines indicate feedback loops that are subsequently transformed.

FIGURE 5.2B The relationship between food production and urbanization in colonial North America (Mexico). The red lines indicate feedback loops that have emerged out of the precolonial situation and are subsequently transformed. (After Barton et al. 2015; by permission)

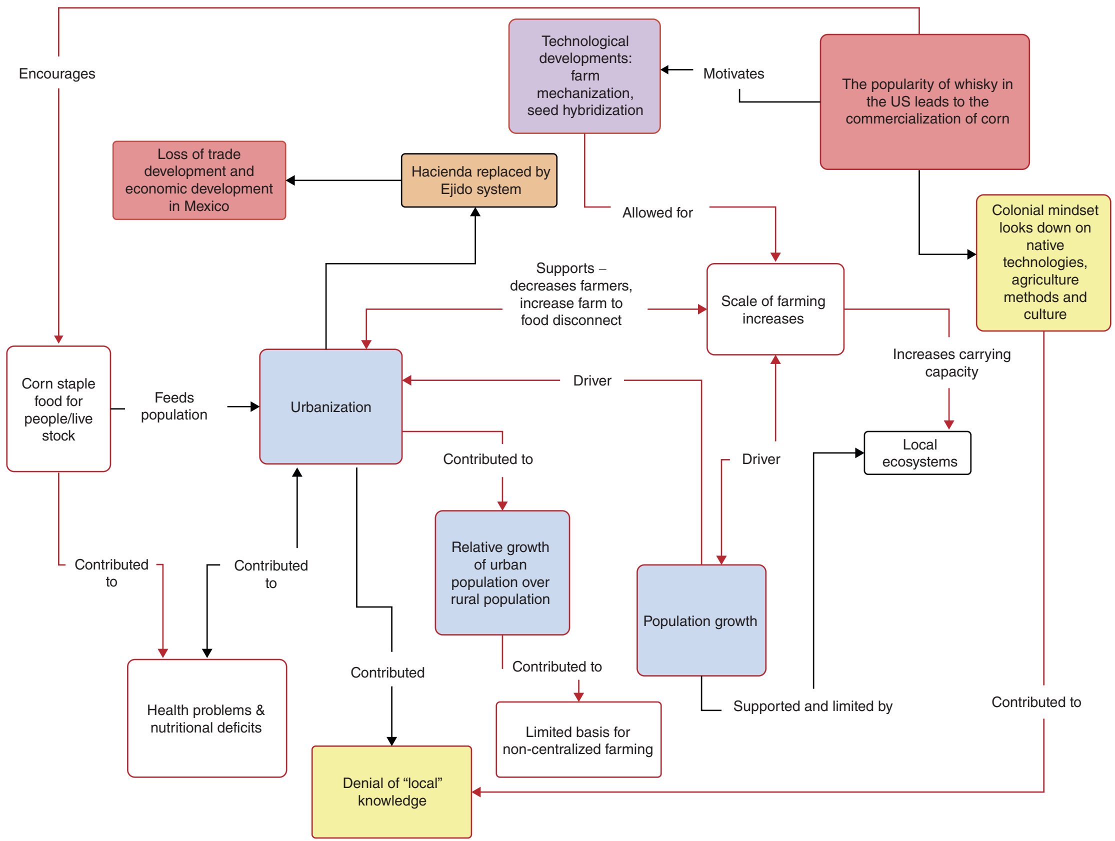

FIGURE 5.3 The relationship between food production and urbanization in Mexico under the impact of industrial North America. The red lines indicate feedback loops that have emerged out of the colonial situation and are subsequently transformed. (After Barton et al. 2015, by permission)

increased, in part enabled by increasing mechanization; local knowledge is ignored; corn becomes the universal staple, leading to more health problems but enabling the feeding of the increasing masses in the (mostly North American) cities, which entails in the end that many more people live in the cities than in the countryside that feeds them. International and long-distance trade (and the concomitant political and economic dependencies between nations) emerge and grow.

Essentially similar processes have of course been part and parcel of many instances of the emergence and collapse of complex societies, such as in China, Mesopotamia, Egypt, and Mesoamerica. The institutions and the relationships between them were different, but the underlying dynamics initially pushing such systems toward increasing complexity and then tipping them into disaggregation are the same. In Chapter 10 I present yet another historical case of this kind of dynamic in much more detail. But similar second order dynamics are of course also relevant to the present, as the last section of this book will show.

The Accumulation of Unintended Consequences

Short-term approaches, even if they include a century or two, leave long-term unintended consequences of human actions in the dark. We will deal with the importance of such unintended consequences extensively in Chapters 16–18, but a brief description is essential at this point. These unintended consequences result from the fact that as human beings we have only a very partial perception of our environment, and therefore undertake actions based on a biased and limited knowledge of the effects of those actions. These actions affect many more aspects of our environment than we are aware of. Some of these unintended and unanticipated consequences only emerge much later. When Henry Ford, for example, invented the serial production of affordable automobiles, he was not aware of the environmental and social consequences of having over a billion of them drive around the globe, heavily contributing to atmospheric pollution with CO_2, NO_2 and other greenhouse gases, but also leading to the rise of "new" cities, such as Phoenix and Las Vegas in the western USA, that cannot function without cars and other motorized transportation. I am arguing throughout this book that a failure to look at the unintended consequences of societal decisions has been an important cause of crises in human history, and is a major cause of the crisis in which we find ourselves. Some such unintended consequences may emerge centuries or even millennia after the event or process that triggered them. Yet for a full understanding of the long-term dynamics of a system, it is essential that these consequences are taken into account. Limiting our investigations to a century or two will at best catch a subset of them.

Summary

Geology, archaeology, and history can now provide the data and information to develop a more coherent long-term perspective that enables us to overcome some of these four categories of limitations (e.g., Berger & van der Leeuw 2007). Although the information presented by those disciplines is often too fragmentary or partial to deal with small-scale changes, it is able to provide an insight in long-term transformations in sufficient detail to outline a crude look at the genesis of the present (van der Leeuw 1998, 2007). Therefore, combining such a long-term skeletal perspective with a short-term and more detailed perspective, which can be derived from studies focusing on the recent past and the present, we are able to understand socioenvironmental dynamics more precisely, putting meat on the bones. We can then begin to map path dependencies and take more than two or three spatiotemporal scales into account, for example. And all this is necessary to holistically understand the challenges that we are facing today.

NOTE

1 The example given here and many others presented by the Resilience Alliance are for relatively short-term dynamics in which society is an important driver, but the idea is also valid for dynamics with longer temporalities; Chew (2007), for example, has a longer scale view of developmental cycles that incorporates forest and soil health and climate to make a broader, very long-term "perfect storm" sort of cyclicity.

6

Looking Forward to the Future

Introduction

In order to strive toward sustainability, though we can profit from studying the past and the processes that led to the present, we also need to develop tools to look into the future itself. That poses another, very different, set of challenges.

As I argued in Chapter 3, the emergence of modern academic science and scholarship was, and still is, based upon the idea that one must be able to corroborate any hypothesis, demonstrating the correctness of any observation. This has heavily biased our scientific perspective toward the relationship between present and past, explaining present phenomena by offering a perspective on the past that could be interpreted as leading to present-day observations. Such a perspective could be informed by documents (in the widest sense) pertaining to that past, such as archaeological artifacts, historical texts, fossils of extinct animal species, etc. But of course that does not help us to elaborate a relationship between the present and the future. Nothing can be documented about the future, so from a scientific career perspective looking at the future is not very rewarding.

As stated in Chapter 1, it is one of the tenets of this book that thinking about the future must indeed be developed into a coherent approach, even though we may at present not quite see what that approach will look like. After all, it took western science four centuries to develop current scientific approaches to relate the present to the past and the past to the present. At the beginning of that process scientists were casting around without much sense of where their ideas might lead, just as is the case for scientists today who are looking at the future. There is therefore in my opinion no reason why we cannot develop approaches to thinking more systematically and coherently about the future. Moreover, in the last century and a half or so, many of the natural sciences have developed theories and models about processes of many kinds that are so accurate that they allow the (generally short-term) prediction of future behavior of a range of systems. A recent, but for many people rather abstract, example is the proof of the existence of gravitational waves. But there are many such examples: based on our knowledge of physics and mechanics, engineers can closely anticipate the performance of an engine, the solidity of a bridge, the destructive power of a nuclear bomb. Astronomers can predict the current and future position and many characteristics of planets and stars. Medicine can predict the efficiency of a new vaccine, the probable course of all kinds of epidemics, and the evolution of many illnesses. In all these cases, such predictions are based on (near) complete understanding of the dynamics involved.

Some of the predictive power of science applies to the very long term (billions of years), such as in astrophysics. But it can also apply to the very short term (microseconds) such as in the case of the complex processes leading to a successful hydrogen bomb explosion, or even ultra-short term (sub femtosecond) interactions such as in photon–matter interaction. Whether such predictions are dependable is related to the complexity of the phenomena concerned. Prediction is much less effective for complex systems such as phase transitions, self-organization (the emergence of snowflakes can be predicted, but not their structure), and the kind of physics treated in Chapter 7. Even in a limited domain such as the economy, scientific prediction is often more fantasy than reality because it is based on dynamic equilibrium models that assume that the current situation may change, but if it does, it will do so only incrementally.

The highly complex issues related to human individuals, societies and their environments generally involve many more dimensions and parameters than those I have just mentioned, so that explanations, let alone predictions, in these domains are very much more difficult. Yet, in view of the acceleration the world is currently going through, we can no longer delay the development of a deliberate strategy to learn from the past about the present and for the future in terms of socioenvironmental matters and the dynamics playing out in societies (Dearing et al. 2010; van der Leeuw et al. 2011; Costanza et al. 2012; van der Leeuw 2014). This being the case, how do we go about it?

Past Perspectives on the Future

When in our quest for understanding we have looked at the past to gain insights about the future, we have rarely used the resultant knowledge to its best advantage. We have derived different (often discipline-dependent) chains of cause and effect, which have been (more or less linearly) extrapolated via the present into the future. The future has thus been negotiated via uncertain and partial extrapolations from different visions of the past and the present, and this is clearly suboptimal. For one, this approach does not open the door to alternative historical trajectories. More importantly, it does not help us understand our relationship with the future. It views the past and the future as "foreign lands" (see Hartley 1953), rather than as projections in different (temporal) directions from the present – the point at which we have the ability to modify the social-ecological evolutionary process according to our ideas.

One conclusion from this state of affairs is that the perspective we develop should be a holistic one – we should not fall back into the trap of separating challenges and research topics into separate disciplines. Designing such a holistic approach requires that we find ways to simultaneously observe patterns in many dimensions, a kind of observation for which traditional Western science is not very well equipped. One way to illustrate this is by reference to the difficulty of solving the Rubik's cube. One cannot get the cube "in order" (so that each side has one homogeneous color) by dealing first with one side, then the next, and so forth. The only way to arrive at order is by looking at the patterns on all sides simultaneously and not favoring any particular side at any time.

Analogue and Evolutionary Approaches to Understanding Past and Future

In a paper coauthored with Dearing and others (Dearing et al. 2010), we distinguish two different ways of relating the past to the present: an analogue and an evolutionary approach. The former is the one we have traditionally used to relate past and present (Meyer et al. 1998; Costanza et al. 2007). We compare the past and the present as different case studies and search for differences and similarities that might help us to better understand the present – how it came about, how it functioned, where observations about the past may serve as lessons for our own situation, and what we might do about undesirable aspects of that situation.

In a paper (van der Leeuw 2014) based on a study by Aschan-Leygonie (van der Leeuw & Aschan-Leygonie 2005), for example, I briefly compare two economic crises in the southern French "Comtat Venaissin" region, in the 1860s and in the 1960s, and ask why the first crisis was quickly resolved and the second was not. This leads us to understand that the seeds for the first solution had already been sown before the crisis emerged, and that the crisis was immediately seen as urgent and threatening, so that coherent action was undertaken. The second crisis developed much more slowly, was not seen as urgent, and forced the region to adapt to a situation that was totally new, so that it could not draw upon preexisting marginal solutions as it had in the first crisis. As a result, the second crisis dragged on and had lasting economic consequences.

Though such analogues offer insights into differences and similarities between cases and sensitize the expert, past examples are by definition imperfect matches with the present, especially in view of the very rapid changes the Earth system (including many societies) has undergone over the last century or so (Wescoat 1991; Meyer et al. 1998). As a result, many (but not all) such comparisons between past and present have engendered "just so" stories that alert their audience to potential dangers, often by overemphasizing similarities and underplaying differences between the past and the present.

In my opinion it would be more productive to compare the different cases from a systemic and evolutionary perspective, and to distill from such comparisons an improved general insight in the structure, dynamics, and evolution of the Earth system under different conditions. In such an approach, each case study serves as if it were a past experiment that, if followed in detail over at least some part of its trajectory with an emphasis on the emergence of novelty (novel technology, novel ideas, novel institutions, etc.), would have provided knowledge about the (un) intended outcomes of past dynamic interactions between the components of the system under different conditions. Such knowledge may permit us – once sufficient instances have been studied and their contexts, boundary conditions, structure, etc. have been brought to bear on the actual dynamics observed – to begin to outline models of the interaction of a number of the more general processes to which such systems are subject. A good example is the work of Zhang et al. (2007), who looks at how the accumulation of measures to improve the financial productivity of an economy (for example through streamlining the production chain) ultimately leads to an understanding of the need for fundamental change in the overall organization of labor in that chain. It seems to me that, ultimately, such approaches may enhance systematic assessments of postulated generalized complex system behaviors that can help us develop insights into the future states of these systems (Hibbard et al. 2010).

It is also useful for illustrative purposes to look at evolutionary theory in biology. Although biologists cannot make clear predictions about the emergence of new species, it is possible in genomics to point to probable gene modifications and their impacts, and thus to distinguish probable from improbable futures in the evolution of a species.

Such a systemic evolutionary view of the past focuses on a perspective in which the present remains continuously and strongly connected to the past (Carpenter 2002). But owing to the systemic nature of the perspective, these connections are different from those usually developed by historians because the emphasis is on the dynamic structure of the system studied. They address processes that operate over longer time scales than the example mentioned above; they involve time lags, contingencies, emergent effects, and legacies that are integral to the functioning of the contemporary and future system.

By integrating observational, documentary, and reconstructed data, evolutionary studies could thus provide a developmental perspective on socioenvironmental processes that is critical to understanding all the elements of contemporary system dynamics, including the second order dynamics that are continuously modifying the boundary conditions within which socioenvironmental systems operate. Such long time-series of data and information may be the only way to confirm complex system behavior (e.g., alternative steady states, the adaptive cycle, contingent and emergent properties, and feedback mechanisms) in real-world systems. We can then ask fundamental questions relevant to managing socioecological systems: "Which ecosystem processes or services are apparently stable and resilient?," "Which are trending beneficially upwards?," "Which are on downward trends?," "Which combinations of stresses have led to such current environmental degradation?," "What are the predisturbance properties that could point to targets for environmental restoration?"

Finally, this approach is much better suited to deal with the no-analogue situation that we presently face with respect to the sustainability of humans and their societies on Earth.

Ex Post vs. Ex Ante Perspectives

There are of course fundamentally important epistemological issues with looking into the future. Whereas reductionist science has developed an ex post perspective that examines the origins of phenomena observed in the present, and summarizes those in terms of a limited number of dimensions – often in the form of cause-and-effect narratives or formalizations – that is of course not possible if one wants to develop perspectives on the future. Such perspectives must be developed from an ex ante point of departure, focusing on studying the emergence of novelty (new ideas, techniques, institutions, etc.) that is formulated in terms of possibilities or probabilities.

When I introduce this distinction in my classes, I ask students to think of the first time they fell in love. When that happened, most of them would have been trying to work out how their affair might evolve (developing an ex ante perspective on what was happening), and they would have found an overwhelming, and often contradictory, number of potential futures that confused their feelings. But looking back (from an ex post perspective) on the episode several years later, whether the affair had been successful or not, they would have constructed a very limited number of causal narratives about it.

This also happens to other events and situations, of course. In general, humans think and conceive of many different futures and they conceive of only one or a few pasts. They usually conceive of futures in terms of possibilities and probabilities, risks and uncertainties, involving a relatively high number of dimensions. But they tend to conceive the past in terms that involve a much lower number of dimensions, often only one or two, and construct narratives based on chains of cause and effect. Ex ante they speculate what might happen, but ex post they construct a causal chain about what did happen, describing the origins of where they are at that point.

For the moment, there are no firm ideas about how to assess the relative probabilities of such ex ante future scenarios. But thanks to the work of scientists such as Fontana (2012), we can begin to sketch a roadmap that will bring us closer to our goal. In a paper by Bai et al. (2015) to which I contributed, we propose the outlining of a number of possible trajectories from the present into the future that are compatible with our understanding of the past dynamics that have brought us to the present, and then asking which of these futures is plausible. To determine this, we analyze which among the projected futures would run into internal or external obstacles, inconsistencies, or other challenges, to the point that it would not be realistic to expect them to materialize or persist. In essence, we look at the inherent affordances while trying explicitly to avoid what appears unsustainable, acknowledging that striking this balance is never easy and will always involve both uncertainties and values.

In the next step, we try to decide which of these futures is desirable, limiting the plausible choices further. This should lead to a wider societal and scientific discussion around the question about the kind of future we see for ourselves and our species (see Lévèque & van der Leeuw 2003). In this discussion, the basic values of the society involved need to be made explicit, and linked to the desirable futures selected. Once such a discussion has focused its efforts on a limited set of specific scenarios for its future, we can ask what we need to do to achieve this or that future.

This approach is deliberately solutions-focused but does not aim for immediate solutions that perpetuate the current path dependency, because it is a core thesis of this book that the unintended and unanticipated consequences of every human action and innovation play such an important role that the future is ontologically uncertain. Rather, its goal is to identify potential out-of-the-box ways forward that seem plausible and desirable as well as sustainable over the long term.

Another approach, used for example by Saijo (2017), is to begin by looking at desirable futures by positioning oneself as far as is possible in the future, generating from that perspective a range of desirable futures, then back-casting to the present and designing a roadmap that might achieve the desirable goals by adopting probable trajectories. In this chapter, this is further elaborated in the section on scenario building.

In the end, one may have to develop ways in which these two approaches, forecasting and back-casting, can each be developed in their own right, followed by an episode in which their integration can be negotiated. In doing so, approaches used in engineering, business, and related disciplines would be adopted.

The Role of Modeling

Models (computer- and others) are important novel tools for thought and action (for an easy-to-read general summary of the concept model, see Apostel 1960). They can represent very complex dynamics in ways that allow us to look at them both ex post and ex ante. Such tools are now commonly used in a wide range of disciplines, including the natural, life, environmental, and economic sciences, and in contexts that range from academia to all the major financial and economic institutions (such as governments, central banks, the International Monetary Fund, the Organisation for Economic Co-operation and Development) and the defense establishments of many countries. Outside such institutions, they are known as computer games, and they may involve hundreds of thousands of actors.

Where it is possible to represent evolutionary processes as a set of rules, whether mathematical, numerical, or logical, there is the chance to create simulation models that can be used as management tools. The models used in the Limits to Growth studies (Meadows et al. 1974, 2005) were developed around the idea of a world in which different social and environmental processes are interconnected through flows of energy, materials, and information. By creating a dynamic mathematical model, the authors were able to simulate future patterns of growth and decay in energy demand, resource use, environmental quality, etc. As the sustainability agenda grew stronger, there were increasing numbers of calls for similar modeling tools that can simulate alternative future states of socioecological systems at regional scales, and as a result a whole industry of such modeling emerged.

A key requirement for sustainable management is to be able to gauge the future risk that alternative strategies will transgress major environmental thresholds by looking at thresholds and tipping points, such as for example the minimum density of vegetation cover that protects the ground from runaway soil erosion. Therefore, modeling tools need to be able to operate over at least several decades (but to capture second order dynamics they may need to cover centuries or even millennia, see van der Leeuw 2007), and, importantly, they need to capture the likely big surprises that are inherent in complex systems (Dearing et al. 2006a, b; Nicholson et al. 2009).

Why Model?

We live in a complex world where human actions commonly have unforeseen and unwanted consequences. In the scientific as well as in the political arena two strategies have emerged to cope with this complexity: theory and computer simulation. Theories are ideas about causal relations that are used to inform understanding, choices, and decisions. Given that even the most brilliant theoretician has limited capacities for deductive reasoning, theories are necessarily of limited complexity. Computer simulations are also based on ideas about causal relations, but these are often so complex that only teams of highly trained specialists can put them together. Moreover, not even these specialists can claim to understand all their logical corollaries. Those are the ones that we model in order to understand them.

In a paper published in 2004, I give some reasons for modeling that in my eyes are important. For one, models enable researchers to economically describe a wide range of relationships with a degree of precision usually not attained by the only other tools we have to describe them: natural languages. Because each discipline has its own vocabulary and approach, one of the major difficulties in pluri- or transdisciplinary research is to find modes of expression that are acceptable to all the disciplines involved, and free from the connotations of any or all of them. Models can indeed be used to express phenomena and ideas in ways that can be understood in the same rigorous manner by practitioners of different disciplines, including the natural and social sciences and humanities. An example is the "percolation" model that I use in Chapter 11 to investigate transitions between information processing networks.

Another important advantage of formal models is that the domain of application of formal models is unlimited. It includes all aspects of any discipline. Thus, models may include, for example, kinship, ritual, choice, and behavior, alongside aspects of the dynamics between society and the natural environment upon which it is predicated.

Moreover, I find formal models particularly useful in a multi- or transdisciplinary context because they are sufficiently abstract not to be confounded with reality, and sufficiently detailed, rigorous, and (in the case of some computer models) "realistic" to force people with different backgrounds to focus on the same relational and behavioral issues. Models can therefore dissolve blockages and misunderstandings between disciplines by showing that the match between the phenomena to be predicted after running the model and the actual observed phenomena is close, non-existent, or somewhere in-between.

No less important in a social science context is the fact that formal models are formulated in a different language from the descriptions of the phenomena to be modeled. This has several advantages, of which the most important is possibly that it allows us to abstract in order to highlight features that are in our opinion relevant. It is a common assumption, for example, that one may not compare apples and oranges. Yet if one wishes to explain why oranges are better at rolling in a straight line than apples, one invokes an abstract dimension (roundness) and compares both kinds of fruit in terms of that dimension. The applicability of any particular model to a set of phenomena does not follow naturally from the nature of the phenomena but is defined by the person who applies the model.

Formal models can therefore, at least in theory, be useful in solving problems in which it is important to infer relationships between the observed behavior of certain phenomena and characteristics of these phenomena that remain to be identified.

Moreover, certain kinds of formal models are able to describe the changes occurring in complex sets of relationships with great precision and economy. I will give an example of this in Chapter 14. Owing to these properties, modeling is very suitable for formalizing dynamic theories about certain complex phenomena, which can then be compared with our observations. It facilitates putting flesh and clothes on the bare bones of sequential static data sets by helping them to link dynamic processes to their static outcomes. It should be noted, however, that this implies a somewhat different use and status of the models involved than is common in certain disciplines.

And finally, certain classes of formal models allow us to study how interactions between individual, non-identical entities at a lower level result in patterns at a higher level. This is particularly relevant in the study of many of the collective "hairy" or "wicked" phenomena that are the subject of the social sciences, where the interactions between individuals create the society, which in turn impacts upon the behavior of the individuals or groups concerned. Because of this property, such models are particularly interesting for those of us who study society from a self-organizing perspective.

Support Models and Process Models

Let us now look in more depth at the role of two different kinds of models (van der Leeuw 1998b, 14). In politics, in industry, and in commerce, computer simulations are commonly used as support models: models used to infer the most likely consequences of given actions in some real-world-like dynamic system. Indeed, the computer science and modeling literature often implies that support models are the only rational way of using computer simulations. Computerized models, one learns, are abstract representations of concrete (i.e. real-world) dynamic systems. One will also read that a system is "a set of rules, an arrangement of things, or a group of related things that work toward a common goal" (www.yourdictionary.com/system).

In practice, these models hardly ever hold true over the longer term. In such models, causal relations manifested in the real world are only understood in quantitative terms. We know that poor communications and low food production may limit the growth of an urban center, for example, and can often specify a number of equally plausible mathematical relations that exhibit similar properties. But unfortunately we seldom have theoretical grounds for favoring one of these plausible sets as the definitive model to use.

There are other kinds of models. Process models are used to investigate ideas about a perceived, but imperfectly understood, dynamic system. By analyzing the model in a manner consistent with the perceived mapping between the model and the theory it represents, one searches for logical implications inaccessible by traditional hypothetico-deductive methods. If the underlying structure of the model is quite simple and the range of behaviors it can exhibit is considerable, the study of how the model operates will produce results that are more widely understood than those of support models.

It is equally important to realize that the same set of modeling tools can be used for two very different analytical tasks. Support modelers use computer simulations as test beds for policies, while process modelers build computer simulations as test beds for theories. It is conceivable that one who only ever builds support models could sustain the notion of a system as a group of components with a common purpose or that of a model as an abstract representation of a concrete system. For a process modeler, however, these ideas are manifest nonsense. For him or her, a model is a concrete representation (in the form of equations, marks on paper, switch states in a computer) of an abstract system (a theory).

The distinction between the traditional use of models as abstract maps of concrete systems and the use proposed here of models as concrete maps of abstract systems is not merely a nice rhetorical point. It has profound methodological and ethical implications. On the methodological front, it suggests that the principal function of a model is to evaluate theories and, ultimately, to suggest new theories for future evaluation.

On the ethical front, this distinction forces us to acknowledge that the output of any computer simulation is only as reliable as the theory it represents and the data it uses as input. That does not imply that the use of support models is inherently unethical. We live in a world where current policies must change for the better if humans are to avoid global disaster. Support modeling may be the only means by which complex political, ecological, or sociological theories can be harnessed and put to work. However, if we are to manage our affairs responsibly, we not only need the best support models available, but we also need to accept that the "real world" (whatever that is) may not endorse them.

In most sustainability science, models are common currency. They are used to extend into the future the analytical perspective that has allowed us to understand the socioenvironmental dynamics that have brought us to the present. Procedurally, they are therefore usually inserted at the end of a chain of reasoning, and serve to extrapolate from the present into the future. This leaves the whole construct heavily dependent on the (usually linear) scientific understanding of what drove the past and drives the present.

Challenges to Integrated Modeling of Socioenvironmental Dynamics

In a paper recently published by Verburg et al. (2015), the principal kinds of models that are currently in use are outlined, with some of their characteristics, advantages and challenges (see Table 6.1) as well as some examples of each of these categories. First among these, and relatively rarely touched upon, is the fact that the data brought together in many models have been collected by different disciplines with different schools within each discipline concerned, and often for different purposes. They have been collected with different questions in mind, different disciplinary epistemologies, different methods, and different techniques. This is both a current and a growing problem, as ever-limited research funding forces us to increasingly rely on data collected in the past. We need to develop the practice of systematically extending the metadata commonly included in databases, to include (1) the questions the data were trying to answer, (2) the methods and techniques used in collecting and in analyzing them, (3) the sampling, units of observation, and units of analysis associated with the data, (4) the working hypotheses involved in the research, and (5) the epistemological status of the information derived from the data.

- *Moving beyond conceptual models.* There are many examples of conceptual frameworks devoted to the description of socioecological systems in terms of causal frameworks or systems diagrams that conceptualize the interactions between different system components. Their development is an essential part of any research approach, but one could argue that they are granted too much importance in terms of their role in understanding how a system works, in forming a basis for modeling or even in deciding the sequence of research steps. Conceptualizing the real world is important, but we should remember that more often than not we are simply producing lists of key elements with probable links, and emergence tells us that these may all change through time. Frameworks and conceptual models should be treated as first steps in creating hypotheses that could be tested via a suite of tools and methodologies: they have limited value in their own right because they are the means to an end. This is particularly true in the case of integrated assessment models. Even when they have a generic set-up, they are often not well suited for addressing a specific problem or question and we should avoid defining our research questions by the structure of a (conceptual) model rather than focusing on the societal questions as these are emerging. The tail should not wag the

Table 6.1 Different modeling approaches, with some of their characteristics

Generic model category	*Notable model types*	*Coupling*	*Scales*	*Data and computing*	*Complex dynamics*	*Policy tools*	*Validation and skill*
Deterministic process-based biophysical models	Global climate models; Earth System models	Low potential; social subsystem often represented by plausible pathways and emission scenarios	Mainly global (20–200 km) resolution and long (decadal) timescales	Large data and computing requirements	Theoretically capture feedbacks and emergence in biophysical processes. Lack of feedbacks with other (socioecological) system components	Limited because of high complexity. Scenario results are input in intergovernmental processes	Difficult to validate. Comparisons against historical data and model inter-comparisons are common
Deterministic economic models	General and partial computational equilibrium models	One-way coupling in which biophysical subsystem often reduced to climate effect on the agricultural sector	Regional to global. Often limited spatial detail (world regions); timescales often limited to several decades.	Large data and computing requirements	Feedbacks only accounted for through market mechanisms	Dominant use in ex ante assessment of policy instruments	Difficult to validate. Comparisons against historical data are scarce while model inter-comparisons are common
Reduced-complexity social-ecological models	Integrated Assessment Models. Earth system models of intermediate	Moderate potential but biophysical and social sub-models often	Regional to global scale with decadal to sub-decadal timescales	Somewhat reduced data and computing requirements	Top-down usually lacking feedback or emergence (some EMICs can simulate abrupt	Scenario results are aimed at input into policy processes; models used for ex ante assessments	Limited as above. EMICs tested against paleo-climatic records (e.g., ice cores)

Table 6.1 (*cont.*)

Generic model category	*Notable model types*	*Coupling*	*Scales*	*Data and computing*	*Complex dynamics*	*Policy tools*	*Validation and skill*
	complexity (EMIC). System Dynamics Models	simply coupled in an integrated model environment			changes). Social subsystem often reduced to profit optimization or simple heuristics		
Agent-based social-(ecological) and cellular (social)-ecological models	Agent-based models (ABMs), land-use change models	High potential but not frequently implemented	Generally local to regional scale and relatively short timescales with often annual resolution	Rule based. Strong variation in data and computational needs. Strongly relying on either theory or empirical data	System-level dynamics often emerge as a consequence of low-level interactions and feedbacks	Limited application, but examples of participatory use exist	Either based on ability to reduce pattern and dynamics or particular empirical data. Increasing focus on validation of system behavior
Simple toy socio-ecological models	Conceptual models, games	Highly variable but high potential	Any scale	Mostly low. No use of empirical data	Able to simulate complex dynamics but with oversimplified assumptions	Low potential. Learning tools	Mostly not applicable

Source: Verburg et al. (2015), published under CC-BY-4,0.

dog! Any model building or application should start with a clear rationale for the choice of a particular model approach or system conceptualization based on the questions and hypothesis of interest.

- *Modeling safe operating spaces.* A significant development in recent global environmental change research has been the introduction of the concepts of planetary boundaries and safe operating spaces for humanity (Rockström et al. 2009a, b; Steffen et al. 2014), in order to focus on identifying the critical limits or thresholds for major biophysical variables that steer the climate, biosphere, and hydrological systems that underpin social wellbeing. Modeling safe operating spaces to a level that can inform policy thinking will require information about the desirable and undesirable development pathways for humanity at a range of spatial scales. There is a gap between oversimplified toy models that can simulate complex social-ecological change at global scale (e.g., Motesharrei et al., 2014) and global climate models that can capture complexity but only for the climate system. To inform the discussion on safe operating spaces, there is a need for a new suite of models that moves away from the conventional approach of driving models forward in time in the light of particular scenarios, and instead focuses on stable and unstable social-ecological dynamics associated with alternative development pathways. One recent example of such an approach is the project "The World in 2050" (Sachs et al. 2018).
- *Feedbacks and emergent properties.* Owing to the long, relatively independent history of most of the disciplines involved, we lack the systematic integrated, transdisciplinary, holistic, and in-depth knowledge of the feedbacks between the different parts of socio-environmental systems. In designing (conceptual) approaches to address feedbacks, the issue of scales comes to the fore. The natural, earth, and life sciences have essentially gathered information at local, regional, and global scales and synthesized it to develop models to predict patterns globally. The social sciences and humanities have gathered their information and synthesized it at the local scale. There is thus a need for ways to downscale (provide higher resolution of) environmental information and to upscale the information on societies. The former is complex enough, but inroads are being made in that domain. The latter is much more difficult and probably demands substantive methodological development beyond simple statistical aggregation.

- *Connecting dynamics at multiple scales*. In both the debate on different epistemologies and the discussion of feedbacks, different scales and scalar interactions play important roles. The current world is characterized by global scale changes in Earth system dynamics, emerging from local changes in human interactions with the environment. The emerging global challenges translate into impacts on local realities, and most solutions to manage these have to be implemented at local scales. This brings about the challenge to represent such cross-scale dynamics in modeling tools. Prompted by the fact that for a long time the climate and Earth sciences were the primary disciplines to study greenhouse gases and their consequences at the global level, the efforts of the United Nations were directed at finding global solutions to these challenges, for example suggesting the creation of a $100 billion Green Climate Fund. But in doing so, they did not take into account that this involved different cultures, different societies, and different economies. What was proposed was a uniform solution, a united effort of burden-sharing to avoid irreparable damage to our environment. If, on the other hand, the challenge is seen not as an environmental one but as a societal one, then it is clear that not all societies can deal with it in the same manner. As a result, the Green Climate Fund has only raised $30 billion a year. Introduced in the run-up to the 2015 United Nations Climate Change Conference (COP 21), the trend of allowing different societies to define their own contributions to mitigate climate change is, from that perspective, an improvement. To use models to assist in finding potential solutions to these challenges requires the capacity to represent the local societal dynamics in the context of global processes, and vice versa.
- *Codesigning models*. While models are mostly used as tools for researchers aimed at expanding their mental capacity to explore system functioning, new perspectives and demands on modeling are emerging in terms of the interactions between the users and creators of models and society as a whole.

Figure 6.1 provides an overview of different ways in which science and society may interact in the context of the design and use of models. Such codesign and coproduction of research has become important in global change research (Cornell et al. 2013), with repercussions for modeling. Codesign of research questions may change the nature of the questions and, therefore, have consequences for the suitability of the modeling tools available. While many

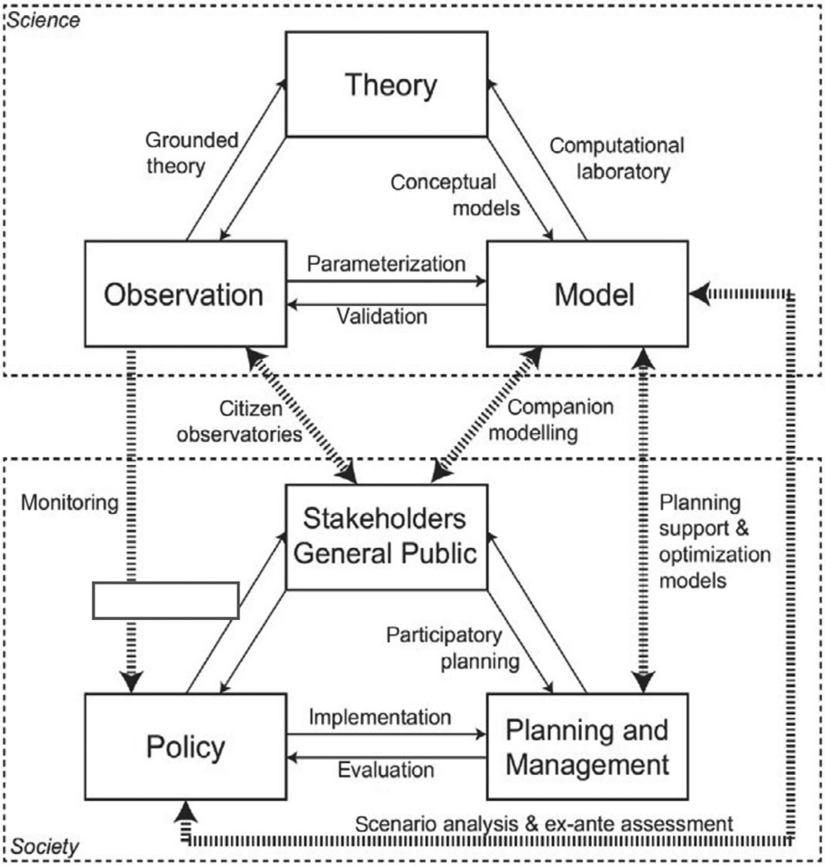

FIGURE 6.1 Schematic representation of codesigned modeling. (Source: Verburg et al. 2015, published under CC-BY-4.0)

modeling tools are built from the perspective of exploring system function, they may not be able, or are not optimally designed, to answer questions that emerge from the interactions between researchers and stakeholders. Research models need to be transformed into operational models so that choosing the right model for the question at hand becomes even more important (Kelly et al. 2013). Apart from codesigning models to better address societal questions, codesign should also involve data-gatherers and non-modelers in the design process. This way, model design can be better matched to available data and data collection to the needs of the model.

- *Modular architectures*. Most models are written to be stand-alone. The disadvantage is that investments in redesigning all model components make the development of new models extremely expensive. To tackle the challenges outlined in this chapter a diversity of approaches is needed. Component-based modeling brings about the advantages of "plug and play" technology. Models wrapped as components become functional units that, once implemented in a particular framework, can be coupled with other models to form applications. Frameworks and architectures additionally provide the necessary services such as regridding tools, time interpolation tools, and file-writing tools. A model component can communicate with other components even if they are written in a different programming language (Syvitski et al. 2013). Plug-and-play component programming benefits both model programmers and users. Using this framework, a model developer can create a new application that uses the functionality of another component without having to know the details of that component. Models that provide the same functionality can be easily compared to one another simply by unplugging one model component and plugging in a different component. Users can more easily conduct model intercomparisons or build larger models from a series of components to solve new problems. To ensure that one model's output variable is appropriate for use as another model's input, a precise description of the variable, its units, and certain other attributes are required.
- Finally, we need to consider the *position of the modeling effort* in the chain of actions that leads to understanding the dynamics. Generally, thus far, in developing prognoses about the future, models have been positioned at the end of an argument that is built upon scientific understanding of extant conditions and drivers of the trends. But following what has been said about ex ante models, what would happen if models were taken as the starting point of the argument? Rather than present deviations from an existing trajectory, they could then inspire scientific research toward a better understanding of potential futures and their implications, including potential unintended consequences. This is the domain of scenario analysis.

Scenario Building

The other main tool that we have in thinking about the future is "futuring" or scenario-building. This is an approach that was initiated by Shell PLC at the time of the first oil crisis (1973). It has since been developed in a wide range of domains driven by the long-term planning requirements of certain industries (energy, reinsurance), and adopted by governments (e.g., Singapore, Dubai) and supranational institutions such as the World Bank. But it has also played an important role in thinking about sustainability, more or less in parallel with the development of modeling, such as for example in the work of the Intergovernmental Panel on Climate Change (IPCC); see the various IPCC reports (e.g., Nakicenovic & Swart 2000) and the global research program "The World in 2050" (Sachs et al. 2018), and also the various projects about transitioning from the present to more sustainable futures, such as Hammond's "Which World?" (2000). Futuring is currently emerging as a discipline in a limited number of institutions in the academic world. It uses a mixture of modeling and scenario analysis techniques to coherently develop multiple perspectives on the future. In view of its increasing importance in considering futures, scenario analysis merits some attention.

Scenario design and scenario analysis are based on the assumption that anticipation is an oft-overlooked or ignored capability that we need to operationalize and use in the present situation. After all, we always talk about feed*back*, but only rarely about feed*forward* (Nicolis n.d. presents an early discussion), a point recently made very convincingly for economics by Beckert (2016). It begins by qualitatively imagining a number of potential futures along the lines presented at the end of the last section, focusing first on futures which are the result of out of the box thinking and thus disconnected from the present, and then considering the plausibility of these. As these potential futures are analyzed and detailed, flesh is increasingly added to the various skeletons.

This is an exercise in imagining and logically analyzing the implications of alternative possible outcomes. It does not try to show one exact picture of the future. Instead, it deliberately presents a number of alternative futures and the roadmaps leading to them. In contrast to prognoses, scenario building and scenario analysis do not use a conscious extrapolation of the past. They do not rely on historical data and do not expect past observations to be valid in the future. Instead, they try to consider a wider range of possible developments and turning points, which may (but need not) be loosely connected to the past. In short, several scenarios are demonstrated in a scenario analysis to show possible future outcomes that can serve as goals to be pursued. It is useful to generate at least a combination of an optimistic, a pessimistic, and a most likely scenario, but a wider range of fundamentally and structurally different scenarios can also be useful.

Scenario analysis is different from modeling, but widely uses models. Models are often used to build scenarios, but scenarios are also often used to begin the process of model building. In the former case, the model is the link between the present and the future, and the forecasting scenarios are extrapolated from the models. In the latter case, the scenarios are exercises at designing out-of-the-box futures, and models are used to link the future with the present through back-casting.

What would the development of scenarios for analysis entail? In outlining this, I follow the paper by Bai et al. (2015) mentioned earlier. It should include recent advances in cognitive science, asking how the cognitive categories are formulated, and how decisions are made, both individually and collectively. Among other things, this would open up the question of the relationship between feedback and feed-forward (anticipation), which is fundamental to human behavior (we all live between past and future), but which has thus far not been given its due in how we model or construct scenarios (Montanari et al. 2013; Sivapalan et al. 2014). It would also imply exploring the role of creativity, intuition, and imagination in how to deal with uncertainty. Thus far, reductionist science has generally left these questions alone, or at least not studied them scientifically or integrated them in our scientific perspective on the world. Arthur (2009) broaches this issue at the interface of technology and economics, which can be extended beyond those domains into the wider study of all our cultural and social institutions. What drives innovation in those domains? Are invention and innovation stochastic, as is often argued, or not (Lane et al. 2009)? These remain open questions until we have a better understanding of the possibilities for facilitating innovations, and the spaces within which innovations occur (see Chapter 12).

Exploring multiple dimensions of innovation spaces is challenging but essential. One approach I mentioned earlier is to take a set of phenomena and project them into a high-dimensional space to identify a large number of potential relationships between them (Fontana 2012). The space is then reduced to fewer dimensions by determining which of these relationships cannot explain the phenomena at hand. Coupled with the enhancing capacity to collect and relate big data, this might be a fruitful path to reduce the path dependency of scenario development. Computing power can in principle be used not just to reduce complexity (as in the case of statistical methods), but also to increase it, if the appropriate software is developed. A reconceptualization of the role of scenarios also includes a review of the field of economics, where discussion is often predominantly about the allocation of resources within existing (technological, social, institutional, and environmental) structures. For an excellent and, detailed discussion of the need to include anticipation in economic reasoning, see Beckert (2016).

But in order to achieve desirable futures, more fundamental questions need to be asked as well: How did the structure come about, and how might it change? What are the regulatory mechanisms involved? What happens when an existing structure becomes more and more complex? Does it become more efficient and/or resilient? What does that mean for its adaptability, its capacity to change? A promising emergent field of study is therefore the attempt to bring evolutionary thinking and complex systems approaches together with behavioral and other kinds of economics and organization science in the design and analysis of scenarios (see Wilson & Kirman 2016).

Regrettably, for all the potential power of scenario building and scenario analysis, as for example shown in the work of the Oxford (www.sbs.ox.ac.uk/faculty-research/strategyinnovation/oxford-scenarios-programme-0) and Singapore (www.csf.gov.sg) futuring centers, or in the many scenarios developed by business, finance, and non-governmental organizations, this approach has not yet reached a degree of maturity in academia that is sufficient to include it centrally in our most current toolset to think out of the box about multiple sustainable futures.

For one, a broader use of scenarios in public deliberations and collective decision-making would involve the option to explore multiple potential futures with the situated knowledge of multiple stakeholders (see Wilson & Kirman 2016). But part of the challenge seems also to be that in the communities where they are used, many scenarios are too smooth, too formulaic, too predictable, and do not open up the full gamut of expectable and unexpected consequences of our choices between trajectories to move forward into the future. They seem not to be fully integrating the implications of conceiving the challenges in front of us in different domains as true complex systems, and are therefore subject to ontological uncertainty. Developing more advanced models would benefit from an academic effort that is not directly and immediately linked to applications in the real world and could delve into many advances in fields such as political, social, and cognitive science, including the idea that our individual choices are primarily determined by our emotions, rather than by reasoning, and investigations into the dynamics responsible for collective decision-making.

7

The Role of the Complex (Adaptive) Systems Approach

Introduction

The perspective that I am proposing in this book is firmly anchored in the so-called Complex (Adaptive) Systems (CAS) approach that has been developed over the last forty or so years, in both Europe and the USA. It is the approach that the multidisciplinary ARCHAEOMEDES team experimented with under my direction in the 1990s, looking at a wide range of sustainability issues in all the countries of the Northern Mediterranean rim (van der Leeuw 1998b). In this chapter, I am heavily drawing on that real-life and real-world experiment, which was the first in the world.

Systems Science

In order to understand the approach and the context in which the CAS approach has emerged and is being used, I need to go back a little bit in the history of science, to the development of noncomplex systems science around World War II and its immediate aftermath. One cannot point to a single person to whom the basic ideas of systems science go back – some argue for predecessors as early as pre-Socratic Greece and Heraclitus of Ephesus (*c.* 535–*c.* 475 BCE). Clearly there were major scientists whose ideas were moving in this direction from as early as the seventeenth century: Leibnitz (1646–1716), Joule (1818–1889), Clausius (1822–1888), and Gibbs (1839–1903) among them.

For our current purposes, two names are forever associated with this approach, Norbert Wiener and Ludwig von Bertalanffy. The applied mathematician Wiener published his *Cybernetics or Control and Communication in the Animal and the Machine* in 1948, while the biologist von Bertalanffy launched his General Systems Theory in 1946, and brought it all together in *General System Theory: Foundations, Development, Applications* in 1968. But a substantive number of others were major contributors, among them Niklas Luhmann (1989), Gregory Bateson (1972, 1979), W. Ross Ashby (1956), C. West Churchman (1968), Humberto Maturana (1979 with F. Varela), Herbert Simon (1969), and John von Neumann (1966). The approach rapidly spread across many disciplines, including engineering, physics, biology, and psychology. Early pioneers to apply it to sustainability issues are Gilberto Gallopin (1980, 1994) and Hartmut Bossel (Bossel et al. 1976; Bossel 1986).

Systems science shifted the emphasis from the study of parts of a whole, on which mechanistic science had been founded in the Enlightenment, to studying the organization of the ways in which these parts interact, recognizing that the interactions of the parts are not static and constant (structural) but dynamic. The introduction of systems science, in that respect, is a first step away from the very fragmented scientific landscape that developed after the university reform movement of the 1850s. Some of the scientists involved, such as von Bertalanffy (1949) and Miller (1995) went as far as to aim for a universal approach to understanding systems in many disciplines.

An example of the importance of systems thinking in the social sciences is presented in Chapter 5, mapping system state transitions in the Mexican agricultural system under the impact of growing urban populations in North America. Such thinking focuses on the organization that links various active elements that impact on each other. They are linked through feedback loops that can either be negative (damping oscillations so that the system remains more or less in equilibrium) or positive (enhancing the amplitude and frequency of oscillations). In the earlier phases of the development of systems thinking the focus was on systems in equilibrium (so-called homeostatic systems, such as those keeping the temperature in a room stable by means of a thermostat) and thus on negative (stabilizing) feedback loops. However, from the 1960s the importance of morphogenetic systems (in which feedbacks amplify and therefore lead to changes in the system's dynamic structure) was increasingly recognized (e.g., Maruyama 1963, 1977). Such positive feedbacks are involved in all living systems. This shift in perspective also implied that systems needed to be seen as open rather than closed because to change and grow systems need to draw upon resources from the outside, specifically energy, matter, and information. Positive feedbacks in open systems are responsible for their growth and adaptation, but can also lead to their decay. If living systems were only composed of positive feedback loops, they would quickly get out of control. Real-life systems therefore always combine both positive and negative feedback loops.

Complex Systems

The introduction of positive feedbacks and morphogenetic systems clearly prefigured the emergence of the wider Complex Systems (CS) approach. This is a specific development of General Systems Theory that originated in the late 1970s and early 1980s both in the USA (Gell-Mann 1995; Cowan 2010); Holland (1995, 1998, 2014; Arthur 1997; Anderson 1988, with Arrow and Pines), and in Europe (Morin 1977–2004; Prigogine 1980; Prigogine & Stengers 1984; Nicolis & Prigogine 1989). It is focused on explaining emergence and novelty in highly complex systems, such as those that create what we called "wicked" problems in Chapter 2. It has many characteristics of an ex-ante approach. Moreover, it is not reductionist, viewing systems as (complex) open ones, subject to ontological uncertainty (the impossibility to predict outcomes of system dynamics, cf. Lane et al. 2005). It moves us "from being to becoming" (Prigogine 1980), emphasizing the importance of processes, dynamics, and historical trajectories in explaining observed situations, and the very high dimensionality of most processes and phenomena.

When focused, as in this book, on integrated socioenvironmental systems and sustainability, the CS approach is focused on the mutual adaptive interactions between societies and their environments, and thus we speak of Complex Adaptive Systems (CAS). It emphasizes the importance of a transdisciplinary science that encompasses both natural and societal phenomena, fusing different disciplinary approaches into a single holistic one. It also shifts our emphasis away from defining entities and phenomena toward an approach that includes looking at the importance of contexts and relationships. This chapter will first briefly outline the most important differences between the Newtonian (classic) scientific approach and the CAS approach by means of examples drawn from different spheres of life. Then it will show, in the form of an example, how such an approach can change our perspective.

The Flow Is the Structure

The basic change in perspective involved is presented by Prigogine (1980) as moving from considering the flow that emerges when one pulls the plug out of a basin full of water as a disturbance (and the full basin as the stable system) to considering the flow as the (temporary, dynamic) structure and the full basin as the random movement of particles. He illustrates this by referring to the emergence of Rayleigh-Bénard convection cells when one heats a pan of oil or water.

As soon as a potential (in this case of temperature) is applied across the fluid, particles start moving back and forth across that potential (in this case the heat potential between the heated pan and the cooler air above it), that moves the hot particles in the liquid from the bottom of the dish to the top in the center of each cell, and the cooler cells back from the top to the bottom at its edges. That causes a structuring of their movement into individual, tightly packed cells. The flow of the particles transforms random movement into structured movement.

But the important lesson to retain from this example is the simple change in perspective on what is a structure and what is not, from which it follows that flows are dynamic structures (rather than static ones) generated by potentials. Irreversible direction (and thus change) therefore becomes the focus, rather than undirectedness or reversibility (Prigogine 1977; Prigogine & Nicolis 1980). Along with the perspective, the questions asked change as well, as do the kinds of data collected, and indeed the kind of phenomena that arouse interest. We will see in Chapter 9 that if we transpose Prigogine's idea of dissipative flows (flows that dissipate randomness or entropy) into the domain of socioenvironmental systems, the idea of "dissipative flow structures" (as Prigogine calls them) provides us with a very powerful tool to develop a unified perspective on human societal institutions. For example, the banking system consists of a set of institutions and rules around the flow of wealth, from poor to rich and vice versa. Large migrations as we see today in Europe are flow structures triggered by a huge differential in ease of life between war-torn/poor, and peaceful/wealthy places.

Structural Transformation

As we see in Chapter 5, the problem of understanding the long-term behavior of (natural and societal) systems that undergo state changes is inextricably bound up with questions of origins and emergence (van der Leeuw 1990), which we might more generally and neutrally subsume under the heading of structural transformation.

The central issue in any discussion of complex dynamics concerns the problem of emergence, rather than existence (Prigogine 1980). Understanding the structural development of emergent phenomena is not only the key to a better characterization of complexity, but to an understanding of the relationship between order and disorder. While these are easily defined and distinguished in physical systems, for example, this is much less obvious for societies. What is an ordered or an un- or disordered society? The same is true for the concept of equilibrium. Again, in physical systems one can observe the state of equilibrium (non-change) relatively easily, but in societal systems this is more difficult. Among other things it depends on the scale of observation.

How do such dynamic systems emerge? It is a characteristic phenomenon of complex systems that they are considered self-organizing, owing to the interactions between entities in the system. In societal systems, individuals interact in many different ways, and the result of those interactions is the (dynamic) structure of the society, which can be observed as a pattern (see Figure 7.1). That pattern, in turn, impacts upon the interacting individuals or other entities. To a large extent, these processes are

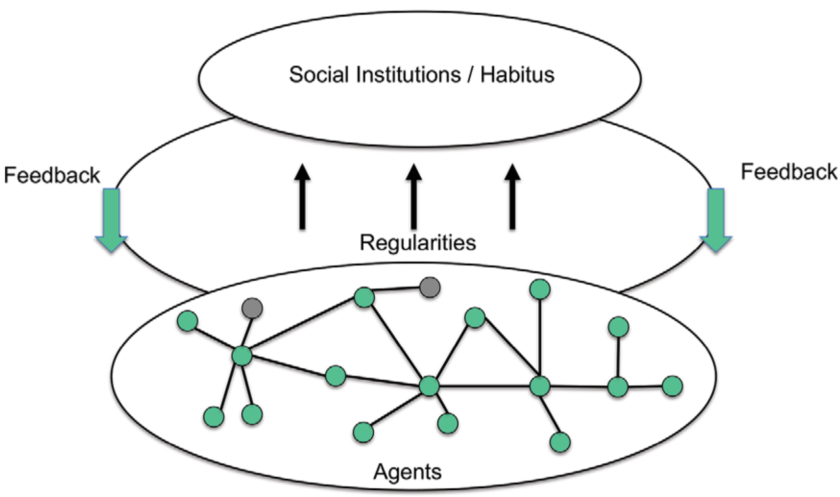

FIGURE 7.1: Interactions between individual entities at the lower level create patterns observable at the higher level which, in turn, impact on the interactions between individual entities.

also the ones that are implicated in the construction and evolution of the spatial inhomogeneity that we recognize in landscapes.

The most important part of the realignment I propose by applying CAS is to actively supplant evolutionary ideas of progressive and incremental unfolding in favor of models that recognize the nonlinear dynamical aspects of structures, and thus underline the importance of instability and discontinuity in the process of societal transformation and -evolution. In that context, I also need to point to another essential concept that has played a major role in the development of this approach: the concept of phase transitions. The reader will encounter this concept extensively in the third part of this book. It is the idea that the underlying dynamics of a self-organizing system can reach a state in which they will change their behavior fundamentally. The conditions under which this happens may be predictable, but the result of the changes is not, and different states of the restructured system may emerge. For example, the temperature and humidity under which snowflakes appear are entirely predictable, but the geometric features of the flakes themselves are nevertheless entirely unpredictable. These are phase transitions that have, of course, been observed since the early history of mankind. But complex systems theorists have developed interesting and novel ways to understand such structural changes in dynamics, pointing out that zones of predictability and unpredictability can coexist. In the social sciences, such phase changes are generally referred to as tipping points. (For a detailed introduction to this topic see for example Scheffer 2009.)

History and Unpredictability

A fundamental characteristic of the CAS approach to emergence is the fact that it emphasizes both history and unpredictability. By considering observed patterns at a macro-level as the result of interactions between independent entities at a level below, at once the relationships between these entities are of fundamental importance to explain the patterns observed, and because the entities are independent it is impossible to predict their collective behavior, so that in the case of complex adaptive systems the pattern observed is also unpredictable.

A good case in point is the major traffic jam that prevents one from getting to the airport that I mentioned in Chapter 2. All the drivers who are part of it have their own reasons for driving and their own planned trajectories. As their paths cross and intersect, there are points where their movements impact on each other to the point of immobilizing them.

Situations like this cannot be explained a posteriori. The only way to understand them is by identifying and studying the history of the dynamics involved at the level of the individual participants. Helbing very successfully applied this approach to pedestrian traffic problems and has now been extending it to more general societal challenges (e.g., 2015, 2016).

The closest well-known theoretical position in the social sciences is that of Bourdieu (1977) and Giddens (1979, 1984), who emphasize the relationship between individual behavior and collective behavior patterns (habitus to use their term) that are anchored in a society through customs and beliefs. To understand a group's habitus one needs to go back in time and identify the dynamics that were responsible for originating the habitus's different components.

Because the complex systems approach is ex-ante in its study of the emergence of phenomena, it describes such phenomena in terms of possibilities and (at best) probabilities, in effect pointing to multiple futures and options. It can therefore not predict with any certainty as is done when a (reductionist) cause-and-effect chain is assumed. At best it can, under certain circumstances, point to places in a system's trajectory when one change or another is probable.

Underlying this change in perspective is the following reflection. Any attempt to deal with the morphogenetic properties of dynamic systems must acknowledge the important role played by unforeseen events and the fact that actions often combine to produce phenomena we might define as the spontaneous structuring of order. The observation that apparently spontaneous spatiotemporal patterning can occur in systems far from equilibrium, first made by Rashevsky (1940) and Turing (1952), was then developed by Prigogine and coworkers. These have coined the term "order through fluctuation" to describe the process (e.g., Nicolis & Prigogine 1977).

The fundamental point is that non-equilibrium behavior – an intrinsic property of many systems, both natural and social – can act as a source of self-organization, and hence may be the driving force behind qualitative restructuring (state change) as the system evolves from one state to another. This assumes that dynamic structures rely on the action of fluctuations that are damped below a critical threshold and have little effect on the system, but can become amplified beyond this threshold and generate a new macroscopic order (Prigogine 1980). Evolution thus occurs as a series of phase transitions between disordered and ordered states; as successive bifurcations generating new ordered structures

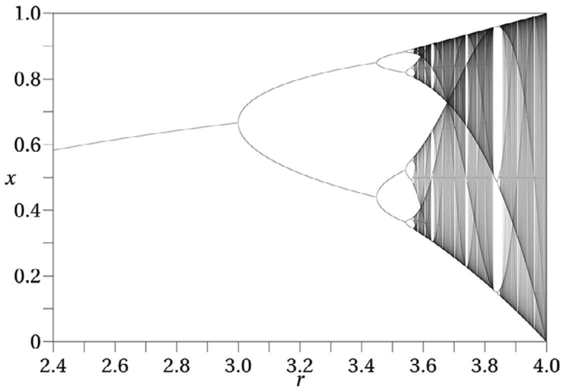

FIGURE 7.2 Bifurcation diagram of a logistic population dynamic. For a detailed explanation see https://en.wikipedia.org/wiki/Logistic_map. (Source: Wikimedia Commons, published under CC-0)

(Figure 7.2). An interesting example of this is the logistic map developed to look at the dynamics between population reproduction (where the current population is small) and population starvation (where the growth will decrease at a rate proportional to the value obtained by taking the theoretical "carrying capacity" of the environment less the current population).

In this perspective, instability, far from being an aberration within stable systems, becomes fundamental to the production of resilience in complex systems.[1] The long-term evolution of structure can be seen as a history of discontinuity in geographical (or other kinds of) space; i.e., history not as a finely spun homogeneous fabric, but as being punctuated by a sequence of phase changes resulting from both intentional and unintentional actions, such as have been postulated for biological evolution by Gould and Eldredge (1972). Such discontinuities are in fact thresholds of change ("tipping points" in more recent popular parlance), where the role of agency and/or idiosyncratic behaviors assumes paramount significance in the production and reproduction of structures.

Chaotic Dynamics and Emergent Behavior

For biological, ecological, and, by implication, societal systems, the discovery of self-induced complex dynamics is of profound importance, since we can now identify a powerful source of emergent behavior. Far from promoting any pathological trait, aperiodic oscillations resident in chaotic dynamics perform a significant operational role in the evolution of the system, principally by increasing the degrees of freedom within which it operates. This is another way of saying that chaos promotes flexibility, which in turn promotes diversity.

In turn, this throws light on some of the problems inherent in the concept of adaptation, a difficult concept in the study of evolution. Briefly put, since the existence of chaos severely calls into question concepts such as density-dependent growth in (human and) biological populations, we might be able to see a theoretical solution in the coexistence of multiple attractors (see below) defining a flexible domain of adaptation, rather than any single state. We thus arrive at a paradox where chaos and change become responsible for enhancing the robustness or the resilience of the system.

From a philosophical perspective, it might be said that the first thing that a nonlinear, dynamic, or complex systems perspective does is to effectively destroy historical causation as a linear, progressive, unfolding of events. It forces us to reconceptualize history as a series of contingent structurations that are the outcome of an interplay between deterministic and stochastic processes (see Monod 2014). The manifest equilibrium tendencies of linear systems concepts also stand in contrast to their nonlinear counterparts by virtue of the fact that nonlinear systems possess the ability to generate emergent behavior and have the potential for multiple domains of stability that may appear to be qualitatively different.

Nonlinear systems can thus be described as occupying a state space or possibility space within which multiple domains of attraction exist. For societal systems, this is a consequence of the fact that they are governed by positive feedback or self-reinforcing processes, and that they are coupled to environmental forces that are either stochastic or periodically driven.

Diversity and Self-Reinforcing Mechanisms

Clearly, the conditions around which systemic configurations become unstable and subsequently reorganize or change course have no inherent predictability; the diversity that characterizes all living behavior guarantees this. It is this diversity that is critically important from an evolutionary perspective because it accounts for the systems' "evolutionary drive" (Allen & McGlade 1987b, 726). The existence of idiosyncratic and stochastic risk-taking behaviors acts to maintain a degree of evolutionary slack within systems; error-making strategies are thus crucially important (Allen & McGlade 1987a). In fact, without the operation of such non-optimal and unstable behaviors, we effectively reduce the degrees of freedom in the system and hence severely constrain its creative potential for evolutionary transformation.

One of the enduring issues isolated by the above methods is the importance of positive feedback or "self-reinforcing mechanisms," as Arthur (1988, 10) has characterized them. Processes such as reproduction, co-operation, and competition at the interface of individual and community levels can, under specific conditions of enhancement, generate unstable and potentially transformative behavior. Instability is seen as a product of self-reinforcing dynamic structures operating within sets of relationships and at higher aggregate levels of community organization. This is clearly the case in a range of phenomena, from population dynamics to the complex exchange and redistribution processes such as occur in most food and trade webs. Of crucial importance to an understanding of these issues is the fact that networks of relationships are prone to collapse or transformation, independent of the application of any external force, process, or information. Instability is an intrinsic part of the internal dynamic of the system.

Focus on Relations and Networks

The relational aspect of the complex systems approach is another major innovation in its own right. Much of our western thinking is in essence categorization – or entity– based. In a fascinating essay, "Tlön, Uqbar, Orbis Tertius," Borges (1944) evokes how nouns and entities (things) are essential to much of western thinking by arguing that in a world where there are no nouns – or where nouns are composites of other parts of speech, created and discarded according to a whim – and (thus) no things, most of western philosophy becomes impossible. Without nouns about which to state propositions, there can be no a priori deductive reasoning from first principles. Without history, there can be no teleology. If there can be no such thing as observing the same object at different times, there is no possibility of a posteriori inductive reasoning (generalizing from experience). Ontology – the philosophy of what it means to *be* – is then an alien concept. Such a worldview requires denying most of what would normally be considered common sense reality in western society.

Accepting that entities are essential to much of our western intellectual tradition raises a question about verbs. A language without verbs cannot define, study, or even conceive of relationships, whether between entities, different moments in time, or different locations in space. Verbs, and relationships, are essential to conceive of process, interaction, growth, and decay. In moving from being to becoming, emphasizing that structures are dynamic, the complex systems approach brings these two perspectives together, highlighting the need in our science, as in our society, to think and express ourselves in terms of both entities and relationships.

This in turn has triggered one of the major innovations of the complex systems approach: the conception of processes as occurring in networks that link participating entities. Currently one of the cutting edges of the complex systems approach, popularized by Watts (2003), this is an important innovation in many domains of social science research, with a certain emphasis on mapping the links (edges in network parlance) that link entities (called nodes in network science), and drawing up hypotheses about the ways in which the structure of the links impacts the processes driven by the participant entities (Hu et al. 2017). These networks can often be decomposed in clusters with more or less frequent interactions, thus allowing us to view the dynamics of interaction as occurring in a hierarchy of such clusters.

Whereas it is acknowledged in the natural and life sciences that the organization of complex systems in such clusters is a major factor in determining their trajectories, this is much less generally accepted in some of the social sciences, where the idea persists that looking at individuals and at the whole population (by means of statistical tools) is sufficient. Lane et al. (2009) argue for adopting an organization perspective in the social sciences, as identification of different levels of organization seems especially relevant because societies are composed of many different network levels between individuals and their societies. At each such level, the networked participants differ, and so do their ideas, concepts, and language.

Deterministic Chaos

The complexity of dynamical systems is in large part a consequence of the existence of multiple modes of operation. Much of the inherent instability in, e.g., exchange systems, reflects the dominance of highly nonlinear interactions. It is the role of such nonlinearities that has led to observations on the emergence of erratic, aperiodic fluctuations in the behavior of biological populations (May & Oster 1976) and in the spread of epidemics (Schaffer & Kot 1985a, b). These highly irregular fluctuations (often dismissed as environmental "noise") are manifestations of deterministic chaos. The important contribution of this work (Lorenz 1963; Li & Yorke 1975) is that it demonstrates that chaotic behavior is a property of systems unperturbed by extraneous noise. As a result of subsequent observations in the physical, chemical, and biological sciences, we now assume that the seeds of aperiodic, chaotic trajectories are embedded in all self-replicating systems. The systems involved have no inherent equilibrium but are characterized by the existence of multiple equilibria and sets of coexisting attractors to which the system is drawn and between which it may oscillate.

Another important characteristic displayed by all chaotic systems, whether social, biological, or physical, is that, given any observational point, it is impossible to make accurate long term predictions (in the conventional scientific sense) of their behavior. This property has come to be known as "sensitivity to initial conditions" (Ruelle 1979, 408), and simply means that nearby trajectories will diverge, on average exponentially. In popular language, this is known as the "butterfly effect" – the idea that the flapping of the wings of a butterfly somewhere in the world may engender major changes elsewhere. Or, in terms of the well-known science fiction writer Ray Bradbury (1952), that someone treading on a piece of grass in the distant past may have an impact on a presidential election of today …

Attractors

The evolution of a dynamical system is acted out in so-called phase space. Imagine the simple example of the motion of a pendulum (Figure 7.3a and b). If it is allowed to move back and forth from some initial starting condition, we can describe its state by recourse to speed and position. From whatever starting values of position and velocity, it returns to its initial vertical state, damped by gravity, air resistance, and other forms of energy dissipation. The phase-space in which the pendulum dynamics are acted out is defined by a set of coordinates, displacement, and velocity. All motions converge asymptotically toward an equilibrium state referred to as a point attractor, since it "attracts" all trajectories in the phase space to one position. Moreover, the system's long-term predictability is guaranteed.

A second type of attractor common in dynamical systems is a limit cycle. The representation of this in phase space indicates periodic cyclical motion (Figure 7.3c), and like the point attractor it is stable and guarantees long-term predictability.

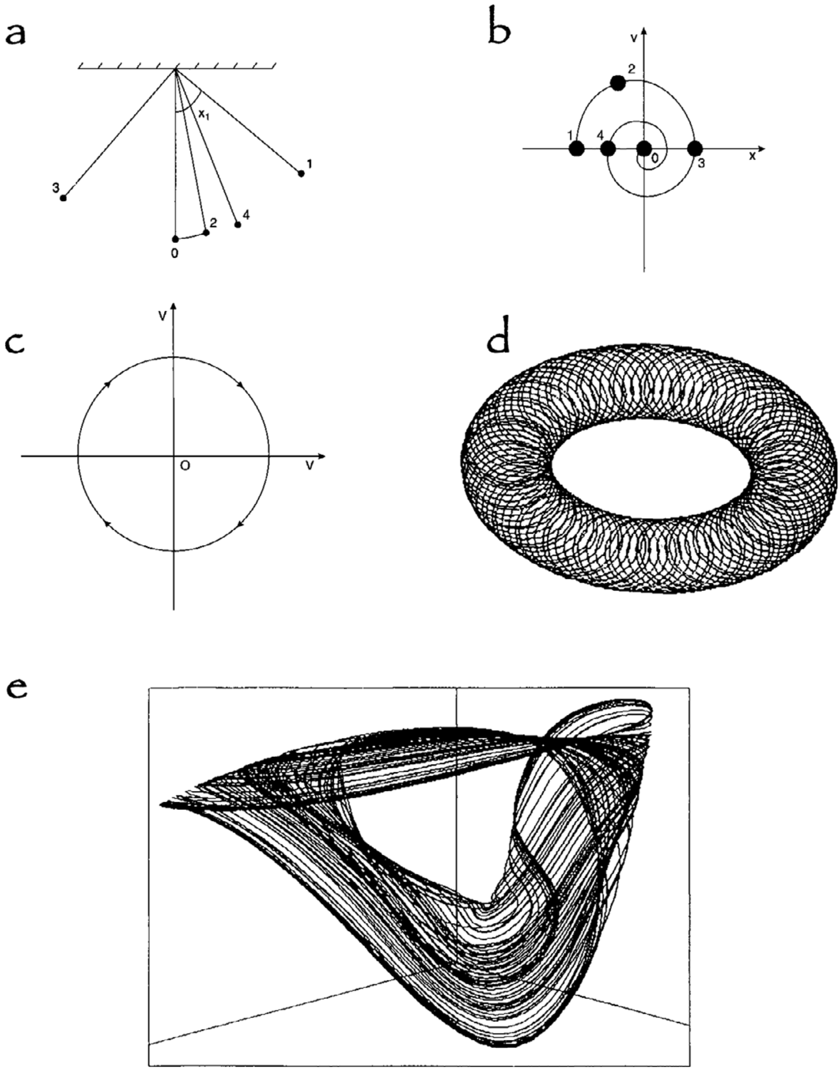

FIGURE 7.3 Different kinds of attractor. For explanation see text. (Copyright van der Leeuw)

But, unlike the point attractor, the periodic motion is not damped to the point that the system eventually moves to a single, motionless, state. Instead, it continues to cycle.

A third form of attractor is known as a torus; it resembles the surface of a doughnut (Figure 7.3d). Systems governed by a torus are quasi-periodic, i.e., a periodic motion is modulated by another operating on a different frequency. This combination produces a time series whose structure is not clear, and under certain circumstances can be mistaken for chaos, notwithstanding the fact that the torus is ultimately governed by wholly predictable dynamics. An important facet of toroidal attractors is that although they are not especially common, quasi-periodic motion is often observed during the transition from one typical type of motion to another. As Stewart (1989, 105) points out, toroidal attractors can provide a useful point of departure for analyses of more complex aperiodicities such as chaos.

There are many other ways in which various combinations of periodicities may describe a system's behavior, but the most complex attractor of all is the so-called strange or chaotic attractor (Figure 7.3e). This is characterized by motion that is neither periodic nor quasi-periodic, but completely aperiodic, such that prediction of the long-term behavior of its time evolution is impossible. Nonetheless, over long time periods regularities may emerge, which give the attractor a degree of global stability, even though at a local level it is completely unstable. An additional feature of chaotic attractors is that they are characterized by noninteger or fractal dimensions (Farmer et al. 1983). Each of the lines in the phase space trajectory, when greatly magnified, is seen to be composed of additional lines that themselves are structured in like manner. This infinite structure is characteristic of fractal geometries such as Mandelbrot sets (Mandelbrot 1982).

As a final observation in this classification of dynamical systems and attracting sets, we should note that beyond the complexity of low-dimensional strange attractors we encounter the full-blown chaos characterized by turbulence; indeed, to a large extent, the quintessential manifestation of chaotic behavior is to be found in turbulent flows, for example in liquids or gases. Examples of this highly erratic state are a rising column of smoke, or the eddies behind a boat or an aircraft wing.

Multi-Scalarity

The links in a complex systems network can occur at very different spatiotemporal and organizational scales, and the multi-scalarity of the complex systems perspective is one of its important characteristics. Traditionally we select only two or three of those scales (macro, meso, and/or micro) to analytically investigate the processes involved. In most cases, that will give us a rather limited and arbitrary insight in what is actually going on. Hence, dynamic modeling of the interactions between many different spatiotemporal scales has become an important tool in CAS work. In landscape ecology, for example, Allen and colleagues (1982, 1992) have developed an approach in which they sort component dynamics of a complex system based on their clock time, distinguishing different levels in a temporal hierarchy. In such a hierarchy, components with a faster clock time can react more rapidly to changing circumstances, whereas the components with a slower clock time tend to stabilize the system as a whole.

This has in the last decade and a half led to the elaboration of novel tools to understand the dynamics of complex multi-scalar systems, drawing heavily on different modeling techniques, whether defining the dynamic levels in terms of differential equations or doing so in agent-based models through the definition of the rules that the agents follow.

Occam's Razor

Yet another important aspect of the complex systems approach is the fact that we can no longer heed the old precept that, when confronted with two different solutions, choosing the simpler of the two is best. Indeed, that "rule of parsimony" – which is also called Occam's Razor after a medieval Franciscan friar, scholastic philosopher, and theologian (*c.* 1287–1347) – is one of the important building blocks of reductionist science. It leads to striving for scientific clarity by reducing the number of dimensions of a phenomenon or process, and thus ignoring seemingly irrelevant yet pertinent information. That in turn facilitates the kind of linear cause-and-effect narratives that we find increasingly counterproductive in our attempts at understanding the world around us.

The complex systems approach, on the other hand, searches for the emergence of novelty, and is thus focused on increases in the dimensionality of processes being investigated. It is the fundamental opposite of the traditional reductionist approach. Rather than assuming that phenomena are simple, or can be explained by simple assumptions, it assumes that our observations are the result of interactions between complex, multidimensional processes, and therefore need to be understood in such terms.

Some Epistemological Implications

Before we conclude this chapter, we need to devote a few words to some of the epistemological implications of the complex systems approach. One of these concerns the nature of subject–object relationships. As it is acknowledged that the "real world" cannot be known, the object with which the person investigating a problem has to cope is no longer the real world, but his/her own perception of that world. Thus, new relationships are added to those between the scientist and the objects of his or her research, notably between the researcher and his perceptions of the phenomena studied: the observer's subjectivity is acknowledged and taken as the basis of all understanding, even if the methodology involved is a scientific one (van der Leeuw 1982).

This change in perspective is of crucial importance because it loosens the (implicit and often unconscious) tie between the models used and the observed real world. Implied is an alternative to the search for the (one) truth that we have so long strived for in (neo) positivist science. Rather than study the past as closely as possible in the hope that it will be able to explain everything, we need to acknowledge that studying a range of outcomes, investigating a range of causes, or building a range of models of the behavior of a system is a more valuable focus. These models may be known, whilst the phenomena can never be known, if only because the infinity of the number of their dimensions implies that all knowledge must remain incomplete. Thus, the focus is on generating multiple models that help an essentially intuitive capacity for insight to understand the phenomena studied. It brings the awareness that models are at once more and less than the reality that we strive to perceive. Although explanation and prediction may be schematically symmetrical, and are argued by some positivist philosophers of science (e.g., Salmon 1984) to be logically symmetrical as well, the fact that the one uses closed categories and the other open ones implies that they are substantively absolutely asymmetrical. As scientists, we have to acquiesce in this because it is all we will ever be able to work with. And it opens up the potential to do much more than we have hitherto thought.

Other implications concern the nature of change. I have already mentioned that in the traditional approach change does, or does not, manage to transform something preexistent into something new. Change is a transition between two stable states. In the CAS perspective developed here, change is presumed to be fundamental and never to cease (even though the rate of change may be slow). This approaches the historical ideas of Braudel (e.g., 1949, 1979), who saw change as fundamental and relative, occurring at different rates so that compared with the speed of short-term change, long-term change may seem to equal stability. Stability is thus a research device that does not occur in the real world. Making use of it is concomitant with using an absolute, non-experiential timescale. One's perception of time is necessarily relative and both dependent on the position of the observer and related to the rate of change that occurs. Both these aspects are part of our everyday experience, summed up by the anomaly that when we are very busy, we seem to be able to fit more experiences (thoughts, emotions) into what at the time seems a period that goes very fast, because we hardly stop to think. On the other hand, in a period when we have little to do, time seems to stretch endlessly. Yet, looking back on our lives, we seem to have been subject to a sort of Doppler effect, because the periods in which much happened seem longer than those in which little occurred, even though measured in days, months, and years they are not. Thus, to construct a state of absolute stability, it is necessary to avail oneself of neutral time or absolute time, which is independent of our experience.

The nature of change is – not surprisingly – also different in the two approaches. In the traditional systems approach (when the situation is not one of oscillation within goal-range), developments converge, so that diversity is reduced and information is made to disappear. In short, developments through time are thought to accord with the Second Law of Thermodynamics. But that approach is only suited to the study of non-living phenomena in closed systems. The dynamical (complex adaptive) systems approach, on the other hand, focuses on divergence, on growth. It is therefore best suited to research on change in an amplification network, such as the mutual amplification mechanisms that effect changes in ecosystems, whereas the analytical approach prevails in the study of the structure of established relationships, such as genetic codes.

Finally, the way in which the level of generalities and that of details relate to each other is quite revealing of the underlying approach chosen by a researcher. Owing to its after-the-fact perspective, the analytical approach has more of a tendency to stress the generalities to explain the details. On the other hand, a perspective that is not sure of its perception of the phenomena as they present themselves, or even of the fact that it perceives them all, is less able to point to specific general elements, but is more likely to see the result as the interaction of all (or most of) the perceived details involved. Such an explanation would be in terms of the patterns resulting from the interactions of individual decisions, their similarities, and their differences, as well as their relationships to each other. Such explanations would necessarily be of a proximate nature.

NOTE

1 To avoid a long, distracting exposé on resilience at this point, I simply refer to the Merriam-Webster definition: "an ability of a system to recover from or adjust easily to misfortune or change." The concept is discussed at some length in Chapter 5.

PART II

8

An Outline of Human Socioenvironmental Coevolution

"*In the long run, History is the story of information becoming aware of itself.*" (Gleick, 2012, 12)

Introduction

In the first part of this book, and particularly in Chapters 4–7, I have presented the basis of this book's argument by presenting some of the salient characteristics of my approach, such as taking a long-term ex-ante perspective, learning *from* the past *about* the present *for* the future, using complex systems thinking, etc.

This chapter begins the presentation and discussion of the central theses of this book by drawing an outline of the long-term coevolution of human societies, focusing on the interaction between cognition, technology, social organization, and societies' relation with the environment. It will be followed by six chapters that describe the dynamics involved at different spatiotemporal scales, and from different perspectives.

Two of the chapters in this middle section use the same perspective but elaborate it at different scales. The first of these, the current chapter, first outlines aspects of the very long-term coevolution of human cognition (from *c.* 2.5 MY BP to *c.* 0 CE) with its technology, societal organization, and environment. Chapter 15, which begins the third part of the book, is the continuation of this story, focusing on how the European world system emerged and evolved over the period from *c.* 1000 CE to the present. That chapter instantiates Wallerstein's perspective on the "Modern World System," (1974–1989) and emphasizes, at the European scale, the three major tipping points that have, each time, brought that system to the edge of disintegration, and the changes that, nevertheless, enabled it to continue its growth and evolution to encompass the global system of the present day.

Chapter 10 looks at eight centuries of socioenvironmental evolution in the western Netherlands in some detail and emphasizes the bootstrapping process that transformed the technology, the environment, the economics, the institutions, and the geography of that region. It sees that process in terms of the continued interaction between solutions and challenges. In that process, unanticipated consequences of earlier actions play a fundamental role.

In Chapter 9, I develop parts of a theoretical approach that enables me to consider these case studies as instances of transformations in the organization of information processing. This approach adopts Prigogine's "dissipative flow structure" idea to explain how the interaction between flows of energy, matter, and information together structure more and more complex societies. In Chapter 11, that approach is then discussed on a more theoretical level by looking at information processing as a percolation phenomenon, in which the relationship between network activation and network size in terms of the average number of edges per node determine the main characteristics of the system.

Making information processing the explanatory core of my approach, and combining it with the Complex (Adaptive) Systems (CAS) perspective that emphasizes the need for the study of emergence, prompts me to look at inventions (Chapters 12 and 13) as shaped in the interaction between the material niche created by a technological system and the perception thereof by the agents in it. To conclude this middle section of the book, I then describe a model of the dynamic of transformations in the transition from village to town systems (Chapter 14).

Human Information Processing Is at the Core

The core of my argument is that societies are collective information-processing organizations, and that the evolution of human information processing is therefore at the center of the long-term evolution of human societies. Why have I chosen this approach, which is different from most other social science approaches to the long-term evolution of humanity (except for a few archaeologists such as Wright (1969) and Johnson (1982), and the economist Auerwald (2017)? The reason is that I am here looking for a general rather than a series of proximate explanations of changes in human behavior over long-term time. In other words, I am looking for a dynamic that can explain the emergence of human societal behavior under a wide range of circumstances, as well as explain how that behavior has changed.

It seems obvious that human responses to the environment, as well as human technology and human social and economic behavior are determined by human cognition and organization. (See Leroi-Gourhan's fundamental treatment of these relationships: 1943, 1945, 1993). Our cognitive apparatus is the universal interface between each one of us and his/her environment, shaping how we perceive that environment and the nature of the actions we could potentially undertake. This apparatus is acquired through learning from an individual's earliest days, and that learning is shaped by the sociocultural and natural environments in which it occurs. This in turn shapes the ways in which human beings behave. An individual uses the tools for thought and action he or she has acquired in order to ensure his or her survival, that is to ensure his or her continued subsistence and fulfill any other needs the individual might have. It is such use of tools for thought and action that I here call information processing – the gathering of information about an individual's or group's circumstances, and the organization and execution of actions appropriate to those circumstances.

But this is only part of the overall argument. Contemporary science is based on the assumption that there are three fundamental commodities in nature: matter, energy, and information. The first two of these are essential to the physical survival of individuals, whether human or nonhuman. Energy can be turned into matter and vice versa, and both are subject to what physicists call the law of conservation, which implies that they cannot be shared but can be transmitted. The person who hands over an object, or performs an energy-related task, is no longer in possession or control of the energy or matter that was used or handed over. Information and its processing determine how we acquire matter and energy, and what we do with it. But, contrary to the other two commodities, information can actually be shared: if I show someone how to do something, that does not mean that subsequently I no longer know how to do it. Tools for thought and action can be shared.

Taking the argument one step further, it is easy to see that human societies are dependent on the sharing of these tools for thought and action. The set of such tools that a group of people or a society share is what we commonly call their culture – their institutions, ways of doing things, knowledge about how to survive in different environments, artifacts, etc. Hence, human societies are collective information processing organizations.

The long-term evolution of human societies is therefore in the first instance the evolution of human information processing (or, as recently described by Auerswald (2017, 1) "the advancement of code"), and this chapter is meant to present the reader with a 3 million year overview of human history from that perspective, based on a series of papers I developed with Dwight Read (2008, 2009, 2015).

That history can be divided into two parts, the first of which is essentially biological (the growth of our brain and its cognitive capacity), whilst the second is essentially sociocultural (learning to exploit the full capacity of the evolved brain). Hence, this chapter is divided into two major sections, presenting respectively the biological evolution and the cultural evolution of cognition. The chapter concludes with a description of a simple model that can integrate the two.

It should be emphasized that each of these two sections is based on insights and knowledge from different disciplines and subdisciplines. The first part derives from arguments in evolutionary biology and evolutionary psychology, and therefore is based on an essentially life science epistemology and argument, and data deriving from ethology, paleoanthropology, and cognitive science. It attempts to reconstruct the evolution of the cognitive capabilities of the human species leading up to the present by comparing the capabilities of living primates, the fossil remains of – and the artifacts made by – hominins and modern humans at various stages of their development, and the physical and behavioral characteristics of modern human beings. This leads to a patchwork of data points and ideas that, in so far as it coherently holds together, finds its principal interest in the fact that it raises new questions and provides a basis for the arguments in the second part.

That second part, on the other hand, derives from arguments in archaeology and history, which are based on humanities – and social science epistemologies, and data and insights from archaeological, written historical, and modern observational sources. It attempts to outline the development of societal organization from small roaming gatherer-hunter-fisher bands, via villages, urban systems, and empires to the present-day global society, with a focus on the roles and forms that energy and information processing assume in that development. In combining these approaches, I am using the constraints and opportunities afforded by the bio-social nature of our species to explain observed phenomena in human history, and couching the explanation in systemic terms, which many archaeologists and most historians may initially have difficulty recognizing. My justification for doing this is the fact that most, if not all, transdisciplinary research must aim to constructively upset the practitioners of the disciplines involved in order to raise new questions and challenges for consideration by the communities practicing these disciplines as well as by others, and thus to stretch the envelope of our knowledge and insights. I hope that the direction in which I have attempted to stretch that envelope can make a contribution to the current sustainability debate.

The Biological Evolution of the Human Brain

The first part of the coevolution story concerns the physical development of the human brain and its capacity to deal with an increasing number of simultaneous information sources. The core concept that is most relevant here is the evolution of the short-term working memory (STWM), which determines how many different sources of information can be processed interactively in order to follow a particular train of thought or course of action.

There are different ways to reconstruct this evolution (Read & van der Leeuw 2008, 2009, 2015). Indirectly, it can be interpolated by comparing the STWM of chimpanzees (our closest common ancestor in the evolutionary tree that produced modern humans) to that of modern human STWM. In the act of cracking a nut, 75 percent of chimpanzees are able to combine three elements (an anvil, a nut, and a hammerstone), which leads us to think that the STWM of chimpanzees is 3 ± 1 (because 25 percent of them never master cracking nuts). Experiments with different ways of calculating the human capacity to combine information sources, on the other hand, seem to point to an STWM of 7 ± 2 for modern humans. This difference coincides nicely with the fact that chimpanzees reach adolescence after three to four years and modern humans at age thirteen to fourteen. We therefore assume that the growth of STWM occurs before adolescence in both species, and that the difference in the age at which adolescence is reached explains the difference in STWM capacity (Figure 8.1, see Read & van der Leeuw 2008, 1960).

Another approach to corroborating the growth of STWM is by measuring encephalization – the evolution of the brain to body weight ratio of modern humans' ancestors through time. The evolution of these ratios is based on the skeletal remains of each subspecies found and, as shown in Figure 8.2, corresponds nicely to the evolution of the STWM as has been

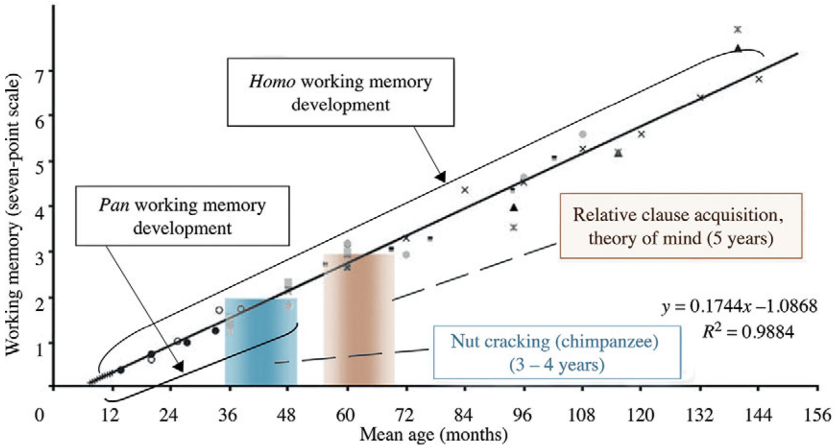

FIGURE 8.1 The relationship between cognitive capacity and infant growth in *Pan* and in *Homo sapiens sapiens*. The trend line is projected from the regression of time-delay response (Diamond and Doar, 1989) on infant age. Data are rescaled for each dataset to make the trend line pass through the mean of that dataset. Working memory scaled to STWM = 7 at 144 months. The "fuzzy" vertical bars compare the age of nut cracking among chimpanzees with the age for relative clause acquisition and theory of mind conceptualization in humans. [Data on STWM are here represented by the following symbols: • = Imitation (Alp 1994); + = time delay (Diamond & Doar, 1989); □ = number recall (Siegel & Ryan 1989); x = total language score (Johnson et al., 1989); x = relative clauses (Corrêa 1995; ■ = count label, span (Carlson et al., 2002); o = 6 month retest (Alp 1989); ▲ = world recall (Siegel & Ryan 1989); • = spatial recall (Kemps et al., 2000); ♦ = relative clauses (Kidd & Bavin 2002); -, spatial working memory (Luciana & Nelson 1998); —— = linear time delay (Diamond & Doar 1989)]. (Source: Read 2008 under CC-BY-NC)

established based on the way and extent to which these ancestors were able to shape stone tools (see Read & van der Leeuw 2008, 1964).

Whereas both these approaches depend in fact on extrapolation and therefore do not provide any direct proof for our thesis, the study of the way and extent to which the various subspecies and variants preceding modern humans have been able to shape stone tools does provide some direct evidence, which is summarized in Table 8.1. This links the evolution of actions in stone toolmaking with the concepts that they define, the number of dimensions involved in manufacturing actions, and the STWM required, and refers to stone tools that provide examples of each stage. It shows how it took at least about 2 million years for the human STWM

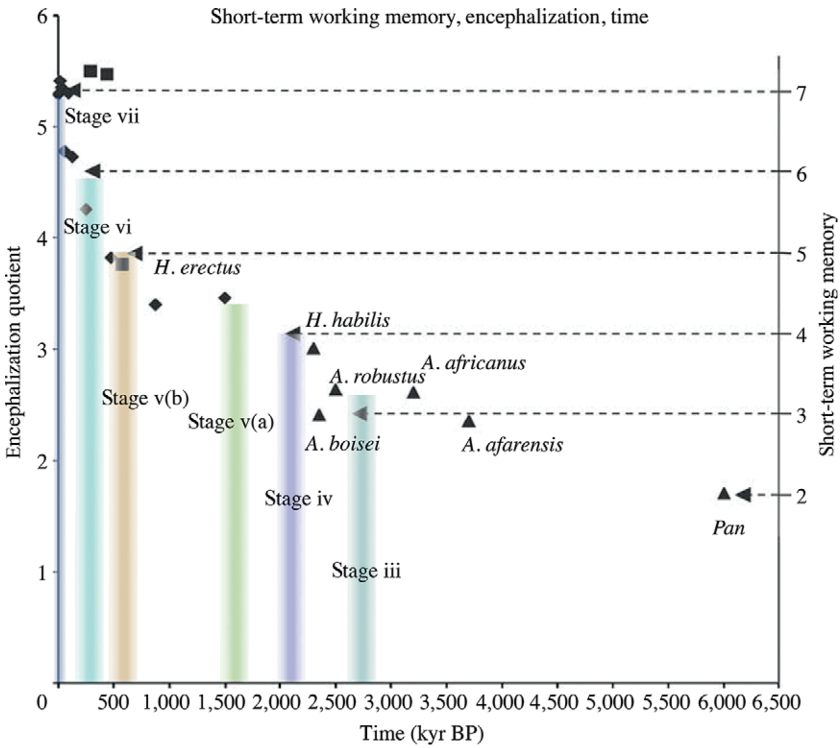

FIGURE 8.2 Graph of encephalization quotient (EQ) estimates based on hominid fossils and *Pan* (Chimpanzees). Early hominid fossils have been identified by taxon. Each data point is the mean for hominid fossils at that time period. Height of the "fuzzy" vertical bars is the hominid EQ corresponding to the data for the appearance of the stage represented by the fuzzy bar. Right vertical axis represents STWM. Data are adapted from the following: triangles: Epstein 2002; squares: Rightmire 2004; diamonds: Ruff et al. 1997. EQ= brain mass/(11.22 * body mass$^{0.76}$), *cf.* Martin 1981. (Source: Read 2008 under CC-BY-NC)

capacity of 7 ± 2 to develop, beginning with the Lokalalei artifacts and ending with the capacity to create blade tools.

Mastering the three-dimensional conceptualization of stone tools (see Figure 8.3 a–d) (Pigeot 1991; van der Leeuw 2000) is a good example of how this worked. The first tools are essentially pebbles from which at one point of the circumference (generally where the pebble is pointed) a chip has been removed to create a sharper edge (Figure 8.3a). Removing the flake requires three pieces of information: the future tool from which the

Table 8.1 Evolution of stone tool manufacture from the earliest tools (stage 2, > 2,6 M. years ago; found in Lokalalei 1) to the complex blade technologies (stage 7, found in most parts of the world *c.* 50,000 BP). Columns 2–5 indicate the observations leading us to assume specific STWM capacities; Column 8 (bold) indicates the stage's STWM capacity and column 9 the approximate age of the beginning of each stage. Column 10 refers to the relevant artifact categories documenting the stages. For a more extensive explanation, see Read & van der Leeuw 2008: 1961–1964).

Stage	*Concept*	*Action*	*Novelty*	*Dimensionality*	*Goal*	*Mode*	*STWM*	*Age BP*	*Example*
1	Object attribute	Repetition possible	Functional attributes present; can be enhanced	0	Use object		**1**		
1A	Relationship between objects		Using more than one object to fulfill task	0	Combine objects		**2**		
2	Imposed attribute	Repetition possible	Object modified to fulfill task	0	Improve object		**2**	> 2.6 My	Lokalalei I
3	Flaking	Repetition	Deliberate flaking without overall design	0: incident angle < 90°	Shape flakes		**3**	2.6 My	Lokalalei 2C
4	Edge	Iteration: each flake controls the next	*Debitage*: flaking to create an edge on a core	1: line of flakes creates partial boundary	Shape core	1	**4**	2.0 My	Oldowan chopper
5	Closed curve	Iteration: each flake controls the next	*Debitage*: flaking to create an edge and a surface	2: edges as generative elements of surfaces	Shape biface from edge	2	**4.5**		

5A	Surface	Iteration: each flake controls the next	*Faconnage*: flaking used to make a shape	2: surfaces intended elements, organized in relation to one another	Shape bi-face from surfaces	2	5	500 Ky	Biface handaxes
6	Surface	Algorithm: removal of a flake prepares the next	Control over location and angle to form surface	2: Surface of flake brought under control, but shape constraint	Serial production of tools	3	6	300 Ky	Levallois
7	Intersection of planes	Recursive application of algorithm	Prismatic blade technology: monotonous process	3: flake removal retains core shape – no shape constraint	Serial production of tools	4	7	.50 Ky	Blade technologies

Source: Read & van der Leeuw 2015; permission CUP.

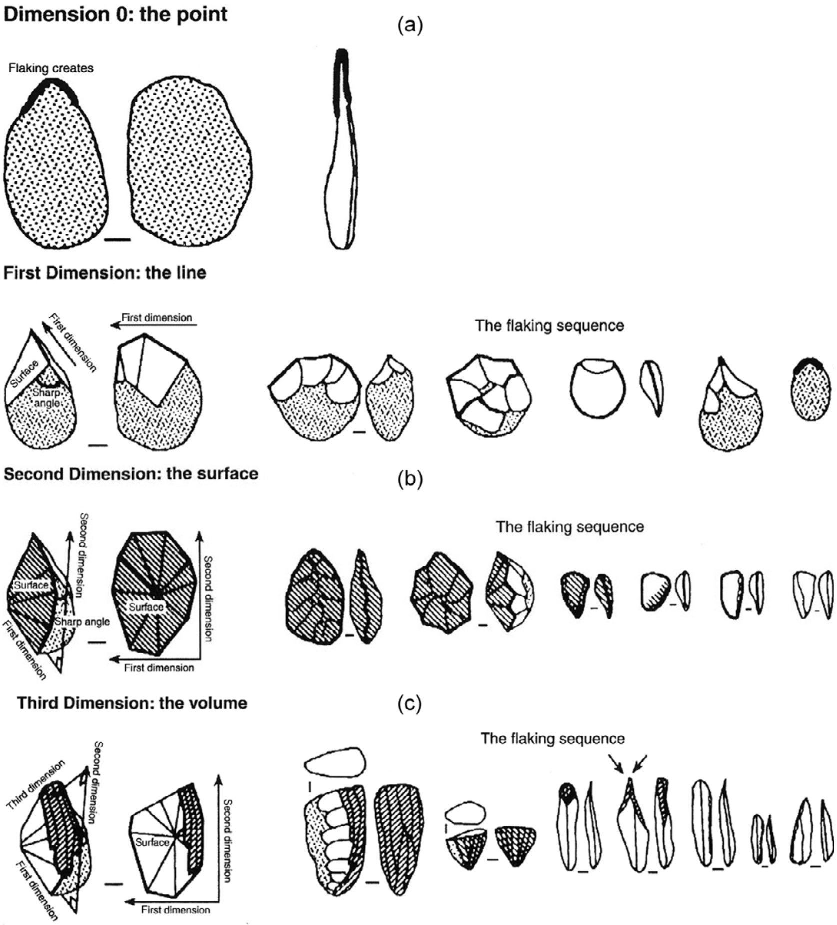

FIGURE 8.3 For humans to attain the capacity to conceive of a three-dimensional object (a pebble or stone tool) in three dimensions takes around 2 million years. (a) Taking a flake off at the tip of the pebble is an action in 0 dimensions, and takes STWM 3; (b) successively taking off several adjacent flakes creates a (one-dimensional) line, and requires STWM 4; (c) stretching the line until it meets itself, defines a surface by drawing a line around it represents STWM 4.5; distinguishing between that line and the surface it encloses implies fully working in two dimensions, and requires STWM 5; (c) preparing two sides in order to remove the flakes from the third side testifies to a three-dimensional conceptualization of the pebble, and requires STWM 7. (Source: van der Leeuw 2000; by permission of the editors)

flake is removed, the hammerstone with which this is done, and the need to maintain the two at an angle of less than 90 degrees at the time of the blow. Here, we therefore have to do with proof of STWM 3. In the next stage, this action (flaking) is repeated along the edge of the pebble. That requires control over the above three variables and a fourth one: the succession of the blows in a line. STWM is therefore 4 (Figure 8.3b). Next, the edge is closed: the toolmaker goes all around the pebble until the last flake is adjacent to the first. By itself, this is not a complete new stage, and we have called this STWM 4.5. But once the closed loop is conceived as defining a surface the knapper has two options: to define a surface by knapping an edge around it and then taking off the center, or to do the reverse – take off the center first and then refine the edge. The conceptual reversibility shows that the knapper has now integrated five dimensions, and his or her STWM is 5 (Figure 8.3c). The next stage again develops sequentiality, but in a more complex way.

In the so-called Levallois technique, making one artifact serves at the same time as preparation for the next, by dividing the pebble conceptually in two parts along its edge (STWM 6). And finally, the knapper works completely in three dimensions, preparing two surfaces and then taking flakes off the third. At this stage, STWM 7 (Figure 8.3d), for the first time the knappers are able not only to work a three-dimensional piece of stone, but also to conceive it as three-dimensional and adapt their working techniques accordingly, greatly reducing loss and increasing efficiency.

Closely observing the tools and other traces of human existence available in the Upper Paleolithic (around 50,000 BP) indicates that, after some 2 million years, people could (van der Leeuw 2000):

- Distinguish between reality and conception;
- Categorize based on similarities and differences;
- Conceive of feedback, feedforward and reversal in time (e.g., reverse an observed causal sequence, in order to conclude from the result what kind of action could achieve it);
- Remember and represent sequences of actions, including control loops, and conceive of such sequences that could be inserted as alternatives in manufacturing sequences;
- Create basic hierarchies, such as point–line–surface–volume, or hierarchies of size or inclusion;
- Conceive of partonomies: relationships between a whole and its constituent parts (including reversing these relationships);

FIGURE 8.4 From left top to bottom, left to right, the image shows the technological advances in stone toolmaking, from an Oldowan chopper, via an Acheulean handaxe, a Mousterian handaxe, a Levallois tool, a Solutrean blade, to a Neolithic handaxe. The first four images refer to STWM stages below 7 ± 2, the last two have reached STWM 7 ± 2. (Source: van der Leeuw 2000, by permission of the editors)

- Maintain complex sequences of actions in the mind, such as between different stages of a production process;
- Represent an object in a reduced set of dimensions (e.g., life-like cave paintings).

The Innovation Explosion: Mastering Matter and Learning How to Put the Brain to Use

After 50,000 BP,[1] and especially after around 15,000 BP, we see a true innovation explosion occurring just about everywhere on Earth.

The sheer multitude of inventions in every domain was truly astonishing, and has accelerated up to the present day. There is no reason to assume further developments of the human STWM, as the experimental evidence indicates that modern humans currently have the capacity to deal simultaneously with at most seven, eight, or occasionally nine dimensions or sources of information, while even a superficial scrutiny of modern technologies, languages, and other achievements shows the wide variety of things that can be achieved with a STWM of 7 ± 2. We would therefore argue that for this next phase, from about 50,000 BP to the present, the biological development of the mind no longer imposes any major constraints, and the emphasis is on acquiring the fullest possible range of techniques exploiting the STWM capacity available. This leads, among other things, to dramatic changes in the nature of the coevolution between human beings and their environments (e.g., Henshilwood & Marean 2003; Hill et al. 2009).

We can distinguish several phases in this process. In the first, the global toolkit explodes, but the gatherer-hunter-fisher mobile lifestyle remains the same. As part of the technological innovations emerging at the time, we see people moving into environments that were until then closed to them because they lacked the tools to survive there. At this time, for example, people began to move into higher latitudes with colder climates, into desert environments, etc., requiring completely novel technological and social adaptations. One way to explain this is to assume that people acted more and more collectively in solving various problems they were encountering, which would imply an increase in the importance, and the means, of communication as well as the pooling of some STWM capability.

In keeping with my fundamental tenet that information processing is crucial to such changes, I attribute the changes occurring from now on in human history to a new dynamic:

> Problem-solving structures knowledge —> more knowledge increases the information processing capacity —> that in turn allows the cognition of new problems —> creates new knowledge —> knowledge creation involves more and more people —> increases the size of the group involved and its degree of aggregation —> creates more problems —> increases need for problem-solving —> problem-solving structures more knowledge . . . etc.

In that process, learning moved from the individual to the group because the dimensionality of the challenges to be met increased beyond the capability of individuals to deal with them. This involved the emergence of the above feedback loop (van der Leeuw 2007).

As a result of these developments, about 35,000 years later, in what is called the Late Upper Paleolithic and Mesolithic in Europe, a number of other cognitive functions can be documented (van der Leeuw 2000). These include:

- The use of completely new topologies (e.g., that of a solid around a void, such as in the case of a pot, hut, or basket).
- The use of many new materials to make tools. Although it is difficult to prove that these materials were not used earlier, nevertheless one frequently observes from this time onwards objects in bone, as well as wood and other perishable materials.
- The combination of different materials into one and the same tool (e.g., hafting small sharpened stone tools into a wooden or bone handle).
- The inversion of manufacturing sequences from reductive to additive. In the former approach, which was current up to this time, making tools began with a big object such as a block of stone and smaller and smaller pieces were successively taken off it, so as to gain control over the shape. In the additive approach, tiny particles such as fibers are combined into larger, linear objects – threads – and then into a two-dimensional object (such as a woven cloth), which is finally given shape (by sewing) to fit a three-dimensional object (such as a human being). This implies the cognition of a wider range of scales, and has the advantage that corrections can take place during manufacture, which is much more difficult with reductive manufacturing sequences.
- Stretching and chunking the sequence of actions kept in the mind: distinguishing between (complex) preparation stages (e.g., gathering of raw materials, preparing them, making roughouts, shaping, finishing) yet being able to link the logic of manufacture across these stages (adapting the selection of raw materials to all the later stages of the manufacturing process, etc.).

The resulting invention of new tools characterizes the period until about 13,000 BP (in East Asia) or 10,000 BP (in the Near East), while for the time being the dominant subsistence mode was still characterized by a multi-resource strategy of harvesting various foodstuffs in the environment, but now including a wider range facilitated by the new toolkit, and moving around over increasingly limited distances so as to always stay below the carrying capacity of the environment. In effect, people lacked the know-how to interact with their environment; they could only react to it. They did not invest in the environment (by means of activities such as building long-term shelter, clearing the forest and plowing the soil, or investing in a herd), and therefore, though everyone dealt daily with uncontrollable change, risk was not really important, as risk is incurred when effort or (human, natural, or financial) capital is expended by humans to achieve something, and that is then destroyed (see van der Leeuw 2000).

The First Villages, Agriculture and Herding

In the next stage, *c.* 13,000–10,000 BP, the continued innovation explosion changed the lifestyle of many human populations. The acceleration was so overwhelming that in a few thousand years it transformed the way of life of most humans on earth: rather than live in small groups that roamed around, people concentrated their activities in smaller territories, invented different subsistence strategies, and in some cases literally settled down in small villages (van der Leeuw, 2000, 2007, and references therein). As the information-processing capacity of individual humans did not increase, I join many other colleagues in ascribing these developments to an ever-closer interaction between more and more people, generating a greater density of information-processing capacity by improving communication and collaboration. Together, these advances greatly increased the number of ways at people's disposal to tackle the challenges posed by their environment. That rapidly increased our species' capability to invent and innovate in many different domains, allowed it to meet more and more complex challenges in shorter and shorter timeframes, and thus substantively increased humans' adaptive capacity. But the other side of the coin was that these solutions, by engaging more people in the manipulation of a material world that they now partly controlled, ultimately led to new, often unexpected, societal challenges that required the mobilization of great effort to be overcome in due time.

As part of this process, a number of fundamental changes occurred. First of all, the relationship between societies and their environments became reciprocal: the terrestrial environment from now on not only impacted on society, but society impacted on the terrestrial environment as well. As a result, sedentary societies tried to control environmental risk by intervening in the environment, notably by (1) narrowing and optimizing the range of their dependencies on the environment (by cultivating a single or a few crops), (2) simplifying or even homogenizing (parts of) their environments (by locally removing the natural diversity of the environment and replacing it by a single, or a few, species of plants), and (3) spatial and technical diversification and specialization (by allocating specific spaces to specific activities and developing specific tools for these activities) (see van der Leeuw 2000).

The new subsistence techniques introduced, including horticulture, agriculture and herding, narrowed the range of things people depended on for their subsistence. In the process, certain areas of the environment were cleared and dedicated to the specific purpose of growing certain kinds of plants. This required investment in certain parts of the environment, dedicating those areas to specific activities and delaying the rewards of the investment activities. Clearing the forest and sowing resulted only months later in a harvest, for example. The resulting increase of investment in the environment in turn anchored different communities more and more closely to the territory in which they chose to live. People now built permanent dwellings using the new topology (upside down containers), and devised many other new kinds of tools and toolmaking technologies facilitating the new subsistence strategies practicable in their environment (e.g., the digging stick or the ard, the domestication of animals, baskets and pottery for storage, skin bags or pottery and hot rocks for boiling). Without speaking of (full-time) specialists, certain people in a village began to dedicate more time, for example, to weaving or pottery-making, and provided the products of their work to others in exchange for some of the things they produced. Differences in resource availability and technological know-how thus led to economic diversification and, in order to provide everyone with the things they needed, exchange and trade.

The symbiosis that thus emerged between different landscapes and the lifeways invented and constructed by human groups to deal with them narrowed the spectrum of adaptive options open to the individual societies concerned, and drove each of them to devise more and more complex solutions, with more and more unanticipated consequences that then needed to be dealt with in turn.

Collective information processing among larger and larger groups enabled the continued accumulation of knowledge, and thus the growth of information-processing capacity, which in turn enabled a concomitant increase in matter, energy, and information flows through the society, and thus the growth of interactive groups.

But this growth was at all times constrained by the amount of information that could be communicated among the members of the group, as miscommunication led to misunderstandings and conflicts, and impaired the cohesion of the communities involved. Communication stress in my opinion provided the incentive for improvements in the means of communication (for example by inventing new, more precise, concepts to communicate ideas with, cf. van der Leeuw 1981, 1986), and a reduction in the search time needed to find those people one needed to communicate with (by adopting a sedentary grouped lifestyle).

Finally, as the social system diversified, and people became more dependent on each other, the risk spectrum increasingly included social stresses caused by misunderstandings and miscommunications. Handling risks therefore came to rely increasingly on social skills, and the collective invention and acceptance of organizational and other tools to maintain societal cohesion.

The First Towns

From this point in the story, I will no longer try to point out any novel cognitive operations emerging as human societies grew in size and spread over the surface of the earth because there are simply too many. Instead, I will focus on how the feedback system that drove societal growth as well as the conquest of the material world through innovation posed some major challenges. Overcoming these ultimately enabled the emergence of true world systems such as the colonial empires of the early modern period (Wallerstein 1974; van der Leeuw 2007) and the current globalized world (see Chapter 15).

Throughout the third stage, from around 7,000 BP until very recently, communication remained a major constraint because more and more people were interactive with each other when the size of settlements involved grew to what we now call towns. This stage therefore sees the emergence of a host of new innovations, such as writing, recurrent markets, administration, laws, bureaucracies, and specialized full-time communities dedicated to specific activities (priests, scribes, soldiers, different kinds of craftsmen and women, etc.). Many of these had either to do with improving communication (such as writing and scribes), social regulation (administration, bureaucracies, laws), the harnessing of more and more resources (mining), or the exchange of objects and materials in part over larger and larger distances (markets, long-distance traders, innovations in transportation). As larger groups aggregated, the territory upon which they depended for their material and energetic needs (their footprint to use a modern term) expanded very rapidly, and the effort required to transport foodstuffs and other materials did so too, as did the probability of inter-settlement or intergroup conflict.

This caused the emergence of energy as a major constraint that limited the evolution of urban societies for millennia to come. To deal with this constraint, an interesting core–periphery dynamic emerged to exploit that ever-growing footprint – the exchange of organization against energy. Around towns, dynamic flow structures emerged, in which organizational capacity was generated in the town and then spread around it, extending the town's control over a wider and wider territory. In return, the increasing quantities of energy collected in that growing territory (foodstuffs and other natural resources) provided for the ever-increasing population that kept the flow structure going by ensuring steady innovation (creation of new technology, institutions, and information-processing capacity). These flow structures became the bootstrapping drivers that created larger and larger agglomerations of people and the territories to go with them.

In their emergence, these flow structures always involved longer distance trade, which brought to each individual town products from a network of other towns and regions. This was an inherent aspect of the fact that in order to keep larger populations interested in aligning their values with each other, such systems had to provide new values, which were no longer uniquely based on the immediate needs of the population (food and other ubiquitous materials and activities) (van der Leeuw 2014).

What enabled the urban populations to keep innovating, and thus to enlarge their value space (see Chapters 15–16) and thereby maintain their flow structures, was – again – the growing capacity of more and more interacting minds to identify new needs, novel functions, and new categories, as well as new artifacts and challenges. Writing contributed to that capability by enabling information to cross both time and space, and therefore to help individuals to be informed by the efforts and insights of others.

Underpinning that dynamic is one that we know well in the modern world. Invention is usually (and certainly in prehistoric and early historic times) something that involves either individuals or very small teams. Hence, in its early stages an invention is related to a relatively small number of cognitive dimensions – it solves challenges that few people are aware of (see Chapter 12 for a detailed description of the process). When inventions become the focus of attention of a larger number of people, such as in towns, they are simultaneously understood in many more dimensions (people see more uses for them, ways to slightly improve them, etc.), and this in certain cases triggers an invention cascade – a string of further inventions, including new artifacts, new uses of existing artifacts, new forms of behavior, and new social and institutional organization. In this process, clearly, towns and cities are more successful than rural areas because of the greater number of interactive individuals in such aggregations. This is corroborated by the fact that when applying allometric scaling of urban systems of different sizes against metrics of their population, energy flow, and innovation capacity, population scales linearly, energy flow sublinearly, and innovation capacity superlinearly (Bettencourt et al. 2007). I will return to this in Chapter 16.

The First Empires

The above flow structures continued to grow (albeit with ups and downs) until, after several millennia (from about 2500 BC in the Old World, and about 500 BC in the New), they were able to cover very large areas, such as the prehistoric and early historic empires (The Chinese, Achaemenid, Macedonian, and Roman Empires, for example, in the eastern hemisphere, the Maya and Inca Empires in the western one, and later the European colonial empires all around the globe), which concentrated large numbers of people at their center (and, in order to feed them, gathered treasure, raw materials, crops, and many other commodities from their hinterlands). Throughout this period communication and energy remained the main constraints, impacting on cities, states, and empires.

Thus we see advances in the harnessing of human energy (including slavery), wind power (for transportation in sailing vessels and for driving windmills), falling water (for mills), etc., but also in the facilitation of communication, (e.g., long distance Roman and Inca "highways" over land, the sextant and compass to facilitate navigation on the seas). This enabled societies to create and concentrate wealth that served to defray the costs of managing societal tensions: maintaining an administration and an army, creating a judiciary or other institutions to arbitrate in conflicts, etc.

The Roman Republic and Empire

To illustrate how this long-term perspective works, I will briefly look at the history of the Roman Empire (van der Leeuw & de Vries 2002) in these terms.

The expansion of the Roman republic was enabled by the fact that, for centuries, Greco-Roman culture had spread northward from the Mediterranean. It had, in effect, structured the societies in (modern) Italy, France, Spain, and elsewhere, by means of practical inventions (such as money, new crops, the plough), the building of infrastructure (towns, roads, aqueducts), the creation of administrative institutions, and the collection of wealth. Profiting from this situation, the Romans instituted a flow structure that aligned the organization of the periphery of their sphere of influence with their own culture, creating the channels for an inward flow of matter and energy into the core of the empire. To achieve this, they used an ingenious policy of stepwise assimilation and organization of indigenous political entities based in cities (Meyer 1964), making them subservient to the uninterrupted growth of flows of wealth, raw materials, foodstuffs, and slaves from the conquered territories to Rome. Linking cities across the empire, this flow structure functioned for as long as there were more preorganized societies to be conquered and wealth to be gathered (Tainter 1988). But once the Roman armies came to the Rhine, the Danube, and the Sahara, that was no longer the case and conquests stopped. Then, to keep the flow structure going, a phase of major internal investment in the conquered territories followed, expanding the infrastructure (highways, villas, industries) within the Empire in order to harness more resources for Rome.

As large territories were thus "Romanized," and technologies and institutional solutions spread, they became less dependent on Rome's innovations for their wealth, and thus expected less and less from the Empire. In about CE 250 the innovation/value-creation system at the core stalled. The information gradient between the center and the periphery leveled out, and so did the value gradient between the periphery and the center.[2] This made it more and more difficult to ensure that the necessary flows of matter and energy reached the core of the empire.

As the relative cost (in terms of a military and administrative establishment) grew, the Roman emperors had more and more difficulty in maintaining their grip on the very large areas concerned. By the fifth century CE, the coherence of the western part of the Empire had decreased to such an extent that it ceased, for all intents and purposes, to exist. People began to focus on themselves, their neighborhoods, and their local environment rather than on maintaining the central system. Other, smaller, structures emerged at its edges, and there the same process of extension from a core began anew, at a much smaller scale, and based on different kinds of information processing. In other words, the alignment between different parts of the overall system broke down, and new alignments emerged that were only relevant locally.

To explain the collapse of the Roman Empire, Tainter (1988) thus argues convincingly that only by laying its hands on the treasure accumulated outside its borders in the centuries before the Roman conquest was Rome able to maintain the large armies and bureaucracies necessary to keep its Empire. As soon as there was no more treasure to be gained by conquering, the empire was thrown back upon recurrent (in essence solar) energy, which was insufficient to maintain the flow structure. To deal with the difficulties this caused, the emperors progressively debased their currency until it was worth hardly anything (Figure 8.5).

On the one hand, this reduced the advantages of being part of the Empire, and on the other it reduced the control of the emperors over its wide territory, so that people increasingly fell back on smaller, regional or local, networks. Disaffection or even dispersion of the population followed the cessation of the flows that generated the coherent socio-economic structure of an empire in the first place.

As the alignment of large concentrations of people broke down, innovation also ceased, and in the ensuing period the knowledge base of many different technologies was lost. In Chapter 15, I will pick up the story at

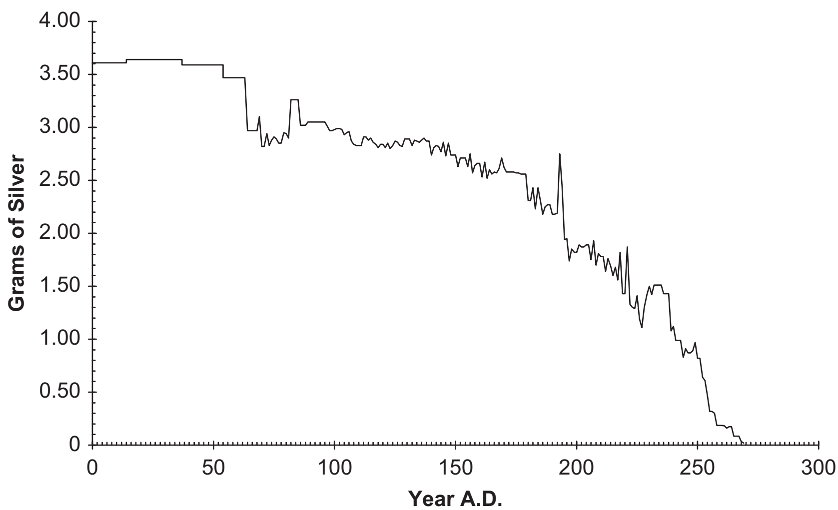

FIGURE 8.5 Graph showing the debasement of Roman coinage following the end of the Roman imperial conquests in around CE 100. (Source: Tainter 2000; reproduced by permission from the author)

this point again, and show how from a very low base Europe managed to reemerge as a major political and economic force that conquered many parts of the overseas world.

Conclusion

We have seen how, initially, human information processing was limited by the biological capacity of the brain to deal simultaneously with different sources of information. Once those limits had been pushed back to enable the human STWM to deal with 7 ± 2 such sources, innovation took off in many different ways. Increasingly, information processing became a collective process, bringing more and more people together in groups dealing with their own specific environment, enabling humans to spread to areas with very inhospitable environments, such as the Arctic. As the number of tools for thought and action multiplied, humans became more and more dependent on communication and interaction. To reduce search times in communication, stable patterns of mobility and settlements were introduced, enabled by techniques to invest and exploit the environment for purposes of more or less stable group subsistence. As the interactive groups, and the interaction within them, grew to the size of small towns, this ultimately led to energy and resources becoming important constraints, and societal dynamics growing in importance, requiring an adaptation of communication patterns and the structure of social networks. The resulting flow structure dynamic exchanged spreading information processing capacity for increases in inward flows of the energy and resources needed for survival. As the footprints of such flow structure cells grew, they ultimately federated large territories into empires. But as the regulatory overhead of empires grew, these found themselves limited in size by energy constraints. This ultimately led to their decomposition, back into smaller units.

Of course, an overview over millennia such as this one only intends to show a general trend, the increase of the dissipative information flow capacity of human information processing over time, and simplifies an enormously complex process. This chapter is not intended as proof of the approach taken in this book, but rather as an illustration to stimulate thinking about how this approach might have played out, and to prompt new research questions that this approach raises.

In Chapters 9 and 11 I will develop the dynamics of this long-term process from a theoretical perspective. In Chapter 10 I will again present a case study, but this time in much more detail, arguing how this coevolutionary process affects all aspects of society. Then, in Chapter 15, I will try to show how European history from the Roman Empire to the present illustrates this process in more detail, and how, from about 1750, the energy constraint was lifted owing to the appropriation of fossil energy, so that information processing – again – became the main constraint.

NOTES

1 All the dates mentioned in this chapter are not only approximate, and differ between different parts of the world, but are also continually subject to revisions as archaeological research progresses.
2 Under the information gradient I understand the difference in information processing capacity between the center (where most information is processed) and the periphery (which lags in information processing capacity). The value gradient is the difference between the periphery (where innovation is rare and costly) and the center (where it is frequent and therefore less costly). As the dissipative flow structure disintegrates, these potentials are leveling off, the center becomes less attractive, and smaller dissipative flow structures emerge as eddies along its edges.

9

Social Systems as Self-Organizing, Dissipative Information-Flow Structures

> "*Theories permit consciousness to 'jump over its own shadow', to leave behind the given, to represent the transcendent, yet, as is self-evident, only in symbols.*" (Hermann Weyl, cited in Gleick 2012, 6)

Introduction

After presenting in Chapter 8 a sketch of the coevolution of human cognition, socioenvironmental interaction, and organizational evolution, we need to look more closely and critically at the concepts and ideas that underpin this view. That raises three fundamental questions – "What do I consider information?," "What is information processing?," and "How is information transmitted in societies?" Those questions are the topic of this chapter, which, in order to solidly ground the book is a little more technical than earlier chapters.

It is the main thesis of this book that societies can profitably be seen as an example of self-organizing human communications structures, whether we are talking about urban societies or other forms of human social organization, such as small band societies or hierarchical tribes. The differences are merely organizational ones, owing to the need to deal with larger information loads and energy flows as human problem-solving generates more knowledge, and the concomitant increase in the population requires more food and other resources.

Although the book's fundamental theses are (1) that the structure of social systems is due to the particularities of human information-processing, and (2) that the best way to look at social systems is from a dissipative flow structure paradigm, it differs in its use of the two core concepts "information" and "flow structure" from earlier studies.

The difference with respect to the information approach presented by Webber (1977), for example, is that I view societal systems as open systems, so that neither the statistical–mechanical concept of entropy nor Shannon's concept of relative entropy can be used, as they only apply to closed systems in which entropy does not dissipate. As Chapman rightly argues (1970), the existence of towns is proof that human systems go against the entropy law, which is in essence only usable as a measure of the decay of structure.[1] That approach therefore seems of little use.

The difference with earlier applications of the "flow structure" approach, such as P. M. Allen's (Allen & Sanglier 1979; Allen & Engelen 1985) or Haag and Weidlich's (1984, 1986) is that I wish to formulate a theory of the origins of societies that forces us to forego a model of social dynamics formulated in terms of a social theory (Allen) or even migration (Haag & Weidlich), as these make assumptions that we cannot validate for the genesis of societal systems. Just like Day and Walter (1989) in their attempt to model long-term economic trends (in the production of energy and matter) must revert to population, we have to revert to information and organization if we wish to model long-term trends in patterning (Lane et al. 2009).

Social Systems as Dissipative Structures

I therefore view human institutions very abstractly as self-organizing webs of channels through which matter, energy, and information flow, and model the dynamics of cultural systems as if they are similar to those of dissipative flow structures. As this conception is fundamental to the argument of this book, I will present it here in a more elaborate form.

A simple model of a dissipative structure is that of an autocatalytic chemical reaction in an open system that produces, say, two colored reagents in a liquid that is initially the color of the four substances combined.[2] At equilibrium, there is no spatial or temporal structure. When the reaction is pushed away from equilibrium, a spatiotemporal configuration of contrasting colors is generated in the liquid. As it is difficult to represent this in a single picture, I refer the reader to a short YouTube video that explains both the history and the dynamics of this so-called Belouzhov-Zhabotinskii reaction: www.youtube.com/watch?v=nEncoHs6ads.

Structuring continues over relatively long time-spans, which implies that during that period the system is capable of overcoming, at least locally, its tendency toward remixing the colors (in technical terms, it dissipates entropy). The structure, as well as the reaction rate and the dissipation rate, depend on the precise history of instabilities that have occurred.

The applicability of the dissipative structure idea to human institutions, then, hinges on our ability to answer each of the following two questions positively:

- Is there at least one equivalent to the autocatalytic reaction just presented that can be held responsible for coherent structuring in human systems?
- Is the system an open system, i.e., is it in free exchange of matter, energy, and information with its environment, as is the case with other living systems?

It seems to me that human learning has many properties that permit us to view it as an autocatalytic reaction between observation and knowledge creation. The observation that social systems came into existence and continue to expand, rather than to decay, seems to point to an affirmative answer to the second question.

This chapter is devoted to exploring these questions further. First, I will deal with the individual human being, and consider the learning process as a dynamic interaction between knowledge, information, and observations. The second part deals with the dynamic interaction between the individual and the group, and considers shared knowledge and communication. Finally, I will consider system boundaries and dissipation.

Perception, Cognition, and Learning

Uninterrupted feedback between perception, cognition, and learning is a fundamental characteristic of any human activity. That interaction serves to reduce the apparent chaos of an uncharted environment to manageable proportions. One might visualize the world around us as containing an infinite number of phenomena that each have a potentially infinite number of dimensions along which they can be perceived. In order to give meaning to this chaos (χαοσ (Greek): the infinity that feeds creation), human beings seem to select certain dimensions of perception (the signal) by suppressing perception in many of the other potentially infinite dimensions of variability, relegating these to the status of "noise."

On the basis of experimental psychology, Tverski and his associates (Tverski 1977; Tverski & Gati 1978; Kahnemann & Tverski 1982) studied pattern recognition and category formation in the human mind. They concluded that:

- Similarity and dissimilarity should not be taken as absolutes.
- Categorization (judging in which class a phenomenon belongs) occurs by comparing the subject with a referent. Generally, the subject receives more attention than the referent.
- Judgment is directly constrained by a context (the other subjects or other referents surrounding the one under consideration).
- Judgments of similarity or of dissimilarity are also constrained by the aims of the comparison. For example, similar odds may be judged favorably or unfavorably depending on whether one is told that one may gain or lose in making the bet.

From these observations, one may derive the following model of perception:

1. Perception is based on comparison of patterns perceived. A first comparison always takes place outside any applicable context (the dimensions in which the phenomena occur are unknown), so that there is no referent and no specific aim. Thus, there is no specific bias toward similarity or dissimilarity. If there is any bias at all, it is either due to intuition or to what people have learned on past occasions, which cannot necessarily be mapped onto the case at hand.
2. Once an initial comparison has led to the establishment of a referent (a relevant context or patterning of similarity and dissimilarity), this context is tested against other phenomena to establish its validity. In such testing, the established pattern is the subject and the phenomena are the referents. There is therefore (following Tverski's second statement) a distinct bias in favor of similarity.
3. Once the context is firmly established and no longer scrutinized, new phenomena are subjects in further comparisons, and the context is the referent. Thus, the comparisons are biased toward the individuality of the phenomena and toward dissimilarity.
4. Once a large number of phenomena have been judged in this way, the initial bias is neutralized, the context is no longer considered

relevant at all, and the cycle starts again, so that further comparisons lead to establishing another context.

5. Ultimately, this process leads to the grouping of a large set of phenomena in a number of categories at the same level, which are generally mutually exclusive (establishing dimensions and categories along them). At a certain point, the number of categories is so large that the same comparative process begins again, at a higher level, which treats the groups as phenomena and results in higher level generalizations.

Thus, perception and cognition may be seen as a feedback cycle between the concepts (categorizations) thus generated, their material manifestations, and the (transformed) concepts that derive from and/or are constrained by these material manifestations. This cycle is illustrated in Figure 9.1.

This learning process is as endless as it is continuous, and could also be seen as an interaction between knowledge, the formalized set of substantive and relational categorizations that make up the cognitive system of an individual, and information, the messages that derive their *raison d'être* and their meaning from the fact that they trigger responses from these categorizations, yet never fit any of them exactly. In that sense, information can be seen as potential meaning.

Because the chances that messages exactly fit any preexisting categories are infinitesimally small, they continuously challenge and reshape knowledge. In this sense, then, information is the variation that creates the (flow) structure of knowledge. Paraphrasing Rosen, one might say that

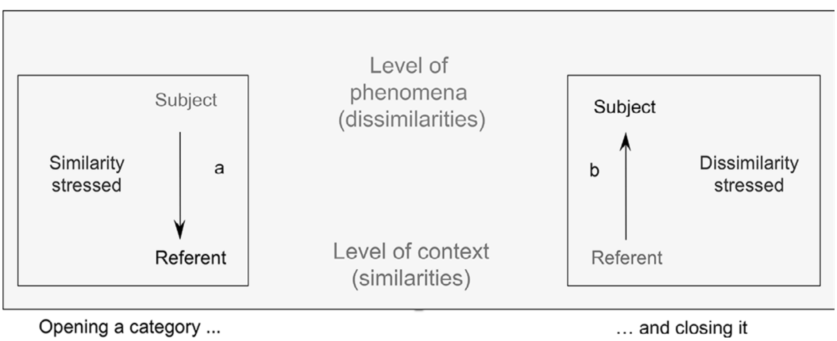

FIGURE 9.1 The dynamics of category formation as described by Tversky and Gati (1978). For an explanation, see the text. (Source: van der Leeuw 1990)

information is anything that makes a difference (or answers a question).[3] But any information also poses new questions.

Communication: The Spread of Knowledge

Because humans are social beings they share, and therefore necessarily exchange, various commodities. This is as fundamental an aspect of human life as perception, cognition, and learning.

Some of these commodities are at first sight entirely material: food, raw materials, artifacts, statuettes, etc. Other exchanges seem predominantly a question of energy: collaboration in the hunt, in tilling the soil, or in building a house, but also slavery, wage labor, etc. Yet a third category primarily seems to concern information: gossip, opinions, and various other oral exchanges, but also their written counterpart: clay tablets, letters, and what have you, including electronic messages.

But in actual fact, the exchange of all commodities involves aspects of matter, energy, and information. Thus, there is the knowledge where to find raw materials or foodstuffs and the human energy expended in extracting or producing them; the knowledge and energy needed to produce artifacts or statuettes, which are reflected in the final product; the knowledge of the debt incurred in asking someone's help, which is exchanged against that help, only to be drawn upon or reimbursed later; the matter transformed with that help; the energy with which the words are spoken; the matter to which symbols are entrusted in order to be transported. The examples are literally infinite.

Knowledge determines the exact nature and form of all commodities that are selected and/or produced by human beings, whether exchanged or not. It literally in-forms substance. Or as Roy Rappaport used to say, "Creation is the information of substance and the substantiation of form."[4] That is easy to see for the knowledge that generates specific sequences of actions with specific goals, such as in the manufacture of artifacts. But it also applies to the simple selection of materials, whether foodstuffs or raw materials of any other kind: transformation and selection by human beings are knowledge-based and consequently impart information. Hence all exchanges between human beings have material, energetic, and information aspects. But as we saw in Chapter 8, matter, energy, and information are not exchanged in the same way, nor do they affect the structure of the system in the same way.[5]

At the level we are talking about, matter can be passed directly from one individual to the next, a transaction in which one individual loses what the other gains. Human energy cannot thus be handed over, as the capacity to expend it is inalienable from the living being that does the expending. Clearly, fuels, animals, and slaves might he thought of as energy that is handed over, but whenever this occurs they are handed over as matter. In an exchange, energy can only be harnessed, so it is expended in favor of someone. Knowledge cannot be handed over either: an individual can only accumulate it by processing information. But knowledge can be used to generate information that may, more or less effectively, be communicated and be used by another individual to accumulate highly similar knowledge. As a result of that process, individuals may share knowledge. In this context, clearly, knowledge is a stock that is inherent in the information-processing system, while information is a flow through that information-processing system.

Not the energy and matter aspects of flows through a society are therefore responsible for that society's coherence, but the knowledge which controls the exchange of information, energy and matter. The individual participants in a society or other human institution are (and remain) part of it because they know how that institution operates, and can use that knowledge to meet their needs and desires. I emphasize this point because often, in archaeology and in geography as well as ecology and economics, the flow of energy or matter is what is deemed to integrate a society.

If we use this argument to assert that in our opinion the flow of information is responsible for the structural form of human societies, this is not to deny that the availability and location of matter and energy play a part in the survival of human systems. Rather, I would like to suggest that material and energetic constraints are in principle of a temporary nature and that, given enough tension between the organizational dynamics of a human institution and its resource base, people will in due course resolve this tension by creating novel means to exploit the resource base differently (through invention of new techniques, choice of other resources, or of other locations, for example).

It would seem therefore that while on shorter timescales the interaction between the different ways in which matter, energy, and information spread through a system count, the long-term dynamics of human institutions are relatively independent of energy and matter, and are ruled by the dynamics of learning, innovation, and communication. These dynamics seem to be responsible for social interaction and societal patterning, and allow people to realize those material forms for which there is a coincidence between two windows of opportunity, in the ideal and the material/energetic realms respectively.

As I am mainly concerned with the very long term, my primary aim in this chapter is to consider the transmission of information in human societies, that is the syntactic aspect of communication. Scholars in the information sciences have expended considerable effort in presenting a quantifiable syntactic theory of information.[6] Although my immediate aim does not extend to quantification, some of the conceptualizations behind these approaches might serve to focus the mind.

The core idea in information theory is that information can be seen as a reduction of uncertainty or elimination of possibilities:

> When our ignorance or uncertainty about some state of affairs is reduced by an act (such as an observation, reading or receiving a message), the act may be viewed as a source of information pertaining to the state of affairs under consideration. [...] A reduction of uncertainty by an act is accomplished only when some options considered possible prior to the act are eliminated by it. [...] The amount of information obtained by the act may then be measured by the difference in uncertainty before and after the act. (Klir & Folger 1988, 188)[7]

There is, however, a clear limitation to the applicability of information theoretical approaches. Their success in quantifying and generalizing the concepts of uncertainty and information has been achieved by limiting their applicability in one important sense: these approaches view information strictly in terms of ignorance – or uncertainty reduction within a given syntactic and semantic framework, which is assumed to be fixed in each particular application (Klir & Folger 1988, 189). In essence, formal Information Theory applies to closed systems in which all probabilities are known. That is why information as a quantitative concept can be said to equal the opposite of uncertainty, and increase in entropy to imply loss of information and vice versa.

In archaeology and history, we deal with open (societal) systems, and we have incomplete knowledge of the systems we study. It seems therefore that one could never successfully apply this kind of quantifiable information concept to archaeology or history, except when studying a defined channel of communication that functions within a defined syntactic and semantic framework, i.e., in a situation where symbols and meanings are known and do not change.

Nevertheless, at least one important conclusion of information theory seems to be relevant, the idea that (within a given unchanging syntactic and semantic framework), communication channels have a limited transmission capacity per unit time, and that as long as the rate at which information is inserted into the channel does not exceed its capacity, it is possible to code the information in such a way that it will reach the receiver with arbitrarily high fidelity.[8] By implication, if the amount of information that needs to be transmitted through channels increases, there comes a point where a system has to improve channel capacity, introduce other channels, or alter the semantic relationship between knowledge and information.[9]

Social Systems as Open Systems

Next, we must answer the second of the two questions asked earlier in this chapter: "Are societal systems in free exchange of matter, energy and information with their environment?" For matter and energy, the answer is evidently positive: humanity can only survive because it takes food, fuel, and other forms of matter and energy from its nonhuman environment, and it transfers much of these commodities back into the external environment as waste, heat, etc.

But the exchange of information with the system's environment may need some further elaboration. Information, as we have used it here, is a relational concept that links certain observations in the "real" realm of matter and energy with a pattern in the realm of ideas in the brain. I have argued above that humans generate knowledge through perceptual observation and cognitive choice, in essence therefore within the human brain, and at the group level within the societal system. Knowledge does not transcend system boundaries directly. Yet perception and cognition distill knowledge from the observation of phenomena outside the human/societal system. Those phenomena are thus, as it were, potential information to the system. We must conclude that knowledge inside the system is increased by transferring such potential information into the system from the outside. Among transfers in the opposite direction, there is first the direct loss of knowledge through loss of individual or collective memory or the death of individuals. But information is also taken out of the human system when words can be blown away, writings destroyed, and artifacts trampled so that they return to dust. And even when the information stored in artifacts is not destroyed, it ceases to function as such as soon as it is taken out of its particular knowledge context, for example because the latter changes as a result of further information processing.

Transitions in Social Systems as Dissipative Structures

An increase in the information that is communicated among the members of a group would seem to have two consequences. At the level of the individual, it would decrease uncertainty by changing the relationship between the syntactic and semantic aspects of human information processing, increasing the level of abstraction (Dretske 1981). At societal level it would increase participation and coherence, so that it may be said that the degree of organization increases and entropy is dissipated.

In an archaeological context, the latter is the more visible, for example when we look at the way in which a cultural system manages to harness an ever-increasing space, or the same space ever more intensively, by destroying or appropriating its natural resources in a process of (possibly slow) social incorporation (see Ingold 1987).

A simple example is that of "slash-and-burn" agriculture. Bakels (1978), for example, has shown in detail how the early Neolithic inhabitants of Central and Northwestern Europe (5000 BCE), who are known as the Danubians, exhausted an ever-widening area of their surroundings in procuring for themselves the necessary foodstuffs and raw materials. The fact that this happened rather rapidly is certainly one of the factors responsible for the rapid spread of these peoples (see Ammerman & Cavalli Sforza 1973).

I have argued (1987, 1990) how in the Bronze and Iron Ages (1200 BCE–CE 250), the local population of the wetlands near the Dutch coast repeatedly transformed an untouched, extremely varied, and rich environment by selective use of the resources in it, resulting in a more homogeneous and poorer environment. As soon as a certain threshold of structuring was reached, the inhabitants had to leave an area and move to an adjacent one.

In both these cases, the information (about nature) that was contained in an area, that is those features of it that triggered a response in the knowledge structures of the population, was used for its exploitation up to the moment that the "known environment" could no longer sustain the population. In the process, the symbiosis between the population and its natural environment changed both, so that eventually the symbiosis was no longer possible, at least with the same knowledge. One example that shows the importance of the relationship between available knowledge and survival in the environment emerges when one compares the knowledge available to the Vikings on Greenland and the Inuit in the same area: whereas the stock of knowledge available to the Vikings was hardly sufficient to survive the cooling of the climate after *c.* 1100 except marginally, the knowledge available to the Inuit enabled them to survive more easily up to the present. This dynamic is further detailed in Chapter 13.

Similar things occur in the relationship between different societal groups. A city such as Uruk (*c.* 4000 BCE) seems to have slowly "emptied out" the landscape in a wide perimeter around it, probably by absorbing the population of the surrounding villages (Johnson 1975). When it could not do so any more, probably for logistical reasons, various groups went off to found faraway colonies that fulfilled the same function locally and that remained linked to the heartland by flows of commercial and other contacts, often along the rivers.[10] The same was customary among the Greeks in the classical period (sixth to fifth century BCE). As soon as there was a conflict in a community (due to errors in communication or differences in interpretation, whether deliberate or not), groups of (usually young) dissidents were sent off to other parts of the Aegean to colonize new lands. These lands were then to some extent integrated into the Greek cultural sphere. That process is no different from the one that allowed the European nations in the sixteenth to nineteenth centuries to establish colonies in large parts of the world.

As we have seen in the last chapter, the Roman Empire slowly spread over much of the Mediterranean basin, introducing specific forms of knowledge and organization ("Roman Culture"), aligning minds. In so doing it was able to avail itself of more and more foodstuffs, raw materials, and raw energy, among other things in the form of treasure and slaves. As the rate of expansion increased, the process of acculturation outside its frontiers – which was initially, during the Republic, more rapid than the expansion – was eventually (in the first centuries CE) "overtaken" by the latter. That brought expansion to a standstill, and led to a loss of integration in the Empire (and eventually its demise).

In each of these cases, structuring was maintained as long as expansion was possible in one way or another. Expansion keeps trouble away, just as in the chemical reaction that I presented as an example of a dissipative, that structure could only maintain structuring by exporting the inherent tendency of the liquid to mix the colors. It is this aspect of societal systems that seems to me to indicate that they can profitably be considered dissipative information-flow structures.

One consequence is that the very existence of any cultural entity depends on its ability to innovate and keep innovating at such a rate that, continuously, new structuring is created somewhere within it and spreads to other parts (and beyond) so as to keep entropy at bay (see Allen 1985; van der Leeuw 1987, 1989, 1990; McGlade & McGlade 1989). From the very moment that innovation no longer keeps pace with expansion, the entity involved is doomed. As we have seen in the case of the Bronze Age settlement of the western Netherlands, that moment is an inherent part of the cognitive dynamics responsible for the existence of the entity concerned. For the Roman Empire, a similar case can easily be made based on the exponential increase in its size, just as for the other examples given. It might be concluded that, seen from this perspective, the existence of all cultural phenomena is due to a combination of positive feedback, negative feedback, noise, and time lags between innovation and dissipation.

Conclusion

The last few pages have tried to argue the case for considering social phenomena as dissipative flow structures, and have outlined some critical elements of such a conceptualization. To begin with, I have tried to find our way through the confusion underlying the concept of information, and to outline my use of the word. Notably, I have pointed to the cognitive feedback between information and knowledge as the autocatalytic reaction underlying the development of the patterning that individual humans impose on their social and natural environment. I have also outlined why, in my opinion, all conceivable kinds of exchange between people have an information-exchange aspect, and that it is the exchange of information that seems to be responsible for the cohesion of social institutions at all levels. To introduce the concept of channel capacity within a given, fixed, semantic, and syntactic framework, I have drawn upon Shannonian information theory, making it very clear that as this theory applies to closed systems it is not otherwise compatible with the general approach I have chosen.

Shifting my focus somewhat, I have then argued the case for modeling human institutions as open systems and have considered whether such systems do indeed freely transfer information in both directions, inward and outward. Finally, I have briefly presented a few of the many available historical and archaeological cases that point to the fact that social institutions dissipate entropy. I have, however, refrained from trying to present a particular theory of entropy dissipation in human systems.

NOTES

1 Gain in entropy means loss of information and vice versa.

2 The Beloushov-Zabotinskii reaction (also called "Brusselator"), is of the following form:

$A \cdot F1+$ and $F1-$, X
$B + X \cdot F2+$ and $F2-$, $Y + D$,

2X + Y · F3+ and F3−, 3X
X · F4+ and F4−, E

3 In his closing remarks at the Cambridge Conference on Dynamical Modeling and Human Systems, December 1990, biologist Robert Rosen presented the definition "information [in the semantic sense] is anything that answers a question."
4 Personal course notes, fall 1976, Department of Anthropology, University of Michigan Ann Arbor.
5 This is expressed in the fact that energy and matter are subject to the laws of conservation while information is not.
6 This has first been attempted in terms of classical set theory (Hartley 1928), and later in terms of probability theory (Shannon 1948), fuzzy set theory (DeLuca & Termini 1972, 1974), and the mathematical theory of evidence (Shafer 1976). See the diagram presented by Klir and Folger (1988, fig. 5.6).
7 The various ways of naming or defining uncertainty that occur in the literature are all related to the specific formal paradigm used to define this opposite of information. Thus Shannon, who uses an approach from statistical mechanics, uses the word entropy, which is reminiscent of Clausius and Bolzmann's work in thermodynamics using the same formal approach. The introduction of fuzzy set theory as a framework for definition has, for example, led to a more general mathematical definition of uncertainty, incorporating among other things the awareness that there are different kinds of it, such as fuzziness or vagueness, dissonance, confusion and nonspecificity, and arrived at by applying measures of belief and plausibility drawn from the mathematical theory of evidence (Klir & Folger 1988, 169–188).
8 In Shannon's formulation, when C is the channel capacity (in bits per second) and H the amount of information being generated at the source (also in bits per second), it is possible by devising proper coding procedures to transmit symbols over the channel at an average rate which is nearly C/H but which, no matter how clever the coding, can never be made to exceed C/H (Shannon 1948, 59; see also Weaver 1969). Dretske points out that this does not limit what can be learned over a channel from a specific signal, as Shannon's only applies to average information transmission (1981, 51)
9 There are a number of different ways to alter the semantic relationship, for example by introducing simplified representations, by breaking a complex representation of a system into appropriate subsystems, or to allow imprecision of description, etc. (Klir & Folger 1988, 192–211). This aspect is clearly extremely important in describing the evolution of human communication and of the structure of social systems through time, but is not the topic of this book.
10 Since this chapter was conceived, a debate has opened about whether the Uruk phenomenon's origins were located around Uruk, or upstream along the Euphrates in the area in which I did fieldwork (Chapter 1). But that is not relevant to the dynamic itself – upstream the same kind of process would have engendered the same kind of result.

10

Solutions Always Cause Problems

Introduction

The purpose of this chapter is to drill down a level, to illustrate by means of an example some of the detail of the long-term flow structure dynamics that are at work in any interaction that involves humans in profoundly modifying their socioenvironment, with an emphasis on the evolution of information processing. To understand this chapter correctly, it is important to realize that technologies, like institutions and tools for thought and action, are also part of the information-processing apparatus that humans create in their interactions with the outside world. All of these are part of the total knowledge that is acquired in the process, and as such codetermine the path dependency of the processing system. Tools serve to streamline decision-making processes because they mechanize some of the decision-making involved, fixing it in a material substrate that enables certain ways of doing things and constrains others.

Technical systems have a very particular place in our dealings with the environment, and should therefore have a particular position in our research into those dealings. Technical systems do not follow the logic of the societal systems in which they are embedded, nor do they follow the logic of the environmental systems with which they interact. In fact, they have their own logic that will be investigated in Chapters 12 and 13. Moreover, they result in artifacts that are in themselves substantiated tools for specific information processing tasks. As such they are themselves part of the driving dynamics of the evolution of information processing that I summarize in Chapters 8 and 9.

The Pre- and Proto-History of the Rhine Delta

The area presently called Rijnland in the Netherlands is situated just behind the Dutch coastline between two ancient branches of the Rhine, near its mouth. The term is also used for the administrative entity that governs water management in the area. In this chapter, I will try to show that such a conjunction is not accidental.[1] Indeed, the management of the environment has not only given rise to new technologies (such as windmills, polders, locks, and dikes), but it has also shaped the institutional development of the Netherlands and many aspects of its societal dynamics. To do so, I will describe the genesis and evolution of the area from around 2000 BCE to the present. In that period, the natural dynamics of the region were completely brought under control of humankind. Tim Ingold (1987) speaks of "*The Appropriation of Nature*."

Like every river, the Rhine has for tens of millennia deposited large amounts of gravel and sand in front of its mouth, in the North Sea. As the sea level rose under the impact of non-anthropogenic climate change, and the deposits built up simultaneously, the river's flow slowed down and the difference in level between water and land diminished, until in many places it was only a few feet. A true delta emerged, in which the sea and the river continually struggled for dominance. Sometimes above and sometimes underwater, the natural levees (ridges) became areas on which vegetation took root. But as long as the sea regularly inundated them during winter storms, and deposited large amounts of sand on the levees, vegetation could not really establish itself.

Around 2000 BCE, currents in the North Sea shifted and caused the slow buildup of a row of levees that protected the area immediately behind it from the sea (van der Leeuw, 1987; Brandt & van der Leeuw 1988). The largest mouth of the Rhine shifted toward the north, fresh water accumulated behind the levees further south, and as the vegetation flourished in this area, which was now protected from the sea, it became a peat marsh.

Eventually, people settled in that marsh, initially on small tufts of peat that were a little higher than the surrounding landscape and on the edges of the creeks that drained it. These early settlements consisted of a very small number of houses (generally one to four). People exploited the land by planting some cereals and other edible plants and by allowing some domesticated cattle and sheep to graze there (Brandt et al. 1984). But the battle against water dominated their lives. One finds drainage ditches around the individual houses, and with time individual houses were built on small artificial mounds (*terpen* in Dutch) to ensure that they were not inundated in periods of high water when storms or high tides in the North Sea blocked the Rhine's mouth and fresh water accumulated behind the dunes (Brandt et al. 1987).

To cultivate their crops, people also had to drain the peat. But as soon as the water table was lowered, the (drying) peat either oxidized or blew away, lowering the level of the land. This engendered a positive feedback loop that made drainage more and more difficult, and heightened the danger of inundations. The drainage ditches grew longer and longer, eventually creating a complicated network. These longer ditches are the first sign that people began to collaborate and organize themselves in the battle against the water.

By about 900 CE, the inhabitants' strategy in dealing with the water changed – rather than building individual mounds for themselves, they began to collaborate in enclosing certain (initially small) surfaces by means of artificial defense systems (dikes, *dijken* in Dutch, levees in US English) several meters high. We may interpret this as a sign that local societal organization had reached a new level.

The Middle Ages: Keeping the Land Dry Leads to the Hoogheemraadschap Rijnland

Around 1000 CE, another factor came into effect: the political organization of the area (see van Tielhof & van Dam, 2006, the most recent authoritative work on the history of Rijnland, upon which I have heavily relied for this chapter, including for the illustrations). Feudal lords began to play a role in the western part of what is now the Netherlands. An endless series of skirmishes between small local potentates ultimately created a political hierarchy. Not surprisingly, this process was somewhat more advanced in the drier parts of the delta than in the wetter areas nearest the coast. In particular, the bishopric of Utrecht, situated on higher ground (the sandy moraines left by the last Ice Age), had a longer history as a political entity than the lower areas immediately behind the dunes, collectively called Holtland (the woodland, from which the current Holland derives). Holland and Utrecht remained politically distinct for most of the Middle Ages, and there was a continuous series of political and military conflicts between their official rulers, the Counts of Holland and the Bishops of Utrecht, as well as among their feudal dependents.

During this time, Holland was administratively divided into several entities (so-called *baljuwschappen*), of which two are particularly

FIGURE 10.1 Administrative units in western Holland, *c.* 1280. Kennemerland and Rijnland were later brought under the authority of the Hoogheemraadschap Rijnland for all matters concerning water. (Source M. van Tielhof and P. J. E. M. van Dam, *Waterstaat in stedenland. Het hoogheemraadschap van Rijnland voor 1857*, Utrecht 2006, by permission Stichting Matrijs)

important for this story: Rijnland, with Leiden at its center, and Kennemerland, with Haarlem as its focus (Figure 10.1). Both their centers were located at the easternmost edge of the natural levees that protected the landscape from the sea and were therefore themselves relatively safe from inundation.

Around 1150, the mouth of the (Old) Rhine to the west of Leiden was definitively closed by the movement of large amounts of sand in the northward current along the coast. This caused the area behind the dunes to suffer more frequently from river inundation, and by 1280 collective action had to be taken on a larger scale. Not surprisingly, the first major collective intervention – the damming of the Rhine upstream to protect the inhabitants of Rijnland from flooding by the river – occurred at the boundary between Utrecht and Holland. Canals were then dug from Leiden to the north and the south, to ensure that the area's surface water could be evacuated without danger to the population of Rijnland. But canals have the unfortunate property that they can, if the water level inverts, also be sources of flooding. Hence, locks had to be constructed at the mouth of both canals (see Figure 10.2).

Notwithstanding these efforts, Rijnland remained very vulnerable to flooding, especially from the two large lakes (Leidse Meer and

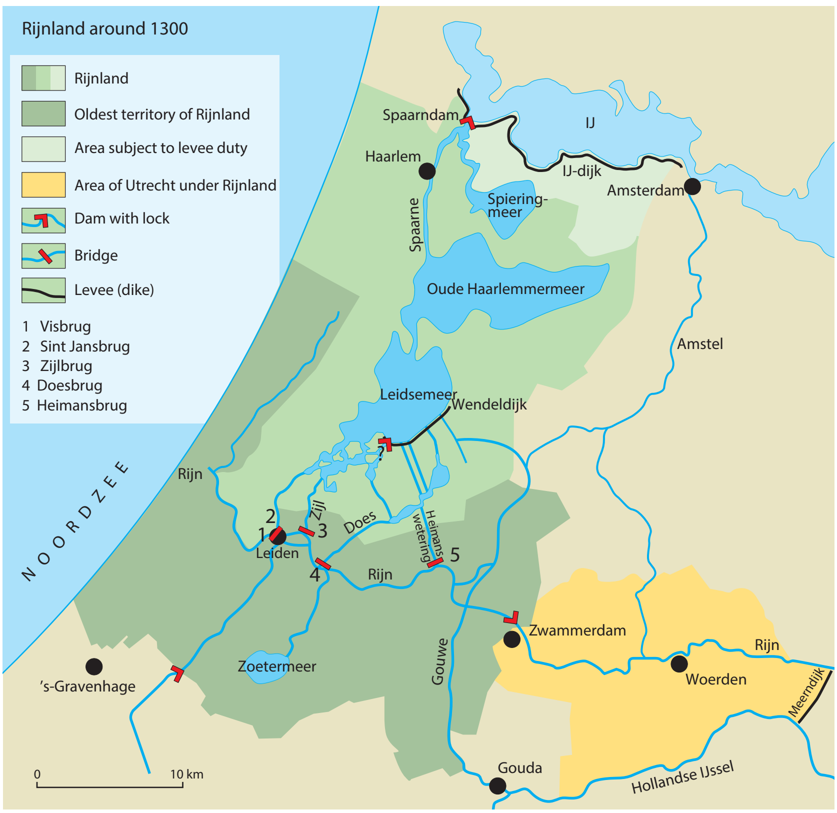

FIGURE 10.2 The situation in around 1300. Rijnland is in diverse shades of green. Note the civil engineering works (dikes, locks, dams) containing and guiding the water of the Rhine to the north and south of the area. (Source M. van Tielhof and P. J. E. M. van Dam, *Waterstaat in stedenland. Het hoogheemraadschap van Rijnland voor 1857*, Utrecht 2006. By permission Stichting Matrijs)

Haarlemmermeer) to the north of Leiden. It quickly became clear that to protect Rijnland from this danger, cooperation was necessary with the terrestrial authorities of Kennemerland, to the north of Rijnland, so that a dam and a sluice could be built at the hydrologically most propitious location; along the edge of the open mouth of the Rhine to the north of Haarlem. This cooperation is the first tangible sign that water management has its own rules and its own geography, which do not necessarily follow those of politics or administration. One cannot safeguard against flooding if there is no unified management. The risk is so great that differences of opinion lead to disaster. Hence, for the purposes of water management, and water management only, the southern part of Kennemerland soon became part of Rijnland. A typically Dutch solution was found: to create a dedicated "water authority," the *Hoogheemraadschap*, which could impose its power on all the other political and administrative authorities within its territory, including the highest, but only in so far as water issues were concerned. From this point forward, there were two Rijnlands, that of the baljuw (the highest civil administrator representing the count), and that of the dijkgraaf (not accidentally called the "count of the dijken." (The territory of the latter (marked by a dotted line in Figure 10.1) exceeded that of the former.)

The Early Modern Period: Land Is Turned into Water

When drained, peat is incredibly fertile, as it consists entirely of decaying or decayed organic matter. Once the medieval water problems at the regional scale had been solved, therefore, the area very quickly became a rich and intensively cultivated agricultural zone. But maintaining the agricultural intensity depended on the ability to continually drain the land. Between plots of cultivated land, narrow ditches (*sloten*) were dug to drain them. These drainage ditches ended at larger artificial or natural waterways, evacuating excess water to the main streams or canals crossing the territory of Rijnland.

As a result of the shrinking of the peat inherent in this loss of water and the oxidation of the organic material due to the intensive cultivation, the surface of the peat descended about 1 m per century, coming closer and closer to the subsurface water table. Because the land became wetter, its fertility declined, as did the yields of the farmers cultivating it. A process was set in motion that ultimately resulted in the surface of the land descending below that of the water. Urgent solutions were needed, again requiring major investments.

As a consequence, levees were built on both sides of the draining waterways to prevent the land from flooding. But to remove excess water, it now had to be moved up and away, instead of downward. To solve that problem, horse- or wind-driven watermills were introduced in 1408, which pumped the water up from the drainage ditches into the major waterways. As a result, a huge number of windmills dotted the landscape.

The lowering of the land surface with respect to the water table also changed the economy of the area. The local reduction in the cereal yield occurred at a time when, around the Baltic, grain was cheap and easy to obtain. This stimulated trade in the small towns, which until then had heavily relied on fisheries. Hence, it became more attractive to let the land (now often soggy) revert to pasture for grazing cattle and sheep. Milk and butter, as well as meat, fetched good prices in the growing towns of the area, and required much less labor than cereal cultivation. In turn, this forced many marginal farmers to find other means of subsistence. Some adopted other rural professions, such as fishing, but many of them moved to the towns, where there was demand for cheap labor in such typical urban activities as trade and industry. Others manned the ships that enabled a substantive growth of commerce from the cities.

The fourteenth to sixteenth centuries saw a very important expansion of urbanization in the area, under the impact of rapidly growing long distance trade and the industrial production of trade goods. Continued misery in rural areas maintained the influx of poor peasants into the cities and kept the price of labor low, thus stimulating shipbuilding and other crafts and industries. which, in turn, drove the rapid urban growth. In particular, the Dutch coastal towns of the thirteenth century became involved in trade between the Baltic countries, Great Britain, and the Atlantic coast of France. They brought dried fish, pelts, and other Nordic items to Britain and France, exported British wool to Flanders, and Flemish (woolen) cloth to France and the Baltic, as well as transporting wine from the Garonne area in Aquitaine to both Britain and the Baltic. As that trade intensified, the Dutch coastal towns of Leiden, Haarlem, and especially Amsterdam grew rapidly and increased the production of their own trade goods.

The industries that thus emerged needed fuel, and by this point most of the original Holtland had little forest left. Indeed, the only locally plentiful fuel was the (dried) peat that was sold in the form of turves for heating and industrial production, such as pottery-making. Consequently, the price of turves increased drastically, and more and more farmers reverted to digging away their land and selling it as fuel. Relatively quickly, this

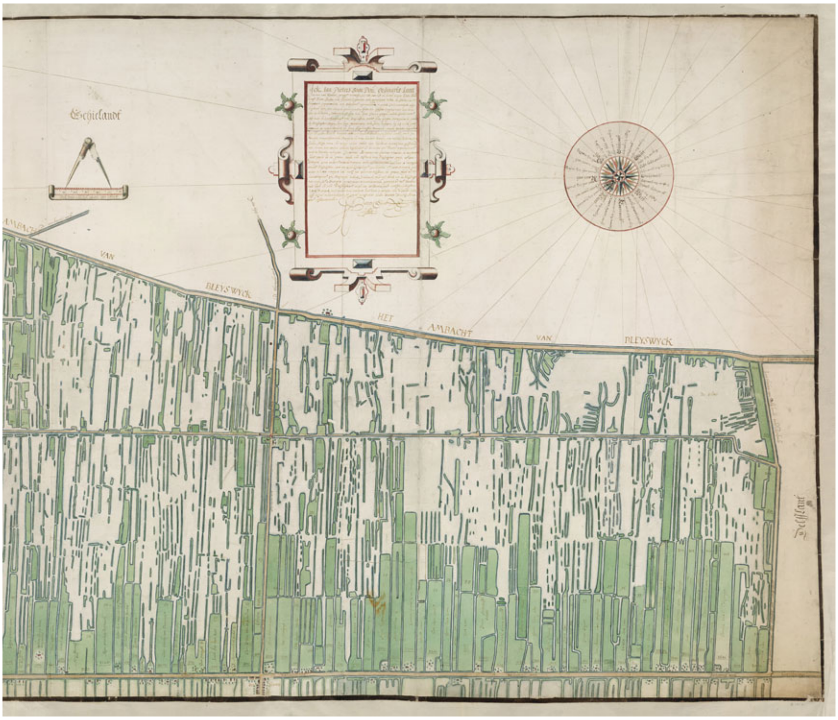

FIGURE 10.3 Detail of a map of a peat exploitation area in the Zegwaard. Author and date unknown. The map shows how the land surface is exploited, and how in certain areas, larger surfaces of water are emerging. (Source: Archive of the Hoogheemraadschap Rijnland number: A-1310 (NL-LdnHHR, Collectie kaarten, A-1310). Reproduced under CC-BY-SA)

created surfaces of open water, which, in turn, became a danger to the remaining land by undermining its stability and subjecting it to flooding in stormy weather (Figure 10.3).

In the last phase of the early modern period, major collective activities dealing with aspects of water management were made possible by concerned volunteerism, which was subsequently replaced by wage labor paid for by a land tax imposed by the authorities of what was now the Hoogheemraadschap Rijnland.

As land was progressively dug away, of course, this reduced the tax revenue necessary for the maintenance of the dams, canals, and locks that kept the water under control. Hence, the water authorities tried to limit peat extraction and increase their taxation-based income by forcing those who practiced it to buy other tax-liable land, to compensate for the loss of income when land was dug away to become water. In the process, the water authorities gained control over aspects of land management.

This became all the more urgent because the increase in open water required another reorganization of water management. Improved locks were installed along the northern edge of Rijnland, which opened to drain the land during ebb and closed to protect the land at high tide (Figure 10.4). To realize these improvements, the Hoogheemraadschap extended its control to all the dams and related engineering works in the area.

The 'Golden Era': Water Is Again Transformed into Land

In the Netherlands, the period 1550–1650 is commonly called the Golden Century. It is the era in which the Dutch gained their freedom from Spain through a war that lasted eighty years (1568–1648), while the Dutch merchant fleet vied with the British for control of the oceans and Dutch merchants, particularly from the western part of the country (Holland and Zeeland), founded trading posts and colonies around the world (Dutch East Indies, Southern Africa, Brazil, Eastern North America, etc.). The Dutch coastal cities grew exponentially, and Amsterdam became one of the capitals of the world. Many urbanites profited from the rural poverty by purchasing tracts of agricultural land, grassland, or peat. From this point onwards, the towns had a direct economic interest in the countryside, and they vied with the Hoogheemraadschap for control over it. In the meantime, the Hoogheemraadschap itself ran into financial problems. An agrarian crisis in the first half of the seventeenth century occurred in parallel with a decline in available peat. As peat became the dominant source of income, the next predictable step was to impose a tax on peat rather than on land. Rising urban wealth and the need to feed a rapidly growing urban population in the seventeenth century led to a rapid increase in grain prices in the 1660s, again tipping the balance between agriculture and stockraising. For a period of some thirty years, agriculture once again became profitable. Hence, some of the (artificial) lakes in Rijnland and other parts of Holland were pumped dry, by first digging a canal around them and then installing at their edges batteries of windmills, each of which lifted the water a little higher until it could eventually be dumped into the canal surrounding the drained area (Figures 10.5a, b). After such an area had been laid dry, drainage ditches were dug across it in a rectangular pattern to ensure the maintenance of a

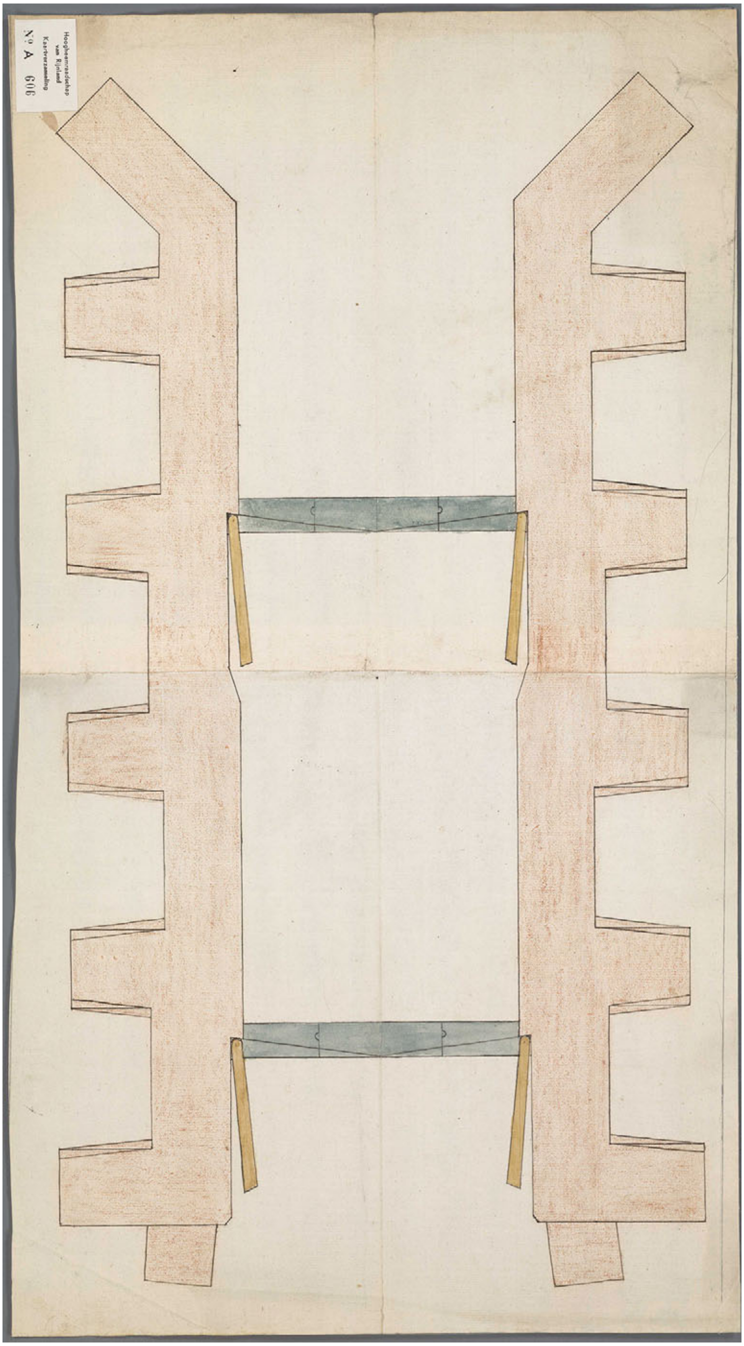

FIGURE 10.4 Top view of the Western lock in the Spaarndammerdijk at Halfweg by Cornelis Cornelis Frederixzoon (1556). The area to be drained is to the north of the lock (top of the illustration). When it is low tide to the south, the lock opens

(a)

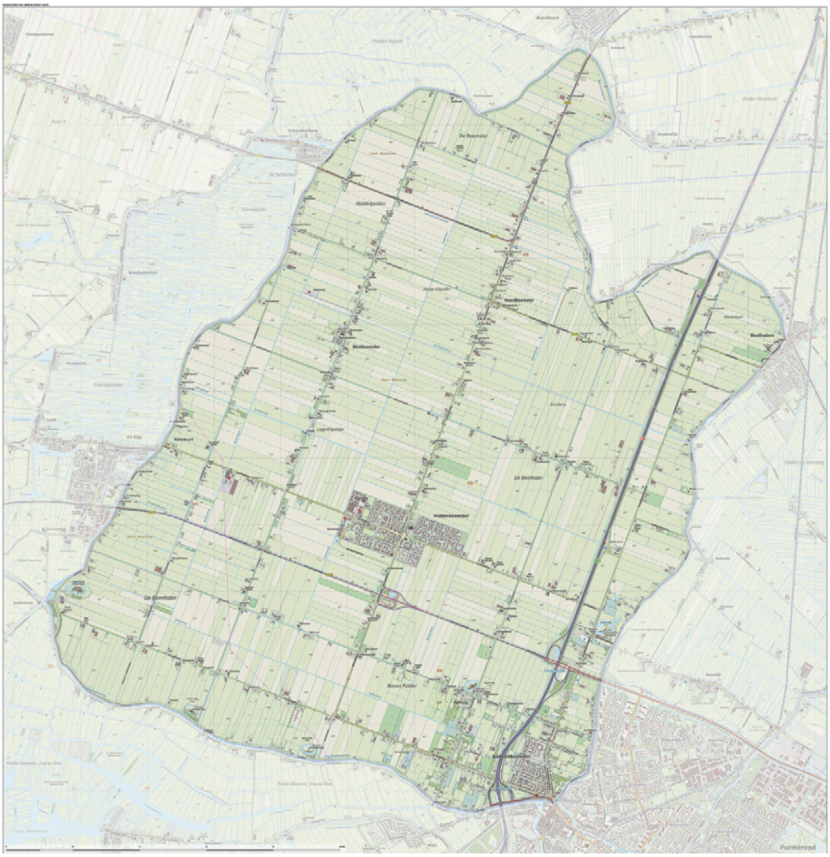

FIGURE 10.5a Topographic map of the Beemster polder in the Netherlands in 2015. One clearly sees the canal surrounding the polder, which served to drain it (and now keeps it dry), and the rectangular spatial organization of ditches that connect to the surrounding canal. At the time of drainage, the water was removed by windmills, as in Figure 10.5b; now it is removed by modern pumps. (Open access CC-BY)

low water table. The fertile clays thus laid bare were quickly turned into rich cereal fields.

The investment needed to do all this, however, was beyond the means of what remained of the impoverished rural population, nor could it be

automatically and allows the water to flow out of the drained area. At high tide, the lock closes automatically, preventing water from flowing in. (Source: Archive of the Hoogheemraadschap Rijnland. Number A-0601 (NL-LdnHHR, Collectie kaarten, A-0601) Reproduced under CC-BY-SA)

(b)

FIGURE 10.5b Set of three windmills near Reeuwijk. Author and date unknown. Three windmills are required to pump the water from the polder into the drainage canal surrounding it. (Source: Archive of the Hoogheemraadschap Rijnland number A-0517. (NL-LdnHHR, Collectie kaarten, A-0517) (Reproduced under CC-BY-SA)

funded by the Hoogheemraadschap as long as its principal source of income was the peat tax. Private investment by rich urban shareholders, associated for this purpose in ad hoc partnerships, took over the financial burden, enabling urban control over rural land.

In 1675, just after a major war (1672–1674) between the Netherlands (or more specifically Holland) on the one hand, and Britain, France, and two German principalities on the other, the main dam protecting the Rijnland against flooding broke on two occasions. Similar events occurred again in the following century. Delayed maintenance may well have been a factor because the Hoogheemraadschap was no longer solvent.

The disaster of 1675 was of such proportions that the towns (led by Amsterdam, Haarlem, and Leiden) loaned the Hoogheemraadschap the necessary funds for repairs and improvements. Subsequently, the Hoogheemraadschap began raising funds for maintenance and investment by issuing bonds against future revenue from the peat tax.

The cities' inhabitants, many of which already owned land in Rijnland, subscribed to most of these bonds. The loans set in motion a process whereby the cities and their inhabitants ultimately established control over the Hoogheemraadschap and the rural environment that surrounded them.

Regaining Lost Ground

After about 1700, agriculture did not return to profit in a major way until the second half of the eighteenth century. At the same time, underwater peat exploitation neared the limits of what was feasible with the technical means available at the time. Income from peat (and the peat tax) declined, while protecting the banks of the lakes became an increasingly urgent and costly affair. Inhabitants and authorities were therefore faced with the question of whether it was worthwhile to continue exploitation of the area.

Deserting it would have led to major inundations and other problems. The solution chosen was to further transform water into land. The few attempts at draining small man-made lakes in the seventeenth century had demonstrated that the rich soils at the bottom could be profitably used to produce grain, meat, milk, and milk products. Hence, Rijnland and other authorities devised schemes to fund the drainage and reclamation of many of the lakes, borrowing money against future tax freedom or investing some of their own funds. The positive results of this venture initiated a

FIGURE 10.6 Owing to the insolvency of the Hoogheemraadschap it could not repair the dams; the cities Haarlem, Leiden, and Amsterdam took control over the whole area. (Source: M. van Tielhof and P. J. E. M. van Dam, *Waterstaat in stedenland. Het hoogheemraadschap van Rijnland voor 1857*, Utrecht 2006) (by permission of Stichting Matrijs Utrecht)

phase of major land reclamation focused on lakes of limited depth and size all across Rijnland and, in effect, all over Holland.

During the eighteenth century, plans to drain the (huge) Haarlemmermeer were considered several times. This large surface of open water was an important part of the transportation network, yet its size and shallow depth made it very dangerous to shipping whenever there were high winds or storms, and its edges were regularly inundated. In particular, with strong western winds, its eastern edge became a real cemetery for ships (Figure 10.7); hence the name for Amsterdam's airport, Schiphol, which literally means "hell for ships." But the huge costs

(a)

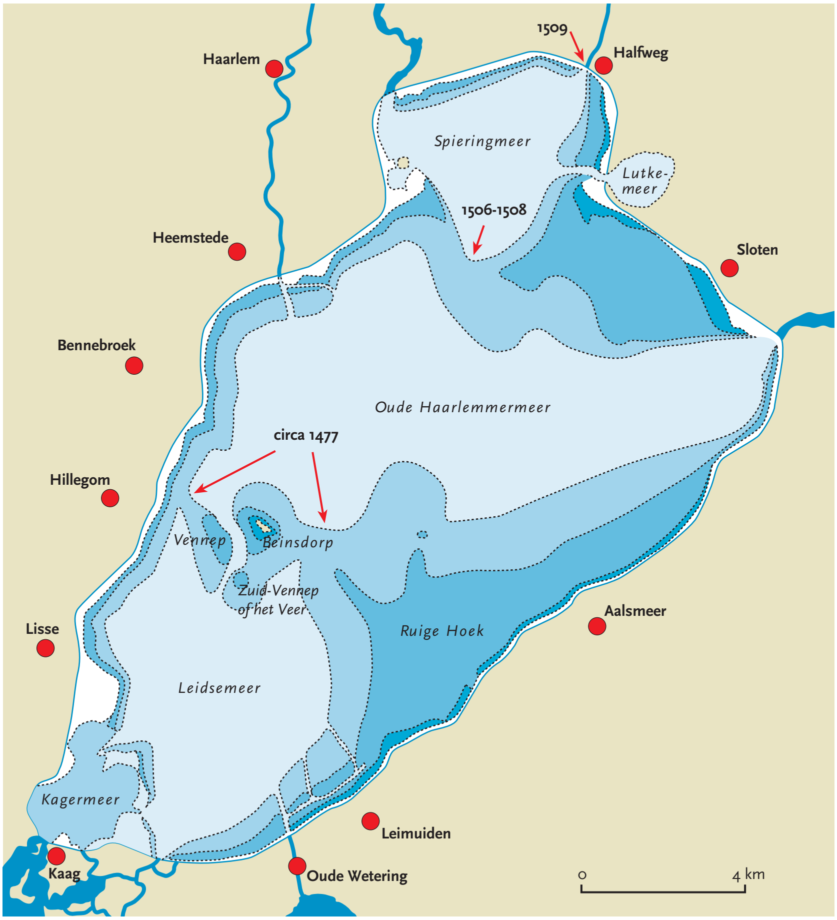

FIGURE 10.7 Peat excavation weakened the edges of the lake, and open water caused wind and water to batter them (Figure 10.7a). The lake doubled in size between 1250 and 1848, and with a strong wind from one direction the water level on the opposite shore could be driven up a meter or so, inundating the land (Figure 10.7b). (Source: M. van Tielhof and P. J. E. M. van Dam, *Waterstaat in stedenland. Het hoogheemraadschap van Rijnland voor 1857*, Utrecht 2006). (By permission of the publisher, Stichting Matrijs Utrecht)

(b)

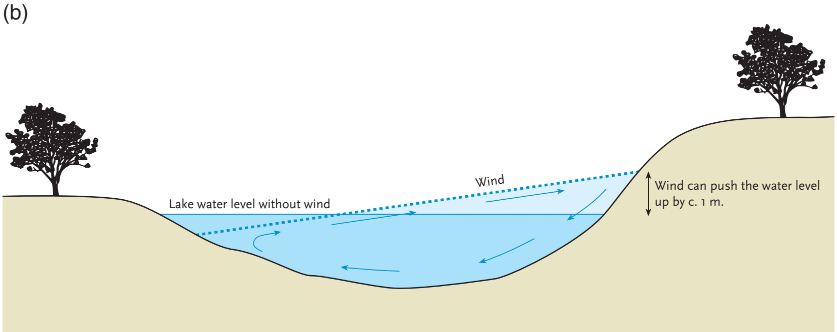

FIGURE 10.7 (*cont.*)

involved could not be borne by the Hoogheemraadschap or other local or regional authorities, in part because the eighteenth century was a much less wealthy time for the Netherlands than the preceding one. Time and again, the plans were postponed.

After the French occupation of 1795–1814, the federation of provinces that constituted the Republic of the Seven United Netherlands (Republiek der Zeven Verenigde Nederlanden) was replaced by a kingdom that included Holland, Zeeland, and the five other provinces. Simultaneously, in the East Indies, a novel landholding and exploitation system (in the form of plantations) substantively increased the income of the nation and the state. The state now had the resources needed for the project, and the invention of steam engines to drive the pumps made draining the Haarlemmermeer technically feasible.

But it was not until a furious hurricane in November 1836 drove the waters as far as the gates of Amsterdam, and another on Christmas Day the same year that sent waves in the opposite direction to submerge the streets of Leiden, that the mind of the nation seriously turned to the matter. On August 1, 1837, King William I appointed a royal commission of inquiry, and in the following May the work began. A canal of 61 km was dug around the lake, fittingly called Ringvaart (Ring Canal), to enable water drainage and boat traffic that had previously gone across the lake. The dug-out earth was used to build a dike between 30 and 50 m wide around the lake. The area enclosed was more than 180 km² and the average depth of the lake was 4 m.

As the area had no natural drainage, around 800 million tons of water had to be pumped into the Ringvaart by mechanical means to transform it into land. Unlike the historic practice to drain polders using windmills, steam powered pumping stations were used, a first. Three steam pumps were built: the Leeghwater, the Cruquius, and the Lijnden.

Pumping began in 1848, and the lake was dry by July 1, 1852. Rather than being incorporated into any particular existing administrative organization, it was given the status of an independent municipality within the province of Noord-Holland. The state thus directly assumed control over the newly reclaimed territory.

With the reclamation of the Haarlemmermeer, the history of water and land in Rijnland comes to a provisional end, as no major reversals or new reclamations have subsequently occurred in the area.

The Aftermath

But elsewhere in the Netherlands, well into the twentieth century, this project was followed by other, increasingly ambitious, ones. Initially, these reclamation projects were concerned with large parts of the so-called Zuiderzee, the large open water in the center of the country. In 1929, it was closed off from open sea by a dam connecting the provinces of Noord-Holland and Friesland. Draining the first of the polders in what was now called the IJsselmeer (ex-Zuiderzee), the Wieringermeerpolder, was completed in 1930. During World War II, this was followed by completion of the Noord-Oost Polder (1942). After the war, two huge new polders were also reclaimed, respectively called Oost Flevoland and Zuid Flevoland. In total, 1650 km^2 of land were reclaimed in the 1950s to 1980s).

A last major flood occurred in 1953 when large parts of Zeeland and Brabant were inundated by a combination of an extremely high tide and a strong westerly storm. This came at a time when the dams protecting these areas had been weakened by lack of maintenance during World War II and its aftermath.

It led to a major project (the so-called Delta-werken) that now protects the area, but the idea to reclaim more land was abandoned when the Netherlands opened its trade borders more and more to agricultural products from elsewhere in Europe in the context of the emergence of the European Union (EU) (Figure 10.8).

Both in the case of the reclamation projects in the IJsselmeer and in that of the Delta-werken, only the national government had the means to undertake them, and it therefore exerted its authority over them. In effect, from its first emergence out of the sea until 1986, the whole of Flevoland

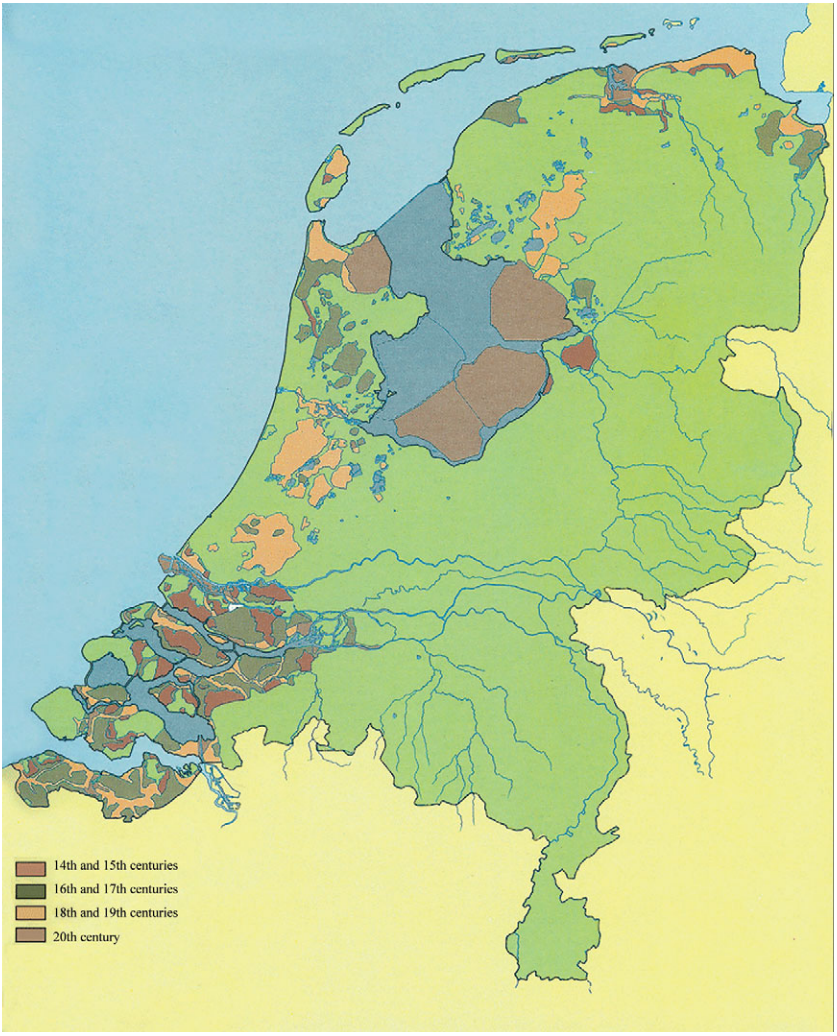

FIGURE 10.8 Overview of the areas of the Netherlands that were artificially drained in various periods of the country's history. (Source: van der Leeuw)

and its inhabitants was subjected to the authority of a single person appointed by the government, the *Landdrost*!

Summary and Conclusion

The outline of the story recounted here is well known; the western Netherlands were created, as well as peopled, by its inhabitants. Water was initially a threat from which to flee and then something to be contained. The point is that not only the land itself, but new technologies, institutions, a new spatial organization, and much of Dutch culture emerged from the interaction between people and water.

The need for drainage and containment first led people to collaborate and to develop new techniques to deal with the dangers of both short-term floods and long-term degradation of terrestrial resources. The dynamics coupling environmental limitations and social initiatives resulted in newly invented management techniques that addressed and frequently solved differences of opinion and created powerful institutions. Thus, the first supraregional authority, the Hoogheemraadschap, under its president, the dijkgraaf, was created in response to the water management issue – an issue that could not be left in the hands of much smaller political principalities.

In the struggle, water was transformed into land for cultivation and grazing, and this land was then transformed into lakes by selling it in the form of turves to fuel hearths and industries. Ultimately, these lakes were drained to recreate agricultural land when the need was felt.

As a result, the surfaces of large parts of the western Netherlands were lowered to between 1 and 6 m below sea level, creating a situation of extreme vulnerability to any sea level rise that might be caused by climate change.

One of the important lessons of this story is that a kind of cyclical "Tragedy of the Commons" is taking place. It evidences the ongoing battle between individuals, institutions creating opportunities for individuals by containing the water, individuals creating new water-related threats, the calls for strengthened institutions, etc.

Individuals first colonized these low-lying parts of the delta. As they drained it for cultivation, or to build small artificial mounds to keep their houses and animals dry during floods, other longer-term threats emerged that could not be dealt with individually. Large-scale drainage systems were dug, and instead of building individual artificial mounds, people began collectively to protect land against floods by building dikes. In the process, they created institutions such as the Hoogheemraadschap to guard their collective interests. Once that was done, and cultivation enabled people to make a good living, land degraded and the economy arose and the economy shifted to grazing. Grazing is less demanding of the land and the drainage infrastructure than agriculture. When land became unsuitable for even that form of exploitation, the same individual interests transformed land into fuel. Thus, it created open water and undermined collective safety as well as the institutions that had been put in place to protect against the water.

From another perspective, it is all about spatial and temporal scales. Ultimately, when water became a local and regional threat once more, and there was insufficient land to provide food, the tendency was inverted by non-rural individuals who saw the benefit in, and provided the means to, collectively transform water into land. These means were derived from activities elsewhere, first in different urban sectors of the regional economy (successively fishing, regional trade, industry, and banking) and later on the high seas (long-distance trade and piracy), or, after 1815, in the Dutch colonies. In the process, the area became increasingly dependent on other parts of the world, other resources, or other feedback cycles (the spatial scale of the system was stepped up each time a disaster threatened or hit). Thus, the reclamation of the Haarlemmermeer was funded in part by the increasing stream of riches gained in the Dutch East Indies, where a system of intensive plantation agriculture for the European market had been instituted. In turn, the reclamation of Flevoland was made possible by the economic boom after World War II, to which the birth and growth of the EU was also closely related. In the end, the integration of the EU made further drainage uneconomic because the agricultural products that could be grown there were now made available more cheaply elsewhere.

As long as the local and regional cyclical lows did not coincide, the highly artificial and very costly system could be maintained. Local profits could be made thanks to investment of funds gained elsewhere. In Rijnland this was the case when either urbanites or the cities as institutions collectively intervened to fund the protection of land against water. Nevertheless, if there was a temporal overlap between lows in both regional and more global cycles, problems hit with redoubled severity, such as in the eighteenth and the first half of the nineteenth century. Then, disaster could only be averted by yet another increase in the spatial and the temporal scale of the system. For example, by invoking the help of the national government to drain the Haarlemmermeer, the frequency with which problems hit was dramatically reduced and both the material and institutional infrastructure that maintained the polder in a steady state was strengthened. In the process, the scope and scale of threats and institutions bootstrapped themselves to eventually encompass all of the Low Countries, shaping much of Dutch society to this day.

The story beautifully illustrates the role of risk perception in generating unintended consequences in environmental management by society. In attempts to deal with frequently occurring events in the interaction between people and their environment (such as the seasonal inundations that led people to invent artificial mounds), human intervention leads to new perspectives and new actions (such as the enclosing of whole areas by artificial levees). However, these changes frequently engendered new risks, of which neither the nature nor the frequency was known. When these risks materialized (in the form of decadal or even centennial floods, for example), other means were sought to deal with them, and the changes wrought in the environment introduced yet more risks – again of unknown nature and frequency. The investment to maintain these solutions could prove too costly for the local population, resulting in the additional risk of an area becoming dependent on another region's economic cycles.

In each instance, the solution to an imminent challenge was based on interventions in the environment that triggered other challenges, both environmental and societal, down the line. The latter were less frequent and involved a larger timescale. As a result, over time the risk spectrum shifted from relatively frequent, spatially limited risks to less frequent but more consequential risks. Ultimately, the accumulation of risks with unknown, longer, temporalities led to another set of risks that could burst upon the scene simultaneously: a time-bomb or crisis, such as the current environmental crisis.

A conceptually similar story, about the emergence of modern finance and long distance trade in Renaissance Florence, has been elaborated by Padgett and others in great detail (Padgett & Ansell 1993; McLean & Padgett, 1977; Padgett 1997, 2000; Padgett & Powell 2012), based on the analysis of 50,000 lives of Florentines in that period. It shows wonderfully how social relations, initially around city squares and plazas, led to financial exchanges, the availability of more capital, the need for better accounting (leading to double-entry bookkeeping), longer and longer distance trade, and many other aspects of both financial and power relations. It also shows the power of the complex systems approach in promoting understanding of societal dynamics.

In addition, as part of the ARCHAEOMEDES project, Christina Aschan-Leygonie did an interesting and related study on why, in the Haut Comtat in France, a crisis in the 1860s was quickly resolved and another one, a century later, was not (van der Leeuw & Aschan-Leygonie, 2005). I refer to this in Chapter 6.

Although the exact nature of the changes that emerge in the process of innovation may be unanticipated, the fact that changes will emerge is far from unexpected. Similar situations and chains of events have occurred whenever and wherever people tried to impose particular solutions to the challenges posed by the environment. They seem profoundly inherent in human interactions with the environment, as those interactions are often based on making a distinction between us and our environment, although that environment is not ours to possess or on which to impose our solutions. In the current extreme form, that is a particularity of western culture that has become more and more prevalent since the fourteenth century, as outlined in Chapter 3.

Maybe we should take a closer look at the worldview of such societies as the Achuar, who do not make such a Manichaean distinction between themselves and their environment (Descola, 2005), and from that starting point attempt to reconstruct how our present worldview might have evolved from a position like theirs. To conclude, let us therefore spend a little time looking at how we might indeed change our perspective so as to get a better grip on these dynamics.

First of all, and inherent in the Complex Adaptive Systems perspective, the point of view that we choose should be an ex-ante perspective rather than the much more common ex-post perspective. To understand new phenomena, we should be following the process of their emergence, rather than studying the origins of the current situation. We should develop a perspective that goes with the arrow of time, rather than against it. A necessary corollary of that position is that our approach should not reduce the number of dimensions taken into account in order to generate understanding (as much of science still does), but should enhance the number of dimensions taken into account. While studying to learn from the past, we should do this in order to learn for the future. This advocates for methodologies that inherently increase uncertainty and require us to embrace it, a reframing of uncertainty as positive and an advance. Needless to say, in practice, both in the academic domain and in the world of application, one encounters enormous resistance to this idea.

Part of this is the fact that we must move away from using one or a few causal chains to explain the present, and in general start thinking in multiple alternative scenarios (Bai et al. 2015). By evaluating these, and in particular by comparing the unintended consequences of the choices made (by individuals or systems) with those that would have occurred had another option been chosen, we will get a much better grip on the relationship between choices and unintended consequences, and thus reduce (unperceived) risks as we move into the future.

Crucial in all this is the fact that we have not been able to do all this until now – indeed, our centuries-long intellectual tradition, the inherent limitations to our information processing, as well as other factors militate against such an approach. But with the information age, a number of barriers may be about to be taken away, or at least reduced. For one, modern terabyte data-dense monitoring may overcome, at least to some extent, the under-determination of our ideas by our observations. Secondly by (much) more closely integrating computing into our societal information processing than has been done to date, we may be able to take into account many more dimensions of the phenomena and processes we deal with in our decision-making. But for that to happen, we must begin to harness computing in a different way, emphasizing our capability to move from lower to higher dimensionality as well as in the other direction (as we do now). This amounts to creating the tools to move from the past to the future as well as in the reverse direction. Essential in developing this capability is the need to use much more extensive modeling, and in particular agent-based modeling to enable us to understand how an ensemble of individual actions creates collective patterns and processes (van der Leeuw et al. 2011). If we are able to achieve that at least to some extent, it may help quell fears about increasing uncertainty. If you know with certainty that you have to navigate through a hundred different uncertain possible outcomes, this is better than not knowing the scale of uncertainty in your future, and this is especially relevant if you are transitioning from the comfort of an illusory belief that there are just three or four possible outcomes.

NOTE

1 The case study in this chapter has previously been published in the *Danish Geographical Journal*, and is here reproduced by permission from Taylor & Francis.

11

Transitions in the Organization of Human Societies

Introduction

In Chapter 8 I presented an overview of my vision of the long-term evolution of human societies with an emphasis on the transition from a biologically constrained cognitive evolution to a socially constrained one. In Chapter 9 I introduced the concept of dissipative flow structure as a tool to understand that information flow drives the coevolution between cognition, environment, and society. In Chapter 10, I drilled down into history and showed how technological advances in a region, made necessary by environmental circumstances and in interaction with the economy, transformed society and its institutions in a continuous back and forth between solutions and the challenges that these raised. Ultimately, they lead to the current landscape, technology, economy, and political organization of the Western Netherlands. In this chapter I want to step back again to a more general perspective and emphasize the nature of the principal, different system states that occurred in the second, sociocultural part of the long-term trajectory outlined in Chapter 8. This will show the role of changes in information processing structures that are responsible for such transitions.

Ever since the classic series of proposals by Sahlins and Service about the evolution of societal organization that appeared in the 1960s (Sahlins & Service 1960), it has generally been acknowledged that there have been a number of transitions in societal structure as societies grew in size and complexity, even though the details of these transitions have been open to much discussion. In the perspective that I am developing in this book, such transitions are essentially transformations of the structure of their information processing apparatus. In this chapter, I will look in some detail at these structures from an organization perspective.

Information Processing and Social Control

The wide literature on information-processing, communication, and control structures in very different domains presents us with (for the moment) three fundamentally different kinds of such structures. These differ notably in the form of control exerted over the information processing, regulating who has access to the information and who does not, but also determining to an important extent these structures' efficiency in processing information and in adapting to changing circumstances, such as the growth of networks, or to various kinds of external disturbances. These differences have a number of consequences for the conditions under which each kind of communication structure operates best. I will first describe some of these consequences for each of these types of control structure.

Processing under Universal Control

When the universe of participating individuals is small enough that all know each other, messages can be sent between all participants. Even though, inevitably, some members of the society associate with each other more than others, the contacts between individual members are so frequent that information can spread in myriad ways between them. Communication therefore does not follow particular channels, except maybe in special situations. Moreover, because so many different channels link the members, there are no major delays in getting information from one individual to another. If a channel is temporarily blocked, a nearby channel, which is hardly longer, will convey the information immediately (Figure 11.1).

In addition, there is no control over information. Because each member of the group receives information from a number of different directions, and sends it on in different directions as well, there is ample opportunity to compare stories and thus correct for biases and errors. Although it takes time, groups in this situation usually manage eventually to have a highly homogeneous "information pool" on which to base their collective decisions.

The situation is that of small group interactions described by Mayhew and Levinger (1976, 1977) in terms of the relationship between information flow, group size, and dominance of individuals in the group.

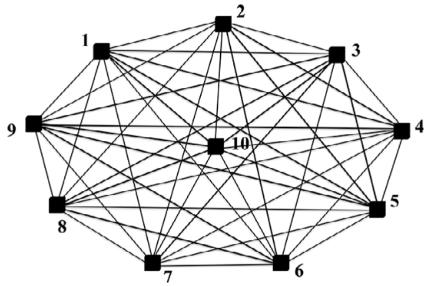

FIGURE 11.1 Graph of egalitarian information processing with universal control: all individuals are communicating with all others. (Source: van der Leeuw)

It applies to egalitarian societies, in which control over information is very short lived and is accorded to specific individuals as a function of their aptitude to deal with specific kinds of situations, because these individuals have a particular know-how of the kind of problem faced. As a result, no single individual or group can ever gain longer-lasting control over such a society. In such situations, the homogeneity of the information pool is further aided by face-to-face contact. In such a contact situation, it is possible for the sender and the receiver of messages to communicate over many channels: words, tone of voice, gestures, eyes, body language, etc. Communication is therefore potentially very complete, detailed, and subtle. Mutual understanding can be subtle and can connect many cognitive dimensions, even though these remain relatively fuzzily defined.

Mayhew and Levinger (1976, 1977) also show how the amount of time needed for each interaction between the members of the group effectively limits the size of such groups. The (logistic) information flow curve in a small group rises exponentially with the addition of members, until there is not enough time in the day to talk sufficiently long to everyone to keep the information pool homogeneous. Yet homogeneity is essential for the survival of the group because it keeps the incidence of conflict down. Increasing heterogeneity will immediately cause fission until the maximum sustainable group size is reached again. Johnson (1982) presents a large number of cases of societies organized along these lines. It should be noted that this kind of communication model is thus confined to very small-scale societies. It limits communication to what can be mastered by all individuals in the group and avoids the emergence of any specialized knowledge such as we see in more complex societies, thus also limiting the overall knowledge/information that can be shared.

For an ethnographic study that highlights these dynamics, without using the terminology I have adopted, see Birdsell (1973).

Processing under Partial Control

When some participants know of all others, but others do not, some people can directly get messages to all concerned whereas others cannot do so. Such asymmetric situations arise when the group concerned is too large to maintain an egalitarian communication system or a homogeneous information pool. From ethnography and history, we know a wide range of societies that communicate and decide in this manner. They are extremely variable in overall size, as well as in the size of their component units, their communications, information processing structure, etc.

Processing under partial control is fundamentally different from universal control over communication and decision-making because it relies both on communication and on noncommunication between members. Members of the group usually communicate with some others, but not with the remainder of the group. The usual form that communications structures take in these societies is a hierarchical one (Figure 11.2), because it is the most efficient way to reduce the number of communications needed to (eventually) spread information from the center to the whole group (Mayhew & Levinger 1976, fig. 8).

Evidently, such communication structures generate considerable heterogeneity in the information pool. As stories are transmitted they will inevitably change, and for most individual members of the society there is no way to correct this by comparing stories from a wide enough range of different sources.

But because there is relatively little communication crosscutting habitual channels, few are aware of that heterogeneity. This creates a potential problem: when information spreads in unusual ways, its heterogeneity is

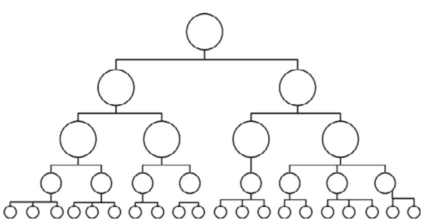

FIGURE 11.2 Graph of hierarchical organization with partial control: some people have more information at their disposal than others. (Source: van der Leeuw)

suddenly highlighted, causing explosive increases in conflict and strong fissionary tendencies. Suppression and control of information is therefore an essential characteristic of hierarchical systems.

As long as the society needs the communication capacity of its hierarchical control structure to remain intact, that structure is acceptable; but whenever the information flow either drops too low or exceeds channel capacity, the hierarchy will be under stress. In other words, as long as it is experienced as an enabling feature, the delegation of individual responsibility to those in control is acceptable. But as soon as the hierarchy is experienced as a constraint, the members of the group will try to forge links that circumvent the established channels. This starves the hierarchy of vital information and reduces its power and efficiency. Hence, frequent system stresses favor the implementation of hierarchical information flow structures, and such structures have a stake in maintaining the stresses concerned, but also in ensuring that they do not exceed certain levels that would tear the societal structure asunder.

Many essential communication channels in hierarchical systems are longer than in egalitarian ones, so that the risk that signals are lost is enhanced. Communications need a stronger signal-to-noise ratio. What is a signal in one cognitive dimension may be noise in relation to most other dimensions. One way in which to create a stronger signal is therefore to reduce the number of cognitive dimensions to which it refers. This can be achieved by strictly defining the contexts of interpretation, for example by imposing taboos or by ritual sanctioning. The establishment of such reduced-dimension cognitive structures manifests itself in the emergence of specialized knowledge in the group, thus widening the spectrum of knowledge, whether that is technological, commercial, religious, or other.

Processing without Central Control

When none of the participants know all the others, none can send any direct messages to all concerned (Figure 11.3). More importantly, in such a situation people necessarily send out messages without knowing whom they will reach or what the effect will be.

Whereas in our first example everyone was in the know and in our second one some were informed and some were not, in this case everyone is partly informed. People depend entirely on this partial information, which they cannot complete. Their information pool is much more heterogeneous, but because it is homogeneous in its heterogeneity, the situation is relatively stable.

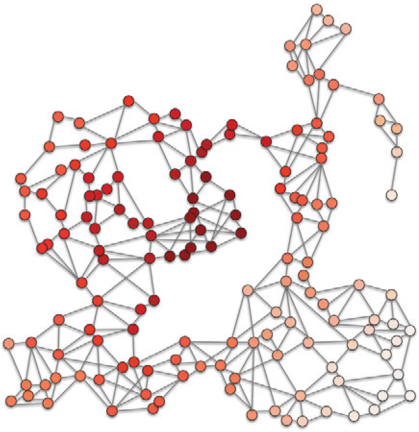

FIGURE 11.3 Graph of random communication network, without any control, in which all individuals have partial knowledge. (Source: van der Leeuw)

In this situation, there are no set communication channels. Instead, there are multiple alternative channels if information stagnates anywhere or if it becomes too garbled. The system is thus more flexible and therefore more resistant to disruption from the outside; consequently it allows for a larger interactive group and a quantum increase in total amount of information processed. By the same token, no set individuals are in control of the whole information flow, which also makes the situation less vulnerable to individual incidents, such as those that regularly mar succession in hierarchical systems.

But on the other hand, more is demanded of the means of communication. More information needs to be passed, and more efficiently, between individuals who are less frequently and less directly in contact with one another. That is, paradoxically enough, facilitated when communications no longer depend on face-to-face situations in which communication occurs across a wide range of media or channels. Written communications can transcend space and time, and they become important because they fix a signal immutably on a material substrate, reducing down-the-line loss or deformation of the signal. But they also avoid transmitting certain dimensions that can be, and are, transmitted in face-to-face communication, and such communication can thus be more precise and avoid simultaneous transmission of contradictory signals.

This third mode of communication is the one that is generally present in (proto-) urban situations. But there it always occurs alongside universally controlled networks (families and other face-to-face groups) and often together with hierarchical communication networks. The different networks are connected via individuals who function in more than one of them. We will get back to such mixed or heterarchical networks in a later part of this chapter.

Phase Transitions in the Organization of Communication

To understand the differences in information processing dynamic that are responsible for these different kinds of social organization, it is useful to look at them from the perspective of a spreading activation network. That will allow us to begin to answer the following two questions:

- How may these different communication structures have come into being?
- How are they affected by changes in the size of the group and in the amount of information processed?

Such a spreading activation net consists of a set of randomly placed nodes (representing individuals) that have various potentially active (communicative) states (μ: the average number of connections leaving one node) with weighted links between them (Huberman & Hogg 1987). Their weight determines how much the activation (α) of a given node directly affects others (such as the degree to which messages get across and/or the degree to which people spread a message further, etc.). After a certain time, the action has run its course and the connection between the nodes lapses into "relaxation" (γ)

The behavior of such networks is thus controlled by two parameters, one specifying their shape or topology (μ) and the other describing local interactivity (α/γ: activation over relaxation), an estimate of the volume of information flow being processed. Visualization of the system is dependent on the transformative twists and turns of topology and the curving forms of dimensional nonlinearities to understand its statistical mechanics.

In assessing its dynamics, it is important to be aware of the fact that in such a model the interactivity (represented by α/γ) and the connectivity of the system (μ) are independent variables. In the two-dimensional graph of α/γ and μ, (Figure 11.4), different zones appear that one can identify as characterizing different types of information processing systems by combining different values for the two variables.

The precise nature of each state of the information processing system is the result of the interaction between these two parameters. We shall see that this only strengthens the implications of the model.

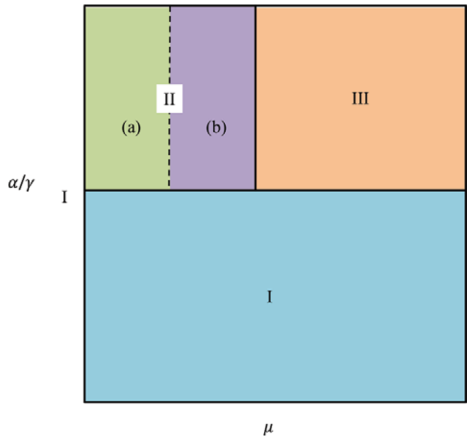

FIGURE 11.4 Phase diagram of a spreading activation net. The vertical axis represents the parameter α/γ and the horizontal axis represents the connectivity parameter μ. Phase space I represents localized activation in space and time; phase space II represents localized but continuous activation; phase space III represents infinite activation. (Source: van der Leeuw after Huberman & Hogg 1986)

The behaviors of both an infinite and a finite case of such a system are represented in Figure 11.4. Essentially, for the two variables μ and α/γ there are three states of the system. In the first (state I), both are small and activation remains localized in time and space. One can think of such activation as taking place in finite clusters with little temporal continuity. This leads to a kind of balancing out. Hence, as long as the activation intervals of the different sources do not change much in relation to the overall relaxation time t, a net in which different nodes give different activation impulses will almost always remain near the point where activation started (state I in Figure 11.4). It is, moreover, remarkable that, in the finite case this stable state is, for very low α/γ, valid irrespective of the value of μ across its entire spectrum left to right. As we shall see, this is one of the key insights of the model.

As α/γ increases while μ is small (state II near 1; i.e., on average each node is connected to only one other node), relaxation becomes more and more sluggish. This initially causes the event horizon to grow in time but remain localized in space: the interactive clusters remain small but gain temporal continuity (state II in Figure 11.4). In a second step, with equally small μ and further increasing α/γ, the interactive nodes also expand in space: the clusters involve more and more nodes (state III in

Figure 10.4). Under those conditions, "ancient history matters in determining the activation of any node, and [. . .] since the activity keeps increasing, the assumption of an equilibrium between the net and the time variations at the source no longer holds" (Huberman & Hogg 1987, 27). A further peculiarity of the transition between states II and III is that, for μ near 1, the size of the clusters involved will know very large fluctuations.

For yet larger α/γ and higher μ, the amount of spreading grows indefinitely in both space and time, and therefore far regions of the net can significantly affect each other, another key insight. The transition to this state (state III in Figure 11.4) is abrupt: a large number of finite clusters is suddenly transformed into a single giant one as the number of nodes with values above this activation threshold grows explosively.

There are many interesting implications of this work for an information-processing approach to societal dynamics. For our immediate concerns, we are particularly interested in the following:

- As long as the α/γ of the different nodes is much longer than the overall relaxation time t, all interaction in such a net remains localized, and the overall system remains in a stable state (state I). Moreover, the above is true irrespective of the number of people with which each individual interacts (the connectivity μ of the network). This might answer one of the most poignant questions of them all: "Why are the first 60,000 years of anatomically and cognitively modern man so particularly devoid of change?" The answer is that there was not enough interaction between the members of the sparse population to make information processing and communication take off. With so little information to process, the degree of interactivity of the people sharing that task does not seem to matter.
- The fact that as α/γ increases while μ remains near 1, small clusters initially only gain in continuity (state IIa), and that only for even higher values of α/γ they spread in space (state IIb). Hence, when the quantity of information processed is only moderately increased, group size will remain small, but individual groups will exist longer in terms of travel through the graph. The quantity of information processed must increase considerably before larger groups of individuals can durably be drawn together in a network. I interpret this as a transition from rather unstable, short-lived, small groups to more stable, longer-living groups of people such as (small) tribes.
- The fact that very large fluctuations in stability and size occur (for μ near 1) at the transition between states II and III; i.e., as the spatial

extent of the activation network grows. According to the model, even as the information flow increases very considerably, provided the interactivity of the people drawn into the network remains limited, both the size range and the degree of permanence of the groups will vary wildly. This would indicate that at this point in development, groups of similar density and interactivity, which process similar volumes of information per capita, might exhibit spectacular differences in size, and that their interaction was far from durable. This would support the view that chiefdoms are unstable transitional organizations. It also applies to our understanding of the size differences in tribes and segmented lineages.

- After this period of heavy instability, a third transition suddenly occurs from groups of very many different sizes (state IIb) to a continuous communication network (state III). This transition is attained by simultaneously increasing both α/γ and μ. In effect, as the volume of the information flow and the connectivity of the population grow, participation in one infinite network is inevitable. But the following particularities of this transition have interesting implications:
  - If one introduces a measure of physical communication distance in the model, and imposes the constraint that the individuals in strongly interacting parts must physically be close to one another, the percolation model develops "clumpiness" in the spatial distribution of interaction in state II. This suggests that although theoretically very large rural social systems are a possibility, practical constraints make the emergence of spatial centers (such as villages or towns) highly probable in the absence of the equivalent of the Internet.
  - The suddenness of the transition is explained by the exponential increase in interactivity and information flow as population density increases. This is compatible with the thesis that large-scale communications systems do not slowly spread from one center, but that a number of centers come about virtually simultaneously. This clearly is the case with urban systems, which always emerge as clusters of towns rather than as single towns.
  - Long-range interactions emerge in state III. As soon as the whole of the system is in effect interactive, it is of course possible that interactions occur that link nodes in very distant parts of the system. This transition is reflected in the archaeological record in the form of long-distance trade.
  - The model seems to indicate that an increase in the volume of information processed alone is not enough to really make the

network develop long distance connectivity. In other words, it is a necessary condition but not a sufficient one: increasing interactivity between participant units is at least as important. Indeed, with low interactivity the effect of a unit increase in the volume of information flow on activation is at best linear, whereas the effect of a unit increase in connectivity is exponential, both on the volume of information flow and on activation.[1]

Modes of Communication in Early Societies

For this section, I am tentatively according the percolation model above the status of a metaphor applicable to the different observed forms of social organization and the changes between them. This metaphor distinguishes several different states of the percolation network and at least four important transitions.

The first state is a very stable state overall, though the individual interactive groups in it are small, very fluid, and ephemeral. The number of nodes in direct contact with any other node may vary. The anthropologist is, of course, immediately reminded of the very fluid and mobile social organization into small groups that was successfully maintained by gatherer-hunter-fisher societies for all of the Palaeolithic. It is generally estimated that such groups consisted of a few families, maybe up to about fifty people. In cases such as those of the Australian Aborigines, the Inuit, and the !Kung, individual members of such societies frequently move from band to band, while bands themselves frequently fuse or fission.

The first transition from this state that becomes visible in the percolation model, as α/γ is increased, transforms small ephemeral groups (state I) into groups of about the same size, but with communications channels that are stable for somewhat longer periods (state IIa). These groups may represent both "great men" and "big men" societies (Godelier 1982; Godelier & Strathern 1991). In "great men" societies, typically consisting of a few hundred people, particular individuals come to play the upper hand in the context of a specific (set of) problem(s). Such individuals as achieve this are generally accorded that status because of their particular knowledge or capability to deal with a situation. As such their influence is delegated to them by the society. In the case of "big men" societies, the individuals who have come to the fore have done so by virtue of their wealth and their role in redistributing wealth among the members of the group. The groups would generally seem to be of about the same size. In neither case is there hereditary transmission of power, although it is easier to become a great (or big) man if your father was so. As far as the model is concerned, this state of the system would seem to include both mobile and sedentary groups.

As α/γ grows further, the percolation model predicts a second transition, from such small, periodically stable groups to groups that are stable over longer periods and exhibit a growing spatial presence (state IIb). I would associate this state of the model with a wide range of generally sedentary societies counting minimally a few hundred or a thousand members (tribes?). All acknowledge some sort of boss. As α/γ grows, these groups become larger and more enduring societies. In the process, μ may also be increasing, but much more slowly. These larger groups I tentatively propose to equate with what anthropologists such as Service (1962, 1975) at one time called "segmentary lineages" and "chiefdoms," more or less stable social formations that may include up to several tens of thousands of people.[1]

If this interpretation is correct, the small, mobile, and ephemeral groups of state I are generally egalitarian, those of state IIa alternate egalitarian information processing with occasional moments of hierarchical organization, particularly in times of stress, and the larger groups of state IIb are usually hierarchically organized. In many instances, cross-cutting affiliations do to some extent mitigate the negative effects of a hierarchical organization among segmentary lineages and chiefdoms.

A detailed comparison between properties of small hierarchies as outlined above (Huberman & Hogg 1987) and empirical observations, suggests (topological) answers to some aspects of the observed behavior of social systems documented by ethnographers (e.g., Johnson 1982). First, it is interesting to note that cooperation between members of randomly interacting graph structures reduces the stability of such groups. This seems to indicate that fission among small face-to-face groups ("bands" in Service's 1962 terms) in "empty space" must have had a very high incidence indeed, which undoubtedly contributed to the long absolute time span over which such groups dominated human social organization.

Next, if we take into account that in small face-to-face groups dominance relations develop with great frequency (Mayhew & Levinger, 1976, 1977), we may conclude from Hogg et al. (1989) that the emergence of hierarchies can be argued to be statistically probable under a wide range of topological conditions. Hierarchies, therefore, need not have emerged under pressure. By implication, we must begin to ask why hierarchies did not develop much earlier in human history, rather than question how their development was possible at all. One possible answer seems to be that there was not enough information to go around to maintain the (much more efficient) hierarchical networks. Under those circumstances, the advantages of a homogeneous information pool may well have outweighed the potential gains in efficiency that hierarchy and stability could have offered. But we should also consider the possibility that such hierarchies emerged much more frequently than the ethnographic record seems to indicate. The speed with which information diffuses increases exponentially in a hierarchy that grows linearly in number of levels. Huberman and Kerzberg (1985) call this effect "ultradiffusion" (discussed here and in Appendix A). This could explain why, if scalar stress increases as a function of size, an increment in the response to stress could decrease with increments of group size (see Johnson 1982, 413).

Indeed, ultradiffusion implies that with linear increases in the number of levels of a hierarchy, the size of the group that communicates by means of that hierarchy can grow exponentially. Ultradiffusion may thus explain the wide range of sizes (10^2–10^4 or more) of the groups that are organized along hierarchical lines, a fact that has long been noted in the study of what archaeologists and anthropologists call, following Service (1975) chiefdoms.

The percolation model predicts a very sudden third transition from spatially localized systems (state IIb) to infinite ones (state III), owing to an extension of the communications network to a (near) infinite number of individuals, with remarkable long-distance interactions. It essentially seems to represent what is known in archaeology and anthropology as the transition to states or even empires, which potentially include millions of people spread out over very large areas. As Wallerstein (1974) has shown, such states and empires also activate large numbers of people outside their boundaries, so that the total number of people involved in their networks may be much larger than it seems.[2]

As I do not know of any enduring infinitely large purely hierarchical systems, I interpret this transition as leading to the introduction of distributed information processing alongside complex and large hierarchical organizations. The distortions and delays inherent in communicating through long hierarchical channels combined with the physical proximity of individuals belonging to different hierarchies will eventually have led to the formation of cross-links in and between hierarchies. This has the advantage that the individuals concerned can collect information received through many channels.

As soon as the average channel capacity can no longer cope with the amounts of information to be processed, the maintenance of the hierarchies concerned will then have become combined with other information processing avenues. We know that the information flows in both states and empires are maintained by both hierarchical (administrative) and distributed (market) systems. Such "complex societies" are the subject of the next part of this chapter.

Hierarchical, Distributed, and Heterarchical Systems

The remainder of this chapter will be devoted to answering questions about the dynamic properties of various forms of information-processing organization. For this I turn to the stretching and transforming capabilities of their topologies, which requires a rather technical discussion of the mathematical underpinnings of the behavior of these organizations, the details of which will not be of great interest to many readers. I will therefore attempt a summary of their main characteristics in this chapter and present some of the mathematical basis in Appendix A.

I begin this inquiry by distinguishing, with Simon (1962, 1969), two fundamental processes that generate structure in complex systems: hierarchies and market systems. I have already presented a (simple) outline of the structure of a hierarchy in Figure 11.2. The essential thing to remember about hierarchies is that they have a central authority. The person or (small) group at the top of the hierarchy gathers all available information from people lower down, and then decides and instructs people lower down the hierarchy. Markets, on the other hand, are distributed horizontal organizations, without central control over information processing. An example is presented in Figure 11.3. Their collective behavior emerges from the interaction of individual and generally independent elements involved in the pursuit of different goals. All individuals participating in them have equal access to partial information, but the knowledge at each individual's disposal differs. Examples of such market systems abound in biological, ecological, and physical systems, and their societal counterparts include the stock exchange, the global trade system, and local or regional markets.

Each of these two modes of information processing has different advantages and disadvantages, and these are fundamental for our understanding of the evolution of information processing in complex societies, as such societies combine features of both these kinds of dynamic structures. These differences concern the systems' stability or instability, their efficiency, the oscillations they are subject to, the likelihood of transitions from one state to another, etc.

The first difference to be noted between hierarchies and market systems concerns their efficiency in information processing. In multilevel hierarchical structures each level is characterized by units that have a limited degree of autonomy and considerable internal coherence owing to the overall control at the top of the hierarchy. As the number of hierarchical levels increases linearly, the number of elements at the bottom (in technical language called leaves) increases geometrically (see the next section, point 1, and Appendix A for an explanation of this phenomenon). Under ideal conditions, the goal-seeking strategies of hierarchical structures maximize or optimize given resources, and can harness and process greater quantities of material, energy, and information per capita than market organizations.

An important feature of market systems is their inherently nonoptimizing behavior. There are two basic reasons for this. First, optimality in such structures would require that each actor have perfect information. But this is impossible since, as Simon (1969) points out, we inhabit a world of incomplete and erroneous information. As a consequence, the mode of operation of distributed systems is best defined as satisficing rather than optimizing. Second, rather than by hierarchical control, behaviors in market systems are constrained by their nonlinear structure. The strength of existing structures, for example, can prevent the emergence of competing structures in their nearby environment – even though these new structures may be more obviously efficient. A useful modern example is to be seen in the American motor industry, which continued the production of large, energy inefficient cars long after it was apparent that smaller cars were more fuel-efficient and less polluting. Overall therefore, market systems are less efficient than their hierarchical counterparts in processing matter, energy, and information. The differences between the market and hierarchical systems probably explain why, even in modern political systems such as those examined by Fukuyama (2015), the best choice of government is a mix of the two (see also next section, point 1).

The next difference concerns the organizational stability of these two kinds of information processing structures. Since they operate on principles of competitive gain and self-interest, market systems are highly flexible and diverse. Political and legislative control in such systems is always difficult, as we see in our current democracies, because people in such distributed systems act on partial and different information and have more freedom to foster different perspectives. Such systems' behaviors can therefore relatively easily become potentially disruptive and even destructive of the organizational stability of society.

This is, of course, not so in the case of hierarchical structures, whose main raison d'être lies in the efficiency with which authoritative control over decision-making is exercised at the top. But this means that the people lower down the hierarchy must sublimate many of their personal desires and aspirations for the good of the system. Autocratic and authoritarian rule systems may emerge to preserve the hierarchy's pyramidal structure and maintain its organizational goals until they are no longer accepted by the base of society.

In view of these characteristics, it is highly improbable that either fully hierarchical or entirely market-based systems would have been able to provide a durable, coherent, structural organization for large societal systems. But the limitations of both hierarchical and market organizations can be avoided if they are coupled in complementary ways (Simon 1969).[3] Such societal structures that combine hierarchical and distributed processing are here called heterarchies.[4] Their hybrid nature dampens or reduces the potential for runaway chaotic behavior and thus increases the information processing capacity of the system. Our next task is therefore to analyze in more detail the relationships between the structure and the information processing dynamics of hierarchies and market systems, and then to determine how they might interact in a heterarchy.

The first issue is the speed of information diffusion in hierarchical and market systems respectively.

Information Diffusion in Complex Hierarchical and Distributed Systems

Complex Hierarchies

Unfortunately, large hierarchies cannot be studied by observing the behavior of their parts (as one can do with small systems), nor can they be treated in a statistical manner, as if the individual components behave with infinite degrees of freedom. They are essentially hybrids of micro- and macrolevel structures, and need an approach of their own.[5] That would involve treating the individual leaves at the lowest levels of a hierarchy statistically, by integrating over them, while considering those at the top static, as they constrain the intervening levels of the hierarchy everywhere in the same fashion (Huberman & Kerzberg 1985; Bachas & Huberman 1987). With that as a point of departure, Huberman's team has developed a number of ideas about the information-processing characteristics of hierarchies that can be summarized as follows (see Appendix A):

1. Independent of the size of the population that a hierarchy integrates, there is an upper limit to the time it takes to diffuse information throughout it. For example, when expanding a hierarchy from five levels to six, the additional time needed to diffuse the information is a root of the time added upon expansion from four levels to five. There is a power-law involved, which relates the speed of information diffusion to the number of levels in the hierarchy. Hierarchies are therefore very efficient in passing information throughout a system and, although somewhat counterintuitive, the more levels the hierarchy has, the more rapidly information is (on average) distributed.
2. If a hierarchical tree is asymmetrical around a vertical axis, such as when the number of offspring is three per node on one side and two per node on the other, then overall diffusion is slower because it takes more time for the information to be diffused on one side than it does on the other side, and that may in turn garble information because, as all transfers pass in part through the same channels, interference and loss of signal will occur. Such constraints might lead one to predict that under unconstrained circumstances, fat and symmetrical trees would tend to develop. Evidence of asymmetrical ones or particularly narrow ones could therefore serve as pointers to such constraints.
3. This may be a major constraint on the hierarchy's capacity to stably transfer undistorted information. To quantify this, we need to look at the overall complexity of the tree (again, for mathematical detail see Appendix A). It turns out that for large hierarchies, very complex trees will have a complexity that at most increases linearly with the number of its levels. That complexity is inversely proportional to the tree's information diffusion capacity.
4. But is the number of levels unlimited? Theoretically, adding one more level to a hierarchy allows for an exponential increase in the number of individuals that it connects. If we assume a constant signal emission rate for leaves at the base of the hierarchy, it follows that the number of signals produced by the individuals at the base also increases exponentially. The diffusion of information through the whole system (see point 1) that permits this exponential

increase, however, is achieved at the expense of reducing the increase in the amount of information that circulates to a linear one. This is done by "coarse-graining," or suppressing detail every time a signal moves up to the next level. Thus, while the speed of diffusion of information increases, the precision of the information distributed decreases.

5. Defining adaptability as the ability to satisfy variations in constraints with minimal changes in the structure, Huberman and Hogg (1986, 381) argue that the most adaptable systems are the most complex, because such systems are the most diverse, whereas the most adapted systems tend to have a lower complexity than the adaptable ones, because the development of situation-specific connections will lower the diversity of the structure. Complexity seems to be lowered when a system adapts to more static constraints, thus lowering its adaptability and its potential rate of evolution.

The fact that these results are due to mathematical/topological properties of hierarchies, and are independent of the nature of the nodes or the connections between them, gives them wide implications, not only for computing systems, but also for social systems in which hierarchies play an important part.

Distributed Systems

Distributed systems are characterized by structural variables such as the degree of independence of the individual participants; the degree to which they compete or cooperate; the fact that knowledge about what happens in the remainder of the system is incomplete and/or that the individual actors are informed with considerable delays, and finally the ways in which finite resources are allocated within the system. Although a formal information processing structure is missing, distributed systems behave in some respects with considerable regularity, whereas in other respects their behavior is fundamentally unstable and irregular. The regularity is evident at the overall level, and is exemplified by the so-called Power-law of Learning (Anderson 1982; Huberman 2001), which states that those parts of a system that have started to perform a task first are more efficient at it. As a result, distributed systems structure themselves universally according to a Pareto distribution.[6]

Huberman and Hogg (1988) study the behavior of such distributed systems by building a model that fits the following description:

> The model consists of a number of agents engaging in various tasks, and free to choose among a number of strategies according to their perceived payoffs. Because of the lack of central controls, they make these choices asynchronously. Imperfect knowledge is modeled by assuming the perceived payoff to be a slightly inaccurate version of the actual payoff. Finally, in the case when the payoffs depend on what the other agents are doing, delays can be introduced in the evaluation of the payoffs by assuming each agent only has access to the relevant state of the system at earlier times. (ibid., 80)

After analyzing one by one the impact of a number of the variables mentioned above, their conclusions give us the following ideas about the behavior of distributed systems:

1. First, they calculate the number of agents engaged in each of the different strategies at any point in time. These strategies have different degrees of efficiency. Only in the case of complete independence of action and completely perfect knowledge by all actors do they achieve optimal overall efficiency. But if imperfect knowledge is introduced, the distributed system operates below optimality: never are all agents using the optimal strategy. In real life, distributed systems satisfice rather than optimize.
2. Where action depends in part on what other agents are doing, the payoff for each actor will also depend on how many others are choosing the same strategy and bidding for the same resources. Independent of the initial values chosen, with perfect knowledge the system will converge on the same suboptimal point attractor, which is the highest available given the constraints involved. That is evidently an entirely stable situation. With imperfect knowledge, however, an optimality gap develops of a size that is dependent on the uncertainty involved. The result is the same for competitive and co-operative strategies.
3. Time delays can also introduce oscillations into distributed systems. If the evaluation of payoff is delayed for a period shorter than the relaxation rate of the system the system evidently remains stable. But longer evaluation delays give rise to damped oscillations that signify initial alternate overshooting and undershooting of the optimal efficiency, and really long delays create persistent oscillations that grow until bounded by nonlinearities in the system. The oscillations depend on the degree of uncertainty in evaluating the payoff: large uncertainty means that the delays are less likely to push the system away from stability.

4. In a system of freely choosing agents, the reduced payoff due to competition for resources and the increase in efficiency resulting from cooperation will push the system in opposite directions. In that situation, a wide range of parameter values generates a chaotic and inherently unpredictable behavior of the system with few windows of regularity. Very narrowly different initial conditions will lead to vastly different developments, while rapid and random changes in the number of agents applying them make it impossible to determine optimal mixtures of strategies. In certain circumstances, regular and chaotic behaviors can alternate periodically so that the nature of our observations is directly determined by their duration.
5. Open distributed systems have a tendency not to optimize if they include long-range interactions. Under fairly general conditions the time it takes for a system to cross over from a local fixed point that is not optimal into a global one that is optimal can grow exponentially with the number of agents in the system. When such a crossover does occur, it happens extremely fast, giving rise to a phenomenon analogous to a punctuated equilibrium in biology.
6. A corollary of these results is that open systems with metastable strategies cannot spontaneously adapt to changing constraints, thereby "*necessitating the introduction of globally coordinating agents to do so*" (Huberman & Hogg 1988, 147, my italics). I will return to this point in discussing hybrid information-processing systems.

Instability and Differentiation

If a system is nonlinear and can undergo transitions into undesirable chaotic regimes, what are the conditions under which it can keep operating within desired constraints in the presence of strong perturbations? Glance and Huberman (1997) demonstrate (for the mathematical derivation, see Glance & Huberman 1997, 120–130) that:

1. In a purely competitive environment the payoff tends to decrease as more agents make use of it, but in a (partly) cooperative environment (agents exchanging information) the payoff increases up to a certain point with the number of agents that make use of a certain strategy. Increases beyond that point will not be rewarded.
2. In the case of a mixture of cooperative and competitive payoffs, as long as delays are limited the system converges to an equilibrium

that is close to the optimum that a central controller could obtain without loss of information. But with increasing delays, as well as with increasing uncertainty, the number of agents using a particular resource continues to vary so that the overall performance is far from optimal. The system will eventually become unstable, leading to oscillation and potential chaos unless differential payoffs related to actual performance are accorded to actors.

3. Accordingly, such differential payoffs have the net effect of increasing the proportion of agents that perform successfully and decreasing the number of those that perform with less success, which will in turn modify the choices that each actor makes. Choices that may merit a reward at one point in time need no longer be rewarded at a later point in time, so that evolving diversity ensues. This has two effects (Glance & Huberman 1997): (a) a diverse community of agents emerges out of an essentially homogeneous one and (b) a series of bifurcations will render chaos a transient phenomenon (see Appendix A for a more elaborate explanation).

In assessing the relevance of this work for the problems we are dealing with, we must first caution that as far as I know it has not (yet) been proven that one may generalize the conclusions at all. But if they can indeed be generalized, the results seem of direct relevance to societal systems. They seem to point to the fact that diversification is a necessary correlate of the stability of distributed systems. This certainly seems to be so in urban systems, which in all cases show considerable craft specialization as well as administrative differentiation, for example.

Heterarchical Systems

I argued earlier that urban systems are, in all probability, hybrid or mixed systems, consisting of egalitarian groups and small hierarchies as well as complex hierarchies and distributed systems. I call these mixed systems heterarchies.[7] Unfortunately, we know even less about such heterarchical systems than we do about either distributed or hierarchical ones. Research in this area is badly needed, notably in order to quantify the values of the variables involved, as there is no overall approach to hybrid systems such as Huberman and Hogg have developed for complex hierarchies and distributed systems. I can therefore do no more than create a composite picture out of bits and pieces concerning each of the kinds of information processing systems we have discussed so far, and then ask some questions.

I will begin with mixtures of egalitarian and small-scale hierarchical communication networks. I conclude from Mayhew & Levinger's (1976, 1977) and Johnson's (1982) arguments that there are substantial advantages to a hierarchical communications structure as soon as unit size exceeds four or five people. At the lowest level this implies hierarchization when more than five people are commonly involved in the same decisions, but at a higher level this also applies to hierarchization of lower-level units. This probably indicates a bottom up pressure for small- and intermediate-scale hierarchization in large, complex organizations.

Reynolds (1984), in an inspired response to early questions on the origins of small-group hierarchization posed by Wright (1977) and Johnson (1978, 1981, 1983), studies the gain in efficiency that is achieved by subdividing problem-solving tasks, rather than treating them as a unit. Depending on whether it is the size of certain problems or their frequency that increases, greater efficiency gains are achieved by what he calls "divide and rule" (D&R) and "pipe-lining" (P) strategies (Reynolds 1984, 180–182). In the divide and rule strategy, the lower-level units are kept independent, and the integrative part of the task is delegated to the lower-level units among themselves in a sequence of independent subprocesses, each of which is executed by a separate unit under overall process control from higher hierarchical levels.[8]

Pipe-lining (P) is a hybrid strategy that involves both horizontal and vertical movement in a hierarchy. It seems to be more efficient when increases in both size and frequency of problem-solving tasks occur, as it optimizes the amount of information flowing through each participating unit. It does so by regulating the balance between routine and nonroutine operations.

Unfortunately, once the systems considered are more complex, it is not so easy to generalize, as each different system may exhibit a range of very different kinds of behavior. One aspect of complex hybrid systems that may have general importance reminds us of pipe-lining. There is a need for reduction of error-making because in such systems many interfering communications pass through long lines of communication and do so with different frequencies. To reduce such error-making, higher-level units may compare information gathered from different sources at their own level with the information coming from sources lower down the hierarchy, and correct errors when they pass the information on to a node higher up. The disadvantage is that this also entails coarse-graining, generalizing by ignoring part of the total information content transmitted through the hierarchy.

Most other arguments in favor of heterarchical systems center on their efficiency and stability. We have seen in this chapter that Ceccato and Huberman (1988) argue that after an initial period the complexity of hierarchical self-organizing systems is reduced, and their rate of evolution and their adaptability with it. The systems become adapted to the particular environment in which they operate. As a result, certain links are continuously activated whereas others are not. The unactivated, nonoptimal ones disappear, so that when circumstances change, new links need to be forged. That takes time and energy.

In distributed systems, on the other hand, nonoptimal strategies persist (Ceccato & Huberman 1988), which seems to affect very large market systems; these therefore also have difficulty adapting. Combining the two kinds of systems into hybrid systems has two advantages. First, the introduction of globally controlled (hierarchical) communications in distributed systems causes the latter to lose their penchant for retaining nonoptimal strategies. Secondly, the existence of distributed connections in the system increases the adaptability of the hybrid structure as well.

The next aspect of heterarchical systems we need to consider is their efficiency. Upon adopting a hybrid strategy, a system will have to deal with many new challenges. It would ideally need the optimum efficiency afforded by a hierarchical system and the optimum adaptability inherent in a distributed one. In practice, a hybrid structure will develop that is a best fit in the particular context involved. As it develops solutions to the specific problems that it faces, its hierarchically organized pathways will become simpler, reducing overall adaptability and possibly reducing efficiency as the original random hierarchy becomes more diverse. On the other hand, its distributed interactions may become better informed and/or improve their decision-making efficiency, and their adaptability will not necessarily be reduced.

Innovation introduces new resources into a system, and will therefore reduce competition or at least mitigate its negative effects. It will increase the efficiency of the distributed actors, which in turn will prompt more and more of them to cooperate, further increasing efficiency gains for a limited time until competition for resources becomes dominant again. This inherent fluctuation of the market aspect of the system is reduced by the much more stable efficiency of the hierarchy.

Similarly, in market systems both the time delays and their oscillations increase rapidly with increasing numbers of actors, whereas in hierarchical systems time delays proportionately decrease with each increase in the number of participants and oscillations are virtually nonexistent. Again, heterarchical systems seem to have the advantage.

Conclusion

The main point of this chapter is to argue that one can indeed make a coherent argument for considering the major societal transformations that we know from archaeology, history, and anthropology as due to an increase in knowledge and understanding, and thus an increase in the information processing capacity of human societies. Viewing this as part of a dissipative flow structure dynamic enables us to understand these transitions as being driven by the need to enable the communications structure of human groups to adapt to the growth in numbers that is in turn inherent in the increase in knowledge and understanding. It therefore presents us with an ultimate explanation for the different societal forms of organization that we encounter in the real world and the transitions between them, an explanation that does not need any other parameters (such as climate pressures, etc.). All these are subsumed under the variable "information-processing capacity."

Appendix A

So that Chapter 11 is readable for a non-mathematically oriented public, and yet it has the solid basis it merits as one of the fundamental chapters underpinning the whole book, I have taken two major sections out of it and present them here.

Ultradiffusion in Complex Hierarchies

Huberman and his colleagues have developed the following approach to the calculation of communication speeds in hierarchies. They treat the individuals at the lowest level statistically, that is by integrating over them, while considering the individuals at the top static, as they constrain the intervening levels of the hierarchy everywhere in the same fashion (Huberman & Kerzberg 1985; Bachas & Huberman 1987).

Huberman and Kerzberg (1985) first transformed hierarchies into structures in which to travel between two points in the lowest branches without leaving the tree, one must go up by a number of levels equal to the ultrametric distance separating the points (Figure 11.5a). Next, those structures were transformed into probabilistic ones, representing the probability per unit time (ε_i) that a unit (of energy in their case, but in ours a unit of information) would pass from one cell to another (Figure 11.5b).

The higher the barrier, the lower the probability (because the information has to pass through more nodes). They then postulated that the time needed to pass between the most directly linked cells would be considerably shorter than the time needed to pass between cells linked

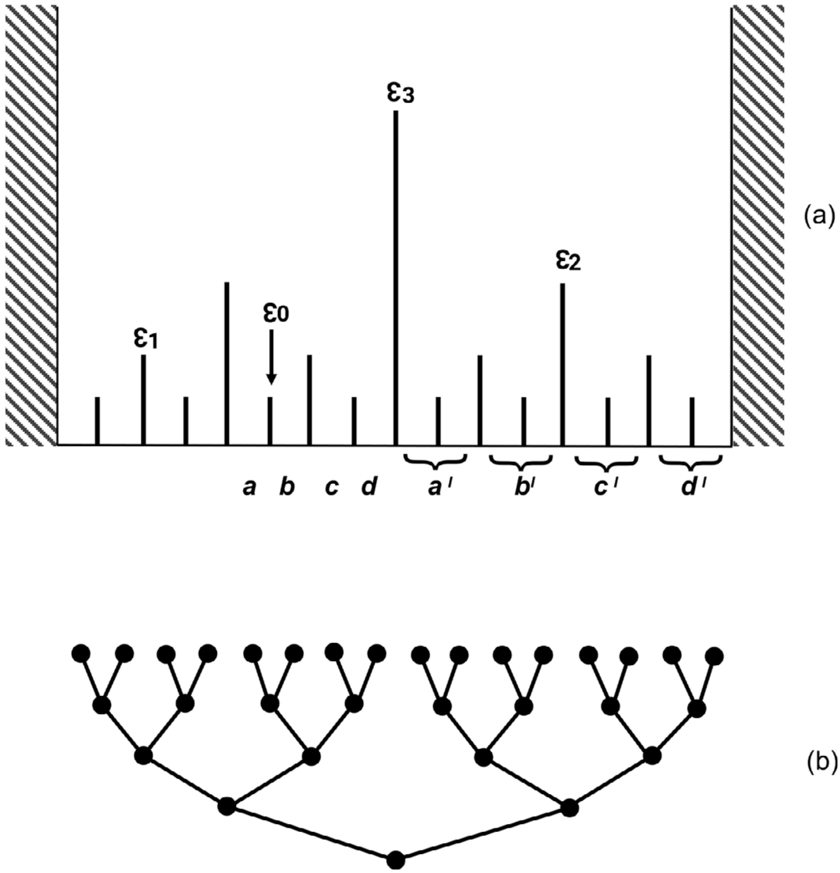

FIGURE 11.5 (a) Hierarchical array of barriers over which a particle diffuses. The barriers are labeled by ε, the probability per unit time that they will be crossed; ε is small for a tall barrier. The hierarchy may or may not extend down to infinity. (b) Ultrametric structure: to travel between two points in the top branches of the tree without leaving the tree, one must go down by a number of levels equal to the ultrametric distance separating the points. (Source: van der Leeuw after Huberman & Kerzberg 1985)

one step further up/down the hierarchy, so that the hierarchy of diffusion times was well-defined.

This seems reasonable from our perspective: if we assume the interaction times needed to transmit a message between two nodes to be more or less equal, going one step further up/down the hierarchy requires at least twice the time to get the message across. After a time $t_0 - 1/\varepsilon_0$, the statistical distribution on both sides of the lowest barriers will be roughly equalized (and all the information diffused), so that these barriers can be ignored. But this changes the relationship between the next highest barriers, requiring that one renormalizes them, as is seen in Figure 11.5b.[9] The same applies for all the further steps up, while after another similar time interval the phenomenon repeats itself. Once the barriers at a certain level have been overcome, the area from which any bit of information is to cross the next barrier is effectively enlarged by a power 2 (see Figure 11.5a), so that more information is transferred. Similarly, after each time interval, the given probability of finding a specific bit of information is effectively valid over a region twice the size of the original one.

The results of this work can be summarized as follows. Independent of the size of the population that a hierarchy integrates, there is an upper limit to the time it takes to diffuse information throughout it. Although that limit is related to the number of levels in the hierarchy, increasing that number does not linearly increase the time involved. When expanding a hierarchy from five levels to six, the additional time is a root of the time added upon expansion from four levels to five. There is a power-law involved, which relates the diffusion to the number of levels in the hierarchy. Huberman and Kerzberg (1985) call this effect ultra-diffusion.[10]

Hierarchy Structure and Interference in Communications

In any hierarchical structure, the frequency of local transfer will be much higher than that of more distant transfer. A hierarchy of timescales will therefore develop, reflecting the rate at which diffusion takes place. As all transfers pass in part through the same channels, interference and loss of signal will occur. This may be a major constraint. One of the consequences is that diffusion is fastest in either uniformly or randomly multifurcating trees, while it is slower in very diverse ones.[11]

In order to quantify this aspect, Huberman & Hogg (1986) define the "tree silhouette" of the hierarchy as follows. Let branching occur at integral multiples of a minimum height interval (Δh), so that the mth generation of all branches, which occurs at height h = m.Δh, has a total number of branches n (h). Then the silhouette slope can be defined as follows:

$$s(h) = -\Delta \log n(h) = 1 \ \log \ n(h), \Delta h \, \Delta h \ n(h + \Delta h) \qquad (11.1)$$

$$\text{and its asymptotic value: } s = \ \lim \ s(h).hf_i\infty \qquad (11.2)$$

Large and small values of s correspond to fat and thin trees respectively. It so turns out that the dynamic critical exponent n, which rules diffusion in a regular uniformly multifurcating tree, equals s; 1-s thus depends only on that tree's silhouette. Indeed, such diffusion is only stable if $0 < s < 1$. As soon as $s > 1$, diffusion becomes unstable and therefore slows down. The same result is obtained when the multifurcation is random, i.e., when the number of branches at each node is determined by an independent random variable. That is intuitively easy to accept, because if large enough, such a tree would also be essentially balanced. But if a tree is asymmetrical around a vertical axis, such as when the number of offspring is three per node on one side and one per node on the other, then the critical exponent n equals s and diffusion is slowest.

In order to characterize a tree's diffusion capacities, it is therefore necessary to devise a measure of a hierarchy's diversity or complexity (Huberman & Hogg 1986). On average, each level of a hierarchy contributes to its complexity the fraction of its branches that generate nonisomorphic trees. The average complexity per leaf is given by the following equation:

$$Ch = \Sigma NI_m, N\,\text{levels}\; NB_m \tag{11.3}$$

In this equation, NI_m is the number of nonisomorphic trees at level $m > 1$ ($m = 0$ is the root) and NB_m is the number of branches at this level. This average complexity per leaf of very large numbers of trees with many levels of complexity has a limit between 5 and 6, while for a large sample the relative frequency of appearance of trees with complexity values between n and n + 1 (in which n = 0, 1, . . .) has a normal distribution with a maximum between 5 and 6. For large hierarchies, very complex trees will therefore have a complexity that at most increases linearly with the number of levels.

Distributed Information Processing

Distributed systems are characterized by structural variables such as:

- The degree of independence of the individual participants;
- The degree to which they compete or cooperate;
- The fact that knowledge about what happens in the remainder of the system is incomplete and/or that the individual actors are informed with considerable delays;
- The way in which finite resources are allocated within the system.

Huberman and Hogg (1988) study the behavior of distributed systems by analyzing one by one the impact of a number of the variables previously mentioned. In order to do so they build a model that has been described on p. 198. The operational conditions of the first simulation are that:

- The perceived payoffs are taken to be normally distributed, with standard deviations around their correct values;
- The difference between correct and perceived values is increasing with the amount of uncertainty in the information available to the agents;
- Information delays cause each agent's information to be slightly out of date.

In the case of (1) two resources, (2) many agents, (3) a mixture of cooperative and competitive payoffs, and (4) agents that are all subject to the same effective delays, uncertainties, and preferences for resource use, the dynamics are represented by Figure 11.6.[12]

As long as the delays are limited, the system converges to an equilibrium that is close to the optimum that a central controller can obtain without loss of information. But as the reliability of the information decreases, the equilibrium moves away from optimality. With increasing delays, it will eventually become unstable, leading to oscillation and potential chaos. Under those conditions, the number of agents using a particular resource continues to vary so that the overall performance is far from optimal. Such behavior can effectively be avoided by according differential payoffs related to actual performance of individual actors rather than a range of generalized payoffs. According differential payoffs has the net effect of increasing the proportion of agents that perform successfully and decreasing the number of those that do not, while modifying the choices that each actor makes. As a result, a diverse community of agents emerges out of an essentially homogeneous one.

In a very interesting, intricate model, Glance and Huberman (1997) then look at how these dynamics are impacted by the expectations of the actors. By creating agents with different expectations and consequently different performance characteristics in extrapolating from imperfect and incomplete information, their decision delays can be related to the periodicity of the dynamics of the system.

With a fixed oscillation, those agents that are able to discover its periodicity will get better rewards, but their discovery may alter the

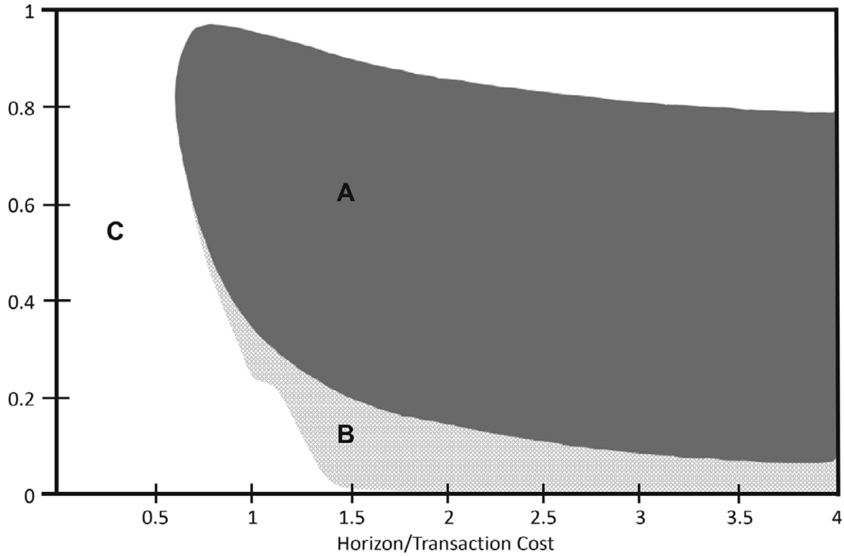

FIGURE 11.6 Phase space stability portrait articulating the interaction between the time horizon of the actors' payoffs (H), their transaction cost (T), and the stability of the system (σ) for a fixed set of payoffs: $G_1 = 4 + 7f - 5.333f^2$ and $G_2 = 4+3f$, $\alpha = 1$, $\tau = 6$. The system is always stable in region C, always unstable in region A, and in region B it either relaxes to a fixed point or goes into a limit cycle, depending on initial conditions (see Glance & Huberman 1997, 125). (Source: van der Leeuw & McGlade 1977 by permission: Routledge)

frequency of the oscillation so that this advantage does not last. Differences in estimation can be due to the procedures used for analyzing the system's behavior. Under these conditions the potentially chaotic oscillation quickly leads to several bifurcations and dampenings. As diversity in performance rapidly increases, the system turns out to be stable when perturbed (Figure 11.6).

I conclude that a very heterogeneously performing set of agents creates a more effective distributed processing system than a homogeneous group. Not only does this confirm the idea that diversity is the cause and condition for stability in a distributed system, but it allows the quantification of the minimum diversity needed in that system.

Figure 11.7 presents the stability regions of the system for very different ranges of agents' delays in evaluating system behavior (and drawing the consequences from it). The parallels between the two diagrams

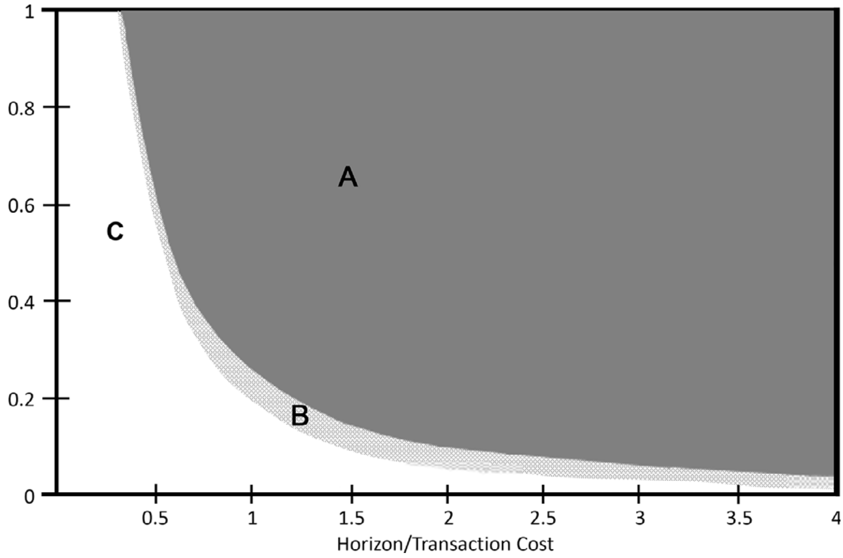

FIGURE 11.7 Phase space stability portrait articulating the interaction between the time horizon of the actors' payoffs (H), their transaction cost (T) and the stability of the system (σ) for a fixed set of payoffs: $G_1 = 4 + 7f - 5.333f^2$ and $G_2 = 4+3f$, $\alpha = 1$, $\tau = 6$ $\sigma = 0.5$, $T = 1$ The system is always stable in region C, always unstable in region A, and in region B it either relaxes to a fixed point or goes into a limit cycle, depending on initial conditions (see Glance & Huberman 1997, 125). (Source: van der Glance & Huberman 1997; by permission Routledge)

suggest to Glance and Huberman (1997) that regardless of the range, one can always find a mix that will generate stability.[13] The payoff mechanism thus turns out to be critical for the behavior of the system, and notably how the payoff delays relate to the information delays in the system.

In all the examples presented by Glance and Huberman, the delays have been shorter than the delays in the system. If payoff delays were based on average past performance, and thus occurred after much longer time lags, this would probably result in very different behavior. But the distribution of rewards is also crucial. Giving rewards proportional to the square of the actual performance increases the speed with which stability is reached, for example, whereas giving all rewards to top performers results in a system that does not reach stable behavior at all.

NOTES

1 One anonymous reviewer argues that this may explain why there was a sudden explosion of "civilizations" in the second wave of complex social organization, after about 1500 BCE, where they had not developed in the first wave (4000–2000 BCE) (Day et al. 2012; Gunn et al. 2014).

2 Rather than detail examples here, I refer to the following papers for a summary: Earle & Preucel 1987; Price & Feinman 1995, Pauketat 2007 and many others) The essence of the argument is that it is very difficult to define clear categories as there are many external and internal conditions that shape the actual social organizations concerned. However, the overall idea that there are political and organizational characteristics of societies that are related to their size and their permanence is accepted. It is therefore expedient to see these as manifestations on a continuum, as I do here.

3 In essence, the current phenomenon of globalization is also part of this process. Whereas until now cultural, socioeconomic and political barriers combined with the relatively high cost of long-distance communication made a global extension of the interactive sphere difficult, the information and communications technology revolution has changed that profoundly over the last fifty years by reducing communications cost to near zero.

4 This is consistent with Wallerstein's idea (1974–1989) that a degree of organizational heterogeneity was essential for the genesis and persistence of the modern world system.

5 Archaeologists reading this section, please note that my use of the concept of heterarchy follows Simon, rather than the somewhat different one used by Crumley (1995), which is better known in archaeology.

6 The problem is not inherent in the hierarchical nature of the systems, but in the differences in mathematical treatment required by problems of different degrees of complexity, such as distinguished by Weaver as "organized simplicity," "disorganized complexity," and "organized complexity" (1969).

7 Indeed, Schrager et al. (1988) present a convincing general derivation of this "law" from the same principles of graph theory that they used for hierarchical information-processing structures.

8 The *Encyclopedia Britannica* defines heterarchy as follows: (www.britannica.com/topic/heterarchy consulted January 7, 2018). "*Heterarchy* = form of management or rule in which any unit can govern or be governed by others, depending on circumstances, and, hence, no one unit dominates the rest. Authority within a heterarchy is distributed. A heterarchy possesses a flexible structure made up of interdependent units, and the relationships between those units are characterized by multiple intricate linkages that create circular paths rather than hierarchical ones. Heterarchies are best described as networks of actors – each of which may be made up of one or more hierarchies – that are variously ranked according to different metrics."

9 This implies, among other things, that the subordinate units do not have the liberty to choose which tasks they execute, or how they do so, as is the case in truly parallel processing systems.

10 I refer those who wish to check the mathematical derivations to the original paper (Huberman & Kerzberg 1985).

11 As they primarily deal with physical systems, they quantify the effect by calculating the auto-correlation function, i.e., the probability that any particle returns to its point of departure. That probability near-geometrically approaches zero. Because it deals with physical systems, this power-law is clearly also dependent upon temperature, i.e., on a potential across the hierarchy. For the moment, it is difficult to define such a potential in the case of information, but one possible way might be to define it in relation to difference in the degree of abstraction with which the information is formulated. This is predicated on the idea that the more abstract the form of organization, the more dimensions of information transfer it applies to, and thus the more chance it has of being transferred between any two individuals.

12 I refer the reader to the original paper for the lengthy mathematical treatment of this issue.

13 Such as may be the result of learning or mutation. However, Huberman does not discuss the details of that mechanism and constructs the model in such a way that only existing types of agents can be rewarded.

12

Novelty, Invention, Change

Introduction

In many political and business quarters, in connection with our current sustainability and environmental change dilemma, we often hear that "We must innovate our way out of trouble." However, this can be misleading, or at best insufficient, if it omits to point out that a 250-year period of unbridled and undirected innovation since the beginning of the Industrial Revolution is actually responsible for many of the unintended consequences of the innovation that we presently have to deal with. Those two and a half centuries of near random innovation in every conceivable dimension of the value space of our current path-dependent societal-cultural-environmental system have led to a rapid acceleration of the frequency and scope of invention and innovation as well as serious challenges regarding our environment. Greenhouse gas emissions are only the beginning. As pointed out by Carson (1954), Huesemann and Huesemann (2011) and many others, if we are to avert a major socio-environmental challenge in time, we need to better understand the role of technology, and innovation in particular, so that we can improve our chances to steer invention and innovation in a direction that is more prudent than the one we are heading in.

In the perspective on (material, institutional, and social) coevolution that I outline in Chapters 8–10, technology plays a special role because it mediates between the human mind and the material world around it. All too often, it has been deemed to follow either a material or a societal logic, but I will argue in this chapter that the technological dynamic is all its own, structuring the socioenvironmental interface and the context of the economy. I will do so by discussing the emergence of novelty – the process that has transformed the world from small groups of hunter-gatherers to a global network of nation-states, enabling humanity to grow to more than 7 billion people, tapping an increasingly wide range of natural and human resources, inventing millions of novel tools, and in the process bringing our planet close to complete environmental destruction.

In Chapter 9, I argued that from the dissipative flow structure perspective continued innovation is in effect the ultimate driver behind societal coherence as well as change, because it ensures the ever further dissipation of chaos (the unknown) that is necessary for human organizations to live and grow. In Chapter 10, I described how that process of continual innovation impacts on the coevolution of a society's technology, economy, institutions, geography and much more, engendering a feedback cycle between solutions and problems. But it is now time to discuss the process of invention and innovation itself in more detail.

Importantly, the model of the coevolutionary dynamics that is outlined in this chapter and Chapter 13 as responsible for technological invention also applies to the non-technological sphere – it can be applied to all forms of change in human societies, and has, *mutatis mutandis*, also been proposed for evolutionary changes in nonhuman organisms (Laubichler & Renn 2015).

Technology as "Tools and Ways to Do Things"

From the long-term perspective of the anthropologist and archaeologist, it is unduly limiting to consider technology in the way that is usually the case in contemporary society – as the totality of knowledge concerning material tools and inventions that we currently use, or in the case of a specific technology a subset of the latter. When applied to the past and to other cultures, this perspective is a typical example of what I call looking through the wrong end of the telescope, taking a modern Western concept and projecting it into the past and onto other cultures in the hope of finding the origins of that concept, that way of doing things, that tool, or that technique (van der Leeuw 2014). As most concepts, categories, and technologies have changed through time, it is usually impossible to define their origins with any precision, as they have morphed beyond recognition between the emergence of a novelty and the current shape. As has been discussed in Chapter 6, rather than adopt such an ex-post perspective on phenomena and search for origins of innovations, we have to adopt an ex-ante one, and search for emergence of novelty (van der Leeuw 2014).

In that light we could more advantageously define technology in the broadest sense as ways to do things. In earliest times, most of these were behavioral, whether individual or collective, while material tools were either nonexistent or very simple. Over time, the balance shifted toward increasing complexity of societies' material culture as well as their societal organization.

As we have seen in Chapters 8 and 10, the immaterial domain has always played an essential role in this. It includes the ways in which people organize their thinking and their behavior, the ways in which they interact with each other and with their environment, the ways in which they transform raw materials into tools, and, in the process, adapt their behavior so as to use these tools effectively. But in my opinion it also includes the much wider realm of how societies organize themselves, conceiving of and implementing institutions, rules, laws, and customs.

In this light, the material and immaterial aspects of technologies (in this wide sense of ways of doing things) are, and always have been, closely interwoven and coevolving through time. Indeed, one cannot imagine the adoption of any technology, even a simple one such as the use of fire, without the important changes it triggered in social behavior: consumption of different foods, storytelling around the fire at night, ability to live in colder climates, etc. The same is true of the introduction of agriculture: different foods, different settlement patterns, different subsistence activities, different divisions of labor, etc. And it is also true for very recent inventions, such as the introduction of information and communications technology, of cellphones, etc. Think only of the fact that nowadays we can be much less organized about how we set up a meeting because cellphones can at any time adapt or fine-tune an existing plan.

Objects and Ideas

First, I need to distinguish between invention and innovation. I understand by invention the process of transformation of substance and substantiation of form that is the essence of creation. It can involve only one or a few people or whole teams, and it can apply to material inventions as well as procedural, conceptual (Schlanger & Stengers 1991), even literary ones (Schlanger 1991).

But it is distinct from innovation, the process of introducing and adopting new elements in society, whether new inventions or older ones that are newly introduced in a society because they have become relevant to that society. Innovation generally leads to the modification of behavior, and potentially also of customs, institutions, and other organizational aspects of a society.

Technological invention and innovation occur in the interface between the realm of phenomena and that of ideas. Ideas are instantiated in some material or organizational form, and when introduced in that form in society give rise to new ideas and new instantiations. I must therefore outline my perspective on the relationship between the respective realms of ideas and things.

Since the Enlightenment, in the western intellectual tradition, we mostly accord phenomena and objects (facts) a status that is independent of our cognitive capabilities. This is expressed by a phrase attributed by my history professor at the University of Amsterdam to the nineteenth-century historian Ludwig von Ranke: "Opinions may change, but facts remain." This position has of course come under scrutiny from the cognitive sciences, which emphasize that the way we understand phenomena is culturally, emotionally, and socially impacted and can vary greatly between individuals. Yet, for example in physics and the natural sciences, most phenomena and processes are still deemed to lead an existence independent of our cognition, and research in these disciplines is generally thought to be aimed at "discovering" them. This perspective has in many instances been extended to the study of technology: the material aspects of various ways of doing things have in our modern minds gained the status of facts, whereas the ideas that have led to their implementation have been given much less attention.

In a similar vein, in economics, resources are often seen as essentially natural, and thus existing outside the social realm. I would argue that, on the contrary, resources do not exist as such unless they have been identified and integrated in society's ways of doing things – until they have been recognized as valuable, and processes and procedures have been developed to socialize them, making them an integral part of a society's flow structure and value space. They derive their value from that integration, which gives them a role in society, and which (re)shapes society in ways that integrate them.

In both instances, the role of the realm of ideas (including values and norms, see Chapter 17) in instantiating our relationship with the environment has been overshadowed by that of the material realm. This then raises the question of how far our ideas are shaped by observed phenomena or how, vice versa, our conception of reality (the world out there) is shaped by our ideas. Clearly, this is a chicken and egg question, and unsolvable. It is not really important for us here, except for one aspect: the relative lifespans of phenomena and ideas. In the traditional, positivist, approach, this was represented by the quote attributed to Ranke: facts outlive ideas. But from the perspective proposed in this book it is the other way around: the fundamental conceptual structure of tools for thought and action, and thus ways of doing things outlives objects and technologies, even if in detail they are modified. Ideas determine how we look at things, what we see, and what we do not see. Phenomena are poly-interpretable, depending on which of their many dimensions are observed by our cognitive apparatus, which is – as we have seen in Chapter 8 – very limited in its dimensionality and differs greatly between people, groups, and cultures, depending on the process of socialization and learning that they have undergone.

Human perceptions are shaped by information processing that is, as Luhmann argued (1989), self-referential within any one society or culture, so that different aspects of our perceptions reinforce each other into a coherent system. This coherence is reinforced by the overdetermination of our observations by past experience (Luhmann 1989, 35; Atlan 1992), which tends to suppress out of the box change and promotes a long lifetime for the values and perspectives that characterize a society or culture.

The Presence and Absence of Change

Before I drill down into the process of novelty creation itself, we need to consider the relationship between change and its absence in our western intellectual tradition. Girard (1990) describes elegantly how, over the last three centuries, the focus in western (for which read European) culture has shifted away from stability toward innovation, as part of a shift from seeing the present in the context of the past to seeing it in the context of the future. As a result, much of our intellectual focus is currently on explaining novelty and change, rather than explaining stability (the absence of change). It seems to me that it is worth questioning this implicit assumption of stability and the need to explain change. One could just as legitimately, with Heraclitus of Ephesus, argue that change is ever-present in open, living systems, and that therefore stability needs to be explained. One would then ask what is responsible for the absence of change in living, open, socioenvironmental dynamics. I conclude that as novelty cannot be perceived without stability, the two concepts are inextricably interwoven, and we must look at their interaction.

It is one of the intriguing advances of genomics that the same regulatory mechanism that is responsible for change is also responsible, under certain conditions, for its absence. Could we conceive of a similar regulatory mechanism in society? Or to put it in more technological terms, what might be responsible both for the maintenance of technological traditions and for the introduction of novelty into them? To begin answering this question, we need to adopt a model of the ways in which a technological tradition is dynamically articulated between the ideas and practices of its practitioners and the physical, chemical, mechanical, and other characteristics of the natural world. And to understand this dynamic articulation, we must apply a combination of an objective perspective on the realities of the physical world and a cognitive perspective on the ways the inventor deals with them.

Perspectives on Invention

It is my contention that the study of invention has been hampered by a confusion between the perspective of the scientist, who looks from the outside at the process of invention, and the perspective of the actor, who is involved in the process. These perspectives are fundamentally different and must be distinguished and applied in conjunction, because in scientific practice, of course, both are interacting; it is in that interaction that invention occurs. The person I here call the scientist usually has a tendency to explain phenomena, procedures, and the conditions for and results of actions in terms of cause-and-effect, whereas the person I here designate the inventor thinks in terms of multiple options for actions and their intended and unintended consequences. The former practices in effect an ex-post perspective, explaining results, whereas the latter's point of view is ex-ante, focused on the challenges of constructively juggling the many parameters involved in creating novelty.

Rather than try and achieve clarity and certainty by reducing the number of dimensions brought to bear on the challenge at hand, as the scientist usually does, the actor thinks in terms of ambiguities, uncertainties, possibilities, probabilities, and experiments, in the process enhancing the number of dimensions taken into consideration. When asked to explain certain phenomena, the actor does so with the totality – or at least the relevant parts – of the complex system in mind that relates to the phenomena in question, and will therefore usually be able to identify several chains of cause and effect that could possibly result in the phenomena in question, whereas the scientist tends to focus on one explanation only.

Invention in Economics

Since an important focus of our coevolutionary approach is the role of innovation in society, and the economy is in many ways the place where that articulation takes place, I will begin with a very brief historical reexamination of some milestones in the economic study of invention and innovation, from Schumpeter via Usher and Rosenberg to the present.[1]

Schumpeter's Focus on the Effects of (Exogenous) Technological Change

Most early twentieth-century mainstream economic theory considered technological change to be exogenous to the economic system, and thus not an object of economic analysis.

Schumpeter's theory of economic development (1934), on the other hand, conceives of invention and innovation as entrepreneurial activities, and focuses on innovation as an act of investment that requires the *ex novo* creation of means of payment by credit institutions. The entrepreneur selects innovative projects that offer profit-making opportunities (1939),[2] and this allows him to obtain funding from financial institutions. But the profit disappears as soon as an innovation is adopted by others. Schumpeter remarks that innovations appear in clusters (1934; 1939). According to him, this happens because a swarm of entrepreneurs will spread the innovation into related industries. This could explain the cyclical behavior of the economic system, because the interest in the new domain may cause ongoing projects to be crowded out by new ones.

Usher's Cumulative Recombination Synthesis

However, one cannot understand innovation without fundamentally understanding the technology itself, as well as the economic and social dynamics that constitute the context in which it operates. It is essential to widen the scope of innovation studies accordingly. Usher moves an important step in that direction. According to him (1929), novelties are not the product of individual creativity, but of the cumulative actions of many individuals operating in a given historical, social, and institutional context with a certain stock of available knowledge.[3] Invention unfolds in a sequence of four stages:

- The first is the perception of a problem, where a certain generally accepted framework is recognized as incomplete and unsatisfactory;
- The next, the setting of the stage, defines the contours of the problem and explores its various dimensions by means of a trial-and-error approach;
- In the third, an act of insight takes place, which produces a solution to the problem;
- In the fourth, a critical revision of the accepted framework leads to the adoption of the innovation.

The pivotal stage is, therefore, the insight. Rather than from intuition or creativity, Usher argues that insight results from a process that is determined by the intrinsic properties of the context within which the solution is explored. This does not mean that this process is propelled by necessity. Perceptions play a role, and chance also plays a part by introducing unforeseen and unpredictable elements. Invention is therefore characterized by discontinuities that are crucial in the transition to a new state of the system, as well as by a progressive synthesis that connects one stage to the next. Insight emerges when various behavioral matrices are associated (Koestler 1964). Once a solution has been found, we no longer separate what we have joined, and the result seems the logical consequence of the premisses involved. But we do not know which things have *not* been taken to their logical consequence.

Usher's vision underlines three important aspects: a particular act of insight may not lead to the solution of the main problem to which it is directed; chance is part of a pattern of events that unfold in a certain sequence; and finally, the choice of the solution to be adopted depends on incentives and constraints that are not only technical but also social, economic, and institutional.

Rosenberg and the Drivers of Technological Convergence

Various scholars, such as the anthropologist Leroi-Gourhan (1943, 1945) and the philosopher Simondon (1958), have noticed that technological change is not random; there is an inherent tendency in the evolution of such change. Economists have initially assumed that such tendencies in technical change are driven by economies in production, but that does not explain the specific sequence or the timing of innovations. Inspired by

Hirschman (1958), Rosenberg (1963, 1969) argues that "complex technologies create internal compulsions and pressures which, in turn, initiate exploratory activity in particular directions" (1969, 111). Two important features of the innovation process are technological imbalances and compulsive sequences. Technological imbalances (which we might nowadays call bottlenecks) often occur in the production process in individual firms or vertically integrated industries. They favor change when initial innovations do not only affect a single stage of the production process but also require modifications in other, preceding or following, stages.

Such technological imbalances occur particularly often in the transfer of technologies from one industry to another (spillovers) for three reasons: because the need to overcome them steers research in particular directions,[4] they often lead to the creation of new, specialized production tools for particular products, and they widely spread a wealth of new, specific technical knowledge. They can thus lead to technological convergence.

Uncertainty can be a trigger for innovation (such as when innovations are adopted to circumvent inputs whose availability is subject to unpredictable variations), but it can also slow down the development and diffusion of new techniques (Rosenberg 1983, 1994). Uncertainty is therefore a key element in the analysis of the innovation process. A central role is played by the social process through which innovations emerge and by the cognitive realm; a process where uncertainty influences both the ways in which the actors behave and the direction and timing of the innovation process.

Arthur: The Observer's Perspective

But to study invention and innovation we must adopt a generative approach; from a perspective that moves upstream against the flow of time, we must move to one that moves downstream with the flow of time. The Complex Systems approach, with its emphasis on emergence, does that to some extent, and it is therefore not surprising that two of the most complete recent attempts to look into innovation have that approach at its origin.

The engineer and economist Arthur (2009) sees a technology as a construct to capture natural, behavioral, social, organizational, or other phenomena for one or more purposes. This does not only include technologies in the traditional sense, but also business organizations, legal or monetary systems, contracts, etc. Technologies are not standalone objects, but instantiations of more general patterns of organization and transformation that can be combined or otherwise reorganized. First, every technology is organized around a central concept or principle that harnesses a phenomenon to fulfill a certain (set of) function(s). Secondly, that principle is instantiated in the form of (physical or social) components that, together, constitute the central assembly of the technology. Thirdly, that central assembly is usually supported by other technologies whose role is to permit the assembly to function appropriately. Fourthly, all technologies are part of a multilevel recursive structure, consisting of technologies within technologies all the way down to their elementary parts, and they are themselves embedded in a hierarchy of organizations of a social, institutional, and/or economic nature that they help function appropriately.

Arthur views the long-term evolution of technology as a kind of bootstrapping from a few simple technologies (such as stone tools) to numerous complex ones (e.g., nuclear reactors, the Internet), driven by the capture of unknown phenomena that can be harnessed into new technologies and the recombination of existing simpler technologies into more complex ones. The capture of unknown phenomena leads on the one hand to cascades of new scientific discoveries and on the other to relatively rapid explosions in innovation within specific domains (groupings of technologies that work naturally together).

Arthur (2009) distinguishes four levels of innovation: (1) new solutions within given technologies, (2) novel technologies, (3) new domains of technology, and (4) the overall technology of a society.

1. New solutions within given technologies. Every technological realization is a human creation involving problem solving, organization, and action, and is implemented by orchestrating the different component parts of the creation (including ideas, tools, and the like) to exploit their advantages and avoid or minimize their drawbacks. This is the process of design, and it entails making sets of choices that reflect the relationship between the realm of ideas and the material and/or social reality that gives birth to the designed object. To understand that relationship, we must evaluate the choices made against the options not chosen in every step of the creative process. Theoretically, for most designs, the number of options is huge. But in practice, many of these are excluded by physical or other constraints. The cumulative effect of the (small) percentage of novel theoretically possible options that are instantiated moves a technology along in certain directions. Coherent sets of such options may become standard building blocks – and may easily replace older

modules that no longer meet the needs of the times. How the blocks emerge is in many ways path dependent on a combination of chance events and processes, so that the solutions implemented are not necessarily optimal.

2. Novel technologies are technologies that use a different principle to deal with the problems at hand. Their emergence is shaped by a conjunction of social needs, experience outside the technological domain they normally apply to, conditions that favor risk-taking, and exchange of ideas and knowledge between individuals. But they come into existence when the needs are conceptually and physically linked with a new, exploitable (set of) principles and their effects. Whether in science or in technology, the core of innovation is this process of linking problems and principles. It entails mental association between the two via a mapping of their functionalities onto each other.
   - Arthur distinguishes three phases in a technology's life span: (1) 'internal replacement' (replacement of borrowed or otherwise non–optimal parts of a technology by better suited ones), (2) 'structural deepening' (adding subsystems to the system to focus, stabilize, and/or improve its performance, or to increase control over it), and (3) 'lock-in and adaptive stretch' (stretching the technology's performance after it has become so embedded that fundamental change is no longer on the cards). Eventually the principle, now highly elaborated, is strained beyond its limits and gives way to a new one that is initially simpler but in due course is elaborated, so that the cycle begins anew. The overall process is not dissimilar from the *Structure of Scientific Revolutions* (Kuhn, 1962).
3. New domains of technology. Often, technological domains coalesce around a central set of principles and tools that are initially developed in other, established, domains. At this stage, large parts of that new toolbox (enabling technologies, understanding of some of the dynamics) are still missing. As it grows, so will awareness of the missing parts, and research will plug the gaps. Once that has advanced enough, an industry will start to grow, starting with small companies. The challenge for them is not so much the development of new products as the triggering of the cultural and social restructuring that is needed to allow the insertion of the domain into the fabric of society. If that succeeds, the domain may spawn new subdomains, starting the cycle anew. When the new domain encounters opportunities to expand, it must adapt both itself and

the relevant part of society to the new functionalities involved. We may view this as the kind of mutual learning that occurs when different cultures interact (acculturation).

- Rather than the identification of new principles, it is this collective learning and implementation process that sets the pace for the evolution of a technology. Among its many constraints are the nature and lifetime of investments in the old, as well as the new, technologies. The replacement requires, moreover, that the economy transforms itself to take the new technologies into account – in that sense technological domains determine epochs in the economy, while the changes in economic structure determine the time involved. All this makes for a very slow process.

4. The technology of a society. In the bootstrapping process, finer and finer distinctions are made over time between different functions and different ways to deal with them. As the number of technologies increases, so does the number of combinations that are possible between them. As technologies emerge in society, they weave a web among them that links principles, implementations, functions, artifacts (including organizations), materials, and intellectual and material tools in ways that are adapted to the way of life and the worldview of the members of that society. The economics of this process heavily impact on its ultimate structure. In that process, one can distinguish discrete – but not necessarily sequential – steps: (1) entry of the technology as a new node into the active collection of technologies; (2) it becomes available to replace existing technologies or components; (3) it sets up new opportunity niches for supporting technologies and organizational changes; (4) older technologies fade from the collective, and their needs are dropped; (5) the novel technology becomes available as a potential component in further technologies; (6) the economy – the pattern of goods and services produced – adjusts to this, including costs, prices, and technologies.

   - In certain cases, once a threshold is crossed, this leads to cascades of destruction and creation.[5] It is important to be aware that this evolution is neither completely random nor in any way predetermined. There are moments in which the evolving technology "chooses" and other times at which it simply advances on its path. That has important consequences for the potential to steer technological evolution - there must be developments we can to some extent predict (at least over a limited time horizon) and moments we cannot.

The importance of the economy in all this leads Arthur to reformulate its role and structure in a very interesting way. Rather than see it as a system of production, distribution and consumption of goods and services, he takes a wider definition: "the asset of arrangements and activities by which a society satisfies its needs" (Arthur 2009, 230), and rather than see the economy as the context or container of its technologies, he sees it as constructed from its technologies. This fundamentally changes the balance between economics and technology studies in understanding innovation. Technologies constitute and shape the economy's structure. The economy emerges from its technologies – and thus continually forms and reforms as its technologies change. As the technology builds, it transforms the structure of the economic flows and decisions, and the transformed economic structure then enables changes in the technologies – the bootstrapping that we have seen for the technology actually also transforms the economy. And in the process, this bootstrapping changes the structure of society, or at least of many of its institutions (such as its banks, but also its ethics, laws, governance, etc.) (see Padgett 1997, 2000).

In conclusion, Arthur offers a first plausible theory of technology, although not (yet) one from which metrics of innovation can be derived. The importance of that theory is that it actually deals with the second order dynamics in which most innovations studied are embedded – it deals with the change of change, both in technology and in economics. It inverts the relationship between technology and economy, and thereby the focus of research on innovation – rather than distilling from economic data policies and measures to improve innovation it argues for the reverse, and whether that will in the end be correct or not is not as important as the fact that we can begin to build on his work to construct a theory of innovation that fuses the technological and economic dynamics into one, and extends both to encompass all forms of human-engendered organization.

Lane and Maxfield: The Innovator's Perspective

Lane, Maxfield, and their collaborators (1997, 2005) focus on how people view, conceptualize, and act in a reflexive way between their known past and their unknown future. In that interaction, ontological uncertainty plays an important role, the uncertainty that is the result of simply not knowing what the future will look like or bring. At the level of the individuals involved, reducing that uncertainty (which depends on the actors' beliefs about the kinds of entities that inhabit their world, about the interactions among them, and about how these interactions might change) in any firm and specific way is the wrong thing to do. But by relating past, present, and future in narratives that create a semblance of order, yet are easy to change, exploration of futures is both enabled and to some extent controlled. Such narratives allow the actors to back into the future. The (reduced) ontological uncertainty involved both allows for invention and limits the total range of inventions likely to emerge. The narrative thus creates a kind of path dependency for invention. An interesting aspect is that there may be a relationship between the extent to which the past is flexible rather than fixed in the actor's mind (which might facilitate the changeability of the narratives) and the facility with which an actor can explore new ideas.

At the level of the local agent network, a similar role is played by the attributions of the actors to the other agents in the network: what are the qualities, functions, relevant attributes of different actors and relationships that are deemed relevant, and how do these relate to one another? Invention is essentially the generation of new attributions (new, different ways to look at an artifact or process; ascribing a new function to it, for example, or suddenly noticing another way to use it, or an aspect of it that one had until then overlooked). Such attributions arise in generative relationships among agents.

Though it is not possible to pinpoint the new attributions that may emerge one might, according to Lane and Maxfield, be able to assess the generative potential of a relationship by considering five characteristics: (1) aligned directedness (degree of alignment of the group of agents toward a particular objective), (2) heterogeneity among the agents, (3) mutual directedness (extent of focus on reciprocal relationships between the agents), (4) appropriate permissions (relevant opportunities for communication among agents), and (5) opportunities for action. These can be seen as the basis for relevant metrics concerning the inventive and innovative potential of the interaction between the agents.

Finally, as Lane and Maxfield move from the local corner of the global network in which inventions may occur to the network as a whole, their concern changes again (and so do the concepts involved). The network is seen as consisting of established competence networks and scaffolding structures put in place to construct new competence networks. The latter are governed by their conventions, both explicit (membership of a professional society) and implicit (a shared way of using expressions and abbreviations). The dynamics between these two consist of search (from a point in the scaffolding network) into the various potentially relevant competence networks, in order to identify potentially alignable members of the scaffolding structure, information dissemination (to the potential new members), interpretation (by the latter), and channeling (using the scaffolding structure to channel activities that may reinforce and expand it).

All in all, Lane and Maxwell's work presents a phenomenology of invention and innovation processes around the concept of ontological uncertainty about the future. Such uncertainty is endemic because the transformation that is brought about by the innovation does not correspond (or only very partially corresponds) to the intentions of the individual agents. Narratives, generative relationships, and scaffolding structures all work to enable agents to cope with ontological uncertainty, in part by temporarily holding it at bay (in narratives), in part by offloading, segregating, and channeling it into special-purpose venues where interactions are highly controlled. At the same time, ontological uncertainty is uncovered, explored, and exploited in special relationships between agents.

But the work also introduces three theories of relevance to invention and innovation studies: the narrative theory of action, the theory of generative potential, and the theory of scaffolding structures. It is our opinion that these together provide a highly relevant and effective toolkit to study the process of organizational change induced by invention and innovation. I cannot here enter into details, but have to refer the reader to the publications mentioned.

Open Questions

Which of the thus far unanswered questions may we expect to be able to answer by applying this approach? As previously mentioned, the measures used in economics to identify invention, inventiveness, innovation, and related phenomena are predominantly a-posteriori indicators. Studying statistical correlations between them helps us to understand the context of invention and innovation, and which conjunction of variables influences the processes, but not how invention and innovation happen. Combining the approaches of Arthur with those of Lane and Maxfield lays the foundations for studying just that. We could then begin to develop the correct metrics to assess change, and then also to impact the process itself.

The distinction between replicative and innovative entrepreneurship is firmly established in the literature. But what interests us is how a non-inventive entrepreneur might become an inventive one. Knowing that would help us promote innovative entrepreneurship in a more focused way, create more conducive social, legal, and economic contexts, and adapt our educational strategies, for example.

Moving a level up, to the community, we remark that the study of innovation has enabled us to characterize at least loosely what makes a community innovative (see Florida 2002), but does not enable us to understand the process by which that community has acquired such an innovative culture. That would be particularly relevant to understanding our current western economies, but also how in parts of those (for example in the financial and information technology domains) excesses are triggered (other than through simple greed).

At all three levels, one important aspect of our work will (again) be to try and evaluate choices made against options not chosen. What is the weight of a particular technical choice in the development of an invention? What is the impact of choosing to develop it for a particular purpose and not for another? How about choosing among one of the many options open to create scaffolding structures? What was (were) the decisive factor(s) in developing an innovative community, and what is the impact of that (those) factor(s) on the form that community takes?

Combining these ideas would enable us to map some of the processes leading all the way from the emergence of the ideas and decisions that engender inventions, via the network dynamics responsible for their spread into the wider world, to their implementation in different contexts, and to their eventual unanticipated consequences for sustainability and the challenges these pose.

Improved understanding of that chain of processes and events should ultimately enable us to modify it in ways that deal more effectively with the initial challenges and minimize or mitigate the unanticipated consequences, so as to ensure improved sustainability of the technology, the economy, and more widely the socioenvironmental system. In the following sections, I will try to illustrate how these ideas might be used in practice.

The Inventor and the Context: Niche Construction

Material innovations play out at the interface between a society and its natural environment. At that interface, techniques do not follow either the logic of the society or that of the environment. Though they relate to both they are not determined by either. To understand the logic involved, we need to adopt a non-determinist approach, in which the role of the maker/inventor's ideas and choices is at the core of our reasoning, and we focus on how it articulates with the outside, material, world. As we saw in Chapter 10, that articulation plays out in the interface between solutions and challenges.

The *chaîne opératoire* approach first introduced by French anthropologists and archaeologists has greatly advanced our understanding of the procedures by which artifacts are created (van der Leeuw 1976, 1993; Lemonnier 1992, 2012; Boëda 1994, 2013; and others), and has drawn our attention to the cultural context of creation. It aims to reconstruct the process of making, from the traces left by the makers' actions on the objects made to the actions that were responsible for these traces. By reconstructing the sequences of action whereby artisans (and users) act on matter in the production (and consumption) of things in order to deal with challenges they face, this method encourages a thoroughly relational, systemic outlook on materials and artifacts. Every object is the outcome not only of, for example, the choice of raw materials, but also how the materials were prepared, how the artifact was then formed, and finished – and how any one choice in the sequence impinges on the others. Hence one begins to see the finished artifact not as some fixed entity, but as a kind of emergent stabilization from among a field of forces that are in some tension with one another – change a pottery firing technique and one may have to change the clay; change a decorative motif, and a different pigment may be required.

But the *chaîne opératoire* approach does not put this process in a wider, equally dynamic context that might help us understand how change occurs in any specific manufacturing tradition. To achieve that, as Knappett et al. (in press) have argued, we need to move from ontology to ontogeny. In thinking about actions, and the humans performing those actions, the next step is to contemplate:

1. Which dynamics may be responsible for variations in the instantiation of a technological tradition, leading to invention and innovation within such a tradition?
2. Given such variation, how do societies maintain a particular manufacturing tradition?

But the two questions constitute a tangled hierarchy (Dupuy 1990), so one could therefore also invert them and ask:

1. How do societies dynamically maintain a particular manufacturing transition?
2. How does the dynamic involved in maintaining a tradition nevertheless allow for the emergence of novelty?

Among the useful concepts that a comparison between the emergence of novelty in biology and in society offers us is niche construction (Odling-Smee et al. 2003). Laubichler and Renn (2015) include this concept in their extended evolution model that emphasizes the links between the internal dynamics of a system and those that create its environment and link both. It reflects the idea that we cannot realistically represent or study invention or innovation without taking into account the fact that it occurs in, partly shapes, and is shaped by, its context. In the process, inventions and innovations create a dependency relationship with their niches in the wider context, and if, for some reason or other, that context changes, the invention may well disappear or be transformed. Conversely, if the innovation is no longer produced, the niche will disappear.

When applying this concept of niche construction to our study of technological invention, and in particular to the relationship between the inventing actor and the context in which invention occurs, we should articulate our perception – which should be as complete and unbiased as possible – of the different functions, materials, techniques, etc. that constitute that context in the world out there with a perspective on that context representing the actor's subjective point of view. That perspective is always partial, biased, and part-driven by social, cultural, and other factors external to the material context of innovation, and its object of study is how the maker's perception articulates these factors with the material conditions of manufacturing.

The stage for this articulation is the interaction between the objective context of manufacturing and the subjective map the inventor has of it. In the process, the external (natural and social) world and the internal (perceptual) world of the actor (partly) shape each other. Over time, this engenders a coevolution that in turn shapes the wider context of invention and innovation in what we call a technological tradition. In this coevolution, each and every technological choice, once it is made, limits the total option set of future choices and generates its own set of unintended consequences, eventually leading to new solutions. The same is true of every social, organizational, and institutional choice made.

The domain in which material and procedural inventions occur, which we could call the technosphere, thus has a logic all of its own, which does in part shape, and is shaped by, the path dependency of a society around its evolving technology.

There are (at least) three levels of knowledge involved in shaping that coevolution:

1. The slowest to change is the collective knowledge that is shared between the members of the community involved. Change at this level involves changing the worldview of the community, its habitus, its approach to technology. The main barrier to such change is that the perspective of the community is limited by the things it has never thought about and which it therefore has no way to describe, analyze or conceptualize. Breaking through that barrier is itself a major invention/innovation. But there can also be conscious social barriers, for example through the protection of intellectual property rights.
2. At the level of the individual one has to take tacit knowledge ('know-how') into account, which has either been subsumed under more conscious conceptual knowledge and customs or resides in the physical, neuro-muscular behavior of the human body. It is difficult to acquire, requiring substantive and often long apprenticeship, but it is also difficult to change as it is not embedded in our conscious memory but is exercised as routine movements and actions.
3. But the individual also has conscious knowledge ('know that'), which is subject to conscious learning and is therefore the easiest and quickest to change. It actively involves the conscious mind, planning and changing behavior. Yet one must remember that such conscious knowledge is also limited by its boundary with the unknown – those processes, questions, and challenges that one has never thought about. It is in this domain that inventions are born most easily.

Looking at the conceptual aspects of techniques in this manner, as anchored in the mind rather than constrained by natural resources and the technological environment, makes a plausible argument for the fact that novelty is limited by the way in which traditions are anchored conceptually and in practice. But how might the same conceptual dynamics engender change? To answer that question, we need to look into the ways in which the practitioners of technologies articulate their relationship with the outside world, and in particular we need to give a central role to choice. Humans are making choices at every step of the way in the manufacture of even the humblest artifact – which means that technologies are mindful and full of intent (and as stated, these choices are typically interdependent as well). That a technological approach then becomes, in this recognition of choice, inherently cognitive (though not by default cognitivist) is worth emphasizing, because it is quite distinct from a materialist or biological outlook.

Creation, Perception, Cognition, and Category Identification

I have already cited the eminent anthropologist Roy Rappaport, who said in a lecture series I attended at the University of Michigan in Ann Arbor in 1977 that "Creation is the simultaneous substantiation of form and information of substance." It involves a back and forth between mind and matter in which a form (an idea) is given shape in the material world. That process is iterative at two levels. The most evident of these is the fact that the maker begins with an approximate idea of what she or he intends to make, and during manufacture both corrects that idea and fine-tunes the product made. But there is also a deeper level in which the process of creation is iterative: that of defining the categories to be distinguished by the maker in the process of making. At that level, the iteration involves the interaction between perception and cognition in the mind of the maker. Modern cognitive science is in the process of learning how this works in the mind, but as a noncognitive scientist I do not pretend to be able to look at this process at that level. Rather, I would like to use the simplified model of category creation that is summarized in Figure 9.1, of which the basic idea is that the process of relating categories to observations is dependent on which of the two serves as a referent.

To summarize, when a concept is being generated, this is a process of comparing an idea as a subject of exploration with phenomena that serve as referents. In such a comparison, the emphasis is on similarities. After a while, the concept is established because one has a good sense of the phenomena that might belong in the category, but not yet of the phenomena that in the end might not. To gain the latter insight, the direction of the comparison is reversed – the category becomes the referent and the phenomena are compared to it. In that process, the mind emphasizes the dissimilarities between phenomena and concept, so that in the end one knows both what belongs and what does not belong in the category.

We have seen how this description of the process of categorization leads one to distinguish between open categories (where one knows which phenomena might belong but not yet which do not) and closed categories (where one knows which phenomena do belong and which do not). It seems to me that this description does indeed summarize for our purposes what goes on in the creative process, leading to the categories adopted from among the many potential ones that the creator does indeed understand and actively exploit in thinking about the manufacturing process. But of course it ignores a number of other factors, such as the emotional ones that are increasingly recognized as important in category formation and decision-making.

On the basis of this schema, one can distinguish three different cognitive spheres or cognitive spaces that are simultaneously present in the mind of a creator during manufacture:

- A certainty sphere that is fully cognized, which is made up of the closed categories in the mind of the maker of (not only material) artifacts, so that he or she knows exactly what is what and has a fixed idea on how to proceed;
- A possibility sphere, which consists of the open categories in the mind of the maker, where the latter is still to some extent undecided and therefore flexible in his or her interactions with matter;
- A problem sphere, consisting of the domain for which there are no categories (yet) in existence, and which therefore is that of the unknown and dimly perceived but unsolved challenges, about which the maker has no idea at all.

If we next look in some more detail at how the maker deals with the problem sphere, we need to take into account that the human perception of the present iteratively relates an assumed past to personal experience and projects the resulting vector into the future. In other words, there is an interaction between perception from an a priori point of view, which opens opportunity for variation, and perception from an a posteriori perspective, which limits variation – the former is focused on emergence, on novelty, and on possibilities and probabilities (opening categories), while the latter is focused on origins, on tradition, and on causality (closing categories). It is in that interaction that invention takes place.

How Are Technical Traditions Anchored?

Next, it is interesting to look at how this interaction engenders both stability and change. Based on a comparative and detailed study of a wide range of past and present pottery-making traditions from different parts of the world that produce highly similar, globular pottery I have in an earlier publication (van der Leeuw 1993) focused on the importance of choice in studying creation, including manufacturing. That has led me to conclude that any approach to exercising a technique is anchored at a minimum of three different levels, in increasing order of flexibility and opportunity for change.

1. First of all there are the temporal, spatial, and functional conceptions of the objects to be made, anchored in the minds of the makers' community. These shape the topology of the objects to be created, their partonomy (the relationship between a whole object and its parts), and the sequence in which the creators create their products. In most technical traditions, all three of these are deeply anchored in the collective as well as the individual (tacit and conscious) knowledge of the individuals involved, and not likely to change. They constitute the domain of the closed categories and as such anchor each individual technical tradition in its own way. New procedures to be introduced are generally such that they take the existing conceptions of topology (space), sequence (time), partonomy, and function into account. Not doing that would make innovation extremely difficult.
2. Next in my overall scheme of things are the executive functions, the tools and techniques acquired to instantiate objects that meet the existing topology, partonomy, function, and manufacturing sequence. Importantly, these executive functions include tools and the ways in which these tools are used. Executive functions are part of the possibility space in the maker's mind. They are generally anchored in both the unconscious and the conscious knowledge of the person practicing a technology. Change in these executive functions will initially involve the conscious knowledge of the maker who experiments with the effects of a change, but once the usefulness of a particular change in executive functions has been established, with time, the tacit knowledge-base will also be involved, through longer-term practice of the actions concerned, so that they become anchored in the musculo-skeletal memory of the practitioner.
3. The third level is that of the choice of raw materials and other components of a technology, including their nature, their quantity, and their preparation. This domain is also part of the maker's possibility space. Except in very constraining and limiting environments, these can be varied the easiest and adapted to changes in executive functions. Often, their adoption depends on the availability of parts, materials, etc. of other technologies. But the choices are made according to the ways in which the practitioners of a technology articulate them with their conceptualizations by means of the executive functions they adopt. That articulation is itself an interactive process.

I am positing that invention is part of the process that creates new categories in interaction between knowledge and data (closed and open categories) that occurs between the certainty sphere (closed categories), the possibility sphere (open categories) and the problem sphere (potential categories), and that the degree of novelty depends on the extent to which each of these spaces is involved.

The Locus of Invention

In practice, this interaction occurs between the (externally defined) context of the manufacturing process (the niche in which invention occurs), which encompasses both sociocultural (customs, institutions, economy, etc.) and material (resources, existing components and technologies, etc.) elements of that context, and the (internally defined) perception the creator has of those components. The articulation between these two is at any time a question of choice, but the choice is not (as is often assumed in the black-box model of novelty creation that relates input and output without looking at the dynamics occurring inside) random or unlimited. Choices are always limited by the reality and the perception of the niche to which the choice relates.

As a starting point, we must therefore attempt to characterize the niche in which a practitioner of a certain technology operates and the total set of contextual variables that might impact on the choices that the individual can make, whether inventive or not. Once that is done, we have to see if we can identify among that set those variables that are actually perceived as sufficiently important to be taken into account in the practitioner's approach to practicing the technology.

In Chapter 13, I have chosen the (admittedly relatively simple) example of manual pottery-making to illustrate the invention dynamic, relying on my knowledge of both the external and the internal perspectives of the context in which that craft is practiced by pre-modern potters (van der Leeuw 1976, 1991, 1993, 1994a, 1994b; van der Leeuw & Pritchard 1984; van der Leeuw & Torrence 1989; van der Leeuw & Papousek 1992; van der Leeuw et al. 1992).

NOTES

1 The first part of this examination is based on a very gracious, unpublished, contribution of Margherita Russo (University of Modena, Italy) to a study into invention and innovation funded by the Kaufmann Foundation that I directed

at ASU between 2007 and 2011. If there are any errors, of course the fault is mine.

2 On the role of interactions among individuals and institutions in Schumpeter's analysis, see De Vecchi (1993).

3 In his view of invention as a social process, Usher drew inspiration from Gestalt psychology, which - originally developed in Germany – became popular in the USA in the 1940s.

4 Rosenberg (1963) cites the example of the profiling drill used in making the hub of bicycle wheels: here, the different speeds with which the inner and the outer part of the hub were worked led to excessive wearing out of the tool, and prompted research into the use of special steels.

5 New and older may lead to confusion. I am here referring to the introduction of a technology that is new with respect to the existing ones in a particular part of the system. Such a technology may indeed have been in existence before, in another part of the system or in a completely different system.

13

An Illustration of the Invention Process and Its Implications for Societal Information Processing

Introduction

This chapter is a direct continuation of Chapter 12, so as to divide a very lengthy exposé into two parts. It has two aims: first to illustrate the argument I made in Chapter 12 with a substantive case study, and second to explore some of the consequences of this vision on invention and innovation for our understanding of societies and societal dynamics. For that illustration, I have chosen pottery-making as an example, based on my personal familiarity with that craft, both from an internal (maker's) and from an external (scientific) perspective (van der Leeuw 1976, 1984, 1993).

The Niche in which the Potter Operates

One can, at least in principle, outline a generalizable external model of the global niche in which the artisan works that is valid for most, if not all, traditions of manual pottery manufacture. It has to include the natural and social context in which the potter works, the raw materials and techniques used and their affordances and constraints, the organization of the work, and finally the range of different functions for which the artifacts can be used and their implications for the products' shapes and other characteristics. As the potter proceeds through the different stages of the manufacturing process, her actions are all focused on dealing with different kinds of challenges that are the result of the interactions between the different variables involved. We could in effect, from the potter's point of view, consider the niche in which she operates as her possibility and problem spaces. How that niche is approached depends of course on the

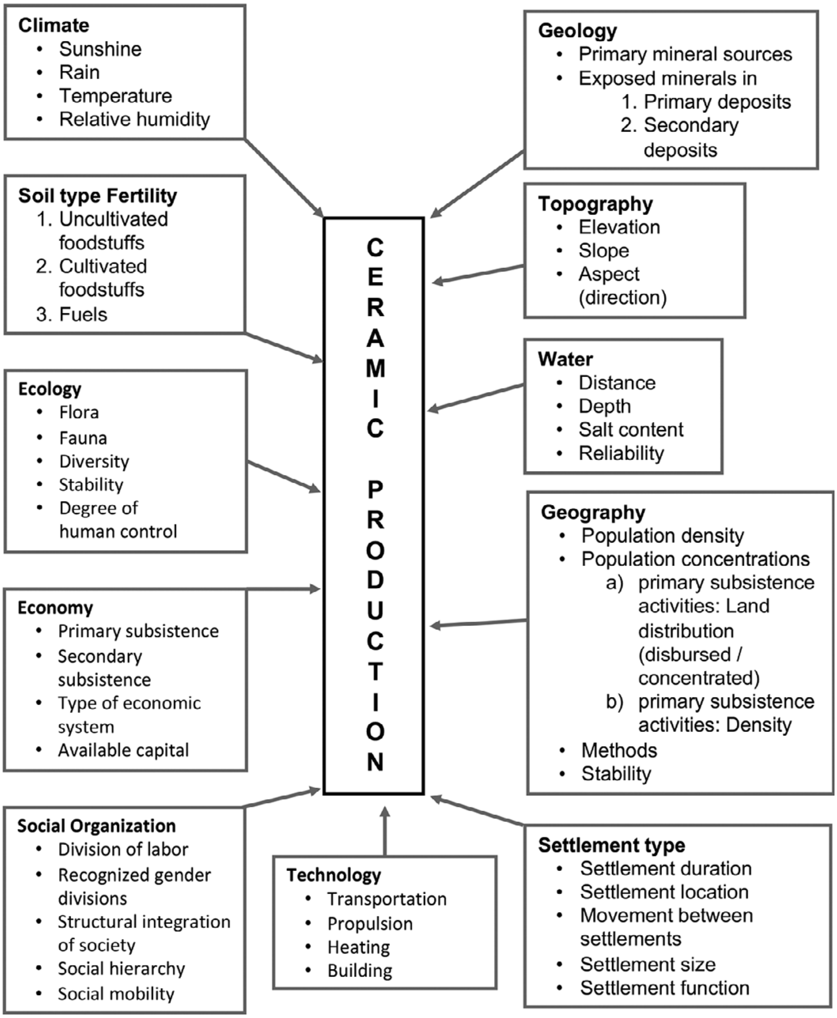

FIGURE 13.1 The wider context of pottery-making includes the physical, geographic, technological, social, and economic environment in which the potter works. Under each rubric only some of the actual variables are presented to give an idea of what each category stands for. These variables will differ from case to case. (Source: van der Leeuw)

particular perspective of the individual potter, which in turn is (part) shaped by the society and culture in which the potter operates.

In Figures 13.1–13.7 I have tried to give a – necessarily incomplete and somewhat simplistic – idea of the niche in which the potter operates, by

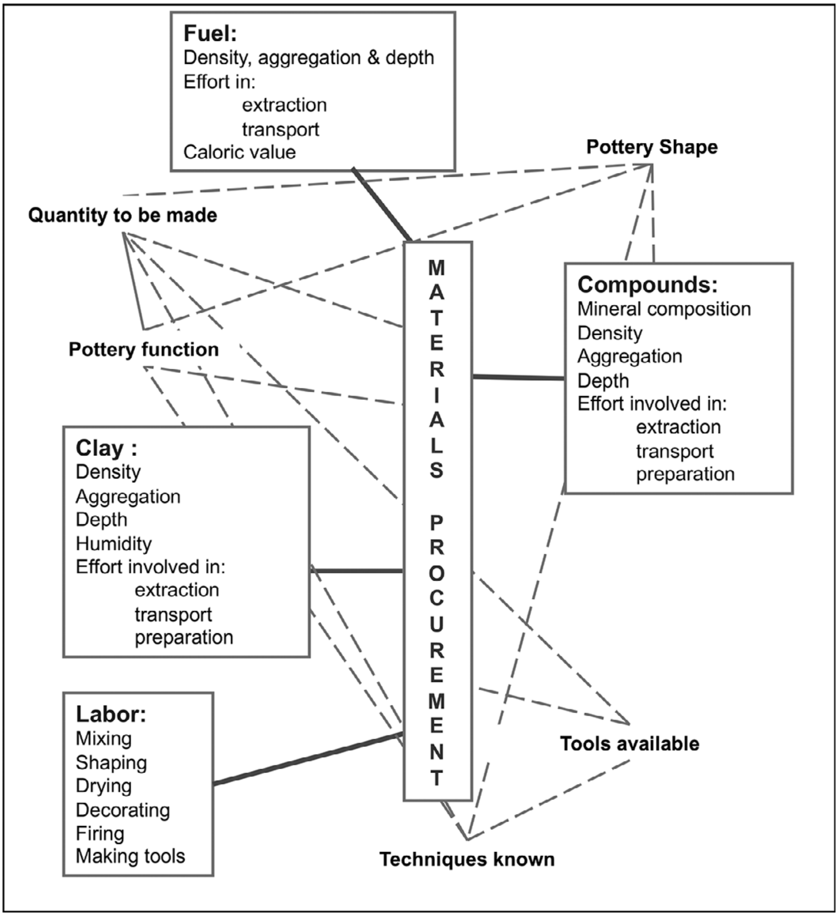

FIGURE 13.2 Once the potter starts gathering the raw materials, she will have a number of variables from the different categories in this figure in mind. If she intends to make cooking pots, for example, the wall of the pot has to be porous because heat gets transmitted into the pot through the water that penetrates the wall. Hence the potter looks for clay with relatively large nonplastic particles in it, or if that is not available she will add such particles. But in deciding which materials to use, she will also take effort into account (depth of clay, distance, effort involved in mixing). (Source: van der Leeuw)

representing some of the variables that she has to take into account as she goes through the various stages of manufacture. It is important to emphasize here that the potter does not consciously take all these variables into account throughout the whole manufacturing process. An important

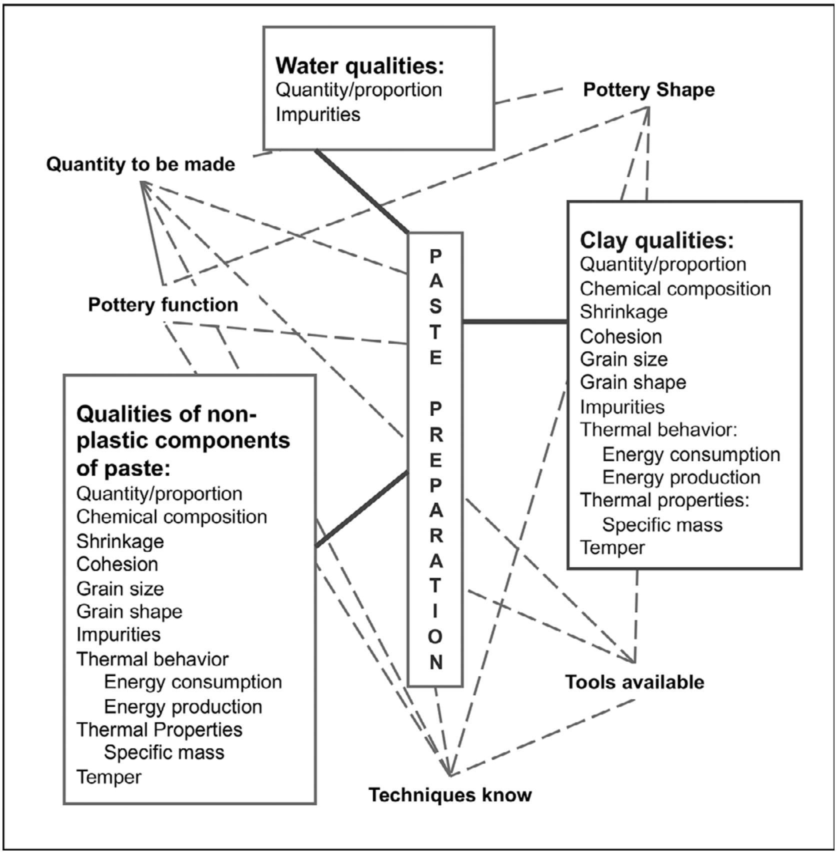

FIGURE 13.3 Paste preparation is a question of dosage and mixing of the plastic and nonplastic ingredients and water. The characteristics of each of these three are taken into account in determining the proportions of each to mix. More water makes the paste easier to shape, but if there is too much the paste will lose coherence. The exact dose of water depends to a large extent on the proportions and the nature of the clay and the nonplastic materials chosen, which in turn depend on the function of the pottery, as we see in Figure 13.2. (Source: van der Leeuw)

aspect of manufacture is that it is staged or chunked in the sense that at each stage in the sequence (as represented by Figures 13.2–13.7), the potter is specifically preoccupied with a subset of the total set of variables that are involved in manufacture. These are considered in detail. But the variables involved in other stages do play a role in the background, as the potter also has an idea of what the end product of each stage needs to be

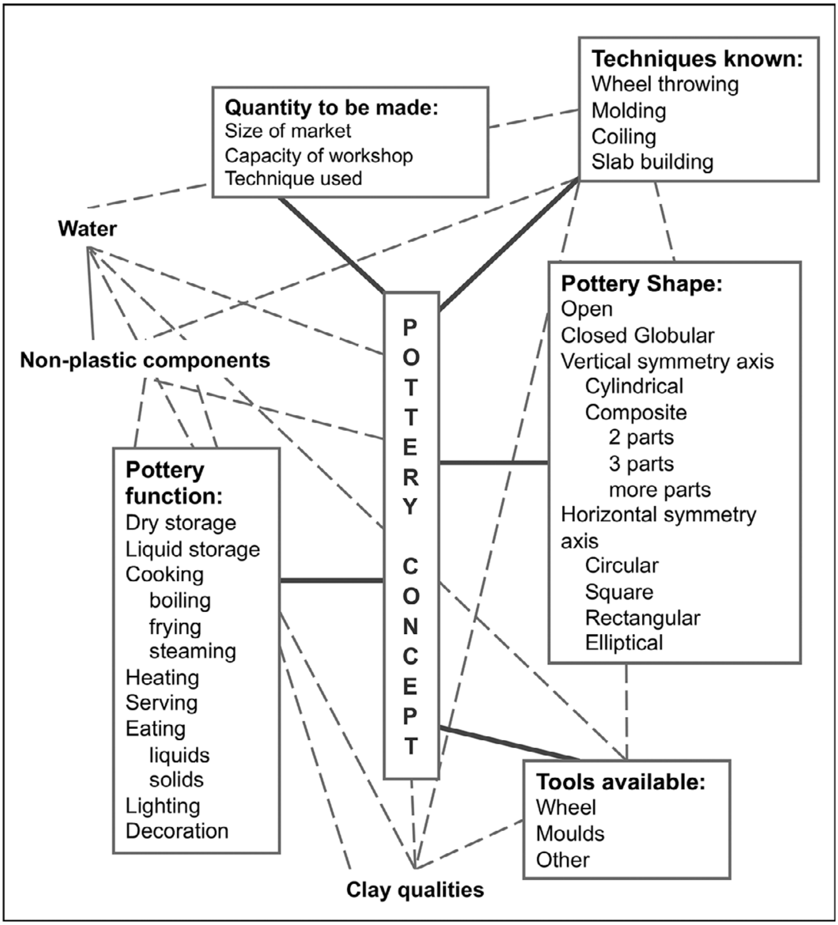

FIGURE 13.4 Conceiving the shape and other qualities of the pottery to be produced integrates the topology, partonomy, and sequentiality of her conception of pottery, her assessment of her capabilities in handling the technique chosen, the function(s) of the pottery to be produced, the nature and quality of the tools at her disposal, as well as the nature of the paste to be used (see Figure 13.3). But it also relates to the quantity to be produced, and thus to the size of the market, the capabilities of the workshop, etc. For mass production, for example, molding or throwing are more efficient than coil building. (Source: van der Leeuw)

in order to satisfy the conditions of following stages, so that the result is a product that fulfills the expectations of the community for which it is produced. Table 13.1 summarizes the technological, organizational, and economic responses of potters to different societal contexts in which they

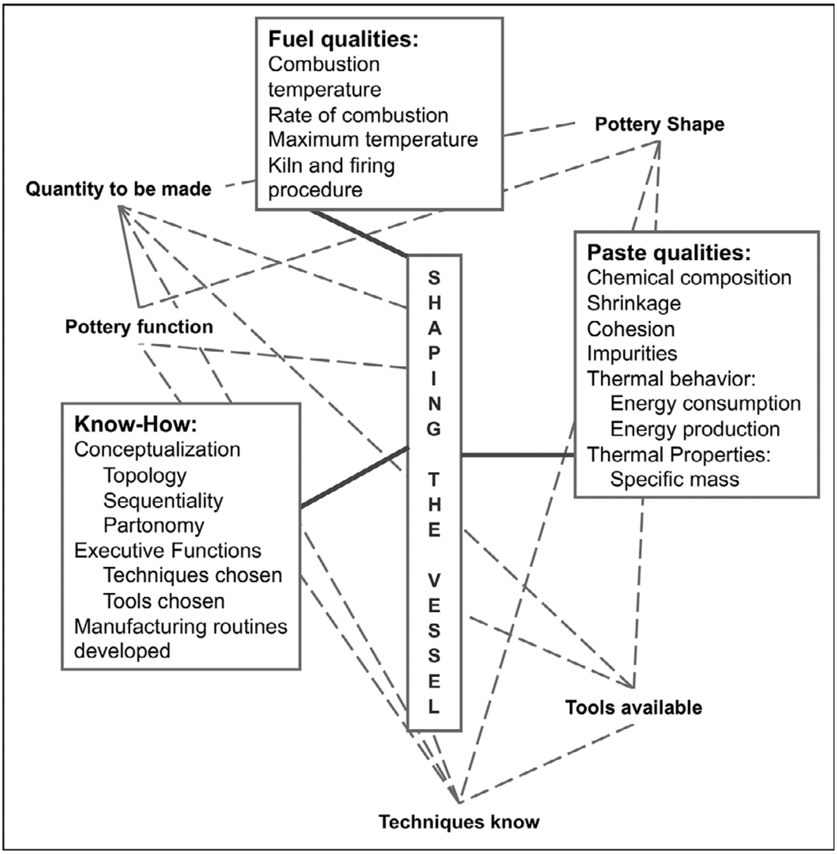

FIGURE 13.5 Once the potter has conceived the vessel, the same factors will play a role in the shaping of the object. In reality, that shaping occurs in two or three phases, (1) shaping, (2) drying, and (3) firing. Much of the shaping will now be a question not of the conscious memory of the potter, but of her know-how, the musculo-skeletal memory and the memory of the nervous system, here summarized under "manufacturing routines developed." The second phase, drying, is one in which only the atmosphere of the pot and the time allotted to drying are controlled. It may be interrupted by some minor modifications in the shape of the pottery or by decoration, but it does not require any major handling. In the third phase, firing, the paste and fuel categories play an important role, but they are integrated in the process of conceiving of the pottery. The categories "fuel qualities" and "paste qualities" have been added to this figure for reasons of space, although they should be seen as part of the last one. (Source: van der Leeuw)

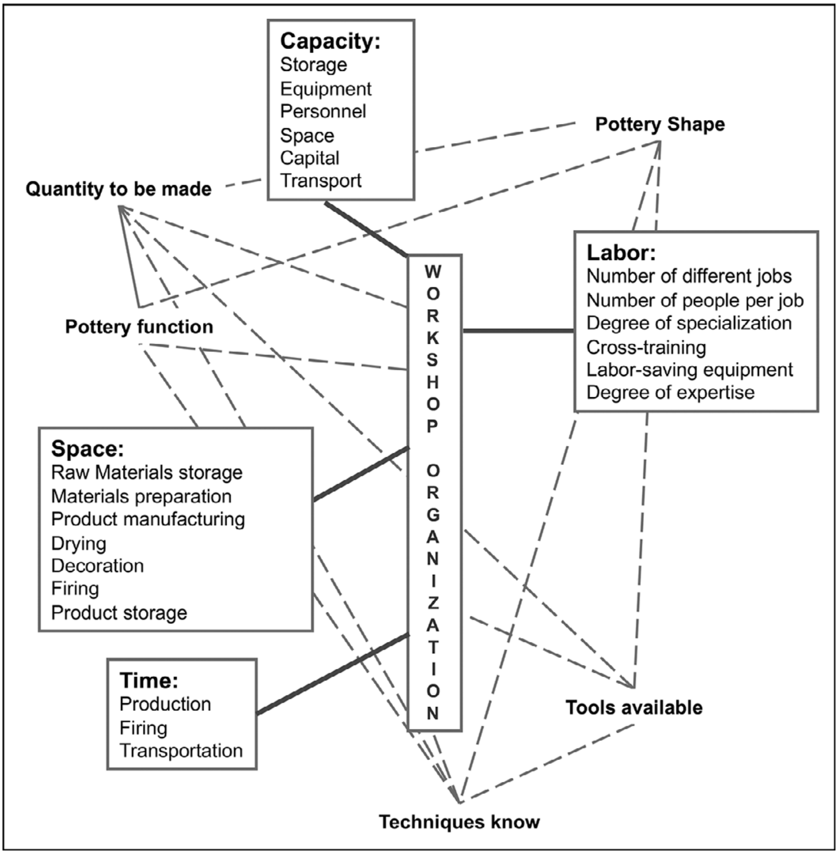

FIGURE 13.6 The workshop organization determines the overall production capacity, but is itself composed of such elements as the degree of specialization of the functions to be fulfilled, and thus the number of people involved in the workshop. That in turn relates to the family structure and the question whether outside help is hired or not. But it also relates to the competency of the members of the workshop, its spatial organization, and the time involved in firing, for example, which is again related to the means of firing chosen and the length of firing time needed for the products made. Ultimately, of course, the workshop's capacity greatly impacts on the quantity of pottery produced, and thus on the economics of pottery manufacture in the place of production. (Source: van der Leeuw)

may work. It is based on a systemic perspective and the assumption that, though there is individual variability, certain generalities can be defined in this domain.

To date, few people have looked intensively at alternatives that might have been open to inventors, nor at the implications of the actual choices

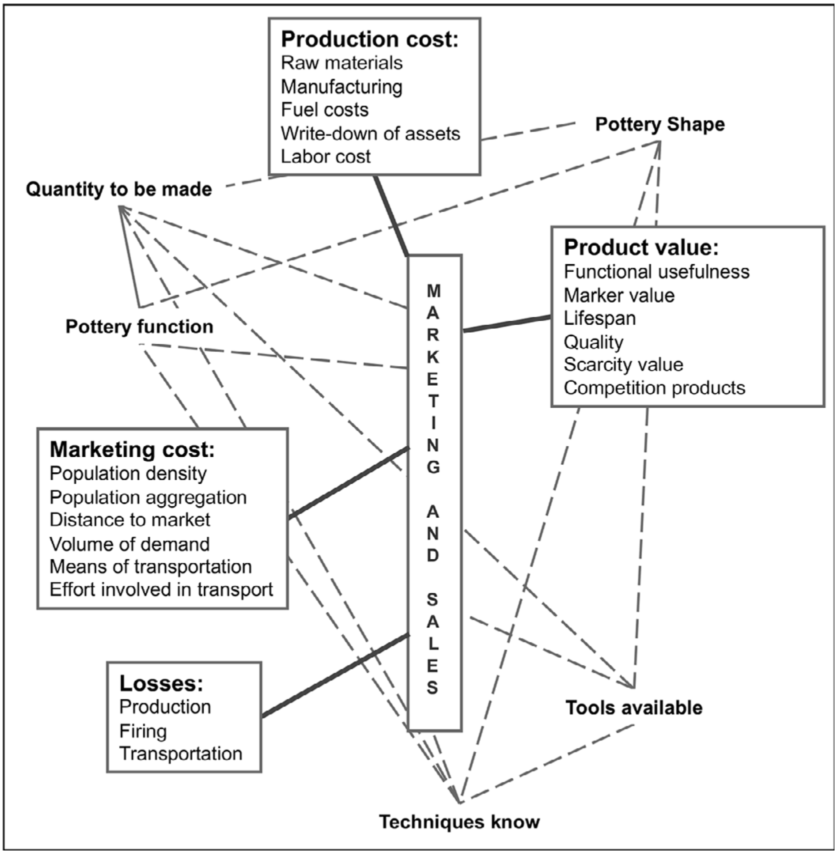

FIGURE 13.7 Throughout the manufacturing process, in all the phases in which the potter conceives the pottery and makes her choices about how to instantiate it, the marketing of the pottery and the organization of the workshop (Figure 13.6) are domains that are systematically taken into account, as together they determine the quantity and quality of the products to be made. (Source: van der Leeuw)

made among these alternatives (Pritchard & van der Leeuw 1984, 11–12). Rather, most have taken such choices as a given, aiming as they did at describing how things were done rather than investigating why they were done in a certain way and not in others.

We have seen in Chapter 12 that we need to investigate the choices made and those not made together, rather than only those made. Choices apply to the modalities of production, but the sets of alternatives among which they figure are anchored in the much wider realm of the perceptions and conceptualizations of the potter, her *mappa mundi* (Renfrew 1982).

Table 13.1 The economics, technology and workshop organization of pottery-making articulate as illustrated here. For simplicity's sake I have distinguished between six different system states that combine these variables. As is clear, these states do not impose the use of specific materials or the manufacture of specific kinds of products, but they constrain the range of manufacturing and firing techniques used as well as the organization of the workshop, depending on the quantity of products to be made and marketed. In general, the larger the number of pots made, the narrower the tolerance for variation, and thus the greater the interdependency between the different variables.

	Variables	*Household production*	*Household industry*	*Individual industry*	*Workshop industry*	*Village industry*	*Large-scale industry*
Economy	Time	Occasional	Part-time	Full-time	Full-time	Part/full time	Full-time
	Number	One	Several	One	Several	Several	Many
	Organization	None	None	None	(Guild)	Certain	Certain
	Locality	Sedent. or itinerant	Sedent. or itinerant	Itinerant	Sedentary	Sedentary	Sedentary
	Hired hands	None	None	None	Some	Some	Labor force
	Market	Own use	Group use	Regional	Village/town	Region (wide)	Regional and ex-port
	Raw materials						
	• Clay	Local	Local	Local	Neighborhood	Neighborhood	N'hood/distant
	• Temper	Local	Local	Local	Neighborhood	Neighborhood	N'hood/distant
	• Water	Local	Local	Local	Local	Local	Local
	• Fuel	Local	Local	Local	Neighborhood	Neighborhood	N'hood/distant
	Investments	None	None	Few	Some	Some	Capital
	Seasonality	Production as needed	Season w/o other work	All yr. except winter	All year in good weather	All year in good weather	All year
	Labor division	None	None	None	Some-considerable	Some-considerable	Detailed
	Time/pot	High	High	Medium	Medium-low	Medium-low	Low
	Status	Amateur	Semi-specialist	Specialist	Specialist	Specialist	Narrow specialist

Table 13.1 (*cont.*)

	Variables	*Household production*	*Household industry*	*Individual industry*	*Workshop industry*	*Village industry*	*Large-scale industry*
Technology	Manuf. technique	Hand/sm. tools	Hand/sm. tools	Hand/small tools	Mold/wheel	Mold/wheel	Wheel/cast/ press
	Tools						
	• Sed. Basin	None	None	None	When needed	When needed	Needed
	• Wheel	None	None; rot. supp.	Turntable	Various kinds	Various kinds	Kickwheel
	• Drying shed	None	None	None	Needed	Needed	Needed
	• Kiln	Open fire	Open fire	Impermanent	(Semi)permanent	(Semi)permanent	Permanent
	Raw materials						
	• Clay	Wide range	Wide range	Wide range	Narrower range	Narrower range	Narrow range
	• Temper	Wide range	Wide range	Wide range	Narrower range	Narrower range	Narrow range
	• Water	Any	Any	Any	Any	Any	Any
	• Fuel	Wide range	Wide range	Wide range	Narrower range	Narrower range	Narrow range
	Range of pots	Narrow	Narrow	Wide	Narrower or wide	Narrow or wide	Narrow or wide
	Functions/ pot	Wide range	Wide range	Wide range	Narrower range	Narrower	Narrower
Examples		Kabyles, N. Africa	Cameroon, Tanzania	Tibet, Turkey	Bergen-op-Zoom Farnham	Tzintzuntzan Djerba	Wedgwood Delft

Source: van der Leeuw 1977; copyright van der Leeuw.

Within the territory on that map, she will find it easy to adapt herself to the requirements of matter and energy, but the boundaries of that territory are the real limits to her capabilities. The proposed shift in approach therefore also opens up a (potentially rich and heavily underexploited) avenue to the study of changes in cognition. We need to investigate how people choose. What determines their perceptions, their biases, their reasoning? Almost certainly, there are aspects to these questions that are highly cultural, as well as others that are more closely related to the biological mechanisms of human beings.

The sciences that could take the lead in such research are notably cultural and social anthropology. Maybe there is a gap in the market for a more sophisticated kind of ethno-archaeology? Even though a large number of descriptions are available in the ethnographic literature of how a certain potter uses a specific technique to arrive at a distinguishable form, hardly any comparative research has been done on the relationship between technique and form, and abstracted synthetic statements on the topic are virtually absent.[1] The basis for research in such a direction has been laid by Krause in his book *The Clay Sleeps* (1985) and other publications (e.g., 1984) that rigorously describe the formal logic of pottery making in three entirely different parts of the world.

Challenges Limit Products

If we want to study choices, alternatives, and variations in *chaines opératoires*, we must also study how, among the many choices that are theoretically open to a person making something, some of these are out of bounds because of specific, material, technical, or other issues.

Let us look at the role form plays in constraining construction techniques in ceramics. Each form poses certain problems of construction to each technique, which can be resolved in a number of ways. I will therefore approach technique and choice comparatively, trying to keep form as constant as possible by concentrating on the techniques involved in making globular or near-globular pots with a simple everted rim. The major constructional problems that such a shape poses are in part those posed by all pottery, in part those related to a specific shape or to a specific technique. Some of those that are relevant to my argument are the following:

1. How to control the shape of the vessel. As the making is a dynamic equilibrium between the potter and the material, control over shape

is not self-evident. It is actually one of the most difficult things to achieve as a potter, especially if no tricks are to be used (van der Leeuw 1975, 1976).

2. How to avoid the vessel collapsing or becoming deformed during construction (van der Leeuw 1976). This problem is in this case particularly relevant to the base, because any pressure on a rounded base focuses on a very small area, and is thus more difficult to handle without deformation than when the base is flat.
3. How to keep the vessel in a fixed position during manufacture. This is another problem particularly relevant to round-based vessels as they cannot so easily be placed on their base.
4. How to ensure access to various parts of the vessel while it is being shaped. This aspect evidently relates to the mechanics of the human body, as well as to any cultural constraints on motion.
5. The speed with which the vessels may be made and the rhythm of work. If the work requires a number of interruptions during shaping, for example, the total day of the potter may have a very different structure than if it does not.
6. The width of the range of shapes that the technique allows the potter. Certain approaches allow the potter to make a wide range of shapes and sizes with minimal adaptations of the technique, while others do not.

These may all be seen as the nonmaterial dimensions of variability against which to assess the choices made by potters working in different contexts with different techniques.[2] How potters' know-how impacts differentially on these challenges is illustrated in this chapter by taking two examples, from different cultures, on how potters achieve essentially the same shape of (globular) pot.

Comparing Two Pottery-Making Traditions in This Light

In the following examples, I compare different ways of making essentially the same form, a simple globular pot, as found in two different pottery-making traditions. The interesting thing about this comparison is that is shows how in both traditions, and in all cases I found, the same set of challenges (as outlined) has constrained the ways in which the potters were able to produce the pots. Differences in manufacturing methods are therefore essentially differences in "work-arounds."

Using the Paddle and Anvil on Negros Oriental, Philippines

In fieldwork in 1981 in Negros Oriental in the Philippines, I observed a number of variations on making globular pots that I have described elsewhere in their context (van der Leeuw 1983, 1984). Here, I will confine my descriptions to the actual shaping of the vessels.

Case 1 (Tanjay, Negros Oriental, Philippines, 1981, Photo 13.8, copyright van der Leeuw). The most traditional (and at the time of fieldwork almost extinct) of these begins with the potter taking a ball of clay, placing it on a simple wooden support that can turn slowly, opening it with a thumb, while the other hand keeps the support turning, and shaping only the rim of the vessel between the thumb and first and second fingers of one hand.

The body and bottom of the pot are shaped the next day, out of the thick, unshaped lump of clay on which the rim sits, by means of a paddle and anvil technique based around a globular anvil inside the pot. The maximum diameter is shaped first, the shoulder next, and the base last, all the while rotating the vessel around its central axis. After another drying period, the pot is polished with a pebble and left to dry until it is ready for firing.

Case 2 (Zamboanguita, Negros Oriental, Philippines, 1981; Photo 13.9, copyright van der Leeuw). A variant makes the rim out of a coil of moist clay that is placed on the bottom of a fired vessel that stands upside-down

PHOTO 13.8 A female potter in Tanjay, Negros Oriental, Philippines makes a vessel by rotating a lump of clay on a small turntable. She began by opening the ball and shaping the rim, while leaving the remainder of the pot unshaped (see the two vessels she is not working on). Next, she is thinning out the wall between one hand supporting it on the outside and the other shaping it on the inside. After some drying, she will shape the bottom of the vessels with a hammer-and-anvil technique, then let the vessel dry and fire it.

PHOTO 13.9 Another female potter in Zamboanguita, Negros Oriental, Philippines is shaping a coil of clay on an inverted, fired pot covered by a piece of coarse fabric that serves as a mold. This coil will be shaped into the rim and upper shoulder of the vessel. The fabric serves to ensure that the wet clay does not stick to the inverted pot. Behind her stand some finished pots, and lies a paddle with which the vessels are given their final shape.

(i.e., on its rim) on a flat surface, and which can turn (unpivoted). The pot is turned with one hand, the rim shaped between the thumb and the index finger of the other, which holds a piece of wet cloth. The rim is then set away to dry. Later, the potter fixes a flat "pizza" of clay to the underside of the rim and places the combination back in the sun for some more drying. The next day, the rest of the pot is shaped out of the pizza by means of the same paddle and anvil action. After some more drying, it is polished and prepared for firing.

Case 3 (Zamboanguita, 1981; Photo 13.10 copyright van der Leeuw). Here, both the upper and the lower part are made separately over an upside-down fired vessel that, as in the last case, can turn unpivoted. The upper part may consist of the rim alone, but more often consists of everything above the maximum diameter. Both the upper and the lower parts are formed by placing one or more coils of paste on a sheet of plastic that covers the mold. The clay is smoothed over the mold both with the

(a)

PHOTO 13.10a The same potter now shapes the base of a vessel over the inverted pot. After some drying, it will be united with one of the pre-shaped rims that lie in front of her, drying in the sun.

(b)

PHOTO 13.10b Once the two pieces have been joined, as in this photo, and have had some time to dry a little, the potter gives the vessels their final form by thinning their wall between a paddle (as seen in photo 13.9) and a rounded stone or piece of wood that serves as an anvil. Once that is done the vessel can be dried and fired.

hands and with the paddle (so that, sometimes, the mold literally serves as a large anvil). Both parts are left to dry for some time and are then joined. The joint is strengthened by beating it with a paddle on a proper (small) anvil. The vessel is then set away to dry until it can be fired.

Case 4 (San Carlos City, Negros Oriental, Philippines, 1981; Photo 13.11, copyright van der Leeuw). The sequence of steps constituting this production method is essentially the same as in case 1, but many more vessels are produced per unit time and the vessels are much larger. The support is in some cases a large potter's wheel (made from a truck wheel) that does not differ from that used in thirteenth-century Holland for throwing. But in this case, the wheel is used as a turntable, rather than a true potter's wheel. It was installed by the potter after he saw on a (Japanese) film of people throwing pots. But when asked he admitted that he had never been able to use it for that purpose. In the end he gave up and used the wheel simply as a turntable for the largest vessels he was making.

Case 5 (Dumaguete, 1981; Photo 13.12, copyright van der Leeuw). This case resembles case 3, except that the pot that serves as a mold has been mounted, again upside down, on a pivot that stands in a bamboo so that the mold can turn much more effectively. The vessels made are bigger and the production is much greater. The upper and lower halves of the vessels are made separately in small series, from several thick coils that are smoothed over the mold with the paddle. They are then joined at the maximum diameter, again between paddle and (small) anvil. They are then set apart to dry until they can be fired.

(a)

PHOTO 13.11a An (exceptionally male) potter in San Carlos City, Negros Oriental, Philippines shapes a vessel on a turntable by opening a lump of clay, then shaping the rim and continuing by thinning the rest of the lump somewhat between his hands.

(b)

PHOTO 13.11b The potter then takes the vessel off the turntable, and places it in a fabric-covered basket so that he can start working on the base of the vessel. Ultimately, the vessel wall is thinned and the vessel given its globular shape between a paddle and an anvil.

PHOTO 13.12 Another female potter, in Dumaguete, Negros Oriental, Philippines is shaping large vessels in two halves, by placing coils on a fired, upturned vessel that is fixed on a stick. The stick is placed in a hollow upright bamboo, so that the whole contraption can turn more freely than the turntables in the earlier photos. Three coils are shaped into the base of the vessel, and then another three coils are shaped over the same mold into its shoulder and rim (as on the photo). Finally, after some drying, the two halves are joined and left to dry until the pot can be fired.

Comparison

Comparing these cases, some interesting parallels and differences spring to mind. In all cases the basic sequence is the same: the lips (or upper parts) are made first (always in the same way), the lower parts later. In all cases, we also see the use of rotation around a fixed vertical axis, but the extent of its use varies. In cases 1, 2, and 4 it is only used to facilitate shaping the rim in a continuous motion, while the other parts of the vessel are made by means of discontinuous motions (between hammer and anvil) not strictly speaking around a vertical axis. But in cases 3 and 5 it is also used in shaping other parts of the vessel. In case 3 the pot is rotated while the paddle beats against the clay in an endless series of individual blows that shape the wall, while in case 5 the hand movement that shapes the vessel walls is continuous, against the rotating device.

In all cases, we also see tools used to determine the final (rounded) shape, be they molds (cases 2, 3, and 5) or anvils (cases 1 and 4). In two out of three (3 and 5) cases in the former group, the shaping tool also serves as a support during manufacture, while in cases 1, 2, and 4 that function is not fulfilled by anything. In cases 1 and 4, where the support is flat, the whole pot is made out of one lump, and that lump is worked in two stages: first the rim, made on the support while it is turned, and then the body, made with a paddle and anvil technique. In cases 3 and 5, where the support is a pot placed upside down, the vessel is made in two halves out of a varying number of coils. These halves are then joined. In case 2, the rim is made first, on an upside-down pot, and the body is made separately (a pizza) but is joined to the rim before the whole is shaped all at once between paddle and anvil.

Invariant elements in the manufacture therefore seem to be (a) its sequence, (b) the use of slow rotation, (c) the shaping of the rim, and (d) the shaping of the body (in all cases a paddle is used, while the mold, where used, is none other than a large anvil). Variations are possible in the (e) use which is made of rotation and its speed, (f) the nature, and (g) the timing of the support accorded the vessel during manufacture, (h) in making it out of one lump or out of several pieces of clay, (i) in the point in the procedure in which different parts of the vessel are welded together, and finally (j) in the drying periods needed. These elements seem to vary with the number of vessels produced per unit time (see van der Leeuw 1983, 1984).

The invariant elements are those that determine how a tradition may develop through time. In this case, for example, we see the introduction of rotation in a form that greatly resembles the potter's wheel (case 4). But the fact that the Philippine sequence begins with the manufacture of the rim inhibits the discovery that one may indeed, very rapidly, make whole vessels on a wheel. That option is only available if the potter begins his manufacturing sequence with the bottom of the vessel, or with some intermediate part. The potter in this case had the wheel, but did not know how to use it for this purpose.

Mold-Shaping in Michoacán, Mexico

In the Mexican province of Michoacán,[3] potters use a technique that, as far as we know, has never been developed in the Old World, i.e., the making of pots by molding in two halves, which each represent either a horizontal or a vertical section of the pot.[4]

Case 6 (Patamban, Michoacán, Mexico, 1989, Photo 13.13, copyright Coudart-van der Leeuw). The paste is kneaded into balls, which are subsequently beat into flat "tortillas." One such tortilla is placed in a fired earthenware mold. The inside of these molds represents the right or left side of a complete upstanding pot rather than the bottom or the top half.

PHOTO 13.13 In Michoacán, Mexico, vessels are shaped in molds. Here, a closed vessel (with its opening narrower than its belly) is shaped by placing a pancake of clay in one half mold, then doing the same in the accompanying half. Both halves are then joined from the inside of the vessel. The vessel is left to dry, and after a while one half mold can be taken off (as here in the photo). A little later the other half can be takes off, the pot placed upside down on its rim, and the outside of the joint removed with a knife. The pot is then dried until ready for firing.

Thus, between the two of them, they dictate the shape of bottom, shoulder, and rim. After the two molds have been joined, the potter cuts excess clay from the future rim with a wire, by moving it along the outside of the joined molds. She then rubs the joint smooth on the inside and leaves it to dry in the molds for several hours. Next, the molds are taken off and the complete pot emerges. The suture will have left a ridge of clay on the outside, which is removed by scraping with a knife, and is then smoothed with a wet rag. A wide range of forms is thus made in one and the same manner.

Case 7 (same location; Photo 13.14, copyright Coudart-van der Leeuw). The manufacture of open dishes, for example, follows a molding technique that is based on the horizontal (asymmetric) plane. Here, the tortilla is draped over a mold that is, like a mushroom, provided with a handle. Once it has been pressed against the mold and smoothed with a wet rag, the potter cuts off the surplus paste at the edges of the tortilla with a wire that is kept between the teeth and one hand, while the other hand rotates the mold against it. If need be, a coil is added to the base to provide a support for the vessel to stand on a flat surface. It, too, is

PHOTO 13.14 In Michoacán, Mexico, open vessels (bowls, plates, etc.) are shaped horizontally by placing a pancake of clay over a mushroom-shaped mold made by attaching a handle to an upside-down, fired, bowl. The potter shapes the vessel by hand against the mold, then shapes the rim by removing excess clay with a wire held between the teeth and one hand while rotating the mold. The photo shows two molds for open vessels above the resultant vessels, and one closed vessel in a vertical half-mold.

smoothed with a wet rag. The pot is then taken off the mold and left to dry.

Case 8 (Huancito et al. 1991, van der Leeuw et al. 1992). The procedure is the same, but the mushroom-shaped hand-held mold has, for large vessels, been replaced by a *tournette* that pivots in a hollow bamboo. On it, the potter places the mold over which she then drapes the pizza to be shaped, just as in the hand-held case.

Comparison

In this approach, although the shape of the mold – and thus the pot that results from the molding – may differ considerably, the manufacturing method is essentially identical.[5] Invariant are (a) the sequence, making flat pizzas of clay and placing them against a mold, then drying and removing them to let the vessel stand on its own, a sequence that is independent of the shape of the vessel, as it creates no single part of the shape before any other; (b) the fact that for shaping, the usual distinction of continuous or discontinuous motion does not really apply; (c) the use of the mold both as a shaping device and as a support for the clay while it is wet; (d) the fact that the only other shaping tools are a thin nylon wire and a little rag to smooth the pot.

Variations occur in (d) whether one mold is used or more, (e) whether the pizza is placed in or over the mold, (f) whether the mold is rotated around a vertical axis or not, and (g) the shape of the mold. In the Michoacán case, the conceptualization of pottery manufacture thus does not wrestle with a sequentiality that begins with the bottom, the top, or even the shoulder or the middle as we have seen in all cases thus far: either the potter makes the body of the vessel all at once (open vessels) over a horizontal mould or makes it in two to four parts that have nothing to do with such a partonomy, joining vertically instead of horizontally, and vertically asymmetrical in themselves. Indeed, the distinction vertical–horizontal is thus rendered irrelevant within this tradition. It is replaced by the distinction between vessels that, topologically, represent half a (deformed) sphere, or a whole one (van der Leeuw et al. 1992).

Some Lessons

Clearly, the approach illustrated here is much more difficult to instantiate for modern technologies. I have had to take a relatively simple example, and one I know well as a ceramicist who has observed the making of ceramics in a number of places throughout the world. But I hope it has allowed the reader to understand better how the details of information processing can contribute to creating a specific information processing structure (tradition).

In particular, in Chapter 12 and in this chapter I have tried to show how, in order to grapple productively with the ways in which inventions change our information processing apparatus by designing new ways to deal with emerging challenges. I conclude that we need to change our intellectual approach in instances like this. We need to accept that the same regulatory mechanisms are responsible for both change and its absence, and that, therefore, both need to be studied together.

In particular, we need to invert the relationship in our thinking between objects and data on the one hand, and our interpretations of these on the other. Objects and data are poly-interpretable and our interpretations are not, because they severely reduce the dimensionality of what is observed. Moreover, there are good reasons to assume that ways of seeing and doing things (traditions) outlast individual instances such as material solutions to specific challenges.

Furthermore, we need to look at the process of invention as an interaction between an external perspective on the niche where invention occurs and an internal perspective on the same. The former is constituted in the physical realm of the various factors that are potential influences on production and innovation, whereas the latter is partial and reflects the biases and choices of the person inventing. In this context, the concept of niche creation that has recently been introduced in biology is of great importance. Once a niche has been constructed, it in turn shapes perceptions and choices.

I believe that seeing the process of invention like this from the inside provides us with a much better insight into the dynamics involved, and might thus, when applied to other domains, help us steer innovation, and thereby contribute to a reflection on the unintended consequences of our inventions (by comparing the choices made with those not made) and thus, it is hoped, allow us to make wiser choices.

But an essential element in all this is how potters, and all other inventors, make their decisions. There is now a wide range of approaches from both cognitive sciences and psychology as well as from economics and other disciplines on this topic, but I will not go into these in detail, simply because there is too much to summarize. The essence of those discussions is, however, that such decisions are shaped both by biological and physical constraints and by the social networks within which the deciders function. These networks are determined by geography, social affinity, profession, and numerous other factors that together shape the value systems of the people concerned. In each case, and this is important to remember, the interaction between the dynamics within the system – whether those of an individual human being or of a social collective – and those in the context within which that system operates drives societal change and determines how a system may change. I will pursue this discussion in Chapter 16 when looking more closely at the concepts of value and value space.

The Role of Artifacts and Technology in Society

Thus far, we have looked at the role of information processing in creating novel artifacts, routines, institutions, etc. But once these have been created, they are integrated into the overall information processing toolkit of society. As we have seen, invention and innovation are essential elements in the maintenance of the flow structures that constitute human societies. But what is their precise role?

Artifacts are rarely looked upon as information processing tools, as part of the set of tools for thought and action that societies create and use in their coevolution with their environment. Yet that is an important reason for their invention because, in effect, they enable society to routinize part of its information processing. To perform a certain task that demands relatively considerable information processing if it is performed with rather simple and general-purpose tools, such as felling a tree with a stone ax, inventing a specialized tool that is more closely geared to the exact actions that are needed to perform that task, such as a saw, will reduce the information processing load of the person executing the action concerned because the tool routinizes that action. Rather than ensure that each blow of the ax hits exactly the right spot at the right angle, once the sawing has begun direction and angle are fixed and do not require any further information processing. Only the back and forth action does.

Looking at it like this, the proliferation of artifacts that has grown over time in many cultures has been due to the need to reduce the information-processing load to counterbalance its increase as a result of the growing number of people involved in the interactive groups, societies, and networks concerned. As such, it also helps to fix certain categorizations and ways of doing things materially, and thus to limit the set of options that will readily be chosen by the society.

This is another level at which the options chosen must be evaluated against those not chosen. An example from the Eastern Highlands of Papua New Guinea that my wife and I experienced in 1990 may illustrate this. In a certain village, the inhabitants invented a way to bend a sliver of bamboo upon itself, creating the kind of tweezers that can help grip objects, not unlike the tools we have in our kitchens. In their case, the tool is used to take sweet potatoes and other tubers out of the fireplace once they are cooked. But in the next village, less than half a day's walk away, they do not have this tool, so they have to find other, more complicated, ways to remove their breakfast from the fire or burn their fingers (which therefore happens regularly). Unfortunately, we do not have enough data to decide between different possible reasons for the difference, but one way to interpret it is that the people in the two villages (who speak different languages) have a different technological worldview. There are many examples of such cultural or traditional differences between nations in the modern world. The Dutch (and South Africans), for example, cut slices of cheese with a very different cheese-knife than the French. Part of the reason is the different consistency of the cheeses, but using a French knife on a Dutch cheese would merely have changed the shape of the pieces that were cut off – not a very fundamental difference, except in the context of differences in worldview about how things should be done.

The ways things are done, including the artifacts used by a society, are part of what binds a society together. Individuals in a society develop habits that are aligned around certain kinds of knowledge. Rather than the objects people use, it is their knowledge about where to find raw materials, how to make artifacts, how to use them, etc., that defines a culture.

The complete set of artifacts that a society uses does indeed to a very substantive extent determine that society's interaction with the material world because it structures actions in a specific way. A well-studied ethnographic example of this are the two main ways in the world in which rice or cereals are transformed into flour – by pounding with a stick in a (wooden or other) bowl as is done in many parts of East Asia, or by grinding between two stones as is done in much of Latin America. The two different physical actions have a wide range of impacts in other parts of their cultures.

Sometimes these are not immediately observable. John O'Shea once told me that the burial customs of a very small community through time – which he studied for his PhD (1987) – were remarkably stable, even though there were very few burials with long periods in between. He then asked, “How is it possible that people remember the rituals over such long times?” I think the reason is that other aspects of the culture and its activities anchored many aspects of the society’s worldview, such as spatial and ritual aspects of its culture in different ways and at different levels, so that people were guided by these choices in recollecting the burial rituals themselves.

Thus, I would argue that the technology of a particular group or society and, particularly, the ideas behind it that are only partly manifest to the people concerned, constitute the skeleton of the behavioral choices of a society, and an important element in determining its path dependent development. One way to visualize this is by looking at cities. As mentioned in the context of Padgett’s outstanding work in Florence (2000), for example, the spatial structure of the city, with its many small piazzas, led to the creation, around these piazzas, of financial transactions among neighbors, and thus gave an essential impulse to the emergence of novel inventions in the domains of accounting, banking, and trading.

In the USA, the geography of the early cities (on the coasts) enabled people to move around on foot, and for longer distances by public transportation. The streets can be, but are not necessarily, at right angles. In the mid-west and west, the (later) cities are much wider spaced and therefore depend on cars for transportation. All of us who live in such cities will be fully aware of the extent to which their plan and their amenities actually structure our lives in many, many ways. Because the life expectancy of the material infrastructure of cities exceeds that of individuals or even generations, such behavioral skeletons constrain much of their inhabitants’ behavior over a long time.

And this in turn links my argument to Arthur’s reversal of the roles of the economy and technology, which I referred to in Chapter 12, the technology of a society being in many ways the infrastructure within which both the society and the economy function. The position that he corrects (the economy as the driver of technology (and society) can be linked to the fact that, in the 1830s–1850s western society inverted the respective roles of society and the economy, from one in which the economy served the society as was the case in most premodern societies, to one in which the society served the economy, thereby opening the road for the emergence of our current market-based capitalist (and more recently financial) system (see Polanyi 1944). I devote more attention to this shift and its consequences in Chapter 18.

NOTES

1 In ceramic studies, I know of only one contribution (Balfet 1984) that contrasts in general terms the forms that result from, respectively, throwing and coiling techniques. But others may have appeared in the meantime, and I would be grateful for any pointers in that direction. Similar comparisons between particular rotative shaping techniques and the resultant shapes have been published by Méry et al. (2010).
2 They are of course matched in the realization of the pots with the specific material constraints of the clay, the tools, and the firing circumstances, even though I am deliberately not discussing these here in order to avoid introducing what, from the perspective I have chosen and outlined, would be a lot of "noise."
3 Observations by me, Dick Papousek, and Anick Coudart in 1989–1991.
4 This is the same way of using molds that is used in European industrial pottery casting. Evidently, there is the certainty of mutual influence since the sixteenth century between Mexican and European pottery-making. I have, however, not yet been able to discover a direct link concerning this aspect.
5 See van der Leeuw et al. (1992).

14

Modeling the Dynamics of Socioenvironmental Transitions

"*Models are opinions embedded in mathematics.*"
(O'Neill 2016: Weapons of Math Destruction)

Introduction

In Chapter 11 I presented the qualities and limitations of information processing in various kinds of societal configurations under, respectively, universal control, partial control, and no control, and used a very simple percolation model to summarize the overall evolution of societal systems as a spreading activation net. In the second part of that chapter I discussed various aspects of heterarchical systems and the ways in which hierarchical and distributed information processing networks interact. It concluded with an argument to the effect that in such heterarchical systems, diversification of activities contributes substantially to the stability of the system.

This chapter is devoted to the dynamics and processes that occur between rural and urban contexts, engendering the transitions between these system states. The increasing connectivity that involves more and more people in the spreading activation net has major consequences for the structure of the information-processing network involved, and we need to look at them. That argument will be based on a complex systems model applied to the dynamics of information processing. Although this chapter is therefore based on a rather technical construct formulated in mathematical terms, I will initially present the argument as far as possible in non-technical terms. To demonstrate the potential and the relevance of the modeling approach, for readers who might be interested in some of the details, I will restate important elements of the argument in mathematical terms in Appendix B. Those who are not interested in this aspect can follow the overall reasoning of the book without interruption.

Second-Order Dynamics

To begin, we can gain a glimpse of the complex dynamics involved in the emergence of urbanism by identifying the long-term change in change dynamics (what I have called the second-order change dynamic) occurring in that process. This can be done by looking at the rhythms of the various processes that are involved. Whatever the societal form of organization, the human and environmental dynamics in it are interlocked in mutually interacting ways.

In rural situations, the environmental dynamic is the more complex and multilayered of the two, and is thus the slower one to change. The human dynamic, on the other hand, consists of relatively few superimposed rhythms and can change relatively quickly because people can learn. As a result, a faster human dynamic is essentially locked onto a slower environmental (natural) dynamic: humans adapt to the environment, and because the environment is slow to change the combined socioenvironmental system is rather stable.

In urban situations the two kinds of dynamic reverse their rhythms: the societal dynamic becomes more and more complex, and therefore more and more difficult and slow to change, whereas the environmental dynamic, in so far as it directly relates to the societal system, is simplified because humans have locally reduced the environmental complexity and diversity of their environment. The environment can now be adapted according to the needs of the society. But as the more rapid dynamic has now become the dominant one, the socioenvironmental system as a whole has become less stable. As Naveh and Lieberman (1984) put it, "the environment has become disturbance-dependent [on society]."

The above reversal is the fundamental one that has brought our societies to their current, unsustainable, situation, and it draws our attention to the fact that the temporal dimensions of the rhythms constituting socioenvironmental interaction are crucial in the coevolutionary transitions we are discussing here. I will come back to these later in this chapter in the form of models that show how these temporal differences affect urban–rural interaction.

Mobile and Early Sedentary Societies

Looking now at the first major organizational transition of society, that from mobile gatherer-hunter-fisher societies to sedentary ones (whether based on stable, naturally available resources such as salmon in the Pacific Northwest of the USA, or based on cultivation such as early farming communities in the Near East, East Asia, and the Valley of Mexico), from the perspective we are developing here we must emphasize a difference that has of course been noted but in my opinion not sufficiently emphasized: the change in the way resources are used. Mobile gatherer-hunter-fisher societies collected what nature had to offer – they had a multi-resource subsistence strategy in which they were wholly dependent on the rhythms of nature, and their only way to adapt to challenges was to move to other places with different natural rhythms. They harvested, but did not in any way invest in, their environment. Over the lifespan of individual gatherer-hunter (mobile) groups, once they had mastered sufficient knowledge of the dynamics of their environment they dealt effectively with change at daily and seasonal temporal scales by moving around from resource to resource. But they probably experienced very variable foraging success, and thus at that scale they experienced high levels of uncertainty, but hardly any risks because they had not substantially invested in the environment.

Sedentary societies, on the other hand, developed a reciprocal, interactive, relationship with their environment in which they invested in the latter by clearing spaces, working the soil, sowing, and waiting to harvest. In the process, they reduced the range of resources exploited by focusing much effort on one or more specific ones. They tried to some – very limited – extent to control some aspects of their environment, and their investment carried some risk with it. This was clearly a dynamic in which humans engaged with their environment, but remained essentially beholden to many of the vagaries of the latter, in the form of climate, soil, vegetation, etc. Herding societies also developed an interactive relationship with their environment, managing the natural dynamics of herd reproduction yet (as far as we know) not investing in a particular place, instead following the environmental rhythms of herds and their resources.

Though the information processing in all these cases was essentially under universal control (hunter-gatherer-fisher societies, early agricultural village societies, and herding societies were and are mostly egalitarian), the transition was the beginning of a shift from societies dominated by natural and slow (environmental) rhythms to environments that are being modified by more rapid human societal rhythms. Initially, because human groups were small and their technologies relatively unsophisticated, the human impact on these natural rhythms was limited, and the complex environmental dynamics ensured long-term overall stability of this mode of social organization and information processing.

But once human dynamic rhythms were introduced into the system alongside environmental ones, because people could adapt more quickly the former rhythms grew in importance in step with the growth of the population involved and the consequent growth in complexity and technological capability of societal systems. Ultimately, they took over so much of the Earth system that we now speak of the Anthropocene as the period in the Earth's history in which humans control (most of) the overall socioenvironmental dynamic on Earth. In the following sections, I will roughly outline how that process followed its course, ultimately leading to the rapid expansion of urban societies that we have seen over the last 150 years.

The Emergence of Hierarchies

How did hierarchies emerge in such societies? An example that I observed in Wiobo village in the Eastern Highlands of Papua New Guinea in 1990 can serve as an illustration. This is a highly isolated area, one of the last areas of Papua New Guinea to be opened up to western observation, this taking place in the 1950s. The society is a horticultural one, in which subsistence is provided locally by exploiting small gardens in which food is grown. When a dwelling for a new couple was being collectively built, a large part of the village came together around a meal prepared in a Polynesian oven. Suddenly an argument broke out between several males, concerning responsibility for a particular task in the village: keeping the landing strip alongside it in a serviceable state (cutting the grass, etc.). After a while, in which different contenders offered different solutions to the challenge, a consensus emerged that one person's suggestion was the best one, and he was elected to be what one could call the keeper of the landing strip.

From an information processing perspective, what was happening cut two ways. On the one hand this process selected a particular channel that favored a specific set of signals over many others referring to the same topic, relegating the others to the status of noise, and on the other hand the group created a degree of vertical integration by according one person control over a specific part of the information flow in the society, and thereby according that person a degree of responsibility and prestige, as well as the capacity to mobilize others for the task concerned. Both aspects of this action clearly rendered the fulfilling of this specific task more efficient by aligning the information processing of the people involved in it.

By thus "electing" candidates who offered what were considered to be the best solutions to challenges faced by the group, a group could create a number of domain-specific (short) hierarchies that improved the group's information processing substantively. Ultimately, of course, coordination between a growing number of such hierarchies, and thus between a number of job holders, would be necessary and would in all probability lead to a kind of coordinator function for which another individual was chosen. It is important to note that in the early stages of this development, these responsibilities were assigned ad hominem, were not heritable, and could also be revoked during a person's tenure.

The First Bifurcation

The next transition is one that sees the expansion of these small, sedentary (or herding) groups. They are still dependent on locally available energy and resources, and their information processing networks are hierarchical within the community. These hierarchies may at this point become more stable, giving rise to so-called great men and big men positions (Godelier 1982; van der Leeuw 1986) that ultimately may even become heritable. As the groups grow, the partial control of the different functional hierarchical information-processing networks creates inhomogeneities in the information pool. Those in control of a hierarchy process more information than others, which makes them leaders, but also leads to misunderstandings and potentially to conflicts. One way to deal with this is for the group to institute occasional or periodic group meetings to reduce communication distances between all members, and thus serve to rehomogenize the information pool and readjust it to changing circumstances, whether caused in the environment by human exploitation or by externally triggered fluctuations in the social or natural environment. One would expect these resets to occur more frequently as maladaptations between the state of the environment and the state of environmental information processing grow.

From a dynamic model perspective on information processing, one could characterize such systems as oscillating around a fixed-point attractor. Stability based on a fully shared information pool dominates.

But the societal system is subject to an oscillation between an accelerating/structuring phase and a decelerating/destructuring phase. In the former, the system is more deterministic, in the latter more stochastic. In more tangible everyday terms, people alternate between strengthening their system around a core set of ideas, customs, and institutions, and the opposite, widening the range of ideas and behaviors.

As contacts intensify, non-hierarchical distributed connections within groups are strengthened by family relationships maintained through networks of marriages. Owing to the combination of hierarchical and distributed information processing networks, information spreads very quickly, correcting imbalances in the information pool. But these societies are still slow to adapt as they are heavily constrained by slow environmental dynamic rhythms and have very few decision-makers (of limited diversity).

The Second Bifurcation

As societies grow in size, the hierarchical aspect of information processing also grows in depth and size, involving more and more people. As we saw at the end of Chapter 11, it also becomes more and more specific by losing a number of its branches as it focuses more sharply on tasks at hand, and thus becomes less adaptive. The distributed information processing network in the society, being more adaptive, gains in importance. We can thus imagine that at some point there could emerge a second bifurcation between hierarchical and distributed communication modes, in which they are separated spatially. This could for example occur when in some locations a faster adaptation of the socioenvironmental system is required than in others because the system is more dependent on the human dynamic than on the environmental one, whereas in other locations it is the reverse. Poorer environments, or environments that are more likely to be handicapped by certain environmental dynamics (climate, water, erosion) might trigger such more rapid adaptations, and favor distributed information processing.

Initially, this bifurcation might simply be enacted by certain people in a settlement who begin to specialize in communicating with others, for example in terms of exchanges or even trade, while others continue to be focused on immediate subsistence activities and to be linked to a hierarchical information-processing system. This would be one way to look at the prestige goods economy (e.g., Frankenstein & Rowlands 1978), which is in some places contemporaneous with emergent proto-urban centers and locally generates a settlement size hierarchy. Physically, this requires a point of connection between the distributed communications network and the hierarchical one. Because it is the point of introduction of new ideas and values, it quickly becomes the apex of the local hierarchy.

Over time, as the community of people linked into a distributed communication network grows, this may lead to the emergence of specialized periodic trading centers, such as the early medieval Northern European trading emporia, examples being Hedeby and Dorestat. These were located in geographical locations that were particularly suitable for communication, such as along rivers (at fords or branching points), along the coast, or at points where other conditions favor them.

In modeling terms, this is an information-processing system in which more permanent and spatially wider-spread communication corridors based on distributed information processing emerge between spatially separated hierarchical islands, structured as stochastic information webs wherever structured and unstructured oscillations form a pattern of interferences (Chernikov et al. 1987). Qualitatively, these webs involve information brokers between different hierarchically organized villages, such as ambulant tradesmen and others who are independent from the village hierarchies. In pre-classical Greece, one could also interpret priests in liminally placed sanctuaries, such as Delphi, as examples of such brokers. Currently, one finds them in very many places in the developing world.

The Third Bifurcation

The third bifurcation could be called preurban smouldering – a situation in which, at a regional level, limited-term and more complex structuring occurs here and there, after a while petering out, then rekindling elsewhere. The existence of long-distance distributed processing corridors that are relatively stable over a period, and sufficiently frequently used to have a sufficient channel capacity (bandwidth) to maintain the information flows involved, permit certain groups of hierarchically organized societies to integrate into a larger system. This has a locally destabilizing effect because the symbiotic, hierarchical systems' connectivity is enhanced through spatial extension (see White 2009). Dealing with this requires increased reliance on distributed information processing and energy obtained from elsewhere, and has probably led to instabilities in these systems, as I argue in Appendix B by constructing a set of dynamic models of these interactions.

Such a fluid and essentially discontinuous process of structuring and restructuring is imperfectly captured by any single spatial, all-encompassing, geometric structure as an explanation of societal organization. For example, under the type of dynamic evolution postulated here, territoriality and the societal boundedness of societies must have been subject to constant redefinition; a political tug of war between competing, adjacent polities for control and supremacy in exchange relations, both within the transportation and communication network itself and outside it. Under such circumstances, preeminent societal control by any single social group is unlikely for other than short periods.

Such essentially unstable systems were not confined to the European La Tène period, on which our models have been based. In Europe we see them again after the collapse of the Roman Empire, in the seventh to eleventh centuries CE. But I would surmise that we see them also in the Preclassic Maya (900 BCE–300 CE) area before the hegemony of Tikal and Caracol, in certain phases of Chinese history (such as the period of the warring states, 475–221 BCE), in the Uruk phase in the Near East (*c.* 4000–3100 BCE), and elsewhere.

An important aspect of the emergence of these long-distance distributed communications is that they infuse local hierarchical systems with new values (materials, objects, technologies, ideas). This enables them to extend the set of values of the community involved, and over time it enables the alignment of more and more people in different local systems into one value system.[1] I return to this aspect in Chapter 16.

The Fourth Bifurcation

In many parts of the world, the first real towns emerge as a network of small, more or less equivalent, city states in what has been called peer–polity interaction, invoking a kind of mutual bootstrapping (Renfrew & Cherry 1987, title). This phenomenon resembles in many ways that of convection and might be modeled as an example of Bénard-like convection (see Chapter 7; Nicolis & Prigogine 1977; Prigogine & Stengers 1984). The peer polity/convection cell model is essentially one of increasing information flow in a local circuit, which has a differentiating and structuring effect on the inhabitants of the cell itself: center–periphery, town–hinterland. The regional and supraregional exchange that takes place is initially effectively stochastic (down the line).

As these cells grow, the cores come to interact more closely and boundary phenomena take over: neighboring cores begin to exchange information on a regular basis, i.e., no longer in a stochastic manner but directionally. In this intermediate phase, long distance exchange becomes hybrid, i.e., between cells it moves stochastically, but once it hits the periphery of a unit, it cannot but go to its center. This entails a major reduction in stochasticity of communication as well as the beginnings of opening up the cells. Once the flows are directional, the cells can become dependent on them; the time delays in communication are drastically reduced, and this enables them to play to each other's needs.

As more and more individuals participate in the (now) heterarchical channels, long-distance communication becomes more and more directional, meets more and more needs, and eventually connects very large spaces to such a degree that the centers become dependent on their trade networks. Importantly, the way the individual centers developed is highly dependent on minimal differences in initial conditions and on the paths they took. Guérin-Pace (1993) sketches this highly variable dynamic at the regional level within a full-grown urban structure. The crucial variable in the transition seems to be the degree of long-distance complementarity.

Eventually, the growth of these large heterarchical systems threatens stability and increases sluggishness in adapting to change. Some degree of separation of interactive spheres may be a response (city states?) as well as internal hierarchization (for example in the early development of Greek city states, in which oscillations took place between tyranny and democracy). The towns eventually become permanent heterarchical systems.

Summary and Conclusion

In this chapter I have tried to outline a trajectory from early egalitarian societies to heterarchical urban ones. In doing so, I have used a conceptual model to link known observations about intermediate stages of this development by assuming several important bifurcation points (transitions, tipping points) between the different states of the information processing system. But I have not discussed the last stage of this evolution, which has led to the current challenging sustainability predicament. That is dealt with in Chapters 15–18. Altogether, it needs to be emphasized that this has no other purpose than to propose a different way to view social evolution from an a priori perspective rather than the existing a posteriori one. Whether such an approach will in the long run help us deal with a number of the issues involved remains to be seen.

Appendix B

Modeling Urban–Rural Interaction

I present this in conjunction with Chapter 14 as a voluntary exercise for the reader, which can be skipped if desired. It is based on a model that James McGlade and I designed to explore the essentially metastable dynamics of regional information-processing structures in the context of the European Iron Age (van der Leeuw & McGlade 1997),[2] but work that I have since done on the urban–rural dynamic in modern Epirus (van der Leeuw 2000) and Ancient Maya (van der Leeuw 2014) confirms that it is also relevant for the transformation of rural Epirus settlements and the emergence of the large Maya centers, and I think it might be interesting for other areas of the world where cities emerged. But that is subject to testing. To illustrate how such a model can help us conceive of such a complex trajectory, I will try and summarize its main elements.

To begin with, we investigated the generic dynamics of urban impact on a rural environment, assuming that the rural environment is self-organizing, and that the dynamic can be described as a sigmoid growth process according to the following equation (Gallopin 1980, 240):

$$dR/dt = B(R-T)(K-R); R > 0 \qquad (14.1)$$

The important properties of such rural production can be summarized as (see Figure 14.1):

- Whenever R (the rural environment's production, represented by the black line in the figure) is above the upper asymptote K, for example at E, it tends to decrease and move toward that asymptote.

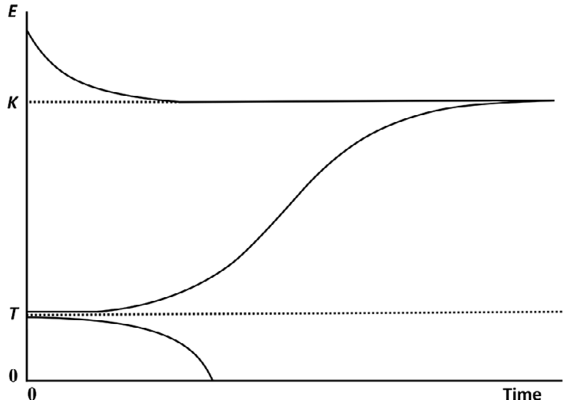

FIGURE 14.1 Generic time behavior of rural production according to the relationship *dR/dt* = *B(R − T) (K − R) ; R > 0 (1)*, in which *R* = rural environment production (represented by the black line in the figure); *T* = lower threshold; *K* = upper asymptote; *B* = a positive growth function. (Source: van der Leeuw & McGlade 1997, by permission from Routledge)

- Whenever *R* is below *K* (but above the extinction threshold *T*), it converges on *K* in a sigmoid or logistic way.
- Whenever *R* is below *T*, it decreases to zero [*R* stops at zero because equation (14.1) is restricted to positive values of *R*].

Given this pattern of rural production, how will urban impact on the rural economy play out? This can be seen as a combination of urban development (*U*) and its rate of growth (*dU/dt* or *U**). The impact of urban growth on the rural environment can then be written as:

$$dR/dt(=U^*) = B(R-T)(K-R) + mU + ndU/dt; R > 0 \qquad (14.2)$$

in which both *U* and *U** are exogenous to the rural sector, and the relationship between *U* and *U** is not taken into account at this stage. The coefficients *m* and *n* indicate the sign and the strength of the unitary effect of urban development and its rate of growth on the rural environment, and can be considered as being composed of two factors, one accounting for negative, constraining effects, while the other accounts for positive, enhancing effects. Their sum gives the net effect: thus, *m* = *(y − g)*, *n* = *(e − v)*. One can then distinguish a number of effects of urbanism upon the rural sector, thus:

- *m* and/or *n* = *0*: absence of a net effect of *U* and/or *U ** upon *R*.
- *m* and/or *n < 0:* the net effect of urbanism (and/or its growth) is harmful, or exerts a negative effect on the rural environment.

- m and/or $n > 0$: The net effect of urban development (and/or its growth) is beneficial to the rural sector.

This equation's equilibrium values are not constant, but depend on the values of $\phi = mU + nU^*$. For different constant values of ϕ, the equilibria can be displaced (see Figure 14.2), where $\phi+$ and $\phi-$ indicate positive and negative values of ϕ respectively.

Additionally, when $\phi^+ > \beta TK$, the zero equilibrium becomes unstable ($dR/dt > 0$, and thus R begins to grow). For both ϕ^+ and ϕ^-, the upper equilibrium is stable, and the lower is unstable, if the equilibrium value of $R(R^*)$ is greater than $(K + T)/2$. For $\phi^- = -[(K - T)/2]^2\beta$, both equilibria collapse into one, such that R tends to move toward R^*, if $R > R^*$, but it tends to move away from R^* when $R < R^*$. Thus, for all practical purposes, this point is unstable. To the left of $\beta[(K + T)/2]^2$ there is no equilibrium, and the rate of change of R is always negative (R tends to go to zero for all values of ϕ^- lower than this).

The behavior of this system, particularly when the effect of urbanization (ϕ) can be assumed to change relatively slowly with respect to change in the rural sector (R), can be regarded as an example of Thom's (1989) fold catastrophe (see Zeeman 1979). This catastrophe exhibits three basic properties: bimodality (because of the double stable equilibria), discontinuity (catastrophic jump) and hysteresis (the path differs according to the direction of change).

Our analysis has, so far, assumed that the only effect of urban development on the rural environment was a negative one on rural subsistence production. It is represented in the model by the fact that the upper equilibrium value of the rural sector is significantly higher in the absence of urban development. But the influence of the urban sector need not necessarily be deleterious because the two sectors are largely symbiotic, particularly within the later prehistoric context: the rural production also has an impact on the urban one.

To examine this, we might look at the potential effects of urban development on T, the lower unstable threshold of the rural system. As we have noted earlier, T is a value of R such that if $R > T$, R tends to go to the upper stable equilibrium, and if $R < T$, R tends to go to zero. If T is very high, that means that rural production must be maintained at a high level, so as to avoid collapse (the highest possible value for T is when $T = K$, in which case the system collapses). $T = 0$ implies that rural subsistence production will tend to regenerate, even if R is pushed around zero values. Finally, increasing negative values of T affects the initial speed of growth of R when $R = 0$.

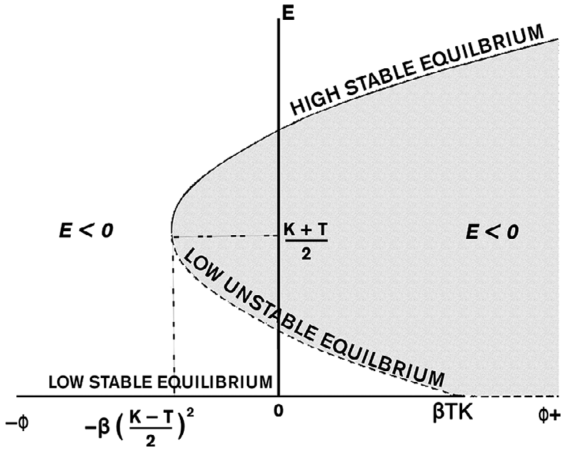

FIGURE 14.2 The rural environment equilibria represented as a function of $f = mU + nU^*$. For an explanation, see text. (Source: van der Leeuw & McGlade 1997, by permission from Routledge)

It is reasonable to infer for the model that different rural settlement systems might be characterized by different values of T. Those rural systems with an ability to recover rapidly from perturbation, such as relatively fast-growing settlements in the initial stages of colonization, should have a low value of T. By contrast, systems with a high T, such as systems whose persistence depends on management (agriculture), are probably characterized by a high degree of complexity and are relatively fragile and prone to collapse.

Another way in which urbanism can affect the persistence of the rural sector is by changing K, the upper stable equilibrium. When K is at its maximum, the rural production system is maintained at a peak of sustainability with a high rate of growth that is able to sustain major interaction with towns. Measures that are likely to modify K affect the maximum capacity of the rural environment, such as genetic improvement of crops (which increases K) or agricultural soil degradation through overuse, decreasing K.

Finally, urban development can alter the rural environmental system by affecting β, the parameter controlling rural production. Increasing β induces faster growth (or collapse) at all levels of urban development. The systems with higher ϕ can support greater levels of extraction or exploitation.

We have thus far treated urban development as a single parameter ϕ; however, remembering that $\phi = (y-g)U + (e-v)U^*$, the distinction between urban development, U, and its rate of growth, U^*, becomes important with respect to the viability of responses to rural over-exploitation or potential collapse.

In summary, this model shows that sudden shifts from either center-based or rural-dominated landscapes to mixed settlement structures are a function of t. In this approach, long-distance trade is a factor in engendering unstable morphogenetic transitions. Let us now look at those dynamics in more detail.

Modeling Rural–Urban Interaction in a Regional System

Our assumption here is that slow gradual improvements in connectivity (e.g., the transportation network) have a discontinuous effect (Mees 1975). To model that, we start out with open, small, rural settlements in a localized landscape. The population of that area is initially assumed to be constant and divided between rural (p_r) and agglomerated (p_a). U_r and U_a are considered the utility levels of respectively the rural and the agglomerated populations, and t is the long-distance transportation cost of traded goods, and a proxy for communication. The level of t determines the size of the flow of trade goods and communication: if it is above a certain threshold all trade and communication is absent, but below that level, the lower the cost the larger the volume of trade. The demographic dynamics are represented by a utility maximizing migration function, given by:

$$dp_r/dt = p_r p_a(U_r - U_a) = -dp_a/dt \qquad (14.3)$$

The behavior of the system is illustrated in Figure 14.3. In the absence of trade and communication (t is high), E_m is the only stable equilibrium, representing a certain mix of rural and agglomerated population (Figure 14.3a). As the cost of trade and communication decreases, the system's dynamic can assume two forms (Figure 14.3b and c), depending on the overall population density, the average productivity of the region, and the agglomerated-rural area productivity difference.

With high population density and high productivity difference in favor of agglomerations, E_a is the stable equilibrium and the population is completely devoted to the products created in the agglomerations for long-distance trade. If the productivity difference is in favor of rural productivity, E_r is the equilibrium and rural products will be traded. We must conclude that this model relates any potential sudden shifts from

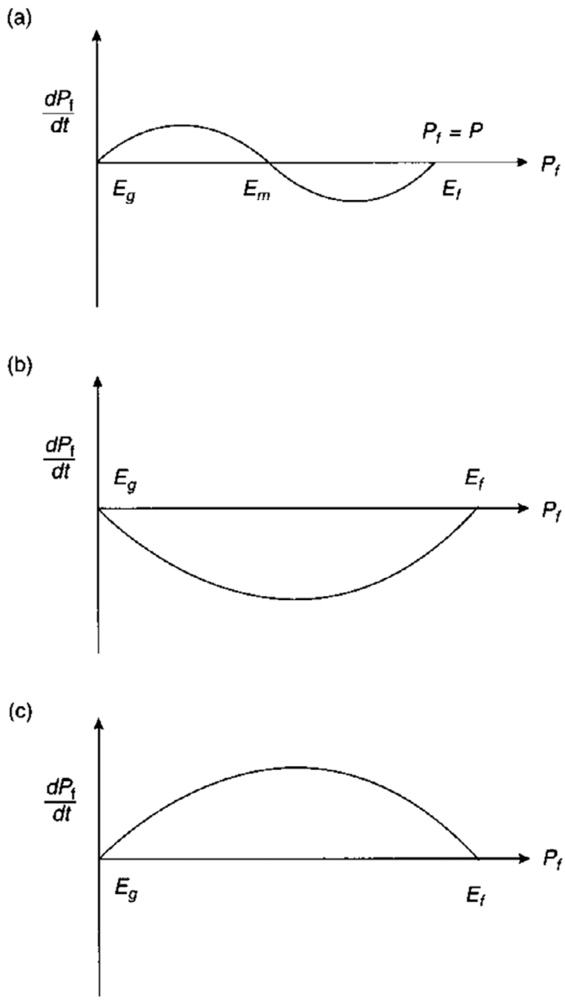

FIGURE 14.3 (a) Urban/rural equilibrium in the absence of long-distance trade; (b) center specializing in long-distance trade; (c) long-distance trade in a rural area. P_t is the urban population P_f the rural population; U_t is the urban and U_f the rural utility level; t is the long distance transportation cost. Above a certain threshold of t there is no trade (and very little, if any, information flow), but as t declines, trade and information flow increase. E is the equilibrium. (Source: van der Leeuw & McGlade 1997, by permission from Routledge)

either agglomeration dominated or rural-dominated landscapes to mixed settlements to the level of t.

With a high t, the only stable equilibrium is E_m, which is a mixture of urban–rural interaction. As t declines, interaction can take two forms as illustrated in Figure 14.3b and c, depending on: (1) the overall population density, (2) the average productivity, and (3) the productivity difference between urban and rural areas. In the case of Figure 14.3b, high population density and a high productivity differential has only E_g as a stable equilibrium. But when rural production for long-distance trade dominates, E_f is the stable equilibrium.

Concluding this qualitative analysis, we could state with some assurance that discontinuous and sudden shifts from either an urban-dominated or a rural-dominated regime to a mixed one are a function of the volume of trade, as it reflects the changes in the logistical networks enabling the connectivity.

If we now go a step further and look at how fluctuations in the rise of agglomerated central settlements are related to the interaction between faster and slower dynamics, we can do so by assuming (with Andersson 1986) a third order system of differential equations consisting of a fast one:

$$dY/dt = -T(Y^3/3 - rY - X) \tag{14.4}$$

and a slow one:

$$dX/dt = -T^{-1}Y \tag{14.5}$$

Here, r is a control parameter, and T an adjustment speed coefficient. Y is a center's production capacity, and X its access to a transportation and communication network. The model permits us to study discontinuous changes in centers' production as a function of access to the transportation/communication network. Figure 14.4 illustrates the relation between these two, where discontinuous changes in the value of urban productivity (Y) can be produced as a value of X (access to transportation and information). As the system's knowledge base (X) grows through access to information, it follows a trajectory in the L-zone of the system.

Assuming that abrupt changes in the dominance of individual centers are to be expected because of their unstable sociopolitical structures, these can be related to gradual changes in local resource accessibility. While the slow variable (productivity) is dominant, the fast variable can nevertheless flip the situation into another regime.

We might reasonably hypothesize that a form of network expansion through communication, trade, alliance, and even domination generated a slowly expanding system controlled from key locations occupied by the centers. In what follows, we see that network as a proxy for the information processing system. From Figure 14.4, we can see that as this

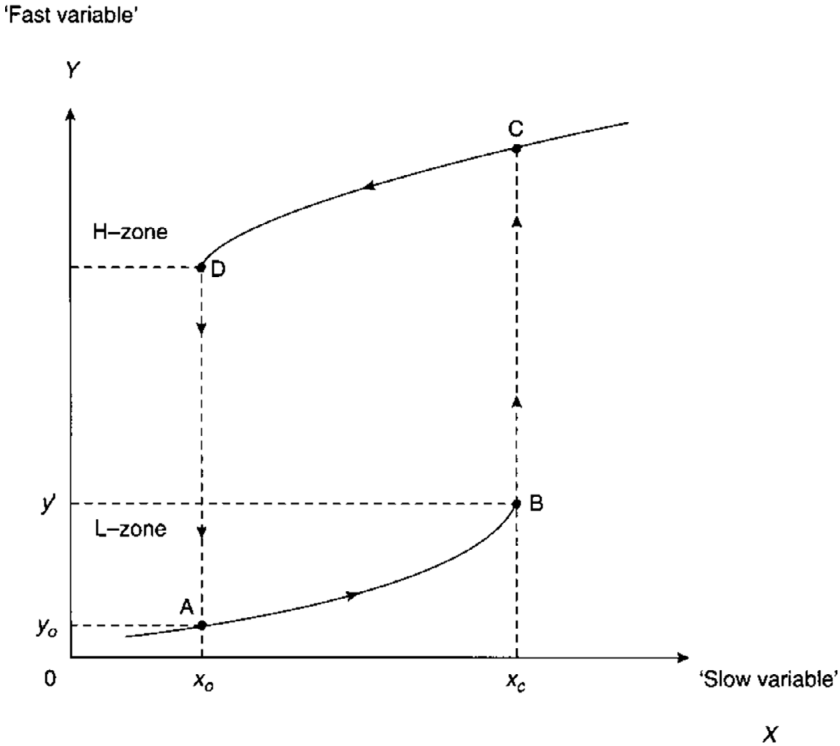

FIGURE 14.4 A generic cycle of fast and slow variables. *A* is the system's initial state; *X* is a slow variable symbolizing interactivity and knowledge; *Y* is a fast variable representing system evolution. In the *L*-zone, structures are stable; *B* is a threshold of change in urban productive activity (bifurcation point). In the *H*-zone, unstable structures emerge; at *D* the system returns to the initial state *A*. (Source: van der Leeuw & McGlade 1997, by permission from the publisher, Routledge)

network infrastructure and, consequently, the system's knowledge base (*X*) gradually grows, it follows the trajectory located in the *L* zone of the figure. The initial conditions of the system are given by *A*. As *X* changes, ultimately a point *B* is reached – a threshold beyond which the productive capacity of the urban system changes markedly. At this bifurcation point, the equilibrium loses its stability and a phase transition takes place. In this far from equilibrium phase (*H*-zone), the speed of change is determined by constraints on environment (natural resources), production techniques, and population (labor force). A prominent feature of this type of nonlinear analysis is its cyclical nature. If, for example, the transportation/communication network linking the centers is disrupted by other external competitive alliances or by warfare when the system is in the *H*-zone, unstable alliance structures are produced, and the system may follow the trajectory depicted on the *H*-zone until it converges on the initial state at *D*, and finally returns to the *L*-zone.

The role assumed by the critical points *B* and *D* needs to be further elaborated, so as to make the model dynamics easier to grasp. The essential underlying process is one of divergence, since a smooth but minor change in the transportation/communication network infrastructure can cause abrupt and unexpectedly large fluctuations in the equilibrium value of the production in certain locations. This (relatively sudden) phase transition takes place no matter how slowly the overall network capacity increases. By implication, the expansion of centers may simply be triggered by the addition of one small but important link in the network. Slight differences in transportation/communication conditions, for example as a result of changes in alliance structures, may eventuate major differences in the production capacity, if the centers' growth parameter finds itself at a critical point.

Modeling Instabilities in Inter-Regional Trade

This implies for example that the inherent instability in the communication and trading patterns of proto-urban centers in the phase in which they find themselves in the H-zone is largely a consequence of the interaction between slow and rapid dynamics. It has a major impact on the emergence of centers in a rural environment, as well as on the interaction between those centers and their rural environment once they have emerged. To conclude, I will briefly describe this, too, in modeling terms.

This model (based on McGlade 1990, 158) is not concerned with the fate of individual centers, but rather with a global regional dynamic. It assumes that there is initially limited interaction between centers in two regional systems involved in the limited export and import of specific high value goods, and denoted by X and Y. The dynamic system involved can be written in the following way:

$$dX/dt = F(X) - H(X) - X; \tag{14.6}$$

$$dY/dt = F(Y) + H(X) \tag{14.7}$$

where:

$$F(X) = rX(1 - X/N) + X^2 Y \tag{14.8}$$

$$F(Y) = -X^2 Y \tag{14.9}$$

$$H(X) = Q(K, L) - mK - C = \mathrm{Q_o K^m L^n} \quad (14.10)$$

thus we have:

$$dX/dt = rX(1 - X/N) + X^2Y - X[Q_o K^m L^n - mK - C] - X \quad (14.11)$$

$$dY/dt = -X^2Y + X[Q_o K^m L^n - mK - C] \quad (14.12)$$

where r is the intrinsic rate of growth in commodity production; N is a production saturation level; Q is a measure of economic output; with Q_o as the initial value of Q; K is commodity stock; L is labor; m is the rate of commodity stock depreciation; C is consumption.

The production function *H(X)* is modeled as a nonlinear Cobb-Douglas function, with m as an exponential capital growth rate and n as an exponential accounting for the growth rate of labor. *H(X)* functions as an autocatalytic element in the system, effectively establishing the reaction-diffusion structure of the model.

Initially, region Y is seen as a major importer of prestige goods, with relatively little control of the trade routes. The $(+X^2Y)$ term is essentially the status income accrued and exhibits strong self-reinforcing properties owing to the growing monopoly of the region in controlling trading transactions. The $(-X^2Y)$ term represents constraints acting to prevent a total monopoly; it accounts for the loss of revenue as a result of the ability of the Y region to take part in alternative exchange systems. Additionally, the model assumes that the wealth of the X region – owing to its pre-eminence in trade – will grow as a logistic function over time, so long as the status quo is maintained, but will be reduced by any competing flow from region Y.

The steady state of this system, i.e. the state for which $dX/dt = dY/dt = 0$, corresponds to critical states X_o and $Y_o = F(X)/H(X) = (Q_o K^m L^n - mK - C)/rX\ (1 - X/N)$.

The critical transition point at which the system becomes unstable is given by:

$$H(X) > (1 + F(X)^2) = (Q_o K^m L^n - mK - C) > (1 + rX(i - X/N)^2 \quad (14.13)$$

For example, when $F(X) = 1$, the critical point is unstable for $H(X) > 2$; as *H(X)* is increased, a Hopf bifurcation occurs, with the result that the system is attracted toward a limit cycle trajectory. Figures 13.5a–d show this behavior for increasing values of *H(X)*, since it is this function which controls the action/reaction nature of the trading system.

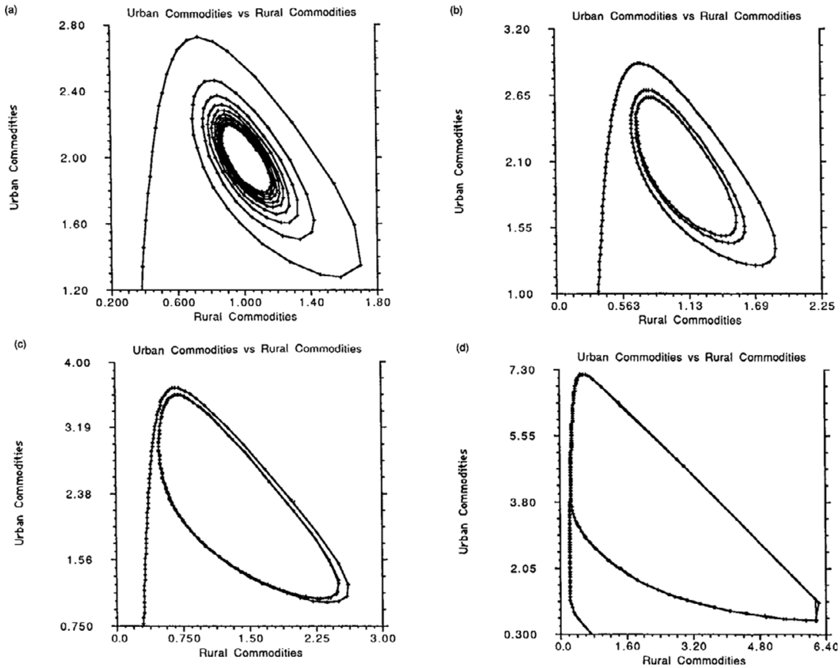

FIGURE 14.5 Simulation results of the center–rural environment interaction model (see text). (Source: van der Leeuw & McGlade 1997, by permission from the publisher, Routledge)

Instability is generated by purely endogenous factors, i.e., owing to the non-linearities in the system and their amplification by positive feedback mechanisms embedded in trade/exchange dynamics.

Trading systems are also subject to external fluctuations, for example owing to periodic increases in the volume of trade/exchange at particular times of the year. This we shall simulate by introducing a sinusoidal forcing term of amplitude *a* and frequency *f*. (see Tomita & Kai 1978). Thus, equation (13) becomes:

$$dX/dt = rX(1-X/N) + X^2Y - X[Q_oK^mL^n - mK - C] - X + a\ \cos(ft) \quad (14.14)$$

Figures 14.6a–d show the results of such a perturbation, pushing the system progressively toward unstable orbits through a sequence of period-doubling bifurcations on the route to chaos.

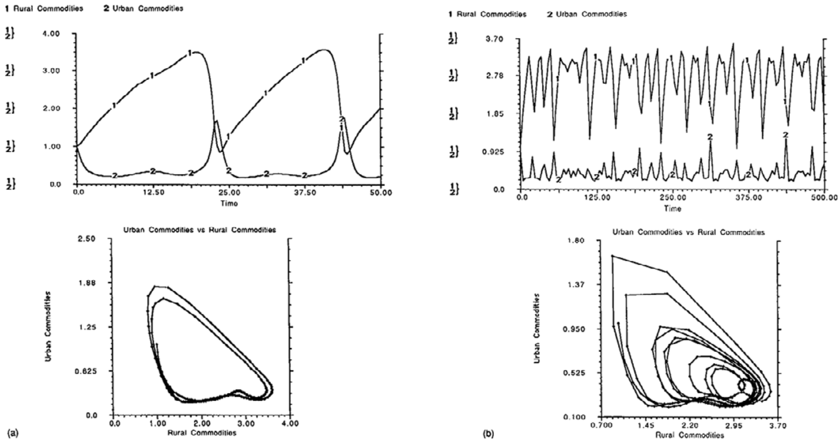

FIGURE 14.6 Another set of simulation results, showing how the system is slowly driven to chaotic behavior. (Source: van der Leeuw & McGlade 1997. Reproduced by permission from the publisher, Routledge)

Conclusion

These models are presented mainly to make the important point that many potential evolutionary pathways were open to such a system, given our stress on the twin concepts of nonlinearity and metastability, and their role in generating discontinuous evolution – particularly in logistical networks.

Modeling approaches such as these, based on open dissipative ideas can now be integrated into a new program of spatiotemporal dynamics that will demonstrate structural morphogenesis within urban and proto-urban settlement systems. More generally, what I have tried to demonstrate in this chapter is that archaeological approaches to questions of urban evolution have much to gain from an alignment with dynamical systems concepts – an alignment that is much more than metaphorical. Indeed, it is clear that the open, dissipative nature of urban/rural dynamics and their propensity to evolve through discontinuous transitions cannot be adequately understood by recourse to normative models; they require the combination of creative insight and experimental qualitative methods, which is the unique contribution of nonlinear dynamics. An interesting attempt to build further in this direction by modeling a number of the major transitions in societal systems is the recent volume edited by Sanders (2017), that looks at dynamic transitions from the Paleolithic to recent times in this manner.

Finally, I would like to stress again that none of these models pretends to represent reality, but they serve to help focus our minds on some of the issues concerned. Even if such a representation were theoretically possible (I do not think so), it is much too early to adopt one. For the moment, we are in that delightful phase of playing with hypotheses, and I have tried to show that there are wholly different games out there, which bring us some glimpses of insight that add to our understanding.

NOTES

1 This leads me to conclude that the size of the value space of a society must in some way or other be commensurate with the size of the overall group that is being aligned. This hypothesis has important implications for the present, and the difficulties encountered in and around globalization. I explore this in Chapter 17.

2 Not being a modeler myself, I owe a great debt of gratitude to James McGlade for his contributions to the original paper and this excerpt from it, reproduced by permission of Routledge.

PART III

15

The Rise of the West as a Globally Powered Flow Structure

Introduction

In the first part of this book (Chapters 3–7) I outlined a personal perspective and approach to the dynamics of human long-term coevolution with the environment, grounded in the evolution of human cognition. In Chapter 8 I have presented a narrative indicating the perspective on the history of human–environmental coevolution that this approach leads to, and in Chapter 9 I presented an outline conception of the interaction between society and its environment in terms of dissipative flow structures. Chapter 10 presented a more detailed case study of the dynamics of long-term evolution in a socioenvironmental system. In Chapter 11 I added a theoretical underpinning to that perspective and Chapters 12 and 13 presented my approach to the process of invention that is at the core of social and technological change. In Chapter 14, I showed how modeling dynamical systems can help us understand the emergence of urbanization.

These chapters have tried to pave the way for a focus on another central theme of the book: the present and its relationship to the future. In this part of the book, I will move our focus from the distant past toward the more recent past, the present, and the future. Chapters 16–18 argue that the information and communications technology revolution is an underestimated accelerator of the sustainability conundrum in which we find ourselves. Chapters 19–21 are dedicated to a discussion of potential futures.

The Rise of Western Europe 600–1900

To prepare the way, I will first present the last 1,500 years or so of western European history from the dissipative flow structure perspective. During that millennium and a half, we see a gradual strengthening of the urban (aggregated) mode of life, but this millennial tendency has its ups and downs and manifests itself in different ways. A second long-term dynamic is that of European expansion and retraction. Both reflect different ways in which the European socioeconomic system strengthened itself vis-à-vis the external dynamics that it confronted. To quantify these attributes, we will emphasize changes in the following proxies, where available:

- The demography of the area concerned: relative population increases and decreases;
- The spatial extent of European territorial units, as a measure of the area that a system can coherently organize;
- The spatial extent and nature of trade flows as a measure of the information-processing potential between the center and the periphery, and thus of the area from which raw resources are brought to the system – its material footprint;
- The density and extent of transport (road, rail, water) and communication (telephone, etc.) systems as a proxy for the density of information flows;
- The degree and gradient of wealth accumulation in the system, as an indicator of innovation and the value gradients between the center and its periphery;
- The innovativeness of particular towns, regions, and periods.

Many of these proxies cannot comparably be measured for each and every historical period and region. Moreover, they operate at different rates of change. But proxies are for the moment all we have if we want to cover the whole period. For subsets of it, interesting datasets are found in Piketty (2013) but also in Le Roy-Ladurie (1966 [1974], 1967 [1988]), Slicher van Bath (1963), and many others involved in agrarian history, particularly represented in the French journal *Annales: Économies, Sociétés, Civilisations*.

The Dark Ages

After the end of the Roman Empire we observe across Europe a weakening of society's structure and coherence (e.g., Lopez 1967). Between 600 and 1000 CE, the fabric of society reached a high level of entropy (both in the sense of growing disorder and in the sense of reduced dissipation of the flow structure governing the dynamic) in western Europe, where the traditions of Greco-Roman urban culture were only conserved to a minimal extent. In South-Eastern Europe, under the Byzantine emperors, appropriate decentralization ensured that more of the culture developed for another millennium.

We will in this chapter mainly focus on western Europe. In this period, there was an enormous loss of knowledge, in crafts and trades for example, as well as an abandonment of infrastructure. The flow structures exchanging organization for energy and matter were limited to the immediate environment. Trade and long-distance contact virtually disappeared, towns saw their population dwindle (the city of Arles was for some time reduced to the perimeter of its Roman arena), and most villages were abandoned. Society fell back on local survival strategies and much of Roman culture was lost. Only the Church maintained some of the information-processing skills it had inherited, especially writing and bookkeeping, and a semblance of long-distance interaction.

The First Stirrings: 1000–1200

This was a period of oscillation between different small systems, in which cohesion alternated with entropy even at the lowest levels. In Northern Europe, trade connections forged in the (Viking) period before 1000 CE led to the transformation of certain towns into commercial centers, later loosely federated into the Hanseatic League. But these towns remained essentially isolated islands in the rural countryside, linked by coastal maritime traffic.

Duby's classic study (1953) shows how, from about 1000 CE, society in Southern France began to rebuild itself from the bottom up. Although the urban backbone of the Roman Empire survived the darkest period, a completely new rural spatial structure emerged, even relatively close to the Mediterranean. There, in a couple of centuries of local competition over access to resources, various minor lords climbed the social ladder by conquering neighboring resources and positions of potential power, leading to the emergence of a new (feudal) social hierarchical structure.

The local leaders with the best (information-processing and military) skills were able to attract followers by providing protection for peasants who bought into the feudal system. The peasants in turn provided surplus matter and energy to support a small army and court. In the process, more wealth accrued to the favored, and we see the resurgence of a (very small and localized) upper class with a courtly culture in the so-called "Renaissance of the twelfth century that included tournaments, troubadours, and other (mostly religious)" artistic expressions in Southern France and adjacent areas. A similar process occurred in the Rhineland, where a separate cultural sphere (Lotharingia, named after Charlemagne's son Lotharius who inherited this part of his father's empire) developed on both banks of the river. Further east, in Germany, this period saw the decay of whatever central authority the Holy Roman Empire had and the rural colonization of Eastern Europe. At this time parts of Europe began to look outward: it was the time of the crusades against Islam (1095–1272) that culminated in 1204 in the (short-lived) conquest of Constantinople, which brought large amounts of information to western Europe in a – for the times – very efficient manner.

The Renaissance: 1200–1400

Three major phenomena characterized the next period: (1) the establishment of a durable link between the southern and the northern cultural and economic spheres, (2) the major demographic setback of the Black Death in the fourteenth century, and (3) the beginnings of the Italian Renaissance. The link between south and north was established in the eleventh and twelfth centuries, overland from Italy to the Low Countries via Champagne, and then connecting with the maritime British and Hanseatic trade systems. In the thirteenth century this connection became the main axis of a continent-wide trading and wealth creation network, enabling urban and rural population growth (Spufford 2002) and eventually driving rural exploitation in many areas to the limits of its carrying capacity, as well as pushing farming out toward more distant and less fertile or less convenient areas.

The impact of the bubonic plague was very uneven. Where it hit badly, it profoundly affected both cities and the surrounding countryside, bringing people from the periphery into the traditionally more populous urban areas (where the plague had hit hardest), thus increasing both the degree of aggregation of the population and its average per capita wealth (see Abel 1966). Other profound changes occurred in the cultural domain, including a reevaluation of the role of religion, life and death, society and the individual, together shaking society out of its traditional ideas and patterns of behavior. (Some of these are mentioned in Chapter 3.)

These phenomena contributed to a localized era of opportunity in Northern Italian cities, where the interaction of cultural, institutional, technical, and economic inventions led to a uniquely rapid increase in the information-processing gradient between the urban centers and the rest of the continent. In this Renaissance, architecture and the arts flourished, while the foundations were laid for modern trade and banking systems. Padgett (1997), for example, describes brilliantly how financial and social innovations went hand in hand to transform the Florentine banking system, drawing in more and more resources and investing them in an ever–widening range of commercial and industrial undertakings that, in turn, transformed practices in these domains. Long-distance trade reemerged as a major force in development, for example between Venice and the Levant; the travels of William of Rubruck, John of Montecorvino, and Giovanni ed' Magnolia are examples of these contacts, from the mid-thirteenth and early fourteenth centuries.

Many of the ideas developed in northern Italy were relatively quickly adopted in the trading centers in the Low Counties, such as Ghent and Bruges, which became rich and powerful based on the wool and cloth trade with England.

The emergence of a bourgeoisie in these places set the scene for systemic change: from this time onward, reaching the top of the heap was limited to geographic areas where urbanization led to concentrations of more – and more diverse – resources, as well as more effective information processing because towns were linked in Europe-wide information flows.

The Birth of the Modern World System: 1400–1600

This period marks the central phase in the continent-wide transition from a rural, often autarchic, barter economy to a monetized economy driven by towns, in which craft specialization and trade set the trend (Wallerstein 1974–1989). The transition introduced fundamentally different system dynamics. The dominant cities are increasingly market- and trade-based heterarchical structures, as opposed to the egalitarian and hierarchical ones in the rural landscape. Simon (1969) defines such structures as those emerging, in the absence of hierarchy and overall control, from the interaction of individual and generally independent elements, each involved in the pursuit of separate goals, and with equal access to (incomplete) information; competition for resources characterizes such organizations. As we saw in Chapter 11, contrary to hierarchical systems, heterarchical ones do not strive to optimize behavior; they can link much larger numbers of people, especially if they are organized as networks with nodes, and they are more flexible.

In this first phase of urban dominance, the world of commerce and banking expanded across different political entities, cultures and continents. Much of both southern and northern Europe, including Britain, Scandinavia, and the Baltic, were now integrated into the European world system. Rural areas saw their interaction with towns increase. Cities began to look attractive to farmers in an overpopulated countryside continually disturbed by armies acting out others' political conflicts, and this led to a wave of rural emigration to towns, relieving the population pressure in the countryside and keeping the urban labor force cheap. That in turn enabled industrial expansion.

This period is the heyday of city power. Urban centers were not controlled by political overlords; rather, they controlled these overlords' purse strings, as in England (London) and the Netherlands (Amsterdam). Urban elites put to work the enormous gains in information-processing capacity made during the Renaissance. Through relatively unregulated commerce and industry, commercial houses (e.g., the Fuggers) amassed enormous wealth, used it to bankroll the political conflicts and wars that disrupted the continent, and thus extended their economic and political control over much of the continent. To this effect, they created extensive information-gathering networks linking every important commercial, financial, and political center.[1]

This is also the period of the first voyages to other continents. By investing in these distant parts, European traders added new areas along the information-processing gradient, in which the commonest European product (such as glass beads) had immense value in faraway territories, while the products from those regions (such as spices) had a high value in the traders' homelands. The huge and immediate profits made up for the risks, and this long-distance trade initiated for the trading houses centuries of control over an increasingly important resource-rich part of the world. As a result, this period has the steepest information gradient from the center of the European World System to its periphery, and the steepest value gradient in the reverse direction. But toward the end of the period that gradient began to level off in the European core, as cities in the hinterland, and eventually territorial overlords, began to seriously play the same game.

The Territorial States and the Trading Empires: 1600–1800

The rulers of Europe had inherited legitimacy, or something approaching it, from the Roman Empire, but that did not pay the bills. Their need to keep up a certain status was a financial handicap until they could leverage their legitimacy against financial support by exchanging loans for taxes as their principal source of income. A degree of territorial integration and unity was achieved in many areas by 1600,[2] transforming the heterarchical urban systems into hybrid heterarchical-hierarchical ones including both towns and their hinterlands.

The regions that first achieved this (Holland, England, and Spain) had the most extensive long-distance trade networks providing the steady income necessary to maintain rulers' armies and bureaucracies. As a result, the city-based economic system was transformed into one that involved the whole of the emerging states' territory. Inevitably, the value gradient leveled out as the Europeans in the colonies assimilated indigenous knowledge and shared their own knowledge with the local populations, but this was for some time counterbalanced by the discovery of new territories, the introduction of new products in Europe, the improvement of trade and transport, and the extension of the reach of the trading empires. But ultimately the leveling of the information gradient led toward independence, as in the case of the USA, or, as in the East Indies or Africa, to the transformation of the trading networks into colonies under military control. These saw the local production of a wide range of necessities for the colony as well as western-controlled production systems for products needed in Europe, and a degree of immigration from Europe. As a result, the European core and the colonies became economically more dependent upon one another.

The same leveling off occurred in Europe as more people began to share in the production of wealth and its benefits. The profits from long-distance trade enabled an increase in the industrial base of the main European nations, achieved by involving more and more (poor) people in production and transformation of goods. The tentacles of commerce and industry spread into the rural hinterlands, aided by the improvement of the road systems. As a result of both these systemic changes, the flow structure that had driven European expansion became vulnerable to oscillations between rich and poor, separated by a growing wealth gap.

An important milestone in this process, which I consider in Chapter 18, is the Treaty of Westphalia (1648), which established the structure of European international relations for several centuries, until very recently. It was based on the principle that rulers of nations would not interfere in other rulers' territories, and was thus a way to help stability in "interesting times."

Using the term that I introduced in Chapter 7, one could say that with this event the European nations solidified themselves as Bénard cells, independent, coterminous units that were each driven by dissipative flows of energy and information.

The Industrial Revolution and its Aftermath: 1750–2000

But as the overall structure of the European system began to fray at the edges, the massive introduction of fossil energy as a resource and the concomitant Industrial Revolution reestablished the information gradient across the European empires and the value gradient between the colonies and the heartland. The resulting shift was profound (Figure 15.1). It gave European dominance a new lease of life, but at the expense of major changes. From a zone in which internal consumption of high-value goods imported from elsewhere generated most of the wealth, Europe became the mass-producer of a wide range of goods for export to the rest of the world.

To maintain this system, it had to create wealth in the periphery that would allow the local populations to acquire European goods. It did so by creating in the colonies large-scale production systems for raw materials that were transformed in Europe into products sold to the same colonies.

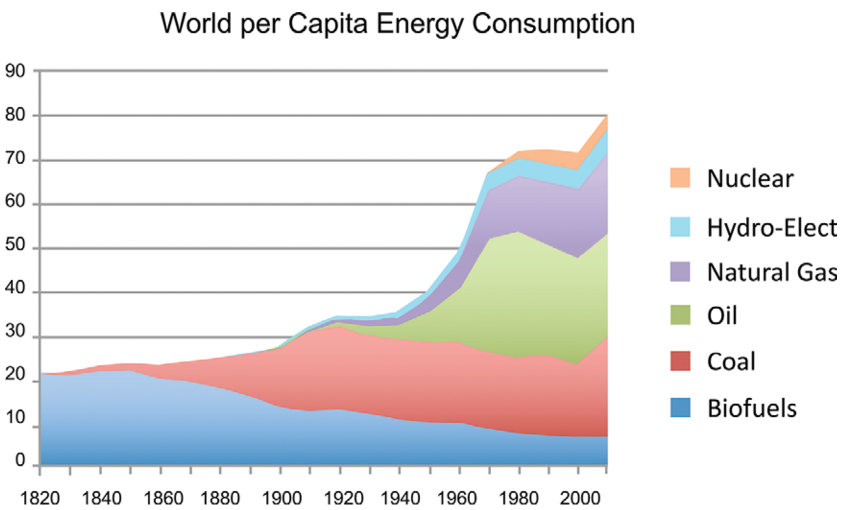

FIGURE 15.1 With the discovery and use of fossil energy and the Industrial Revolution that followed, our global energy consumption exploded. At present, whereas humans need about 100 Wh for their biological functioning, US per capita energy use is around 11,000 Wh. At present, per capita, an average North American uses 1.5 times the energy of an average Frenchman, 2.2 times the per capita energy of Japan or Britain, 2.6 times the energy of a German, 5 times the energy of a South African, 10 times the energy of a Chinese person. (Source: Tverberg, *Our Finite World*, licensed under CC BY-SA 3.0. Published by TWI under CC-BY-NC 4.0.)

Thus, the status of these colonies changed – from producers of goods that had relatively little value locally but high value in Europe, to areas mass-producing low value goods for export to Europe and serving as markets for low-value European products. Maintaining this system required improved political control over the colonies concerned, as it brought large numbers of local people into the system as low-paid labor.

In Europe, the invention of new technologies in both the core and the periphery created much wealth, but ultimately undermined the flow structure by disenfranchising large groups of people. Industrialization tied a large working class into (mechanized) production in low-paid, often dangerous, jobs that gave little satisfaction.[3] Social movements were quick to emerge in the core (from 1848), and up to World War II. Countries that had not been part of the early flow structure aspired to create similar dynamics. The French thus occupied areas of Africa and Southeast Asia. Italy, Germany, Japan, and Belgium – born as nations in the late nineteenth century – had to satisfy themselves with the leftovers of the colonial banquet. This contributed to the causes of the two world wars: these countries sought expansion in Europe (and in Japan's case in Asia) because it was denied them elsewhere.

Finally, between 1940 and 2019, the control over large parts of the world that Europe had thus far enjoyed spread to North America, Australia, Japan, South Africa, and more recently to Southeast Asia, China, and India. Europe and the United States are no longer in sole control of the information gradient responsible for the continued wealth creation, innovation, and aggregation of the World System, but have to compete with these other regions. The world has become multipolar.

Summary

I argue here that the European system has undergone three major transformations to date, dividing its history into four phases. In the first phase, after a predominantly flat, entropic, period (*c.* 800–1000 CE), in which whatever flow structures there were occurred essentially at the scale of individuals', families', or villages' subsistence strategies, we see (roughly between 1000 and 1300) structures that involve information processing by larger (though still small) local units; most of these small rural principalities emerging in Southern Europe, but in northern Europe a few urban ones (the Hanseatic towns) emerged as well. Later in the period, several such rural flow structures were often subsumed under a larger one, leading to feudal hierarchies. But the hierarchical structure of the information networks structurally limited their opportunities of expansion (see van der Leeuw & McGlade 1997).

The second phase (*c*. 1200–1400), was dominated by the death and later a new aggregation of the population in both old and new towns as a result of the Black Death, which caused innovation to take off. It drove a rapid expansion of the urban interactive sphere through long-distance trade and communication. The resulting urban networks that emerged from *c*. 1400 were independent of the rural lords and probably had a novel, heterarchical information processing structure (see van der Leeuw & McGlade 1997), facilitating the growth of interactive groups and the systems' adaptability. In the next two centuries, these cities drove the establishment of colonial trading networks.

But in the sixteenth century that dynamic led to a second tipping point inaugurating a third phase: the beginnings of the European World System, initiated by the discoveries of other continents by European seafarers. New resources were identified in faraway places and fed the accumulation of wealth that was going on. Between *c*. 1600 and *c*. 1800, urban and rural systems were forced to merge by rural rulers who needed to acquire in the towns the funds to increase control over their territories. This led to the formation of (systemically hybrid) states and the transformation of the urban trading networks into colonial exploitation systems. Toward the end of this period (*c*. 1800), these flow structures seemed to reach their limits: innovation stalled in the cities, and the energy and matter flows from the colonies were limited by the structure of their exploitation systems. Europe had reached a third tipping point.

At that point (*c*. 1800) a new technology inaugurated a fourth phase – the use of fossil fuel to drive steam engines, lifting the energy constraint that had limited the potential of all western societies thus far. The innumerable innovations that followed enabled transformation of the European production system at all levels, rapidly increasing the information-processing and value gradients across the European empires again. Girard (1990) outlines how in that process, the term "innovation" changed its value, from something to be ignored or even despised, to the ultimate goal of our societies. As part of this process, our societies became so dependent on innovation that one may currently speak of an addiction that resembles a Ponzi scheme in that innovation has to happen faster and faster to keep the flow structure intact.

I insist on emphasizing two lessons learned from this history. First, wealth discrepancy may well be a societal counterpart to the environmental planetary boundaries that were highlighted in the paper by Rockström et al. (2009), as it seems that wealth discrepancies were at their widest just before the three major transitions in European history: the Black Death, the discovery of the rest of the world, and the Industrial Revolution.

Secondly, in hindsight the progression from the agricultural societies of the Middle Ages to the trading empires of the early modern world, and ultimately to the industrial and post-industrial economies of the last century or so may seem inevitable, but like any story, or history, it is in effect a post-facto narrative that reduces the dimensionality and complexity of what really happened.

From the ex-ante perspective that we are introducing here, at each of the three transition moments mentioned European societies could potentially have engaged in different trajectories, and this continues to be true for the present. Rome could for example theoretically have followed a different trajectory in the second century CE. History is not inevitable. There are times when processes dominated by strong drivers make change very unlikely, and there are moments when unexpected events or people can indeed change the course of history. It is the thrust of this book that we seem currently to be living a moment in history that opens a window of opportunity for the world to change. Hence there are choices to be made. Making those choices requires that as individuals and as a society we retake responsibility for our collective future, instead of leaving that responsibility to a small group of people who are currently, knowingly or not, misusing it.

Another important thing to conclude from all this is that globalization is not new at all, but has been going on since the sixteenth century. We need to take this fact into account when we think and act in the present. In effect, all that has happened is that we have entered a new stage of globalization; a stage that has interesting parallels with the sixteenth- to eighteenth- century colonization of large parts of the world – in that trade was enabled to expand as the political structure of Europe was very fragmented, allowing nascent trade organizations such as the Dutch and English West and East Indies companies to drive the spread of European ideas worldwide. In some ways, states latched onto these trade organizations to bring wealth into their coffers, for example by issuing permits to pirate vessels of enemy nations.

The Changing Roles of Government and Business

I would like to use this section to look more closely (but still in general terms) at the current phase of globalization from a historical perspective, with an emphasis on the respective roles of government and business. As we have seen, beginning in around 1800, the introduction of ways to massively use fossil energy, and the Industrial Revolution it enabled, changed both the economy of European countries and of their colonies. In a nutshell, as the European countries developed industrial mechanization, they also changed their interaction with their colonies, developing governance, plantations, and markets for European products.

Thus, until around 1800 there was an enterprise-driven low-volume but high value flow from the colonies to Europe, with very little in the way of organizational and information processing capacity flowing toward the colonies. After that date, the flow structure involved national administrations, which triggered a much more important flow of organization and information-processing toward the colonies, transforming the latter into western-administered and -run territories owing to an influx of western-educated men and women.

This system essentially continued and expanded during all of the nineteenth and the first half of the twentieth century, facilitated by the discovery of oil, the spread of electricity, and the invention of new modes of transportation (railroads, steam- and later oil-powered shipping, aviation, etc.) and communication (mail, telegraph, telephone, telex), facilitating larger and larger, faster and faster flows of information between the European countries and their colonies, and thus slowly integrating those colonies into the overall information-processing apparatus of their home countries. It is important to be aware that during the nineteenth century and up to World War II, in the colonies business and government worked together and kept each other in balance.

Decolonization began in the late nineteenth century and the first half of the twentieth century in Latin America, and followed in the forty years after World War II in very large parts of Southeast Asia and Africa. It severed the political link between European countries and their colonies, and cut the ex-colonies off from the information flow that had until then "organized" them. But it did not stop the trade flows between the European countries and their ex-colonies. It merely separated (once more) the governmental and the commercial domains, allowing business a freer hand in the new overseas nations after their independence, while governance was still in its infancy.

At the same time, the USA had achieved military and political dominance over much of the world, and because of its liberal philosophy facilitated, if not encouraged, the concentration of economic power in private hands. The so-called Pax Americana of the second half of the twentieth century enabled corporations – which equaled the economies of many countries in size – to dominate industrial production, trade, and communication, slowly leading to a situation in which they became as powerful, or more so, than most countries. In the process, some countries managed to organize themselves to achieve a rapid rise in wealth and economic power (Germany, Japan, Korea, later China and other countries in the BRICS grouping – Brazil, Russia, India, South Africa), often initiated by government-sponsored, large industrial and business clusters that captured markets owing to the initially much lower salaries than those paid in Europe and the USA. The world thus evolved into a multipolar communication and information flow structure.

For the moment, the main lesson to take away from this brief and superficial history is that we have not only seen balance of power shifts between countries, but also a recurring shift in the balance of power between governments and business, since the Reagan and Thatcher era (the early 1980s) to the advantage of business and finance. That development has also hugely increased the value and wealth differentials between the core and the periphery of the system (the haves and the have-nots), as recently brought to everyone's attention by Piketty (2013), and thereby reduced the chances that outsiders could become insiders, creating an extraction-to-waste economy (in terms of raw materials, but also human capital) that is close to reaching (or has reached) its limits in the sense that our planet can no longer deal with it.

Because of the territorial limitations of governance, this system's spread around the globe has enabled, but has also been driven by, the growth of large multinational corporations. The impact of these corporations outside the core of the western world has, slowly but surely, over the last century or so, incorporated regions that were culturally and socially fundamentally different into that extraction-to-waste economy and made that economy truly global – driving individuals, groups, and countries to gradually adopt mindsets, activities, and institutions that are compatible with its underpinning an urban and wealth-driven logic. In the last thirty years, this process has accelerated, and is now reaching the conurbations of China, Indonesia, India, and other countries.

Crises of the Twentieth Century

As part of this process, a number of fields of tension were generated that ultimately caused major crises. The first such to hit western society in the twentieth century was World War I. As we all know by now, it was triggered by a seemingly minor event, the assassination of Archduke Ferdinand, which occurred after a spate of similar assassinations of princes and high nobility. It sparked a release of the tensions that had built up between four major societal configurations in Europe, the Austro-Hungarian, French, German, and British Empires, and inside these empires between rich and poor. The huge destruction it wrought in human and material capital reduced these tensions for a while. The next crisis, however, began not long thereafter in the financial domain, in 1929, being caused by the control of the financial markets by very few people, particularly in the USA. It triggered a major destruction of wealth, increased social tensions in the countries involved, and also coincided, in the USA, with major environmental destruction (the so-called dust bowl). The financial capital lost was not really reconstituted until the run-up to World War II, which was driven (in a revanchist way) by some of the same social tensions that had caused World War I, particularly in Germany.

After the war, a major restructuring of the western world was set in motion, entailing a new financial structure (Bretton Woods, the International Monetary Fund, the World Bank), a new attempt at a global political structure (the United Nations), a new military structure (the North Atlantic Treaty Organization and the Warsaw Pact, the Alliance of South-East Asian Nations, etc.), the opening up of trade flows worldwide (leading to the General Agreement on Tariffs and Trade and the World Trade Organization, and more recently to regional customs unions such as the North American Free Trade Agreement, the European Union, and similar but less integrated regional pacts). Importantly but less visibly, this also caused a shift toward a material wealth model that exported the core of societal tensions from the western world to the rest of the Earth by using human and resource capital in the periphery to accumulate wealth in the western core of the system, thereby minimizing tensions in the western democracies. A large part of this development was driven by the technological innovations facilitated by the plentiful availability of fossil (and later to a limited extent nuclear) energy. These developments ultimately led to the current consumer society and helped create a period of relative social peace in the developed nations.

After about twenty years of rebuilding the parts of the world that had been destroyed by war, in the 1970s and 1980s unintended consequences of the new order, including the dismantling of the colonial empires, began to surface again in the west as well as elsewhere. In the financial domain, dealing with rapid growth in the financial system led to the abolition of the gold standard (1976), which was followed by the "big bang" (1986) that removed (national) policy constraints that had thus far kept the financial markets within bounds, in particular in the USA and Britain. The Reagan and Thatcher regimes contributed to the collapse and the change of regimes in Russia (1989) and in some of the western periphery of the Russian Empire, in countries that had been weakened by the unintended consequences of their communist philosophy of management. In a number of ex-colonies, a revolution of rising expectations led to profound regime changes (e.g., in Indonesia, India, Pakistan, Zimbabwe, and many others; much later South Africa) to the advantage of (small groups among) the original inhabitants.

Underneath all of this, and surfacing particularly from the 1980s onwards, globalization was a major driver of the process, on the one hand increasing trade and the wealth of the core as well as reducing regional risks by subsuming them under global ones, but on the other hand leading to more dependencies between different parts of the world, and thus increasing the chances that minor events in one place could have major consequences for the world system as a whole (the 'butterfly' effect).

Conclusion

From our information-processing dissipative flow perspective, globalization is the latest stage in a process driven by an imbalance between our global societies' capacities to process energetic and material resources on the one hand and information on the other. Information-processing needs over time brought more and more people together, and this required more and more resources. In this process, the information-processing capacity of growing communities increased sublinearly with the number of people owing to the limitations of human short-term working memory and inefficiencies in alignment and communication. But the material and energetic flows increased at first linearly with the number of people, and later maybe even geometrically when the growth of group sizes required increasing investment in infrastructure. As a result, the resource needs of western society drove it to expand its extraction networks across the globe, but without concomitantly expanding the dimensionality of its information processing toolkit. Over an ever-widening area, the globe was exploited in the western way, disregarding the many dimensions of local information processing that were related to local customs, environments, challenges, solutions, and values. Integrating these was beyond the capacity of western societies' information processing, and thus globalization proceeded on an increasingly narrow dimensional basis, around wealth, ever since the discovery and harnessing of fossil energy in the nineteenth century (coal) and twentieth century (oil and later gas) facilitated innovation and an expansion of the western value space. This expansion was based on an elaboration of the same set of core dimensions that had governed the west's information processing earlier.

The forcible geographical expansion of western information processing was not able to integrate the very high number of different dimensions inherent in the different ways in which non-western populations processed their information. The western flow structure therefore spread across the world, maintaining its own ways of processing information, facilitated by a few shared languages worldwide: English, Spanish, and French. This rapidly widened the gap, worldwide, between the dominant (western) information processing system and the cultures and environments it confronted, and thus generated a rapidly growing tension between the available information processing and the kind of information processing that would have optimized local (natural and human) resource use, leading to an explosion of unintended and unanticipated consequences that ultimately caused a series of crises (which in my opinion will continue to occur with increasing frequency and amplitude).

Of course, this tension will impact differentially on the vulnerability, resilience, and adaptability of different scales of the system (Young et al. 2006). But the expansion of the western information-processing system will increasingly undermine societal diversity and the diversity in thought and action that has until now characterized the different cultures on Earth and acted as a buffer against their hyper-connectedness. And finally, I think it will limit, if not render impossible, the expansion of the value space that I discuss in Chapter 16.

It is my contention that these dynamics have not sufficiently been explored, in part because they have been looked at from a national or corporate perspective, in which expansion was viewed as an advantage because it increased financial and economic flows and values.[4] In order to explore them properly, it is essential to take a global and holistic perspective, to develop a "Global Systems Science" that looks at the causes and effects of globalization at the scale at which the phenomenon happens, rather than only looking at the advantages of globalization for individual countries and companies in competition.

As I outline in Chapter 18, in the current age of big data gathering, the information needed for such an approach is fundamental to the continued existence of our societies, and its importance exceeds that of any national interests. We are beginning to see such collection, but it is essentially in private hands (of Google, Facebook, Tencent, and others like them), while governments do not really seem able to compete on the same scale because (apart from the superpowers who are mainly collecting it for defensive and military purposes) they still maintain a national perspective.

NOTES

1 Many rulers and trading houses now had their own spy and courier systems, the first and foremost among them run by the Catholic Church.
2 In Germany, Russia, and Italy the process took much longer, and did not come to completion by the end of the period we are discussing.
3 It created major opportunities for those who mastered one of the newly emerging technologies. For many, education became the way out of misery, reflecting the need for improved information processing to maintain innovation and social cohesion. This led to the education revolution occurring in many countries around the turn of the twentieth century.
4 A group of concerned scientists, including me, has therefore launched a new initiative called Global Systems Science that considers the Earth system (including the socioeconomic component of it) as an integrated system, and attempts thus to elicit and highlight the dynamics behind that and their impact on our planet. For more about this initiative, see Jaeger et al. 2013.

16

Are We Reaching a Global Societal "Tipping Point"?

The Present Conundrum

A central theme of the book is the relationship between the present and the future, and in particular the conundrum in which we find ourselves in the modern world with respect to our environment and the survival (or not) of our current ways of life in a globalizing world. Let us therefore take a look at some of the trends that characterize our current societies globally. Doing so will rapidly show us that although greenhouse gas emissions have been targeted by international politics as the focus of our battle against the destruction of our environment, this is woefully insufficient and actually misleading because it ignores the roots of the problem and oversimplifies the challenge.[1]

If we view the current challenges as societal rather than environmental in origin, there are a number of essentially societal dynamics that are threatening to exceed their own safe operating spaces: demography, food security, financial stability, wealth distribution, urbanization, etc. Fortunately, as part of the efforts of the United Nations (UN) to define sustainable development goals (SDGs) in 2015 and to propose an agenda to reach those goals, the realization has quickly grown in the scientific community that, indeed, the challenge is in large part a societal one (see Chapter 19 for a more detailed discussion of the SDG research effort). Moreover, the recent focus on SDGs has shifted efforts toward viewing the core sustainability challenges through the lens of a multidimensional systemic approach. This is beginning to have an impact on governments as well, with efforts to coordinate ministries and agencies now also including central government functions, such as the ministries of finance, planning, and/or the prime minister's office. Yet the engagement of the social science community is still in its infancy compared with that of the natural and life sciences. For one, because it was initially called upon to respond to issues that the natural sciences defined, it was as it were backed into its main topic: societal dynamics. As a result, much effort has been spent by social scientists studying such topics as climate and society, water and human needs, food (in)security, rather than focusing on studying the internal dynamics of society that have brought us to the current situation. Moreover, there has to date not been enough of a coordinated effort at developing the results of different sectoral approaches to dynamics in various societal domains into a more holistic, scientifically coherent one, based on intellectual fusion between the efforts of disciplinary communities. Neither have the scientific and the economic, financial, and political communities looked closely at the role of unintended, unanticipated consequences of earlier choices.

Briefly discussing some of the main sustainability challenges just mentioned, this chapter probes the depth to which an analysis of our current multidimensional predicament must go. It emphasizes the complexity of the challenge and the need to begin to view it from a complex systems perspective. Finally, it will emphasize that our current situation is due to the effects of unexpected and unanticipated consequences of earlier choices made by our western societies, which are in my opinion the root cause of tipping points throughout history. With that perspective, a "crisis" or "tipping point" is a (usually temporary) situation in which the information-processing capacity of a society is no longer able to deal with the highly complex dynamics in which the system finds itself owing to the shift in risk spectrum that it has undergone over time.

The Environment

Our actions over many centuries have ultimately transformed our environment to the point that the relative stability of the Earth system dynamics that we have, as humans, enjoyed over some 10,000 years, may be coming to an end within this century. Over the last hundred years or so, many indicators of the expansion of the socioeconomic system, both globally and locally, have gone exponential, and so have indicators of its impact on the environment.

Steffen et al. (2005, 2014) illustrate that transformation in a single figure (Figure 2.1). In the last thirty years, moreover, numerous signs have emerged that our current society is close to hitting, or actually has hit, a series of planetary environmental risk barriers (Rockström et al. 2009) (Figure 2.2). After some thirty years of research on changes in the environment that saw our challenge essentially as an environmental one, awareness is growing that we are in effect dealing with a societal challenge. After all, society defines its environment, identifies environmental challenges, and proposes solutions for them. Societal action is therefore the only kind of action that can have caused, and may change, the current trend.

This leads me to argue that as scientists we may until recently have been looking under the streetlights to find the key that we have lost somewhere in the dark beyond the reach of those streetlights. To determine why this has happened would be a highly interesting and important topic of research in its own right. Instead of mainly looking at socio-environmental dynamics to see where there are dangers lurking, and how we might mitigate these so that we could retain our current western lifestyle, we should have been looking more closely at the societal dynamics that created the current conundrum and how we might change that lifestyle.

Might some of the signs that Steffen has collected also indicate that we are crossing, or at least approaching, a set of societal planetary boundaries? In this chapter I will try to explore that question. I will briefly enumerate a number of the dimensions in which our societies are threatening their own safe operating space. Most, if not all, of these are known, but because of the disciplinary and sectoral fragmentation of our worldview and our science, many of them have not sufficiently been linked in a holistic perspective to see what they really mean for our future. Others have not been discussed because they derive from such fundamental values and assumptions in our culture that they are our sacred cows.

Global Demography and Health

Figure 16.1 shows three different projections of the demographic tendencies currently observable worldwide. Notwithstanding the fact that it is difficult to predict the demographic evolution over a whole century, it is one of the most solid forecasts of all, even though in the past effective population growth has often tended to attain the higher ranges of the predictions. The predictions take increasing life expectancy in proportions related to wealth and healthcare into account, and also the fact that as populations grow wealthier they reduce their birthrates. But they do not take the potential nonlinearities into account that might be created by

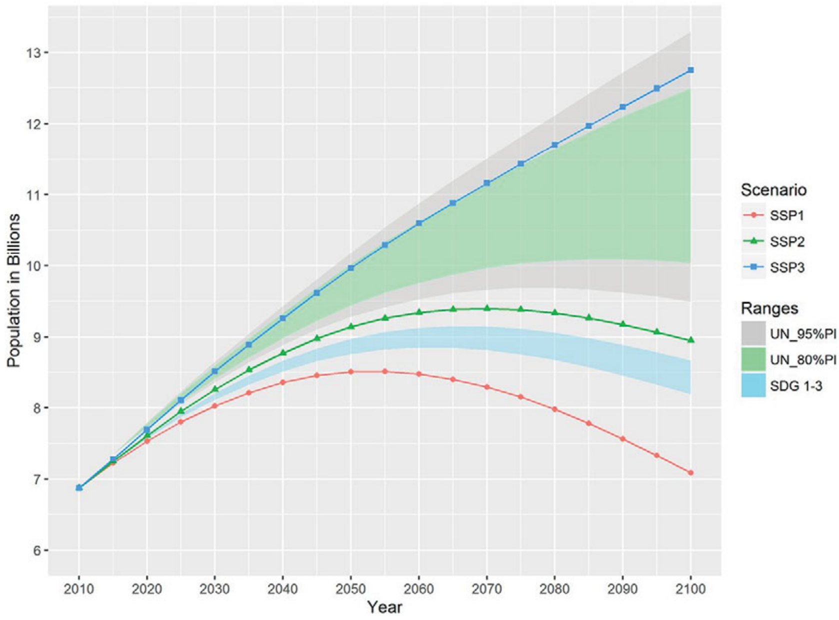

FIGURE 16.1 Projected global population growth 2000–2100 as projected by the three Shared Socioeconomic Pathways (SSP) scenarios and the probabilistic ranges given by the UN. (Source: after Abel et al. (2016), published by TWI 2050 under CC-BY-NC 4.0)

quantum jumps in healthcare, such as the healing of cancers, the potential of stem-cell therapy, etc.

The wide divergence between the scenarios in Figure 16.1 clearly illustrates the difficulties of projecting so far into the future.

These population figures are only one part of the picture. Major differences in the distribution of health are the other. As shown in Figure 16.2, health, as represented by life expectancy at birth, is very unevenly distributed across the globe, and its distribution appears to be similar to that of wealth.

This has direct implications for overall global population growth, which in the coming decades is expected to be principally occurring in Africa (Figure 16.3).

It is generally expected that with growing wealth in the developing world, the crude birth rate will go down as life expectancy increases. In 2018 the population of the world is growing at an average annual rate of 1.1 percent. This rate has been declining since 1965–1970, when it peaked at around 2.1 percent. The fact that world population growth is

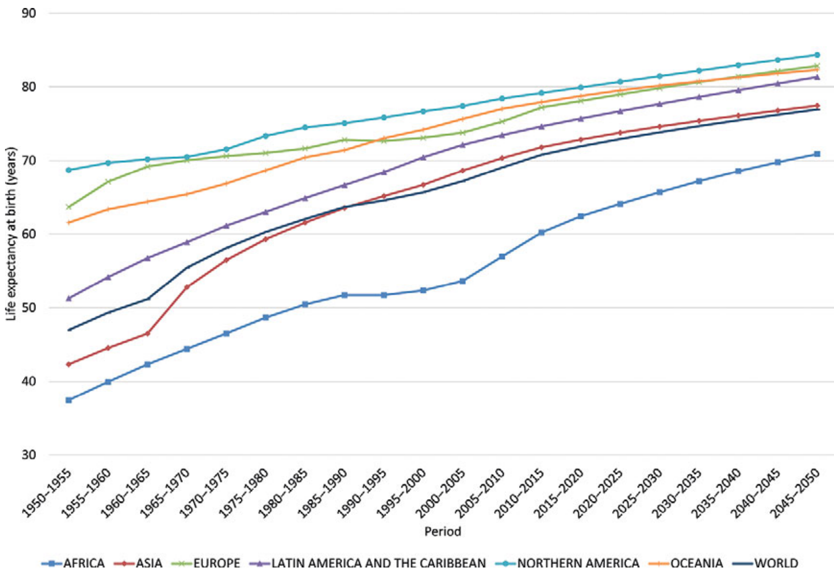

FIGURE 16.2 Life expectancy at birth (years) by region: estimates 1975–2015 and projections 2015–2050. (Source: UNDESA (2017). Figure published by TWI 2050 under CC-BY-NC 4.0)

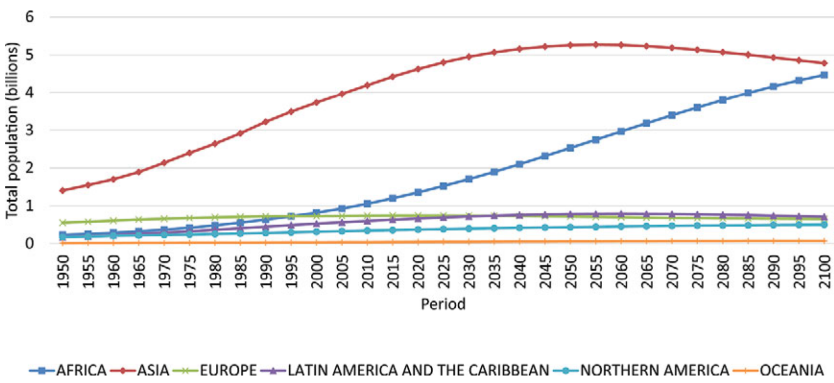

FIGURE 16.3 Population growth by macro-region. Most population growth is predicted for Africa. (Source: data from UNDESA 2017; Figure published by TWI 2050 under CC-BY-NC 4.0)

on the decline can be explained by the Demographic Transition Theory (Notestein 1954). Eventually, according to this theory, all societies evolve from a pretransition situation (stage 1), where fertility and mortality are unchecked and high, thus producing low population growth, to a stationary population (stage 4), when a society reaches low levels of fertility and mortality. This pattern is quite well established and exceptions have so far been of a temporary nature.

The crucial question is, however, whether growth in wealth and decrease in birth rate will manifest themselves at more or less the same rates or not. Another question is how these processes will play out in different parts of the world. No one knows, but it is clear that 200 years of western industrial economy have created important demographic discrepancies that may impact on global sustainability.

Aging

Behind these global figures lurks a potentially major challenge: aging. Generally, it is assumed that growing economies require growing working-age populations. Currently, in a number of developed countries, aging and a low birth rate combine to cause decreasing numbers of inhabitants of working age: Japan, China, Germany. Others still have an expanding population due, for example, to important immigration (the USA, Canada, Australia), but in a general political climate in which immigration is increasingly subject to xenophobia, those fluxes may well decrease. This will have an impact on the size of these economies, not so much from the supply side (where people will probably be replaced by automation), but on the demand side.

The opposite is the case for Southeast Asia and Africa, where birthrates are still higher and the working-age population will be growing for some time. There, the economies will continue to grow, and one of the interesting questions that raises is whether this will also entail a shift in global power balance toward the currently developing countries. That will in part depend on whether, and how far, these countries will be able to develop their technologies and economies, but also their institutions and legal systems. China has shown, over the past few decades, how this can be done.

Global Migration

Another fundamental characteristic of the current world, but with ancient origins, is large-scale migration. It is exceedingly difficult to obtain good quantitative data on the numbers of people involved, and a purely narrative description will have to suffice.

Current research indicates that on a global scale migration has not recently increased substantively, but at local and regional scales it has shifted demographies. According to the UN, during 2005–2050 the net number of international migrants to more developed regions is projected to be 98 million (UNDESA 2017). Such regional migration is likely to further accelerate in the foreseeable future owing to, for instance, climate change, sea level rise, and food and water availability. But there may also be increasing pressure toward migration for societal reasons, such as warfare, failing states, populism, ethnic cleansing, or criminal violence. The rapid spread of information through word of mouth, television and the Internet is contributing to migration in important ways. It triggers widespread "push" reactions in the developing world, driving people living in dangerous or economically difficult circumstances to migrate to the USA, Canada, the EU, and other (mainly developed) countries.

Migration is thus likely to further accelerate in the foreseeable future. The counterpart may be a defensive reaction in developed countries, fed by local populism and identity issues, creating more barriers to migration and globalization such as is currently occurring in Southern Europe and the USA. But then, demographic and economic declines in developed countries may in the end overcome such sentiments. Major environmental disasters and ethnic cleansing will probably further complicate the situation. All in all, we can therefore expect major cultural, social, and economic challenges related to migration in the developed world as well as in the developing world, wherever state control is not willing or able to deal with, or prevent, mass migration.

Food (In-)Security

The importance of these demographic trends becomes clear if one compares them with the evolution of our resource footprint as a global population. One consequence of major innovations in healthcare, and the spread of technologies to make human beings healthier across the world, has been that we are, as Tim Flannery (2002, n.p.) put it, "eating our future." We are facing a potential crisis in the provision of water and food for the world population that could very easily trigger major conflicts. Recent increases in food prices due to speculation are early warning signs that food security may, in the not-so-distant future, become a major challenge worldwide (Figure 16.4). No surprise, then, that the topic has in the past five years emerged as a major concern, both scientifically and politically.

Individual countries are hedging against the possibility that food and water insecurity will threaten their populations, for example by buying

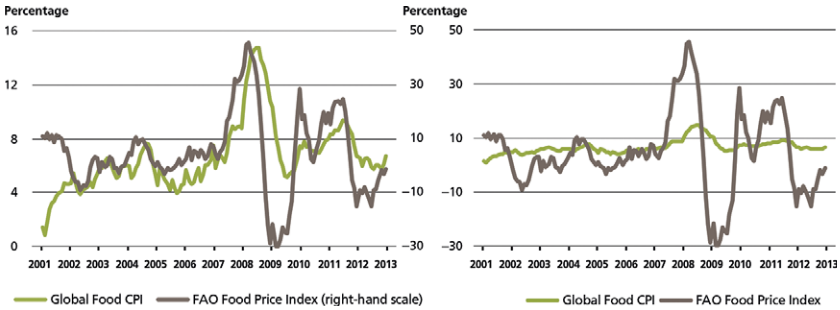

FIGURE 16.4 Food prices remained relatively stable from the 1980s to 2005 thanks to the green revolution, but have recently spiked partly as a result of speculation and ethanol production (Source FAO: www.fao.org/worldfoodsituation/foodpricesindex/en/, downloaded 01/09/2018); Published by TWI 2050 under CC-BY-NC 4.0)

large tracts of land in Africa. But as the population of Africa is growing faster than the population of any other area, one has to wonder whether this strategy will in the end be sustainable.

Fossil Energy

Energy has been a constraint on human societal evolution for most of the existence of the species, but that constraint was lifted with the harnessing of fossil energy in around 1800.

Since then, energy use has increased very rapidly, as was seen in Figure 15.1. Basically, the societal dynamics that are driving our societies have increased average global energy consumption from approximately 20 gigajoules (GJ) per capita per year at the beginning of the Industrial Revolution to approximately 80 GJ per capita per year now. Clearly this is very unevenly divided between the developed and the developing world. In the USA, in 2013, average per capita consumption was in the order of 290 GJ equivalent per year, while in India it was only about 25 GJ. Most of that difference is absorbed in building, maintaining, and running our material and institutional infrastructure. A growing need for energy is fundamental to the way in which the world is currently moving, and energy consumption, for political and economic as well as societal reasons, is not likely to decrease in the foreseeable future.

Yet the total quantity of exploitable fossil energy on earth is limited, and this has, since the 1970s, led to the conclusion that at some point in the future oil as a cheap resource will be exhausted. That point may recently have been pushed back owing to exploitation of new oil gas deposits (but see Day & Hall 2016), the discovery of large volumes of natural gas, and the expansion of renewable energy use, but traditional gas and oil exploration and exploitation is becoming more and more expensive because the superficial sources in accessible areas are being depleted and replaced by fossil fuel from very deep sources (*presal* in Brazil) or extreme climates (Arctic). Though there is coal for many more years, the fact that burning it is highly unadvisable from a greenhouse gas and global warming perspective is forcing us globally to reduce its use.

As energy has been an early target in the world's efforts to reduce global CO_2 emissions, major efforts have been deployed to reduce both the use of fossil fuels and of their CO_2 emissions. Numerous approaches have been discussed and some of them undertaken. Technologies have been invented and improved, such as the application of digital information processing in grids. In particular, substantive measures have been taken to reduce CO_2 emissions (by shifting from coal to oil, then gas, then renewables) and to increase the efficiency of energy use (in electricity generation; insulation of buildings; transport, etc.). But as Figure 16.5 shows, this is still woefully insufficient, partly because only a fraction of total energy ends up being useful (Figure 16.6 in the box below).

The world has currently achieved a total global efficiency improvement of about 2 percent per year. But as concluded by the "The World in 2050" team (TWI 2050, 62), all these efforts are quite insufficient to substantively reduce greenhouse gas emissions. As stated by the International Energy Agency (2017): "While carbon emissions have flattened in recent years, the report finds that global energy-related CO_2 emissions increase slightly by 2040, but at a slower pace than in last year's projections. Still, this is far from enough."

This worrying situation is exacerbated by the fact that the decrease in return on investment in traditional energy capture risks leaving a substantial proportion of the theoretically available (identified) resources in the ground, potentially creating a major financial liability for the institutions that have lent money against those irrecoverable assets (the so-called stranded assets problem). This poses a threat to our current global financial system, as do some of the derived geopolitical risks involved in oil price fluctuations. If countries cannot make enough money on fossil fuels, their political structure becomes unstable (in Venezuela from 2016 to 2019, for example). Moreover, if we continue to reduce global poverty,

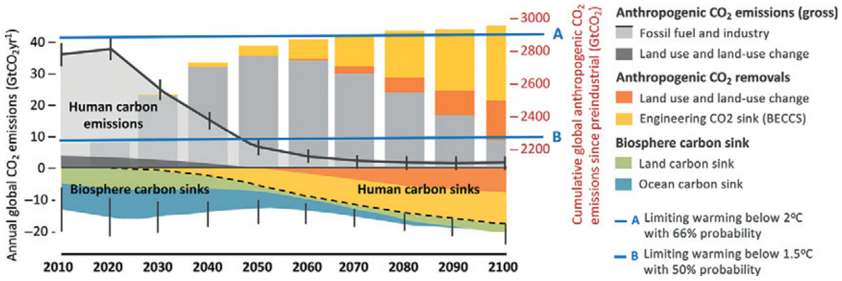

FIGURE 16.5 Cumulative and annual emissions and sinks of CO_2 are shown for stabilizing global climate at below 2°C and 1.5°C. Most of the carbon emissions shown in gray are energy-related. Together with land-use emissions they need to decline toward zero by midcentury. The figure is called Carbon Law as a metaphor to Moore's Law of semiconductors, where a number of transistors on a chip doubled every two and a half years. Carbon Law indicates that global emissions need to be halved every decade. In addition, human carbon sinks need to increase to almost half the magnitude of current positive emissions: This is a tall order. Carbon capture from biomass (bio-energy use with carbon capture and storage – BECCS) and land-use change are here the key. Third, biosphere carbon sinks need to be maintained as atmospheric concentrations decline. The vertical gray bars show cumulative emissions since the beginning of the industrial revolution of some 2,000 billion tons CO_2. This budget, or carbon endowment of humanity, will be exhausted shortly as the remaining emissions for achieving stabilization at below 1.5°C are essentially nil while we still emit some 40 billion tons CO_2 per year. Net-negative emissions are needed to stay within this budget. The remaining budget for stabilizing at 2°C is a bit more generous so that the demand on net-negative emissions can be significantly reduced. The Carbon Law can be seen as a roadmap toward making the Paris Agreement and the SDGs a reality. Pathways shown in this report such as the SSP1 variant focused at the 1.5°C target or the alternative scenarios portray similar dynamics, whereas the latter is unique among stabilization pathways as it does not need net negative emissions because of vigorous changes in end-use technologies and behaviors. (Source: Rockström et al. (2017); Figure published by TWI 2050 under CC-BY-NC 4.0)

one can reasonably expect energy needs to continue to grow. For example, in Saudi Arabia the national increase in energy use is such that the country may cease being a net oil exporter by 2032 (Leggett 2014). If we include in the calculations the energy needed to increase the living standard of the whole global population to a level that guarantees a comfortable life (without going into the excesses of the current West), we will clearly exceed all acceptable levels of fossil energy use from an atmospheric pollution perspective because this would almost certainly involve substantive use of coal, which is currently (and will so remain

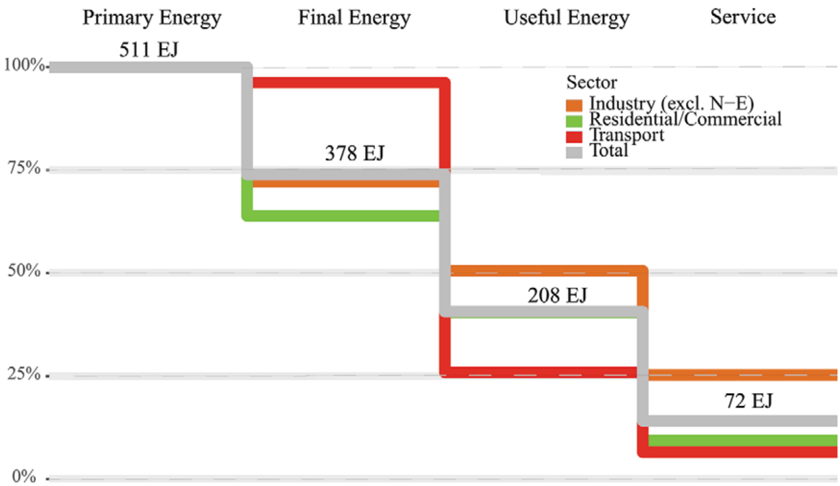

FIGURE 16.6 Energy conversion cascades in the global energy system. Lines show percentage of extracted primary energy delivered as final energy, useful energy, and services respectively for three end-use sectors (industry, residential and commercial buildings, transport) and totals for the whole energy system in 2020. Energy flows exclude non-energy feedstock uses of energy (labeled as N-E). Total energy flows (EJ) are shown at each stage of the energy conversion cascade. Service efficiencies are first-order (conservative) estimates based on Nakićenović et al. (1990) and Nakićenović et al. (1993). (Source: Figure provided by courtesy of Arnulf Grubler and Benigna Boza-Kiss to TWI 2050, published by TWI 2050 under CC-BY-NC 4.0)

unless major technical innovations change the situation) the worst polluter among the fossil energies. Only renewable energy can avoid this energy squeeze, but though its installation is growing exponentially (it now produces about 20 percent of global energy), that is still not fast enough to compensate for emissions growth from fossil fuel (not to mention land clearance, saturation of the ocean's absorption capacity, tundra melt leading to methane release, and so forth).

Finance

We can clearly see that in recent years a very important, and growing, proportion of total financial capital is no longer engaged in the production of goods or services, but entirely devoted to what amounts to speculation. Figure 16.7 shows how the proportion of available capital that is subject to capital gains tax and is therefore not productively invested has been increasing in the USA since the late 1940s and has

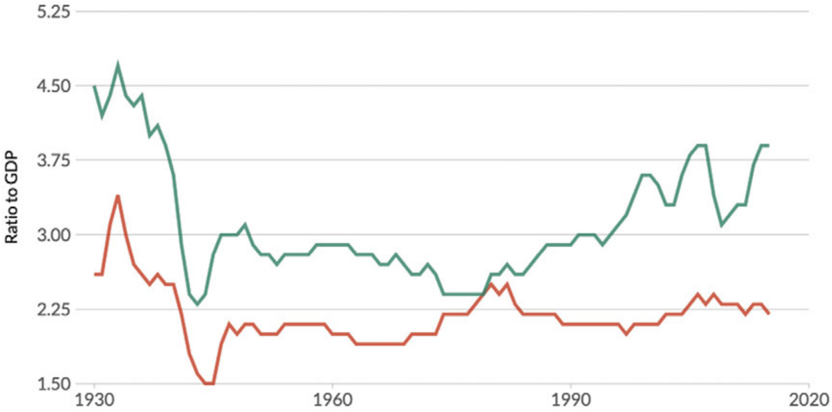

FIGURE 16.7 Fraction of total gross domestic product (in the USA) invested in production (red line, without capital gains tax) and speculation (green line, with capital gains tax). The global recession of 2008 has depressed both trends, but the relationship is still the same. (Data: Washington Center for Equitable Growth (2018), figure published by TWI 2050 under CC-BY-NC 4.0)

recently in some years constituted close to 40 percent of total financial capital. As such speculative capital moves around with worrying (and increasing) speed, for example between developed and developing countries, but also between sectors, individual institutions, and forms of investment, the basis of our global financial systems is substantially, and increasingly, unstable.

The mobility of speculative capital associated with the fact that it is controlled by fewer and fewer people (see below on the "wealth gap") and institutions (some of which are now considered "too big to fail") has had the destabilizing effect of contributing to the rapid succession of financial crises that we have seen in the last sixty years (*The Economist* in 2014 ran the headline "The History of Finance in Five Crises"). There are many different aspects to this trend, but there are several that are so dangerous that we need to include them in our thinking about the future.

Trade, Protectionism, and Investment Flows

Several developed economies are currently moving toward protectionism, under the pretexts of protecting jobs, correcting bilateral trade imbalances, or even national security. This restricts economic growth in the long run, since it inhibits trade in intermediate goods and the creation of value chain niches. It also threatens the existing supply chains in our greatly interwoven global economy. Moreover, the uncertainty produced by the threat of protectionism slows down investment flows in global capital markets, as it generates uncertainty regarding future economic growth (Erokhin 2017). This is aggravated by trends in international aid, migration, climate change, and geopolitics. Protectionism threatens food sustainability by drastically shifting value chains and forcing replacement of staples and other foods with less sustainable varieties. Trade has a major role in stabilizing food prices, as well as shifting production from areas of high environmental risk to less risky areas (IFPRI 2018). The effects of protectionism in developed countries will be felt most acutely in the least-developed countries (LDCs) (UNDESA et al. 2018). Many LDCs are dependent on external demand for commodity exports, as well as foreign aid for budget support (Timmer et al. 2011). In a closed world economy, many LDCs will continue to lag behind more developed economies, and this will have important ramifications in other sectors. LDCs will not achieve the economic growth required for sustainable development without a significant increase in investment. However, many of these countries are unable to attract the levels of investment they require owing to institutional deficiencies, an overdependence on commodities subject to fluctuation in prices, and a dearth of basic infrastructure to support fledgling industries.

Debt

The rapid increase in global indebtedness (see Figure 16.8) is directly threatening overall financial and economic stability. Nominal global debt is currently around 250 percent of gross domestic product (GDP). This includes both government and private debt, and the percentage has been rising for most of the last fifty years, after a major deleveraging phase immediately following World War II. This debt is unevenly distributed among countries, and also between public and private debt, with the latter generally growing faster than the former. As long as the world is – and most countries are – on a growth trajectory this is not necessarily a financial problem, as people have enough confidence that much of this debt will in the end be reimbursed, and because inflation reduces the real debt load.

We have to remember, though, that this whole system is fiduciary, and that if trust in it is for some reason or other undermined it could collapse very easily, leading to major social unrest. As we saw in the 2007–2008

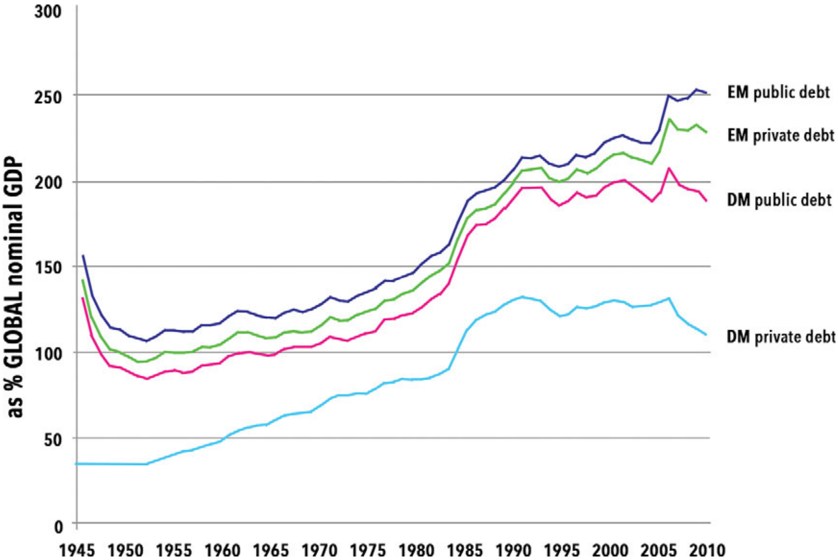

FIGURE 16.8 Private debt in developed and developing countries exceeds public debt. (After Hugman and Magnus (2015), figure published by TWI 2050 under CC-BY-NC 4.0)

Great Recession, there are many hair triggers that may cause such a collapse. And because each crisis is countered by central banks with an increase in their debt levels, the underlying instability increases with each such event (Figure 16.9).

In recent years, we have also seen how several individual nations have seen trust in their financial systems collapse owing to mismanagement or actual cheating (Argentina, Greece, Ireland, Turkey).

That is not affecting world financial stability as long as there are other economies that can serve as lenders of last resort because they are bigger and in better shape. However, with the overall increase in debt level among both large and small countries this mechanism may itself be at risk.

Another aspect of the high debt level is the fact that an ever-larger percentage of GDP is devoted, by governments and individuals, to interest payments, which reduces the proportion of GDP that is available for spending. There is thus an incentive to promote a feedback spiral, increasing the debt to be able to both spend as necessary and pay the interest owed.

Ultimately, this may hit the total amount of funds available for investment and lead to reductions, notably, in infrastructure maintenance (as is currently occurring in a number of developed countries). In certain cases,

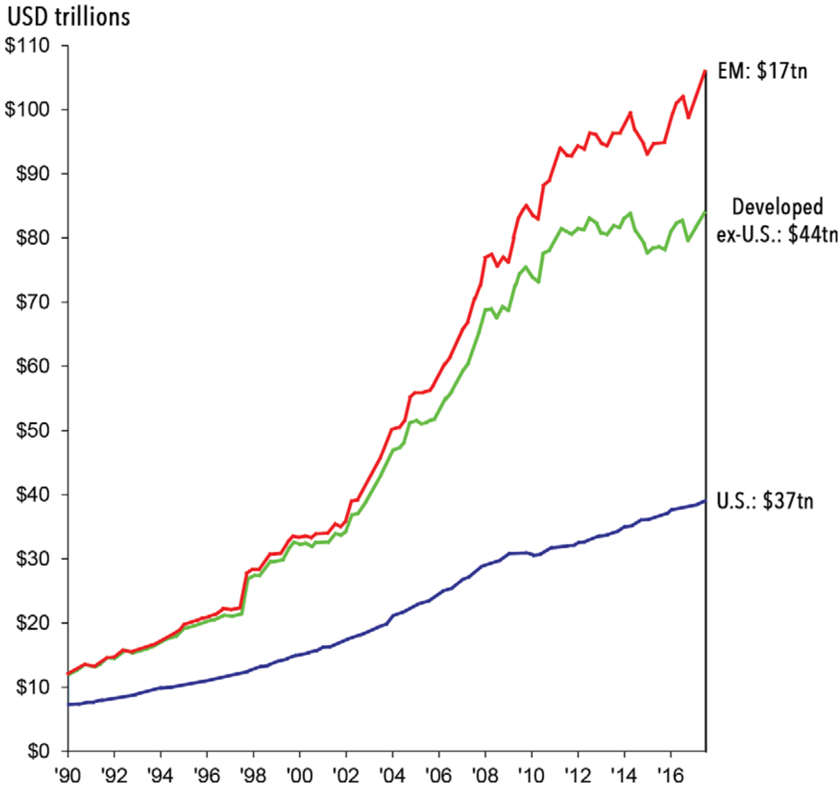

FIGURE 16.9 Public debt in the USA, other developed countries, and emerging markets. After the 2007 debt crisis, public debt increased rapidly, to level off (except in the USA) after 2010. (After Durden (2017), published by TWI 2050 under CC-BY-NC 4.0)

this problem may even limit the potential for further investment in the expansion of productive capacity.

It is easy to see that the information revolution, which has reduced transaction times to milliseconds, and which has linked all financial markets in one large web, contributes further to the potential instability of the global system as a whole.

Aging Populations, Productivity, Savings, Debt, and Pension Systems

I have already mentioned that a major demographic trend is the aging of populations. It has tremendous economic implications that represent a challenge for the sustainability of welfare systems in developed and developing economies. This includes pension and healthcare systems, in addition to a possible decrease in savings and investments (Bosworth et al. 2004). In developed countries, an increased burden will be placed on public transfer systems, owing to the concurrent trends of a growing proportion of pensioners and a diminished tax base. However, the majority of the increase in the population above the age of sixty will occur in the Global South (UNDESA 2017), where the elderly are less likely to have retirement savings plans or to be supported by public welfare systems, and instead depend on assets and labor income. Without the means to support themselves in retirement, many of these people are susceptible to poverty. An aging world population also means that the share of non-communicable diseases in the global disease burden will grow, increasing pressure on countries' health expenditure, adding to the fiscal burden of government budgets.

Low productivity growth in developed economies in recent years has been explained by aging workforces, a slowdown in total factor productivity in the information and communications technology (ICT) sector, declining contributions of trade to economic growth, and stagnation in levels of educational attainment (Adler et al. 2017). Between countries, global inequality has decreased in the last decade thanks to the contribution of China and India in their economic development process. As these and other emerging markets continue to grow, the economic hegemony of the United States and its western allies will gradually be replaced by a multipolar world economy, in which India, China, Indonesia, and Brazil become increasingly important economic hubs for financial services, manufacturing, and innovation (Timmer et al. 2011).

However, this trend does not mean that economic growth will be evenly distributed. Many LDCs are at risk of continued vulnerability to economic shocks for the reasons previously mentioned. Their economic vulnerability is compounded by the fact that many of the LDCs are facing disproportionately high threats from climate change, have rapidly growing populations, and also have weak governments and vulnerable security situations. These trends are inhibiting the ability of LDCs to bridge the gap between themselves and the emerging and developed economies. Without appropriate economic growth and investment, their populations may continue to grow at unsustainable rates, they will not be able to provide adequate education to their youth, and the coverage of health services will remain incomplete and fail to tackle preventable causes of morbidity and mortality (UNDESA 2018).

Innovation and Societal Coherence

The societal implications of the innovation challenge, though major, are much less clearly perceived, and have probably differed across cultures and societies. In the case of the west, I mentioned in Chapter 12 that Girard (1990) argues cogently that between the seventeenth and the twentieth century, society's perspective has shifted from one directed toward the past and therefore encouraging stability ("the future is more of the present") to one that favors change and innovation. That is a fundamental change in our (western) values, and should not blind us to the fact that for many societies change may not have been a fundamental value.

Nevertheless, any society will ultimately lose coherence unless its members continue to see an advantage in being a member of the society (van der Leeuw 2007). This means that the society must maintain a sense of comfort among its members. I would argue that over long-term time, even if ever so infrequently, some degree of innovation is necessary, because when societies reach tipping points in their dynamics, innovation is called upon.

Whether in the material and technical realm or in the socioeconomic one, every innovation requires energy for implementation, whether it is to change the structure of institutions, to change collective behavior, or to create or modify infrastructure. One of the consequences of the harnessing of fossil energy after 1750 has been that, for a considerable amount of time, it was relatively cheap in energy terms to innovate. We have therefore, over the last 250 years, seen an ever-accelerating spate of innovation in the material and technological realms, which has globally brought with it an important population growth (especially in the last seventy years), an emphasis on "progress," an increase in life expectancy in many places, and a huge increase in trade leading to globalization. It is difficult to point to specific single causes for this very complex coevolution, but one argument that has a certain ring to it is that these phenomena are part of the ideology that capitalism (initially industrial, more recently financial) has developed to ensure profits through growth. I return to this topic in Chapter 18.

Whether this process can continue at a sufficient rate to keep our current societal institutions intact will of course in part depend on whether we continue to meet our society's growing innovation needs. But there are some early signs that this is not as self-evident as some think.

One observes in the USA an overall decrease in return on invested capital (Figure 16.10) as well as a decline in entrepreneurship

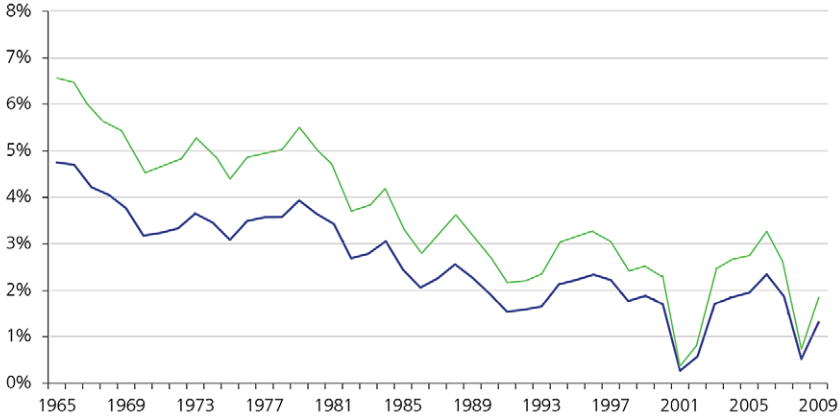

FIGURE 16.10 Evolution in return on invested capital in the USA, 1965–2011. The blue line represents the evolution of return on assets; the green line that of return on investment. (After Hagel et al. (2010), figure published by TWI 2050 under CC-BY-NC 4.0)

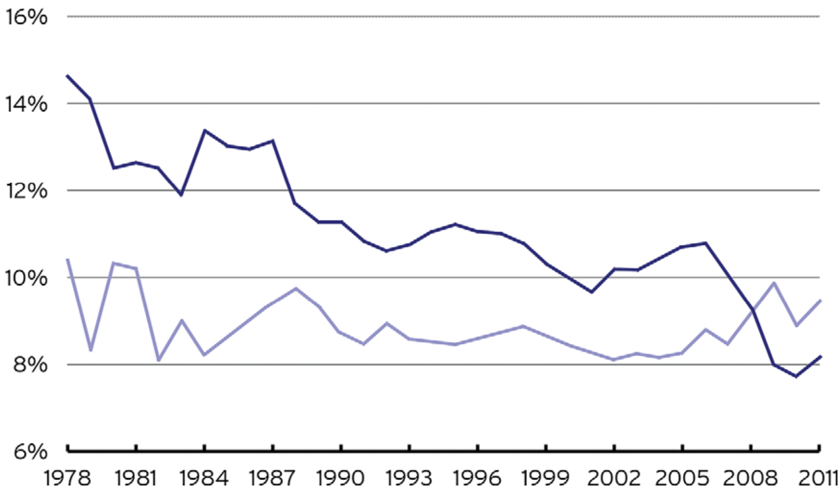

FIGURE 16.11 Annual new firm creations (dark blue line) and existing firm deaths (light blue line). (After Hathaway and Litan (2014), figure published by TWI 2050 under CC-BY-NC 4.0)

(Figure 16.11), which might be linked to an overall decline in the frequency of major innovations.

If we offset the number of patents per innovator against the growth in size of the teams involved in an innovation, we see that innovation involves more and more domains, and becomes more and more difficult and costly. Research on the wealth created by innovations registered at the US Patent and Trademark Office seems to point to the fact that, in terms of the return on investment on such innovations, their impact on the economy is slowing down (Strumsky & Lobo 2015). This may be because the explosion of patents over the last fifty years has made it more and more difficult to come up with something that is so new that it sets an innovation cascade in motion within or outside our current technologies. Another contributing factor could be that the shift toward short-termism in many industries makes it more difficult to develop innovations with long loss leaders. But there may be a more fundamental reason for this: has our value space (the total set of dimensions to which we accord economic value) reached a limit? I will return to this point in Chapter 17.

Wealth Discrepancy

The global economy has created excessive material wealth differentials by concentrating most such material wealth in the hands of a relatively small, if growing, proportion of the world's population, almost entirely in the developed countries (Figure 16.12). This causes a steepening of the wealth disparities within and between countries in another very long-term deep trend, as analyzed recently by Scheidel (2017), which is very difficult to invert, as his many case studies show.

Recently, we observe two opposing trends in this dynamic: a leveling off of wealth disparities between developed and developing nations and an increase of wealth disparities within many countries. This is the

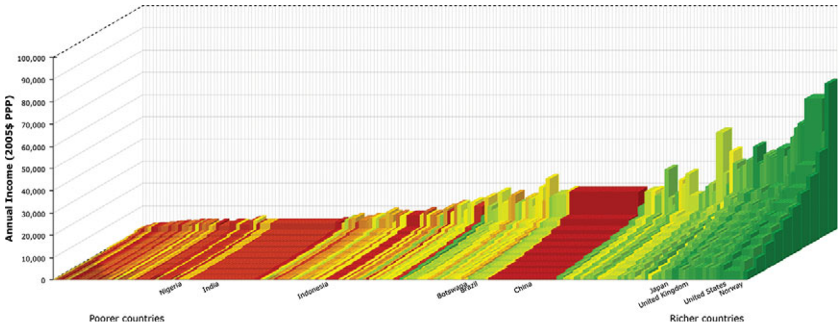

FIGURE 16.12 Worldwide differences in wealth distribution (After: Blundell (2018) based on Sutcliffe (2004). Figure published by TWI 2050 under CC-BY-NC 4.0)

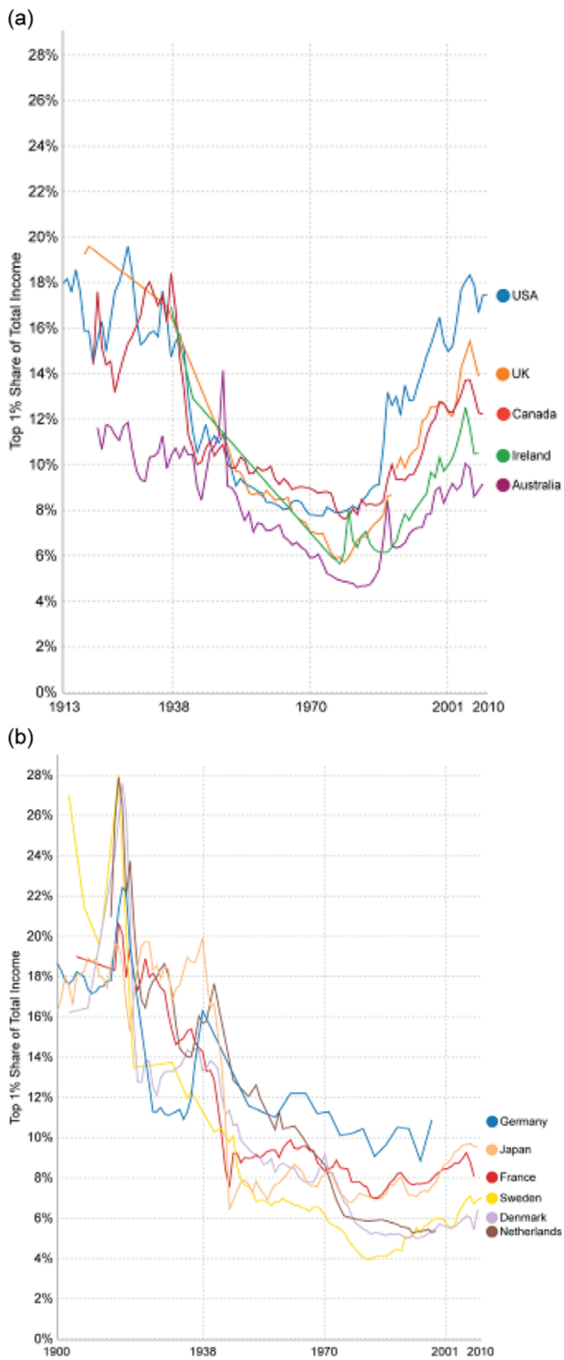

FIGURE 16.13 The 1980s "big boom" in financial regulation has inverted the reduction of inequality in the English-speaking world, but at least until 2010 not in other parts of Europe. (Source: Licensed under CC-BY-SA by Roser 2018; Figure published by TWI-2050 under CC-BY-NC 4.0)

statistical effect of the rich becoming richer in the developing countries (especially the BRICS countries), while within these countries – as well as in the developed world – the contrast between rich and poor becomes starker.

Recent publications, e.g., Piketty 2013,[2] have been drawing worldwide attention to this phenomenon, which some see as an early warning sign of major social adjustments – in the developed nations as a protest against the squeeze of the middle classes, and in developing nations as a revolution of rising expectations triggered by the fact that a small proportion of the population is getting (very) rich.

As is now discussed both in academia and in politics, the growing wealth discrepancy seems a manifest case of a societal planetary boundary that we are approaching, or have already crossed. Hence, I will use this section to discuss it at some length. To illustrate the scope of the phenomenon, I will present some statistics.[3] In doing so, I use the USA and Europe as examples because there are much better data for the wealth gap here than in many other countries.

Particularly since the 1940s, income inequality in the USA has spectacularly risen, from a situation in which 90 percent of the population collectively made about 66 percent of total US income and the top 10 percent about 33 percent. At the beginning of the 1980s that trend was dramatically inverted, coinciding all too closely with the "big bang" in the New York stock exchange, a major deregulation under the Reagan government. In 2012, the top 10 percent of the population received about half the income of the USA.

Figure 16.13 compares the Anglo-Saxon world with that of continental Europe, and shows how the "big bang" of the 1980s has hugely increased the wealth gap in the English-speaking world, but much less so in (continental) Europe. The most important lesson to learn from these differences in policy between continental Europe and the Anglo-Saxon world is the fact that, indeed, governments do shape markets (Mazzucato 2016), and should be regulating them if they want to preserve social peace. If they abandon that role, and important parts of the population grow apart, they are in for trouble. But of course, part of the responsibility for such growing apart rests upon the voters.

In the literature, the widening wealth gap in the USA is related to the relative decrease of manufacture – which provided good salaries for production personnel in factories – owing to automation and outsourcing in the developing world. But it is also the case that with the increased reliance of industry and services on automation and ICT, large parts of the economy in developed countries require higher levels of education to deal with more and more complex tasks. This is a dramatic development that will over time pose major challenges to all governments. They will have to find a solution for the large numbers of undereducated, unemployable people that this trend is likely to generate in the next couple of decades. Improving general education, from the primary and secondary school levels to universities, can profit from ICT to drive down the cost of education, but it urgently requires the review of the contents and skills, as well as the ways in which they are acquired. Recent studies argue for a major revision in favor of promoting student-directed learning (Ito and Howe 2016; see also Chapter 4).

The productivity increase has generally not been used to reward the median family in these countries. Automation, offshoring to countries with lower wage levels, as well as the 2008–2010 economic crisis are among the responsible factors. The extra profits have generally gone to major corporations and the rich and super-rich segment of the population – in the USA most extremely owing to the tax system bias, of which Warren Buffett (one of the richest US citizens) famously said (in 2012) that he pays a smaller proportion of his income in taxes (17.4 percent) than his secretary (35.8 percent). It is only in 2018 that tension in the labor market is beginning to force companies in that country to pay higher wages.

If we look at the evolution of wealth globally (see Figure 16.14), the so-called elephant curve (Lakner & Milanovic 2013), representing the growth in average household income of each percentile group worldwide between 1988 and 2008, we see the combined effect of three trends: (1) rapid and substantive income growth for the poorest part of the world population, especially in some developing countries, but starting from a very low base, (2) absent or low income growth for the middle classes in the developed countries, and (3) rapid growth for the richest people in the developed and some developing countries (notably China). Corlett (2003) shows that differences between countries' population growth rates and the selection of countries included in the statistics (notably Russia, Japan, and China) accentuates some of the contrasts, but this does not fundamentally change the picture that the middle classes in developed countries have not seen any increase in real income in this period.

Turning now from the phenomenon and some of its causes to some of its consequences, we can look at Figure 16.15, which shows the relationship, in a number of countries, between energy use (as a proxy for wealth) and a composite metric, social progress. This indicator combines life expectancy, education (as measured by proficiency in mathematics and

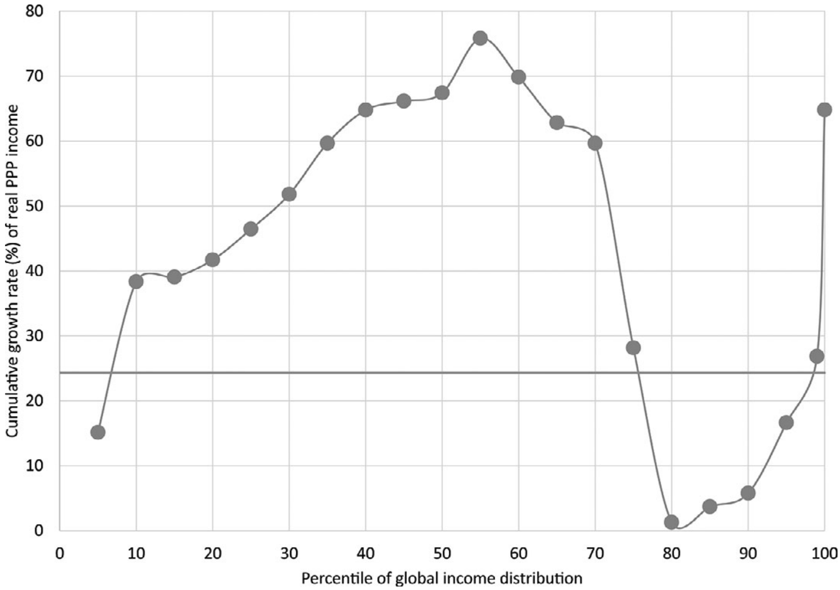

FIGURE 16.14 Global growth incidence curve, 1988–2008. One sees that below the tenth percentile incomes have grown very strongly, while incomes between the tenth and the fiftieth percentile incomes have grown substantially, whereas from the fiftieth percentile to the eightieth incomes have substantially declined. From the eightieth to the ninety-fifth they have grown some, and beyond the ninety-fifth they have grown exponentially. (Source: Licensed under CC BY 3.0 IGO by Lakner and Milanovic (2016); Published by TWI-2050 under CC-BY-NC 4.0)

literacy), infant mortality, homicides, imprisonment, teenage births, obesity, mental illness, social mobility, and drug and alcohol addiction. The relationship is quite convincing.

I conclude by repeating that the growing wealth discrepancy seems a manifest case of a societal planetary boundary that we are approaching or have already crossed. Some see it as an early warning sign of major social adjustments – in the developed nations as a protest against the squeeze of the middle classes, and in developing nations as a revolution of rising expectations triggered by the fact that a small proportion of the population is getting (very) rich.

Urbanization

We should include in this series of stresses that current global societies are undergoing the very rapid increase of urbanization. Urbanization is one

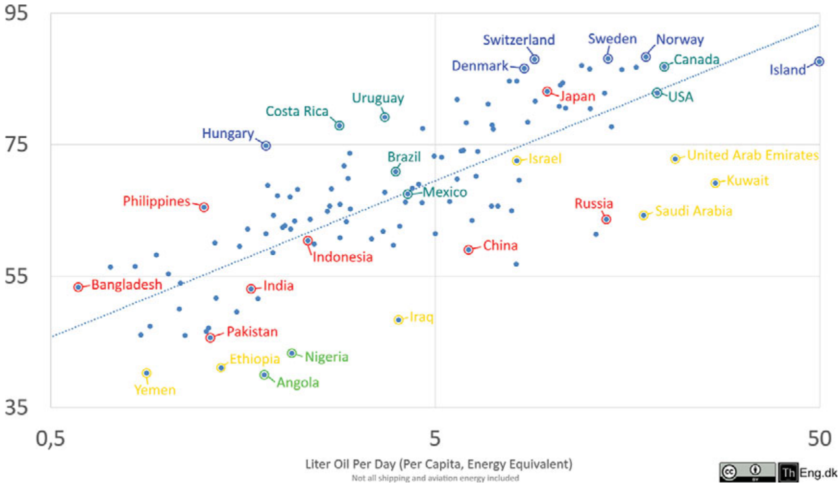

FIGURE 16.15 Social Progress Index vs. energy per country. (Source: Wikipedia (2018), licensed under CC BY-SA 4.0. Published by TWI-2050 under CC-BY-NC 4.0)

of the major drivers of societal and environmental change and is a major topic of discussion in the sustainability context (Seto et al. 2012, 2017). It is in effect the most long-standing materially observable societal transformation that we know, as it originated around 6,000 years ago. Current projections of the growth of urbanization seem to indicate that by 2050, 68 percent of the global population will live in cities (UNDESA 2018). However, it is not clear that such linear projections are trustworthy, as there are a number of factors (high institutional vulnerability, rising transport costs owing to climate change, food security, and potential changes in governance structure) that may force the drivers of urbanization in a different direction.

Although there are possibly as many explanations for the existence of towns as there are towns (Jacobs 1961), one recent approach, proposed by Bettencourt et al. (2007) and Bettencourt (2013) relates their existence and many of their features to societal information processing. Based on allometric scaling analyses, it argues that there is a direct relationship between innovation and urban scale, expressed by the fact that with urban scale (as expressed in population numbers), innovation activities grow superlinearly while energy use grows sublinearly (Table 16.1). Population and services, scale, of course, linearly. The authors argue on this basis that while energy is a constraint in the growth of urbanization,

Table 16.1 Allometric scaling relationship between innovation processing (research and its results, in red), population size (in green), and energy use (in blue). All metrics concerning the creative professions scale superlinearly (around 1.25), those related to the size of the population scale linearly (around 1.00), and those related to energy consumption scale sublinearly (around 0.80). The others are either summations (wages, bank deposits, GDP, electrical consumption, etc.) or less dependent (AIDS, crime) upon any of these three categories.

Y	*Beta*	*95% CI*	*Adj-R2*	*Observations*	*Country-Year*
New patents	1.27	1.25, 1.29	0.72	331	US; 2001
Inventors	1.25	1.22; 1.27	0.76	331	US; 2001
Private R&D employment	1.34	1.29; 1.29	0.92	266	US; 2002
"Supercreative employment"	1.15	1.11; 1.18	0.89	287	US; 2003
R&D establishments	1.19	1.14; 1.22	0.77	287	US; 1997
R&D employment	1.26	1.18; 1.43	0.93	295	China 2002
Total wages	1.12	1.09; 1.13	0.96	361	US 2002
Total bank deposits	1.08	1.03; 1.11	0.91	267	US; 1996
GDP	1.15	1.06; 1.23	0.96	295	China 2002
GDP	1.26	1.09; 1.46	0.64	196	EU 1999–2003
GDP	1.13	1.03; 1.23	0.94	37	Germany 2003
Total electrical consumption	1.07	1.03; 1.11	0.88	392	Germany 2002
New AIDS cases	1.23	1.18; 1.29	0.76	93	US 2002–2003
Serious crimes	1.16	1.11; 1.18	0.89	287	US 2003
Total housing	1	0.99; 1.01	0.99	316	US 1990
Total employment	1.01	0.99; 1.02	0.98	331	US 2001
Household electricity consumption	1	0.94; 1.06	0.88	377	Germany 2002
Household electricity consumption	1.05	0.89; 1.22	0.91	295	China 2002
Household water consumption	1.01	0.89; 1.11	0.96	295	China 2002
Gasoline stations	0.77	0.74; 0.81	0.93	318	US 2001
Gasoline sales	0.79	0.73; 0.80	0.94	318	US 2001
Length of electrical cables	0.87	0.82; 0.92	0.75	380	Germany 2002
Road surface	0.83	0.74; 0.92	0.87	29	Germany 2002

Source: Bettencourt 2007, published by permission PNAS. A more extensive table is found in Bettencourt et al. 2013, fig. S3) information processing, and innovation in particular, is its driver (see also Florida 2014). That would explain why the explosion of urbanization and that of material innovations have gone hand in hand to drive our consumption society to its current heights.

That has created a number of major stresses for the urban component of the global system dynamics (UNDESA 2018). Urban systems are costly and highly vulnerable both socially and environmentally. As can be seen in many developing parts of the world, economic inequality, crime, food insecurity, and lack of hygiene all abound in urban systems unless very costly social and infrastructural measures are put in place. The growth of urban systems has hugely increased the (energy-costly) worldwide flows of goods, including foodstuffs and water, as well as an increasingly wide range of other products across the world. It has thus exploded the footprint of the global urban population. The growth of urbanization should also be seen in the perspective of the rural depopulation that is occurring, or has recently occurred, in many parts of the world, uprooting communities, transforming landscapes, and industrializing agricultural production methods in developed and developing areas.

One of the fundamental questions of capital importance for sustainability in all domains of human endeavor is therefore whether the current trend toward further urbanization will continue as is assumed by the linear projections of our current "business-as-usual" scenarios. In view of our assumption that the need for increased communication has over the long term been one of the major drivers of urbanization, it will be particularly interesting to see how the changes wrought by the ICT revolution will affect global urbanization. For some, this may imply that urbanization is at the core of the tensions our world is seeing. But it seems to me that it is merely one of the many manifestations of the fact that our current mode of life (in the developed countries in particular) is butting up against planetary social boundaries.

Globalization

Another long-term trend that we will need to include in our thinking is globalization itself. For five centuries, the European (and later the western) socioeconomic system has spread across the world. Initially this occurred through trade (1500–1800), then (1800–1945) through military and administrative exploitation, and since World War II in the form of economic colonization. But since World War II a countertrend has also been visible, in which colonies gain independence, find their economic footing, and gain self-confidence (in part through learning from developed countries). Now the Euro-American sphere is coming under increasing political and economic pressure. The rise in importance of the BRICS countries is a sign of this; it is bound to be a source of uncertainty for the coming fifty years or so while the world searches for a new political organization. I will discuss ICT's role in this shift in Chapter 17.

An important underlying trend is that a reduction in the dimensionality of metrics (and awareness) of human wellbeing has emerged. Different cultures and populations have been aligned around the dimension of wealth (GDP) as the one by which they compare themselves and transact exchanges.

Other dimensions such as religion, community solidarity, art, and culture have been decreasing in importance as drivers of decision-making except among focused subsets of societies. This in turn has increased the emphasis on wealth, productivity, and growth, and led to the overexploitation of natural and social capital in many regions.

Current populist movements find their origins at least in part in the need to rediscover those multidimensional communal value sets, as was finely analyzed by Karl Polanyi (1944) and members of his school in anthropology (e.g., Graeber 2001; Munck 2004). Elites have been able to make the transition toward a globalized society, whereas a very large majority of citizens worldwide has been left behind, focused on their local community and thus resistant to expanding the spatial sphere of their identity. This has shaped another deep (second order) field of tension that will inevitably play a major role in structuring our world over coming decades.

Summary

To summarize, there are a number of indicators that point to the fact that some of the resources, both natural and human, on which our western societies and economies of the last couple of centuries have been based are no longer amply available, and that this is, or will soon be, causing stresses in the planetary societal system. Are our societies currently moving toward a tipping point that will, whether we like it or not, force them to introduce major structural changes in the way they are organized? Changes of a scale and scope that we have not seen for centuries because our societies are close to exceeding the boundaries of a societal safe operating space? In this chapter, I have mentioned some of the phenomena that point in that direction. As in the case of the environmental planetary boundaries, the inherent major risk is that the different kinds of societal dynamics described will ultimately come to interact in such a way that they will destabilize the current global order. It is therefore fundamental that we no longer look at these different aspects of the current situation in isolation, but as a complex of interrelated factors.

In that light, it is in my opinion a great pity that the world's attention has so far increasingly been focused on CO_2 emissions, greenhouse gases, and climate change. Though that is, evidently, an important aspect of what is going on in the Earth system, it is only one aspect, and dealing with it in isolation, however difficult that proves to be, will not fundamentally change the socioenvironmental dynamics in which we find ourselves globally.

This is not the first time that humanity has faced such a challenge. Looking back some 10,000 years, there have been at least two other moments in (relatively) recent human history where such very fundamental transitions have occurred: the emergence of sedentary, cultivating societies around 9,000 BP and the emergence of urban societies around 5,000 BP. In principle, therefore, humans are able to collectively make such major structural changes in their social organization. However, in both cases this occurred in the absence of a threat to stability at a global scale, and in both cases the changes took considerable time (centuries, if not millennia). Will the acceleration of innovation that has been triggered by the exploitation of fossil energy, together with the accelerating effect of the ICT revolution, enable us to reduce the time needed for such structural social change to the extent that we avoid disaster? To answer this, I need first to present my perspective on the causes of the emerging crisis.

A Complex Adaptive Systems Perspective on "Crises"

Let me now try to conceptualize the concept of crisis that I have introduced as an important dynamic. The study of crises has led to many descriptive publications, case studies, and doomsday hypotheses, from Gibbon (1776–1788) and Spengler (1918) to Diamond (2005), but it is only in recent years that elements of a more general scientific theory of socioenvironmental dynamics, including societal crises or even societal collapse, are emerging, combining insights from four research domains. The natural sciences have contributed to the set of ideas that is sometimes called the science (or theory) of complex systems that is introduced in Chapter 7 (e.g., Prigogine 1977; Kauffmann 1993; Bak 1996; Levin 1999; Mitchell 2011). Social anthropology has contributed in the area of cultural theory (Thompson et al. 1989) that is at the root of our understanding of the societal reactions to different stages of the resilience dynamic (see Chapter 5), and the sciences of organization and information have contributed to our understanding of the dynamics of organization in social structures extensively discussed in Chapter 11 (e.g., Pattee 1973; Simon 1969; Huberman 1988). Some of these ideas on the nature of organizations have been taken up and adapted by ecologists (e.g., Allen & Starr 1982; O'Neill et al. 1986; Allen & Hoekstra 1992). Finally, the first attempt at a synthesis of these different ideas comes from a collaborative effort of ecologists and social scientists (Holling 2001; Gunderson & Holling 2002; Walker & Salt 2006). I would like, in this section, to proffer a metadescription of what causes such societal crises.

In looking for causes of major transitions ('tipping points') such as the one that we are currently facing, and which all societies have encountered at some point in history, we must move away from any specific external or internal causes such as climate change, epidemics, or political (mis) management. These are of course occurring in certain instances, but one must search at a different level of generality, formulating the dynamics in a different language if one is to move from proximate to ultimate causes; causes that truly take into account that such tipping points occur in the evolution of each and every society, no matter what are their natural environment, their specific internal dynamics, or their external perturbations.

As I will argue in the next section, it seems to me that the crises (tipping points, phase transitions) that we are experiencing might be due to two simultaneous – and related – dynamics that combine to increasingly constrain our societal dynamics, narrowing the range of opportunities for their future and at the same time making management of the present more difficult: (1) the accumulation of unexpected consequences of our past actions and (2) the reduction of our value space. In the remainder of this chapter, I will deal with the former; the latter will get attention in Chapter 17.

Accumulation of Unexpected Consequences

The complexity of the Earth system or any of its subsystems is so generally accepted that it hardly requires demonstration. I have argued earlier (Chapter 7) that we need therefore to conceive of the Earth system and its (natural, social and socionatural) subsystems as a complex adaptive system (CAS) in the theoretical sense of the word; i.e., as fundamentally unstable systems of many active agents, in which both agents and processes mutually affect many other components of such (open) systems. The study of such CAS focuses on the complex, emergent, and macroscopic properties of the system that are due to the interactions of these agents. For all intents and purposes, in practice the number of interactive actors and processes at all scales approaches infinity.

Seen in these terms, the infinite complexity of the Earth system contrasts strongly with the limitations of human perception. We saw in Chapter 8 that experimental research as well as a monitoring of the archaeological record, lead us to conclude that the short-term working memory of modern human individuals limits their perception biologically to at most 7 ± 2 information sources simultaneously (Read & van der Leeuw 2008, 2009). Although over the course of human Holocene history, our species has developed an amazing array of techniques to overcome that handicap, from introducing narratives that symbolically refer to more dimensions to the introduction of many abstract concepts capturing more dimensions and to working together in groups to extend the number of dimensions that can simultaneously be perceived, nevertheless human perception, whether individual or collective, has never been able to capture the virtually infinite number of dimensions that constitute the dynamics of the Earth system, far from it.

I pointed out in Chapters 2 and 5 as well as elsewhere that the consequence of this cognitive constraint is that any human intervention in the environment is based on a very simplified perspective on the processes actually going on in that complex environmental system. On the other hand, human impact on the environment is highly multidimensional, as any human action directly or indirectly affects many of the dimensions of the socioenvironmental system involved, many more than are perceived. As a consequence, any human action upon the environment leads to numerous unexpected or unanticipated consequences (Nowotny 2015). Over long-term time, although our knowledge about a certain system may increase (linearly or even geometrically), owing to the difference in dimensionality between our (individual and collective) cognitive space on the one hand, and the complexity of the system of which we are part on the other hand, the unexpected consequences of our actions increase exponentially. Or in simpler terms, though we may (correctly) imagine we know more (and are thus able to intervene and control more), in effect we know less and less about the environmental systems we are dealing with, because in the process of learning about them and interacting with them, we have changed them very profoundly in many more dimensions than we are aware of. Hence, in reality we are experiencing loss of control.

In every socioenvironmental system we therefore encounter a number of tipping points that are inherent in the human–environmental interaction itself, although they cannot be predicted a priori. Often, such crises are seen as events that are brought about by extraneous or unexpected disturbances, whether these are triggered inside or outside the socioenvironmental system. I argue, however, that such crises (sudden tipping points, or to use René Thom's (1989) word catastrophes) are actually the inevitable result of human intervention in the environment and occur whenever a socioenvironmental system is overwhelmed by the unexpected consequences of past actions. One might therefore rephrase the definition of crisis as "A temporary incapacity of a system to process the information needed to respond to keep it coevolving with the context in which it finds itself as a result of its own antecedent actions."

These unexpected consequences, time and again, lead to the need to make fundamental changes in that relationship – resetting the way in which human societies deal with the environment (see Chapter 10; van der Leeuw 2012), and more specifically how they deal with the relationship between their internal dynamics and those in their environmental context (niches), as formulated by Laublicher and Renn (2015). One way to think of this interaction is illustrated in Figures 16.16a–c. In these figures, the thick line symbolizes in a stylized way the trajectory of the environment of a human system and the thin line the trajectory of the human system's information processing. The basic idea is that, according to the principle of unexpected consequences, any human interaction with an environment transforms that environment and reduces the capacity of the society to interact with that environment. Hence, after some time, the society needs to "reset" its relations with the environment to regain the capacity to interact with it efficiently. The three figures show (Figure 16.16a) how not resetting – or not resetting in time – definitively loses the society's capacity to interact with its environment, (Figure 16.16b) how resetting at regular intervals helps maintain the interaction between society and environment for longer, but at some point

(a)

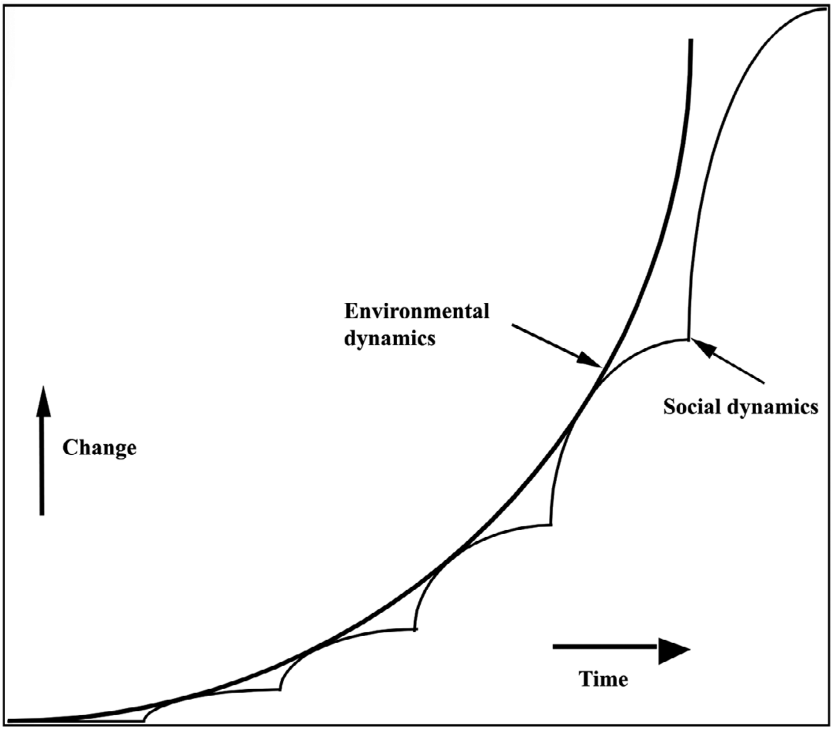

FIGURE 16.16a–c To stay in tune with the environmental dynamics, the frequency and timing of information-processing resets is crucial. (Source: After van der Leeuw & Aschan-Leygonie 2001; copyright van der Leeuw)

at the cost of more drastic resets, and (Figure 16.16c) how irregular and frequent resetting enables the society to maintain closer and more effective interactions with its environment.

It should be added that as the group of interactive humans grows, and its social structure becomes more and more complex, the nature of the required resets changes. Initially, in a simple, small society (such as an isolated village), the resets are predominantly a question of adapting the societal component to changes in the natural one, but as the group grows, and societal complexity grows superlinearly with it, the spectrum of the resets shifts toward the social domain, which comes to dominate the environment.

That shift also has consequences for the frequency with which resets occur and the speed with which they happen in order to retain the cohesion of the society's relations with the environment. Initially, in the

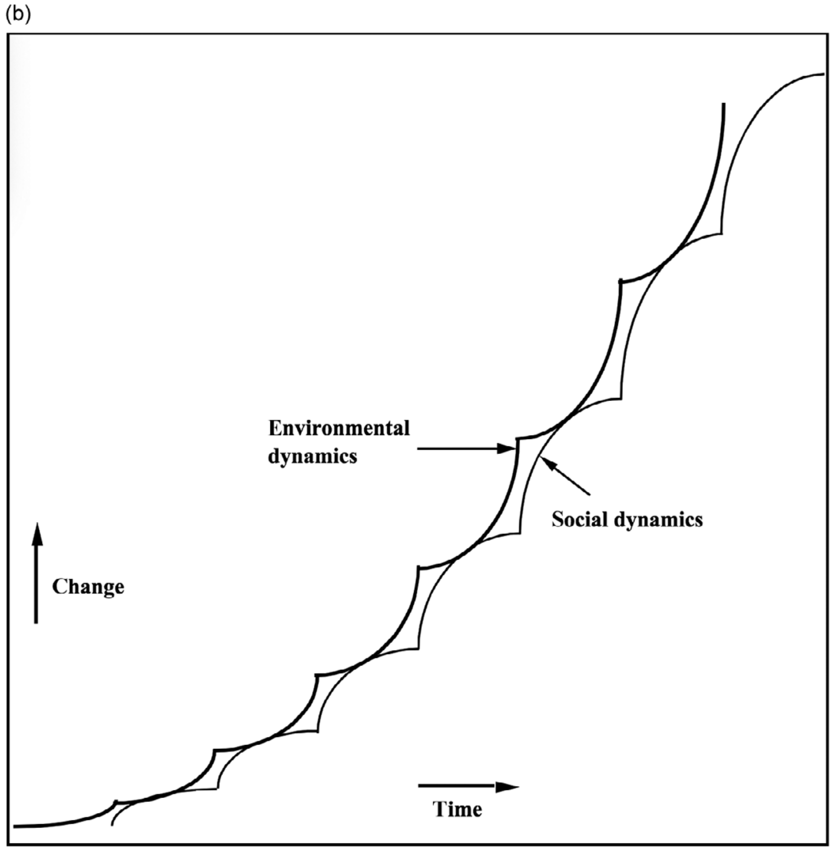

FIGURE 16.16a–c (*cont.*)

simple social situation, the environmental dynamics have a much higher dimensionality and are therefore more complex and slower to change than the societal ones (see Ch 14). The human dynamics, which can potentially be faster (because humans can learn), can adapt to the slower environmental ones. As the societal dynamics grow more complex, and human intervention in the environment has reduced its complexity, the societal dynamics come to dominate the interaction, and societally driven adaptations are likely to follow each other faster and faster. That seems to be the current situation in the Anthropocene.

Finally, I would emphasize that these second order dynamics do not only concern the interaction between societies and their natural environments. Because all human interaction with other human beings, but also

(c)

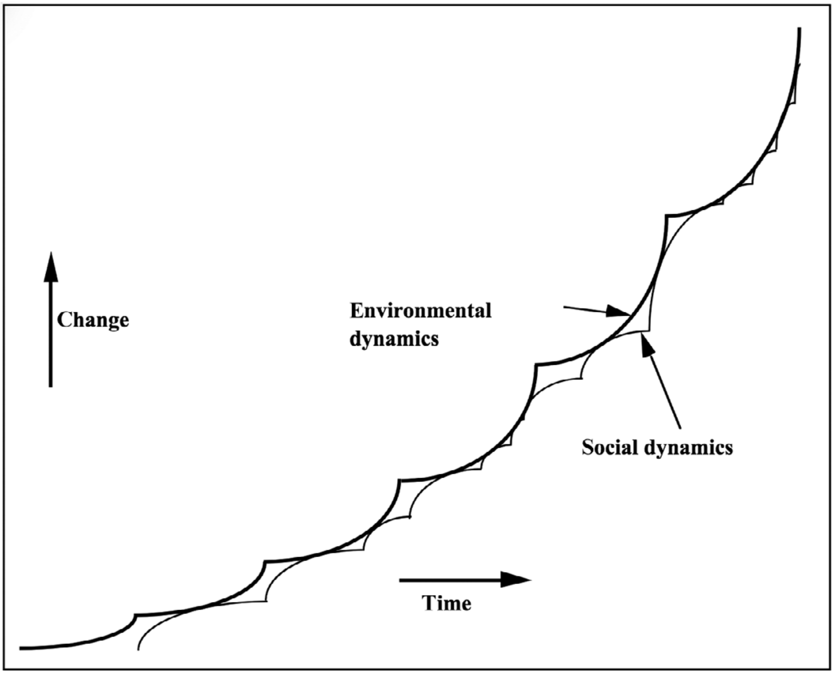

FIGURE 16.16a–c (*cont.*)

with ideas, materials, institutions, and everything else combines the dimensional limitations of human cognition with action upon a system that is much higher in dimensionality, it actually concerns any human perception–action loop, including the ones that play out in the purely societal and social, the technical, and the economic domains.

Referring to the current condition of the world system, I would argue that in the above process we have come now to a point where the gap between our societies and their global societal and natural environments, particularly in the developed nations, has grown so wide that a very major reset has become necessary. The Industrial Revolution is an excellent example of such a reset: the overall growth of European societies led to major societal tensions that were dissolved (after a considerable period of adaptation) into the kind of societal organizations we have nowadays in the western world, including new institutions, new ways of exploiting the environment (particularly in the colonies), new technologies, a huge advance in general education, and so forth. But those nineteenth- and twentieth-century innovations have now served their time, and have become maladaptations in need of a new readjustment (van der Leeuw 2016). Our societies have (temporarily?) no longer the information processing capacity to deal with the accumulation of unexpected consequences of our earlier actions, and are therefore incapable of constructing effective, durable, relationships with our environment(s). That is one of the dynamics that is constraining our current and future development as global societies – we urgently need to move to a basin of attraction that is not dominated by those unexpected and unanticipated consequences of our earlier actions.

NOTES

1 After writing this chapter, I was asked to be lead author of a substantive team writing chap. 2 of the report "*Transformations to achieve the sustainable development goals*" (TWI 2050) prepared by the The World in 2050 initiative under the patronage of the Stockholm Resilience Center, the International Institute for Applied Systems Analysis, and Columbia University. I have gratefully made use of the results of that effort to revise and enrich the materials in this chapter, and thank all members of the team for their contributions.

2 Though there are a considerable number of critiques of his work, and in particular of his policy conclusions, it seems to me that the main phenomenon illustrated by him – increasing wealth differentials – is real.

3 As a non-economist I cannot vouch for the quality of these statistics, or go into the details of the dynamics behind them, but all of them converge so strongly that there is in my mind little doubt about the phenomena responsible for them.

17

Not an Ordinary Tipping Point

Introduction

It is clear that we are hitting a tipping point, but it is no ordinary tipping point. I will argue in this chapter that this moment of crisis is a mega-mega-tipping point. Actually, taking a long-term perspective, it is one of the three most consequential tipping points in human history. The other two were the mastery of matter (which took, as we saw in Chapter 8, a couple of million years to achieve) and the harnessing of fossil energy (which took about two centuries). This raises a question about how leaders can plan in a system where unintended consequences and extreme nonlinear events become increasingly frequent.

One of the themes of this book is to show how the organization and functioning of human societies has always been shaped by challenges in information processing. An interesting role was played in this process in around 300 BCE in Europe, possibly earlier in China, by tokens and (later) coinage and money, whereby the transmission of information through the mechanism of price indicated a combination of values. In Europe, this became especially relevant in the Renaissance, when a variety of fiduciary financial instruments was developed. Financial values became important indicators of the wellbeing of princes and nations as well as individuals, of the desirability of goods, and the risk involved in acquiring them. Another important early phenomenon that played a major role in this process in Europe and China was the introduction of printing, and the huge transformation that this engendered in spreading information much wider (see Bonifati 2008).

But until very recently human societies have never been confronted with the isolation of information as one of the three basic commodities of life (alongside matter and energy). Nor have societies found ways in which to divorce information from most of the material and energetic substrates and channels through which it was transmitted. This process began in the late nineteenth century (see Gleick 2011) and has accelerated in the last sixty years or so. It is only some twenty-five years old as a mass, global phenomenon.

This is not the kind of transition that we will be able to cope with by simply becoming more resilient as individuals or as societies, all the while remaining more or less organized as we have been. If you do not believe this, I refer you to the overview of the ongoing changes by Thomas Friedman (2016). In this book, he sketches the changes that are currently being wrought by acceleration in several domains. Of these, the environmental domain is best known. But other accelerations are playing into the same process, and together they are wreaking the kind of destabilization of our societies that may lead to chaos – in the strict and scientific sense of the word – a drift toward total unpredictability of the behavior of our societal (and therefore our socioenvironmental) systems. The main drivers that Friedman outlines are among those I mentioned in Chapter 16, notably demography, technology, finance, and environment. No doubt governance should be added to these (see Haass 2017). I will deal with each of these in turn. But this is not all. The fact is that the interactions between the accelerations in these domains are only beginning to be perceived; they are beyond our collective control, and so far we have no idea how to deal with the second order changes they may be triggering.

Of course it will not surprise any reader when I emphasize that these changes are intimately related and part of one and the same dynamic that seems to be getting out of hand: unintended consequences of earlier actions and decisions that are being reinforced by the acceleration of information processing, driven by increasing interactivity between more and more people who are in possession of more and more complex and effective tools for thought and action. Several centuries of reductionist thought have both linearized complex phenomena to make them more accessible, and compartmentalized knowledge within disciplinary systems. This in turn has reduced the frequency of intuitive insights into such complex, nonlinear systems. While thinking that they gained more knowledge, people have lost an understanding of the socioenvironmental systems they had modified in their attempt to bring parts of them under control. But before I look in some detail at these changes, I would like to put them in perspective.

The Acceleration of Invention and Innovation

For most of human history, inventions by individuals were only transformed into innovations at the societal level if there was, whether consciously or unconsciously, a need for them (and such a need was not necessarily owing to a challenge; it could be an emotional need, such as in the case of jewelry and similar objects) and if there was enough free energy and matter (wealth, in the sense of human, social, and natural capital) available to implement them. The pace of societal change was limited by these two requirements for societal innovation, and so was the change in value differential between society "insiders" who were part of the innovating community and "outsiders" who were not.

We have seen that this changed from around 1800 with the introduction of ways in which to use fossil energy on a massive scale, and the Industrial Revolution that this enabled. As the energy constraint was relaxed and collective human information processing was favored by new innovations (as in transport, communication, finance, urbanization), the last two centuries saw a rapid acceleration in which information processing ultimately replaced energy as the main constraint, and marketing enabled innovators to create demand for their products. In the process, this fostered an important increase in wealth differentials, the exponential growth of cities, our dependency on the fossil energy industry, and globalization driven by the consumption society. On the other hand, it also fostered the emergence of improved education as a fundamental societal need. The acceleration of information processing is accentuating, at least for the moment, these tendencies. This shift has hugely reduced the chances that outsiders become insiders, creating an extraction-to-waste economy (in terms of raw environmental limits (Steffen et al. 2015).

We saw in Chapter 15 how, because of the territorial limitations of national governance, this system's spread around the globe has enabled – but has also been driven by – growth of the large multinational corporations. Their impact outside the core of the western world has slowly but surely, since 1950, incorporated regions that were culturally and socially fundamentally different into that extraction-to-waste economy and made it truly global. By adopting certain decision criteria in both the economic and the social sphere, they drove individuals, groups, and countries to gradually adopt wealth-directed mindsets, activities, and institutions that are compatible with globalization's wealth-based urban logic.

In the last thirty years, this process has accelerated, and it is now reaching the conurbations of China, Indonesia, India, and Nigeria, for example. This will not only accelerate global warming, resource shortage, and the material basis of our world's social systems, but it will also become more accident-prone because more and more of the dynamics of the system are becoming interconnected, ultimately leading to hyper-connectivity and thus becoming unduly sensitive to minor disturbances in one place or one sector or another (Helbing 2013). This will (inevitably and differentially) impact the vulnerability, resilience, and adaptability of different scales of the system (Young et al. 2006).

The Acceleration in Information Processing

I have used a dissipative flow structure model that is based on feedback and feedforward loops between perception, knowledge, information processing, growth of communities, increased use of energy, and accumulation of unintended consequences to describe the evolution of societal structures through time in dynamic terms. In this long-term development, increases in human information-processing capacity have been central.

Until the middle of the nineteenth century, matter, energy, and information were closely embedded in each other while being transmitted orally, in language, in writing, in the shape and qualities of artifacts, but also in the structure of organizations and institutions. Oral communication between people embedded information in language and gestures, blinks of an eye, or a smile. Artifacts informed substance and simultaneously substantiated information into tools for action, which thus became essential parts of the information-processing systems of societies.

Writing was a major step in disembedding information by substantiating symbols with informational meaning onto different material substrates, and thus facilitating communication beyond immediate interaction between people and beyond unity in time and space. Printing popularized this means of communication. With the telegraph and telephone, other steps on this trajectory were set, transmitting information in the form of pure (electrical) energy, and thereby hugely reducing the cost of communication. But this electrification did not extend to the processing of information.

At the root of the current tipping point is the fact that presently information is processed in the digital form of 1 or 0 (on or off) in electrical circuits. This fundamental difference from earlier tipping points is profound, as it has enabled the emergence of computing, the Internet, artificial intelligence, and all that has come with it.

This disembedding of information processing is (for the moment) the last stage in the story of societal information processing. For the first time in the development of human societies on Earth it has enabled the (semi-) independent processing of information by machines, and this in turn is the major driver of the transition that current human societies are facing. We all know that this digitization of information processing has changed the world, but looking in more detail at *how* it has changed the world is worthwhile.

The Information Explosion

In sustainability science, the term "the great acceleration" captures the fact that since the beginnings of the eighteenth century resource use and pollution of the Earth system have exploded. But in the context that we are talking about here, I want to draw attention to the fact that the great acceleration has, since about 1970, been further speeded up by electronic information processing.

Recall for a moment the information-processing feedback loop that is driving societal dynamics and the transformations in them (see Chapter 8):

> Problem-solving structures knowledge —> more knowledge increases the information-processing capacity —> that in turn allows the cognition of new problems —> creates new knowledge —> knowledge creation involves more and more people in processing information —> increases the size of the group involved and its degree of aggregation —> creates more problems —> increases need for problem solving —> problem-solving structures more knowledge . . . etc.

Until the information and communications technology (ICT) revolution, this feedback was relatively slow – initially it took a very long time to master the processing of matter, then less time to master the use of fossil energy, and lastly even less time to master aspects of information processing by developing electrical and electronic communication systems. But dealing with these tipping points is not the only way in which human information processing has set a limit on the speed with which societies could adapt to change. All our means of information processing, including institutions, economies, languages, and ways of life have all coevolved with information processing over considerable periods of time in which humans were able to change their behavior, adapting to innovations and novel circumstances. In that interaction, information flow and information processing have until recently been the main constraint on the speed of coevolution. Human individual learning, and especially collective learning of groups, accelerated only slowly as long as information processing and communication were constrained by human cognition, which also required domestication of resources, innovation, cultural alignment, building institutions, education, and much more, so that larger and larger groups could become interactive. Interestingly, the groups in society that have generally been more receptive to the importance of accelerated information processing were the Church, some of the nation-states, finance, and the military. The Roman Catholic Church had Europe's first efficient information acquisition and transmission network, and this was followed by those of the major financiers of European princes and kings (e.g., the Fuggers and later the Rothschilds, who made a fortune by being the first to transmit to London the news of the defeat of Napoleon at Waterloo).

But now technology is reducing the temporal dimension of (digital) information processing to (near) zero by disembedding it from humans, transferring it to machines, and collapsing the change in information processing from a slow long-term process into a nearly instantaneous one. This in turn has created the potential for accelerated change, and because more information is processed, an increase in the overall information diversity, which in turn might lead to more change. This is part of the impact of the forty-odd years of exponential technological acceleration in information processing that is summarized in Moore's law, which states that computer information-processing power doubles on average every eighteen months (Figure 17.1).

The result is, on a linear scale, an explosion in electronic processing power (Figure 17.2; for details see Brynjolfsson & McAfee 2011).

But over and beyond this accelerating hardware evolution, the last forty years or so have also seen a very quickly accelerating algorithmic software evolution that has further accelerated our capacity for information processing. Human information processing is no longer able to deal with this acceleration. As roughly calculated by Friedman (2016),

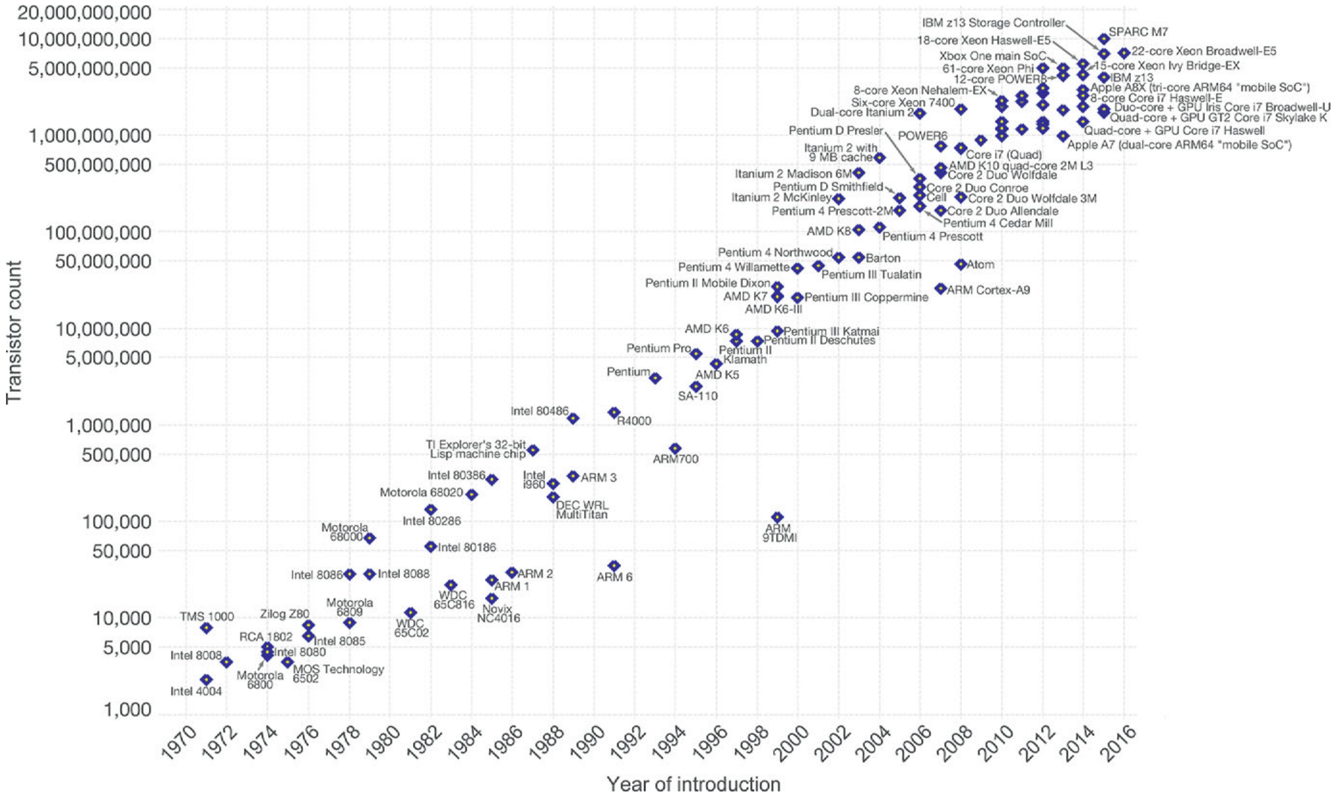

FIGURE 17.1 Moore's law: logarithmic representation of the increase in computer information-processing power 1970–2016. (Source: Wikipedia under CC-BY-SA from *Our World in Data* by Max Roser)

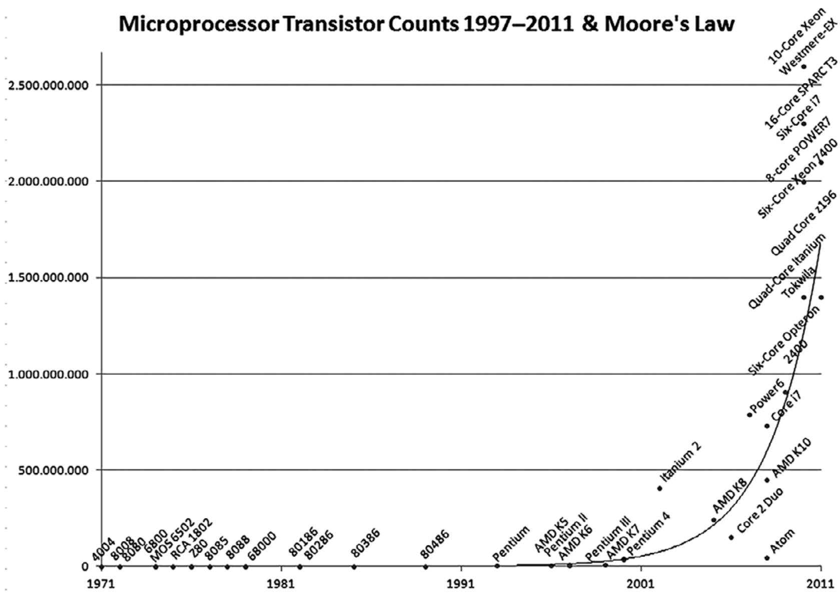

FIGURE 17.2 Linear representation of Moore's law – a very rapid explosion of computer information-processing power since around 2006. (Source: Wikimedia under CC-BY-SA)

technological generations (periods of relative stability between major changes) last some five to six years, while human information processing takes up to fifteen years to deal with such major changes.

This has resulted in a quickly growing gap between the rapid acceleration in the technology of information processing and the capability of the very large majority (99 percent or more) of human beings to deal with this acceleration. Among the people and machines directly engaged in the coupled information-processing system, we see an explosion in the number of dimensional combinations, and thus of their invention space. The elite group able to cope with this is getting smaller and will continue to decrease as machines overtake specialist knowledge that is based on the mastery of data sets, such as routine legal and medical processes. Those who are not part of this small community will be left behind. The elite group has a greatly enhanced opportunity to accelerate invention, but the adaptation of society as a whole to these inventions is much slower. This situation is profoundly affecting our societies in their capability to absorb change – in ways that have never been observed before. I will come back to the social consequences of that acceleration in Chapter 18. Here I want to outline some of the ways in which the ICT revolution seems to be changing basic assumptions about our social and societal dynamics.

Changing Relationships between Society and Space

To begin with, the ICT revolution is rapidly and fundamentally changing our individual and societal relationships to space and time. Many authors have been noting, for a considerable time, that the world is "getting smaller." What is going on? On the one hand, since around 1800 the acceleration of our transportation methods (trains, cars, airplanes) has reduced the temporal investment in going to other places and has increased the frequency of such displacements. But the ICT revolution has very rapidly accelerated this development by enabling anyone to share any information immediately all across the world. Cyberwarfare is one way in which this is manifesting itself: interference in the internal dynamics of foreign nation-states at a level until now impossible.

But the consequences of the changing relationship between humans and space go much further. The first anthropologist I know to dedicate some of his work to the profoundly changing role of space and place in the modern world is Marc Augé (1992), whose study is significantly titled *Non-lieux: Introduction à une anthropologie de la surmodernité* (which may be freely translated as "The absence of place: introduction to the anthropology of hypermodernity"). In particular, Augé focuses on those places where all sense of particularity has been removed so that people move anonymously in them: train stations, airports, etc. One could add many shopping malls in the USA to this category. But Augé draws in part on a more long-standing debate in geography, of which one of the clearest expressions is found in the work of Tuan (1977) who drills down into how human perception and action create a "place," a location created by human experience in a wider, non-experienced, space. In emphasizing that in the current world there are locations where that dimension of human experience has been removed to facilitate movement, flow, and anonymity, Augé in my opinion hits on a core aspect of the impact that ICT will have on our lives.

At a very different level, this development is what I think might ultimately undermine the current reliance on defined territories, such as municipalities, provinces, states, and nations. All of these are in effect administrative entities created to deal with localized, multipurpose information processing. They grew from the bottom up, as political and economic power was spatially extended by subsuming smaller entities into larger ones. This is easiest to follow in France, Germany, and Italy, where unification happened as described in Chapter 14. This led, in France in the seventeenth century and in Germany and Italy in the nineteenth, to the creation of the current European nation-states.

Not all power has always been territorially distributed and limited. In Europe, in the Carolingian era, in case of conflict people were not judged by the rules of the location where they found themselves, but by the laws and customs that were traditional for the tribe or people to which they belonged (Faulkner 2013). The rules and customs of these tribes survive to this day, such as the *Lex Baiuwariorum* (concerning the Bavarians) and the *Lex Francorum* (concerning the Franks). For a long time, well into the Renaissance, foreigners visiting or living in one of the Italian cities were subject to the oversight of the head of their "Fondaco" the entrepôt in which they had to store their wares and which they used as a basis for their trading. All members of a nation were required to reside in the Fondaco allotted to them. Thus, again, they were judged not according to the place where they were, but according to the customs of their nation or tribe. The same is true of the concessions established in Shanghai (China) after the Opium Wars (1830–60): these were extraterritorial colonies granted by the Chinese authorities to groups of foreigners belonging to one of the western colonial powers. Territoriality is not a natural state of affairs, but one created by specific circumstances. It is interesting to note in this respect that the USA is one of the few developed countries that maintains some extraterritorial aspects in its legal system, in particular in taxation (US citizens pay tax on their worldwide income), financial transactions (when they are in US dollars, anywhere in the world, the USA assumes that they are subject to US laws), and the fight against corruption (forbidden by US law wherever it occurs).

The question facing us now is whether, as distance is shrunk to the extreme by the ICT revolution and people are increasingly placeless, other, non-territorial modes of organization might emerge. An interesting example of this is the current policy of Estonia, which accepts applications for e-residency from anywhere in the world. E-residency creates an information technological identity in Estonia, which is valid for any transaction in the world but is governed by Estonian rules, without the need for the parties concerned to be resident in the country. Thus, a global virtual entity and community are being created for transactional purposes, in which location no longer plays any role. Were other countries to follow the Estonian example, location would no longer define the laws and statutes governing a person or firm's transactions; instead, the organization that guarantees the transactions, wherever in the world it is based, would do so. One can imagine many other examples that would give individuals the facility to work globally, not unlike the way in which multinationals have done for a long time, enabled by their financial and legal firepower.

The Impact of ICT on Time and Its Societal Management

The concept of time and its perception constitute a booming research field in psychology, philosophy, and related disciplines, as is clear from the remarkable publications of the International Society for the Study of Time (www.studyoftime.org/), which since 1966 has met once every three years, often in very exclusive locations, but also from numerous papers in a wide range of journals. An interesting summary is presented in Wikipedia (https://en.wikipedia.org/wiki/Time_perception, consulted June 3, 2019). I do not want to explore the many theories and explanations proffered, beyond accepting that time perception is subjective and individual. What interests me here is the evolution of the relationship between the subjective and relative individual perception of time and the societal management of that perception, which requires that people to some extent share, at least for certain purposes such as meeting each other, a sense of time as well as location (but not place in the sense used above). In our society, that is the role of clocks – external, mechanical devices that offer an objective measurement of time, and in doing so control to some extent human behavior. Among the simplest of such devices are sundials, in which a stick projecting a shadow on a calibrated surface indicates time as a function of the path of the sun. It indicates time relatively roughly, at intervals of one hour between calibrations. Another such simple device is the hourglass, in which the flow of water or fine sand between the upper and lower half of the glass is regulated (by defining the size of the hole through which the sand or water moves) so as to empty one half (and fill the other) within a specified amount of time. Its advantage is that it also works at night, which is important on ships, for example. Moreover, the length of the interval can be varied, so that such a device can measure very different units of time. But its disadvantage is that one has to turn the glass every time the flow has stopped, so that the process can begin again.

How have we, in our society, come from such relatively simple, local devices to clocks that measure time in milliseconds or even finer, such as the atomic clocks that now regulate time across the world? Mechanical clocks, introduced in fourteenth-century Europe, had the advantage that they worked day and night, had to be reset less frequently than hourglasses, but initially also had only one indicator calibrating hours. Over the centuries, clock- and watchmakers managed to calibrate time measurement in finer and finer units (minutes, seconds), and related their time measurement also to the motion of the sun, the moon, and certain planets. The core process seems to be that larger and larger communities have delegated their time management to mechanical devices of increasing precision, so that transactions can be managed more and more precisely. In that context, individuals voluntarily suppress their personal, internal experience of time to the societally agreed external time management metrics.

How is the ICT revolution likely to affect this long-term trend? We can imagine this by placing the evolution of time management precision in the context of the wider evolution of our information-processing systems, and in particular the growth of the volume of information that we, as humans, process. The rapid increase in knowledge and the increasing size of networks of interactive people that is concomitant with this increase point to the fact that the amount of information processed by each individual in our societies has grown very rapidly, as has the overall information flow that is managed societally. One wonders whether there might be a dynamic relationship between the size of the flow of information processed by an individual and that individual's time perception on the other. This would seem to be confirmed by everyday experience: the fact that when an individual is very busy (processing a lot of information) time seems to be flying, whereas if information processing falls below a certain level, time is perceived to be moving very slowly. If we adopt such a relationship as a working hypothesis, then the growing volume of information processed by each individual in society would seem to relate to the increasing subdivision of temporal intervals in individual time perception and in societal temporal management. As the ICT revolution is likely to further increase the volume of information processed individually and societally, this would further reduce the size of units of human time management, possibly to the point that only closer integration between people and computers can deal with it.

Exploding Connectivity among Tools for Thought and Action

The acceleration in digital information processing has changed our relationship to information itself in many ways. To begin with, it becomes much easier to deal with very large volumes of information. This has been captured under the term "big data," which has been closely tied to the fact that more and cheaper sensors, increased processing capacity, and cloud memory have exponentially inflated the total volume of information that we can collectively process. But a closer look at this increase also shows that the ICT revolution has engendered an even more rapid increase in the connectivity between different dimensions of the information processed and different information signals.

In the technological domain, for example, the number of recombinant innovations (innovations that link existing novelties in different domains) has been increasing for at least forty years (Strumsky & Lobo 2015). But the ubiquitous availability of information from across the globe, and the improvement in ways to search for, and identify, complementary components is accelerating this process even further. It has enabled an important shift in the economics of innovation in our societies, from reliance on originating (rare) innovations that open up a completely new technology) toward reliance on such recombinant innovations (see Brynjolfsson & McAgee 2011).

This also affects our individual and social lives, through such innovations as search engines and social networks. For those who can connect to the Internet, linking disparate pieces of information has become much easier, and this in turn impacts in major ways on our intellectual and social lives. We can keep up with the detail of one another's lives and can trace the whereabouts and history of people with whom we have lost contact as much as forty or more years ago through social media, and we can quickly explore and link diverse intellectual ideas by using search engines, and thus generate (recombinant) intellectual novelty. Moreover, this capacity can recycle existing information that has thus far been ignored or overlooked.

Reduction of Control over Information Processing

We can now communicate instantly with many people in the world (though about 3 billion are still excluded from this), and at an infinitesimal additional cost in energy, even though the investments in human, financial and material capital to achieve this are very considerable. Those investments have completely changed the human interaction model that has driven societal dynamics up to this point. The fact that anyone can instantly transmit information to anyone, whether one on one, one on many or many on many, and that such information can then be processed individually by all concerned, has created such a huge amount of potential redundancy in the information processing of societies that everyone is instantly informed of everything happening elsewhere on the globe unless they protect themselves against this.

This development is progressively, at least for the moment, transforming information processing without central control (see Chapter 11) into information processing without *any* control. In distributed and heterarchical information-processing systems there have always been nodes that controlled some of the information processed, whether through enforcement, through institutionalization, through incentives, or otherwise. These nodes were the basis on which current nation-states were managing the large numbers of members of these societies, as well as keeping non-members out. Each of these nodes involved only a limited number of people, and there were barriers to the flow of information between them, whether in the form of spatial isolation, differences in culture, identity, or administrative organization and other means. This enabled such nodes to organize themselves, to maintain their (different) organizations over time, and to align their members on certain basic values, procedures, and institutions.

Currently (the early twenty-first century), the spread in information processing that culminated in the Internet and its many applications is removing such voids and barriers. We are witnessing an explosive increase in horizontal information processing, at all levels of society. This has a wide range of consequences. For example, it has further facilitated the imposition of the values of developed nations on other parts of the world, a process that was (slowly) set in motion in around 1800 CE by the spread of colonial administrations and multinational corporations. In most cases where a preexisting non-western approach to information processing was confronted with the western one, the result has been a fusion at the level of the lowest common denominator – material culture, consumerism, and, even more basically, money. Other domains, and other values, were not so easily integrated, and in many instances differences between cultures have now become a source of friction. This focus on a global lowest common denominator has in many places contributed to the relegation of other values (many of which constitute the deeper meaning of wellbeing) to "noise."

Blurring the Boundary between Information and Noise

On a more fundamental level, the loss of control over information processing has changed the status of information itself, which is of course dependent on a distinction between signal and noise. Numerous Internet sites that proclaim to provide news can and do launch egregious information that has little or no relationship with commonly experienced social, political, economic, or environmental realities. For many people, it is difficult to separate such information from that provided by trusted institutions that adhere, more or less, to certain collective standards, and at the collective level this is undermining the distinction between signal and noise – and the alignment of people around sets of values as embodied in (sub)cultures at every level.

In due course, this results in changes in the relationship between data and observations on the one hand, and knowledge or understanding on the other. As I emphasized earlier in Chapter 8, information processing is dependent on a reciprocal, interactive, and self-referential relationship between these two (Luhmann 1989). That interaction is responsible for the distinction between signals and noise. Knowledge or understanding enables someone to interpret patterned data and observations, relating them to ideas, but the fact that the data never completely fit the extant ideas exactly allows the person interpreting them to enhance his or her knowledge and understanding. Over time, this has enabled individual societies to develop, path dependently, different relationships between observations and knowledge or understanding, leading to different cultures. But the reciprocity between phenomena and ideas also facilitates the reverse: to use personal insights or opinions to elaborate presumed data and observations.

In our societies (and our sciences) we have thus far generally adopted the first of these interactions, gaining knowledge and understanding by observing patterns in the realm of phenomena. Now, however, there are people and places on the Internet where the reverse is done, whether deliberately or by default. They present data or factoids that are constructed based on their worldview. In itself this is nothing new – the rumor mill has always, in every society, had this effect. But in the global information society it is often much more difficult, or even impossible, to find out how any piece of information has emerged, and what its relationship to the realm of phenomena is. Over time that could fundamentally undermine the existence of all social institutions, and of the societies that have created them, because it obfuscates the boundaries between the dissipative flows that structure our societal interactions (and give meaning to the information processed by them) and the surrounding stochastic chaos. Individuals would lose their alignment and direction, feel lost and immobilized by indecision, or try to create their own dissipative flow structures based on their own values. Many of these structures are ephemeral, closely aligning insufficient numbers of individuals, and are thus doomed (see Chapter 11), but others gain a wide enough audience to persist and become important in our lives (such as, for example, the Breitbart alt-right website).

A Society's Value Space Determines Signals and Noise

In the relationship between observations, information, and knowledge or understanding, values play an essential role, as they are the basis of what distinguishes between signal and noise. They are, in effect, intangible instantiations of our information-processing structures, and play an essential role in determining or constraining the path dependency of socioevolutionary trajectories. In that sense, they play a role similar to that of artifacts and the technologies underpinning them.

I will now try to delve a little deeper into their importance. My starting point is that a society's values are of fundamental importance for its existence. They align its members around certain information and resource flows, enable them to distinguish between signals and noise, and to communicate, collaborate, and express differing opinions. Communication, collaboration, and differences of opinion are all anchored within a set of – usually partly implicit – values that the members of a society share and the relative priorities they accord them. We could call this the society's value space. I define this neologism as including the total set of dimensions according to which a society attributes value to ideas, actions, institutions, material goods, etc.

Sharing such a value space does not mean that all members of the society have exactly the same conception of these values – it merely means that their conceptions are sufficiently close to facilitate frequent constructive interaction. We could say (with Binford 1965) that people partake in their culture. Their differences are the result of the fact that each person acquires, during his or her lifetime, an individual cognitive system (worldview) that emphasizes certain dimensions of the shared values of a society more than others. Following the extended evolution approach of Laublichler and Renn (2015), one might say that the values of individuals are effectively determined by the socioenvironmental network of which they are a part, and this network, of course, varies for everyone, even if minimally. As a result, all but the smallest social groups that have lived together for a long time in isolation have value differences between their members. (In the term I used in Chapter 11, such societies have more or less heterogeneous information pools.) Those value differences play important roles in a society. For one, they allow individual members or groups within it to create an identity that distinguishes them from other members or groups in the society. That differentiation also drives continued communication and information exchange between individuals. (In the purely theoretical case that all individuals were identical, there would of course be no reason to exchange information, and thus no reason to interact.) Such exchange of information in turn drives societal change and is thus responsible for societies' coevolution with their environments. Observing value differences between individuals, groups, or societies, for example, can give rise to the desire for change and lead to anticipation, while the exchange of information promotes the emergence of novel ideas and values, and thus stimulates invention and innovation. Partaking in a society's information exchange necessitates acquiring knowledge of the society's language, categories, symbol systems, and other aspects of its tools for thought and action, including its organization, its institutions (again, in the widest sense), and its belief systems. As individuals and groups adopt these, in essence they align their ideas among themselves. The interaction between shared values and value differences within a value space is thus responsible for the coherence of groups of individuals within whole societies.

Value differences are also the drivers of material exchanges. Among other things, they can be due to individual or group preferences, to local environmental conditions, to the availability of certain resources, or to the cost (in energy terms) of acquiring them, adapting them to one or more particular (desired) functions, or transporting them. The differences will prompt people to interact, and to exchange both information and material resources and objects. This is the basis of trade, and of our economies.

The Dynamics of Value Spaces

In all societies, values are given according to a wide range of criteria and in a wide range of dimensions, dependent on the networks in which individuals and groups partake. Anthropology can be seen as the study of the different values of different groups, communities, or societies. As such, it focuses on their diversity, and thus on the diversity of worldviews, and has established the fact that, indeed, different societies have very different value spaces. Economic anthropology studies how these different value systems (or value spaces) categorize and accord different values to resources, materials, objects, institutions, and customs, and has developed approaches to explain exchange systems in terms of their value spaces. It has thus emphasized the diversity of exchange systems that results from different worldviews.

When a society is engaged in a growth process, and therefore appropriates more and more matter and energy, it does so by extending its information-processing capacity to more and more people and resources, aligning them but also incorporating in the value space of the society more and more knowledge, so that it can access the necessary matter and energy. It is a corollary, therefore, of any growing society that it expands its value space by innovating, generating new ideas and ways to do things, and thus transforming its organization. Such innovation is fundamental to the survival and growth of any society, path dependently building upon and developing, the core values that anchor the development.

But there are limits to the extent to which the organization can be transformed because another particular aspect of human cognitive systems eventually comes to play a major role. This is the fact that our theories (including our categories and the perceived relations between phenomena) are in effect under-determined by our observations. This is nicely illustrated by Atlan (1992). He takes as example a set of five traffic lights that can each assume three states (red, orange, green). The total number of states of this system is 3^5 or 243. But the number of potential connections between these states, which could explain their dynamics, is actually 3^{25}, or 847,288,609,443. To decide which of these is the "right" one would require a number of observations close to the number of possibilities – something humans never achieve in real life. The corollary of this phenomenon is that our theories and actions are generally over-determined by those among our prior experiences that we consider relevant. As a result, the trajectories our socioenvironmental systems follow are path dependent in the sense that 'change is hard': it is very difficult to deviate from a particular trajectory once one has invested substantive thought and material, institutional, or financial means or efforts in it (let alone emotions). In times of crisis this affects both the speed and the extent of changes that may be implemented.

As I argued in Chapter 9, our current sociocultural and economic structure has been elaborated over time in an interactive process of problem-solving, generating new (unanticipated) problems, solving these problems, encountering new problems, etc.. Structurally, those new elements have been grafted onto an existing information-processing structure every time it was necessary to deal with a challenge.

One sees this most clearly in the inherent development of bureaucracies, but this process is not limited to such organizations – it permeates all we do as humans, including our mental structures. In the course of this process of grafting, certain aspects of our society's mental and practical functioning are smoothed or rendered more efficient, but because every intervention has unintended consequences, such actions also cause unintended (and often unperceived) inefficiencies that emerge with time, again hindering any efforts to deal efficiently with the dynamics that the system is involved in. The accumulation of such maladaptations causes the structure to become less and less efficient, and thus more and more costly to operate.

Simultaneously, as the structure evolves, it merges functions or otherwise simplifies certain parts of its structure to deal with the most frequently occurring kind of information processing that it is called upon to undertake. The combined effect of these two tendencies is that the information-processing structure becomes more and more robust, focused on fulfilling a precise, well-defined set of functions, and resistant to change. Inevitably, in that process, the mental and organizational structure becomes more and more coherent and narrowly path dependent, and it becomes more and more difficult to add new values to the value space. More and more dimensions that are compatible with the structure of the value space will be discovered and exploited by innovation, but ultimately there comes a moment that this becomes increasingly difficult.

To put it differently, a core value system will inevitably lead to the construction of a set of utility functions. Initially these may be relatively loose, representing diversity within a group. Over time, experience and complexity will expand them but also harden them to increase their efficiency. Continued hardening leads to the dominance of a few terms and an effective loss of dimensionality. Eventually the functions can no longer adequately adapt and become brittle. This is what I mean by reaching the limits of a value space. It results in an important increase in unintended consequences of earlier actions (see Chapter 15), and in a reduction of the potential of the value space to facilitate the implementation of new inventions.

This in turn creates an increasing incompatibility of the value space with the environment it is created to deal with. This leads to a tipping point, when the existing value space is opened up, so that the definitions of categories and theories, but also of institutions and customs, are weakened by the reduction of their dimensionalities. They can thus ultimately be destroyed or replaced by other structures that constitute a novel value space.[1]

Wealth as the Predominant Global Metric

From my anthropological perspective, it is astonishing to see the extent to which in our own western culture the dimensionality of the value space has shrunk, leading to an increasing focus on productivity, gross domestic product (GDP), and technology. This has emerged since World War II under the impact of the growing power and influence of free market economics worldwide.

I think this development must be emphasized as an important corollary of globalization. The process began at the time of colonization and has intensified in phases. The first of these began in around 1800 when the European trading colonies became occupied territories producing raw materials for their occupying nations. Over the past seventy years, what we now call globalization further reduced the dimensionality of metrics (and awareness) of human wellbeing as the counterpart of the global growth of interaction between groups and populations from different backgrounds, as it reduced the total information-processing capacity needed to align these different populations. Different cultures and populations, with different values and customs, were progressively aligned along one single dimension, their lowest common denominator: wealth.

Without that reduction in dimensionality, globalization would not have been possible. Imagine that we had to implement global information processing based on the many, many dimensions that different cultures considered important before globalization took hold. That would have overwhelmed our global information-processing system completely. We would not have been able to isolate the relevant dimensions on which to base interaction and around which to create alignment.

Instead, as part of globalization, different populations were slowly but surely accustomed to considering a narrowing set of dimensions as important for them, centered around the wealth dimension, this being the one by which they could compare themselves and transact exchanges. The impact of this is nicely illustrated by Maruyama (1963, 1977, 1980): "If," he once told me, "one reduces the dimensionality of a system to one, people's need to differentiate themselves will be reduced to that dimension. That explains why, on a highway, people tend to distinguish themselves in the speed with which they drive."

Wealth and its metrics, notably GDP, have thus become a dominant dimension of interactive information processing between many different individuals, groups, societies, and cultures around the globe. Although other dimensions are still important, such as religion, community solidarity, art, and culture, there is an increasing tendency toward a reduction in the dimensionality of value sets. Wealth is becoming in certain circles the most important common denominator. In the process, the holistic basis of social interaction is reduced. Fewer and fewer other dimensions of human wellbeing are generally considered worth thinking about, except among smaller, focused subsets of societies. This in turn has moved our global societies toward an increased emphasis on productivity, and led to the over-exploitation of the natural capital of the environment, as well as of the human capital of many regions and groups. The ICT revolution has accelerated and exacerbated this trend by according control over information processing to a smaller and smaller proportion of humanity, giving it the opportunity to accumulate riches and leave the rest of the population behind. The full impact of this development was brought home to me in 2013, when I gave a lecture on sustainability for a business audience in Tempe, Arizona. The speaker after me had only one message: "We need to replace family life with corporate life!"

This trend also has direct implications for the concept of fairness in negotiations. In many societies, in order to count as moral or fair, a reason, principle, or posture toward the world must traditionally reflect a concern with the (multidimensional) wellbeing of the group generally; that is, a concern with the wellbeing of everyone (McMahon 2010). But increasingly, fairness in reciprocal arrangements has become monetized, so that money and wealth are the medium through which equity in reciprocal relations is expressed. As a result, the degree to which monetization of reciprocal concerns – for example, the fact that insurance corporations calculate the value of human life – has impinged on our world is startling.

We saw in Chapter 16 that another negative consequence of this trend is that it has skewed the whole global value system toward increasing wealth differentials between the haves and the have-nots. Initially, this was not very noticeable, because limited communication between these groups constrained the extent to which people could compare themselves with others in these terms. As the growing wealth differences are now more and more effectively communicated (by television, tourism, and now the Internet), this creates new challenges and conflicts. Increasing wealth discrepancy is rapidly becoming a societal planetary boundary alongside the demographic explosion (from 2 to almost 7 billion people in sixty years), and the acceleration of information processing and the changes it entails.

Our Western Value Space seems to Be Reaching a Boundary

Did shrinking the dimensionality of our society's value space contribute to the reduction in the rate of return on investment in innovation that we saw in Chapter 16? That is difficult to determine, but if that is the case it could in turn explain why more and more available funds are being diverted from the productive to the speculative sector. In macroeconomic terms, it might even to some extent explain the leveling off of the growth of our (western) economies that has been reinstated on the scientific agenda by Summers (2016).

Importantly, at a more fundamental level, the progressive closure of our value space and the increase in unanticipated consequences of our actions seems to be related to an observable shift from long-term strategic thinking to short-term tactical thinking. It has shifted the focus of our collective efforts to the immediate, and thus causes us to be caught in a kind of historical myopia that limits and biases our understanding of the second order dynamics that have driven us to this point, as well as our perspective on potential ways to find an exit from the current dilemma. Thus, we are looking for solutions within our current given structure, rather than stepping out of that structure and thinking outside the box.

This is of particular relevance to economics – with policy the most important lever through which one may attempt to change our societal dynamics. In this community there is an emphasis on continuity, rather than the facilitation of change at a time when digital information processing is accelerating change in all aspects of our societies' dynamics. Much of the macroeconomics community in particular lacks a conceptual (and mathematical) tool to conceive of endogenous, discontinuous change. As became disconcertingly clear at the beginning of the recent financial crisis (2007), the dynamic equilibrium models that link supply and demand are traditionally formulated in terms of differential equations and therefore focus on marginal changes of aggregate measures. Therefore they cannot help us to anticipate tipping points or help us think about making structural changes in our current socioeconomic system.

One potential contribution to overcoming this would be to develop the mathematics of discontinuous change, in which supply and demand are not balanced and the market does not always work best. This would open the way for a less productivity- and efficiency-based perspective on economics, which could include value dimensions other than cost and price, and thereby enable a new expansion of our existing value space.

NOTE

1 I owe a debt to Stéphane Grumbach for pointing out to me that a number of current phenomena, such as the blurring of the distinction between gender roles in our societies, seem to indicate that this process is currently occurring in the West.

18

Our Fragmenting World

Introduction

In this chapter, I will place the information and communications technology (ICT) revolution and some of the changing patterns of information processing and communication in our current societies in their historical and socioeconomic context. Considering these longer-term developments must, in my opinion, be an integral part of any attempt to consider the socioenvironmental transition needed to mitigate or (in part, maybe) avoid exceeding too many of the planetary societal and environmental boundaries and causing a disintegration of our current societies.

To devise ways to avoid that disintegration of our current societies might appear to some as impossible as trying to avoid, in 500 CE, the disintegration of the Roman Empire. The rationale for avoiding such a disintegration in our own future is without doubt exceedingly difficult to construct, particularly from a complex systems point of view. Yet that is exactly what we are being urged to do, both as scientists and as citizens. It seems essential to attain some form of sustainability. The crucial questions are whether we love our current societies enough to want to try; and if so whether we have the tools to do it and which changes we are willing to accept.

Answering these positively implies we have to think outside the box, and in this chapter, and Chapters 19 and 20, I will make a beginning with that. In doing so, not being a specialist in either information technology or economics, I will lean heavily on others, in particular Friedman (2016), Brynjolfsson and McAfee (2011), Haass (2017), Ito and Howe (2016), and a range of other authors whose work underpins or relates to their approaches, without necessarily referring to them in each instance. Others will be cited as I proceed.

My main thesis is that the digital revolution has fundamentally accelerated a number of longer-term ongoing dynamic trends in our societies, with both positive and negative effects for different parts of our communities. These new dynamics must therefore be taken into consideration in trying to find a way out of the current sustainability conundrum.

The Race of the Red Queen

To begin with, we have to look again at the impact of the Industrial Revolution, and notably the virtually unlimited availability of relatively cheap energy. As mentioned in Chapter 14, in around 1800 a combination of mining fossil energy and inventing the equipment to exploit it set in motion a long-term trend in which it became ever cheaper (in energy terms) to innovate, lifting a major constraint on innovation and enlarging our knowledge and the value space that maintained society in a more or less coherent form. The process that emerged, following the feedback loop responsible for the coevolution of population, knowledge, and cognition driven by innovation, engendered multiple profound systemic changes, institutional and financial for example, ultimately improving overall health, wealth, knowledge, and resource use, but only in a limited number of places on Earth, where the social conditions were favorable.

A second transition began in the early twentieth century, when mass-production met the newly emerging field of psychology as applied to advertising, triggering a fundamental change in the development of capitalism, toward ever more competition on price, quality, and novelty by exploiting the potential of advertising. The focus of many industries shifted toward mass production and mass marketing, and that drove companies to lower prices further and further, increasing productivity, lowering cost, and gaining larger and larger parts of their markets. Ultimately this produced the consumerist society that we currently see in many parts of the world.

From our theoretical perspective, that development is part of the expansion of the value space necessary to keep a rapidly growing population interested in being part of the European (and later western) socioeconomic system. The competition involved drove innumerable inventions and innovations in all domains of our society, and in the process mechanized a large part of our daily life and its information-processing by creating – even before the impact of information technology – a very large array of technologies, artifacts, procedures, and institutions that were dedicated to particular kinds of tasks. This development began the acceleration of innovation in western societies that we are currently experiencing.

The ICT revolution is in this sense nothing new. It removed a major remaining constraint on innovation by enabling computational information-processing. It is (for the moment) the culmination of a process that began when humans took up the challenge of creating artifacts. But the feedback loops between knowledge, innovation, population increase, and resource use have accelerated to the point that one of my colleagues referred in this context to "The Race of the Red Queen" (Carroll 1999, chapter 2). We have to innovate faster and faster simply to keep the current socioeconomic dynamics more or less on track. As part of that process, major multinational corporations have grown in size to the point that their turnover now equals that of small and medium-sized nation-states, and that in turn has enabled these corporations to cross the borders of many such states and insert themselves in their socioeconomic fabric, creating a powerful transnational economic and political web. I discussed some unintended aspects of this process in Chapter 15.

The Growing Dissolution of Our Global Governance System

One of the corollaries of the growing extent and power of corporations is the dissolution of the power of nation-states when faced with a very different, often equally powerful, kind of player. But there, too, the dynamic is partly a longer-term one, independent of the multinationals or the ICT revolution.

Political scientists and diplomats, such as Bull (1977), Kissinger (2014), and Haass (2017), describe a longer-term development that passed a tipping point in 1991, just after the Cold War. To understand this development, it is relevant to go back a further few centuries, to the Treaty of Westphalia (1648) and the Congress of Vienna (1815), which laid the foundations for the current organization of the European nation-states as well as for the general philosophy that shaped it. These two events, and particularly the Treaty of Westphalia, had many consequences that are often overlooked. They created, for example, the conditions for the development of large-scale industry and business by laying the foundations for national systems of justice that could arbitrate in conflicts.

Up to and including the period of the Cold War (1945–1991), Haass argues, relations between nation-states were governed by a set of rules that were more or less generally accepted. Foremost among them is the idea that governments are sovereign, free to act as they see fit within their territories (states), and that other governments accept this without interference. International political history is about the interaction between this principle and the moments that it led to disagreement, friction, and aggression. Such moments were very often triggered within the nation-states concerned, and it is fundamental for our understanding to keep that interaction between processes within and between nation-states in mind. Just as fundamental is the fact that such a system would not have worked without a degree of balance of power between states. Together, the rules and the balance of power created a kind of order that governed Europe throughout much of the eighteenth and nineteenth centuries, but collapsed in the twentieth century when individual states started pushing the system out of balance, leading to the two world wars and the collapse of several major empires (Russia, the Ottoman Empire, and the Austro-Hungarian Empire after World War I, and the British, Dutch, and French (colonial) empires after World War II). In the process, the "rules" that had governed the interactions between states were sacrificed, presumably without regrets.

After World War II, all efforts on both sides of the Atlantic (i.e. the "Western world") were directed toward reestablishing stability, reinforced by institutions such as the United Nations and its many agencies, the International Monetary Fund, the World Bank and the Development Banks for the Americas and Asia, but also the International Court of Justice and later the European Coal and Steel Community (which evolved into the European Community and the European Union, EU), as well as the General Agreement on Tariffs and Trade (GATT) and the World Trade Organization (WTO). Whether miraculously or not, this effort ensured the survival of a more or less stable geopolitical order for another forty years, mainly thanks to the Cold War between the USSR and the USA, including the threat of so-called mutual assured destruction and the interaction between the North Atlantic Treaty Organization and the Warsaw Pact. With the collapse of the USSR, this order began to fall apart, both between states and within them. As a result, since about 1990, we have seen a growing dissolution of the power and coherence of nation-states.

What happened after the disintegration of the Soviet Union? How did that event trigger changes that destabilized the global order? What were the underlying dynamics, and why is it that on the surface this destabilization was not immediately tangible?

First of all, the collapse of the USSR led to readjustments in the relationships between the USA, Russia, and China, with Russia taking a step down and China one or more steps up on the global power scene.[1] These adjustments of course engendered numerous tensions, but Haass argues (2017) convincingly that in circumstances where the US military completely dominated the scene, competitive activity shifted to the economic sphere, where the BRICS nations in particular (Brazil, Russia, India, China, South Africa), but other nations as well, focused on internal economic development. That in turn required economic interdependence between nations, including the fostering of closer and closer trading relationships. Global increases in wealth became the major goal, rather than territorial conquest; that was where win-win opportunities emerged. As a result, much of the friction between states also shifted to the economic domain, where they could more or less peacefully be negotiated in the context of the GATT, its successor the WTO, and a number of bilateral and multilateral trade agreements.

With the growing interaction and interdependency between nations, the relationship between domestic and international dynamics came to the fore, and this created other potential points of friction, as it increasingly eroded the basis of the Westphalia and Vienna systems – the principle that no nation should interfere in the internal dynamics of other nations. At the same time, many other players, not just large multinational corporations, became involved in international relations, such as the major international non-governmental organizations. They had both ideals and networks within many states, and therefore became players that crossed borders. This hugely complicated the diplomatic system, and helped transform it from a bipolar to a multipolar one as more and more parties gained the wealth and self-confidence to play their own roles.

We see this in the emergence of a number of regional hotspots, such as the Near and Middle East (including parts of North Africa), South Asia (India, Kashmir, Pakistan, and Afghanistan), East Asia (China, the Koreas, Japan, and more recently other countries bordering the East and South China Seas), East Africa (Ethiopia, Somalia and Sudan), as well as Eastern Europe (the Balkans and now Ukraine). In each of these, competition between important regional players led to (potentially) explosive tensions of a mixed economic, nationalist, religious, ethnic, and tribal nature. In some cases these were aggravated by attempts to shape societies along western, democratic, lines where that was clearly highly unlikely to succeed, such as in Iraq.

What was the role of ICT in this transformation? Even before the emergence of the Internet, the ease with which telecommunications such as press, radio, television, and now cellphones crosses boundaries, as well as – in certain areas – the huge explosion in tourism, acquainted people with lifestyles they had often not even dreamt of, and thus created visions and desires that were in many ways unattainable in a short time frame because of their geographic, economic, and social situation. This inevitably accelerated the emergence of many tensions, on the one hand facilitating globalization and on the other generating substantive reactions against it. In my own work in Southern Europe this became evident as soon as we realized that much of the increase in unused, eroded, surfaces was not so much due to environmental factors as it was due to the desire of the traditional farmers in those areas to adopt a different, urban lifestyle (van der Leeuw 1998). The recent ICT revolution, by facilitating horizontal communication across regions, borders, social classes, and various other divides has further accelerated this tendency.

The Spectacularization of Experience

Within individual states, radio and television are among the earlier precursors of full information technology, driven by electronic transmission of information. Their impact on communications had some dimensions that I think are of relevance here. The first of these is that they enabled one-to-many communication, thereby providing a powerful tool to control values and opinions, and thus to align very large numbers of people, many more than could have been reached until then. For one, people did not have to be literate to peruse them, and secondly their visual nature greatly enhanced their impact. In their imagery, they continued a tradition that had its origins in photography and film, greatly enhancing their efficiency because these were now detached from any material substrate.

Another dimension of their spread is the fact that they hugely widened people's capacity to listen to and see fiction, thus enabling people to escape from their everyday existence and live, albeit for a short moment, in a fantasy world.

An early visionary of the challenges this would pose in our societies was Guy Debord, a French author who as early as 1967 argued that

"All that once was directly lived has become mere representation" (Debord 1967, thesis 1) and that the history of social life can be understood as "the decline of being into having, and having into merely appearing" (Debord 1967, thesis 17). In doing so, he pointed to the fact that these media promoted confusing sincerity with authenticity, and substituting emotional images for emotions.

Initially film, radio, and television had as their main goal making people laugh, feel happy, or at least forget their sorrows by watching song and dance, or experiencing a wealthier world in which dramas always end happily. But as the tele-amusement industry developed, it slowly but surely began to address more complicated situations and a wider range of different worlds, some of which were frightening, dystopian, or completely unrealistic. Altogether, this tendency habituated more and more people to live, at least in part, in a fantasy world – a world, moreover, where the consequences of one's decisions and actions could be avoided simply by switching off the electricity.

Economically, this trend was driven by the need to advertise more and more, to create the demand for new products. Over the past half-century or so, this combination of economic necessity and artistic potential has thus led to a blurring of the boundaries between fantasy and reality, as is evidenced in the infomercials that were deliberately intended to associate those two worlds, initially principally in the minds of small children watching early-morning television to allow their parents a couple of hours of rest, but increasingly also by adults who were watching later in the day. More recently this trend has come full circle in the "reality shows" on television that attempt to imitate real-life situations in the media that are traditionally devoted to the world of fantasy. The computer games industry is in some ways a continuation of this trend, but with one major difference: the opportunity to escape into a fantasy world is no longer centrally controlled, nor is the way in which individuals interact with the fantasies thus created.

In that sense, this recent development is part of the overall trend at individuation that ICT has enabled, which many people experience as freedom without realizing that, when an unforeseen calamity occurs, they are dependent on each other and the communities in which they function – and that they thus must operate within the norms of their community to be able to call upon its support when they need it.

Another aspect of this trend is the emergence of the twenty-four-hour news cycle, which presents major events in an abbreviated, simplified, "bite-size" form that is easily digestible. Initiated by CNN in the 1980s, it has now spread around the world and throughout electronic media. The setup of most websites follows the same pattern, leaving it up to the user/reader whether he or she is ready to digest the full message or only a highly simplified form of it, potentially leaving much to the peruser's fantasy.

To summarize, and again referring to Debord, everything that people have thus far experienced directly – in their relations with the natural and social world – has been analyzed, chewed upon, and converted to images. In the process, many of the hidden dimensions of reality have been removed, so that the consumer is presented with a simplified image that has been created according to the vision of the originator of the images concerned. This process has created a growing distance between "real life" experiences and Debord's "spectacularized" experiences.[2]

But there has also occurred another trend, driven by the interaction between the media and the capitalist system based on competition. Since World War II, we have seen the proliferation of different sources of mass communication. In the 1950s and 1960s, each country had just a few television channels. In many countries, these were controlled by government (France and the UK, for example), in others by private organizations with different religious perspectives (the Netherlands), and in yet others by private for-profit organizations (Italy, the USA). Beginning in the 1980s the number of sources of information multiplied, initially by means of cable and satellite TV, leading to a situation in which people could choose between hundreds of channels, many of which were dedicated to a particular kind of information (geography, history, mystery, science fiction, etc.). In the 2000s this proliferation of sources was further facilitated by the emergence of websites. In effect, everyone can now be a source of information for everyone else, on a global scale.

Although this process seems at first sight to be innocuous and directed at providing freedom of information to everyone, it has in recent years contributed to the fragmentation of our worldview and our society by creating and reinforcing different visions of just about any socioeconomic or political issue. In a later section, I will return to the social significance of this phenomenon. For the moment, suffice it to signal that this is another element in the process of effacing the alignment of societies' values, and the distinction between signal and noise that I mentioned in Chapter 17.

Democracy under Pressure

In many developed countries, at least since World War II, the basis of the governance system has been democratic – the population periodically elects representatives who constitute the government. These systems differ. In Switzerland, for example, the government must consult the population by referendum on every important issue. In most other western countries, elections determine the composition and the power to be distributed among a number of parties, ranging from two (in the USA), to three (the UK), or several more of which only the top two have real impact (France), or up to ten or fifteen who then form a coalition that governs according to a compact (The Netherlands). In essence, whatever the system, and whatever the level at which democracy is practiced, individuals delegate their political power to an elected elite, who make decisions for a limited amount of time.

This system works well, once it is institutionalized, as long as the internal tensions in the society are such that they can be worked through by discussion, debate, or vote. If this is not the case, the system is in trouble. I would argue that over the last sixty years or so, in most Western countries, this has worked in part because the inhabitants experienced an increase in comfort and wealth. There seems to have been a connection between the adequate functioning of the democratic system over that period and the rise of the consumer society, including the huge increases in use of raw materials, energy, and human capital not only in the countries concerned, but also in those other parts of the world from which the natural and human resources were extracted to serve these "developed" countries.

This relationship between democracy and exceeding planetary boundaries clearly needs to be investigated and taken into account when looking for ways to deal with our sustainability challenges. Randers (2012) and others have suggested that sustainability is difficult to achieve for democracies because when they have to deal with conflicting interests, decision-making is very controversial and complex. This raises the question whether one could implement a democratic system that did not have an expanding consumerist context.

But there is also an information-processing aspect to the functioning of our democracies: the fact that information flows were to some extent controlled through the media, which limited the diversity of opinions among the population of a country or smaller democratic unit. I referred to this briefly in the last section. The ICT revolution changed that fundamentally, by facilitating communications bypassing any state-related institutions and media. As a result, the Internet is now threatening our democratic institutions, and that threat is accentuated by growing wealth differentials inside and across regions and countries. Edsall (2017) recently drew attention to this phenomenon, quoting Hindman (2008) as saying that the USA may be "transitioning towards a hybrid democratic regime which would keep the trappings of democracy, including seemingly free elections, while leaders would control the election process, the media and the scope of permissible debate by electronic means."

We are seeing this in China, Russia, Turkey, Hungary, and other countries. The recent Brexit referendum and election campaigns in Europe and the USA also demonstrate that the mainstream media and political party organizations have lost much of their power. The vacuum has been filled by populist organizations that find their base in social networks, such as the Five Star movement in Italy or the alt-right movement around the Breitbart website in the USA. Samuel Issacharoff, an authority in this domain, is quoted by Edsall (2017) as pointing to four processes already going on before the impact of the ICT revolution:

> The current moment of democratic uncertainty draws from four central institutional challenges, each one a compromise of how democracy was consolidated over the past few centuries. First, the accelerated decline of political parties and other institutional forms of engagement; second, the weakness of the legislative branches; third, the loss of a sense of social cohesion; and fourth, the decline in democratic state competence. [...] Technology has overtaken one of the basic functions you needed political parties for in the past, communication with voters, [...] Social media has changed all of that; candidates now have direct access through email, blogs and Twitter, along with Facebook, Instagram, Snapchat and other platforms.

But the decay of the role of political parties and the traditional media is only one part of the story. As I write this (early 2017), one of the most salient implications of the information revolution that has suddenly come to light is the issue of "alternative truths," as highlighted in the Brexit and Trump campaigns. This seems to be a direct consequence of the multiplication of sources of information, including websites, television stations, and radio talk shows, as well as of the blurring of the boundary between signal and noise. We have seen that the distinction between the latter two has a direct relationship to the value space of a society, group, or culture. As subsets of the members of that society or group increasingly focus on a narrow set of sources for their information, this leads to different conceptions of truth, signal, and information, in effect fracturing the overall alignment of a society on a specific value space. Hence, as so elegantly formulated by one of President Trump's team (Kelly-Anne Conway), "We [i.e. the Trump team] merely offer alternative truths" (in an interview on

NBC television's "Meet the Press" in the USA on January 22, 2017). It is not surprising therefore that the Trump team considers the media their principal opposition. For them, documenting and corroborating "facts" is no longer a prerequisite for presenting them; the conviction and charisma of the person who presents them, coupled with reference to a particular subset of information sources, appears to be enough. If unchecked, this sets in motion a tendency toward fragmentation and polarization of a society around different categories and values. (This phenomenon is currently summarized under the idea that people live in different information bubbles).

This also raises a question about whether the tendencies presented in the last section, including the spread of interactive computer games, have had an effect on the capacity of the younger generations to distinguish between reality and fantasy. Would living for many hours a day in artificial worlds where the interaction between people's decisions and actions on the one hand and their consequences on the other is artificially enabled and constrained favor a reduction in the capacity to distinguish between fiction and reality? And finally, we need to consider the impact of globalization on our democracies. Recently, Reno (2017) expressed this as follows:

> Globalism poses a threat to the future of democracy because it disenfranchises the vast majority and empowers a technocratic elite. It's a telling paradox that the most ardent supporters of a "borderless world" live in gated communities and channel their children toward a narrow set of elite educational institutions with stiff admissions standards that do the work of "border control." The airport executive lounges are not open and inclusive.

In effect, here we see the result of the fact that a small, and now increasingly narrow, elite in our societies has been able to make the transition toward a (partly ICT-based) globalized society, whereas a very large majority of citizens worldwide has been left behind, focused on their local community and thus resistant to expanding the spatial extent of their identity to communities elsewhere. Here again, the roots of one of the ICT-accelerated processes have been laid long before, in our case in the form of democratic systems in which a small bourgeoisie directed the society as a whole. But the ICT revolution is exacerbating the inherent tension between the governing and the governed by the rapid acceleration of information processing itself.

The Deconstruction of Communities

Now let us look at the next scalar level – that of communities. To introduce this topic, I will go back to a series of classic works in the anthropological and economic literature. First are those of Karl Polanyi, the anthropologist who first developed the substantivist approach to economic anthropology. According to Polanyi, the modern market-driven society was not an inevitable stage in the evolution of western societies, but was planned. He came to this conclusion because he did not see economics as a subject closed off from other fields of enquiry. He saw economic and social dynamics as inherently linked, and noted a major transformation in their relationship as part of the Industrial Revolution. In his *The Great Transformation* (1944, 2001) he makes the distinction between "markets" as an auxiliary tool for ease of exchange of goods in many small-scale societies – in which, generally, exchange is a mechanism to maintain social relations – on the one hand and "market societies" on the other, which are those societies in which markets are the paramount institution for the exchange of goods through price mechanisms, to the point that the substance of society itself becomes subject to the laws of the market. According to Polanyi, roughly from the 1830s in the UK the market began to subordinate the substance of society itself to the laws of the market's "invisible hand." This led to the separation of society into economic and political realms, and the subjection of societies' dynamics and requirements to those of money and the economy. This, he argues, resulted in massive social dislocation and spontaneous moves by society to protect itself. In effect, Polanyi argues that once the "free" market is disembedded from the fabric of society, social protectionism is society's natural response, a spontaneous reaction to the social dislocation imposed by an unrestrained "free" market. To rephrase this in terms I introduced in Chapter 16, it is in the emergence and evolution of the free market that a financial, unidimensional logic was progressively disembedded from the wider, multidimensional, sociocultural logic. Similar arguments have been made by such economists as Keynes (1930) and Frieden (2006).[3]

David Graeber, another economic anthropologist, builds upon these ideas (which were anathema to most macroeconomists, but found wide support in anthropology, sociology, and related disciplines) in his researches into the theory of value (which I referred to in Chapter 16). Graeber (2001) contrasts the multidimensional conception of value among many small-scale societies (Tobrianders, Malagasy, Kwakiutl, Iroquois) with the unidimensional conception of value in economics in the modern world. In his opinion, "The market was a creation of governments and has always remained so" (Graeber 2001,10; Mazzucato 2015). Modern economics, in its emphasis on modeling the value-driven behavior of the (modern) individual, "…relies on trying to make anything that smacks of "society" disappear. But even if one does manage to reduce every social relation to things [. . .] one is still left to puzzle over why individuals feel some objects will afford them more pleasure than others." (Graeber 2001, 9)

It is implicit in this argument that the formalist economists' approach, which only distinguishes individuals and populations, cannot grasp the concept of value because values are accorded according to the social networks in which people participate. We have seen earlier that "value" is a social creation, shaped by the social context of individuals – the ideas shared by the network(s) in which an individual is active. It is therefore generally determined at a different scale than that of the whole population. To include values in our approach, we must move from a population perspective, which treats individuals as statistical units in a population, to an organization perspective, in which the different configurations of relationships between individuals are taken into account (Lane et al. 2009), as can be done in a multilayered network approach to society (White & Johansen 2004; White 2009).

Ronaldo Munck (2004) contributes the third step in this argument when he posits that globalization is at the root of the destruction of social communities as it undermines the multidimensional spectrum of values that keep communities together. In doing so he echoes Polanyi's original assertion that it was the imposition of one-dimensional economic thinking in finance, in the form of the gold standard, that ultimately drove nations to competition, colonization, an arms race in Europe, and finally the world wars. Munck sees globalization as an extension of the attempt at financial global unification that drove the imposition of the gold standard to a number of other economic domains. We are thus reminded of Maruyama's statement (Chapter 16) that on a highway cars can only compete in terms of speed. If wealth is the dominant standard, competition between individuals, groups, and nations tends to be measured mainly in wealth.

But we have to emphasize that, important as it is, the slide toward wealth as an increasingly dominant standard by which people, groups, and nations measure their performance and identity is only one trend among many others. The others have of course also been in existence for a very long time, and continue to play an important role in our societies through the many other values that societies and individuals embrace. Yet they have in some way been eclipsed in public attention by economic values. The important question is whether this is temporary or will be of longer duration. However this may be, an important task ahead is to look more closely into the noneconomic dimensions of the dynamics that are driving societies.

The Transformation of Globalization

In an interesting book, Richard Baldwin (2017) links the transformations in globalization to changes in the movement of goods, information, and people. In the 1880s globalization first emerged, he argues, in the form of (increasingly bulk) trade in raw materials and industrial goods owing to the availability of novel, relatively cheap, and dependable modes of transportation (railroads and steamships). The resulting fall in trade cost enabled the geographic separation of production and consumption, leading to the global expansion of markets while industry grew locally. This fueled a feedback loop of trade, industrialization, and growth that boosted the western (mechanizing) nations' economies in contrast to the economies of other parts of the world. It is the source of the west's huge wealth and the income differences between the north and the south.

From the 1970s, the West's share of global manufacturing declined, and this trend accelerated in the 1990s. Baldwin points to the fact that owing to the ICT revolution there was a sudden decrease in the cost of moving information, and he argues that the ensuing increased facility to coordinate complex activities from a distance facilitated the spread of production into global supply chains. In the process, manufacturing was outsourced from the developed to the developing countries. As this involved the transfer of important know-how, it led to what Baldwin (2017, 5) calls "the global value chain revolution," redefining the international boundaries of knowledge. In particular, it closely linked developed nations' know-how with developing nations' labor into the core of commercial competition and moved industrial organization from a territorial to a network organization.

Baldwin attributes the fact that this shift remained confined to six developing nations (China, Korea, India, Poland, Indonesia, and Thailand) to the still high cost of moving people, and in particular the time-cost of moving relatively well-paid personnel. By concentrating production in a few low-wage countries the cost of moving personnel could be contained, and the more so if the new production countries were relatively close to the older ones. This reorganization led to an industrial expansion that created a huge demand for raw materials and thus caused rapid increases in income and wealth both in the new production countries and in the countries that provided the raw materials.

In the future, Baldwin argues, facilitating people movement by promoting the virtual presence of people at a distance, through improved telepresence and telerobotics technologies, could cause a third fundamental shift, leading to virtual immigration and telecontrol of production, thus further blurring the spatial boundaries between nations. The potential consequences of such a shift are yet to be examined.

The Emergence of the Developing World

I also need to point here to the impact of the emergence of the developing nations on the globalized scene. They are undergoing many of the developments referred to in this chapter without the institutional framework within which they are occurring in the developed world.

Until the 1980s, in most of the developing world, the political and economic systems were still predominantly neocolonial, geared toward furthering the interests of the colonial powers on which the countries involved had depended (Nederveen Pieterse 1989). But from the 1990s several of these countries, profiting from the new wave of globalization just mentioned, could develop their respective economies in ways that challenged the hegemony of their colonial masters and the post-World War II international agencies. This led to the emergence of a wide range of different postcolonial development strategies, based on the natural and social capital of the countries themselves.

East Asia (Japan, South Korea, the Philippines, China, now also Vietnam) was the earliest region in which this happened, followed by some countries in Latin America (Mexico, Brazil, Chile, Venezuela), South Asia (India), and finally Africa (in particular Nigeria and South Africa). This transition can profitably be looked at from the perspective developed by Wallerstein (1974–1989), referred to in Chapter 14. Some countries, in which for political reasons these developments began first (Japan, South Korea), have managed to join the exclusive club of developed nations, while others are on the way (China, Brazil, Turkey, South Africa, Indonesia).

It is clearly outside the scope of this section to go into any detail on these developments, but from the 2000s ICT played an important role in them, and I will try to briefly summarize some of the factors favoring that role, as well as some of the difficulties the development of ICT encounters in these countries. A first difference with the developed world is that whereas wireless telecom and web markets in the developed part of the world are approaching saturation, this is not the case in developing countries. In effect, 2014 data show that the developing countries substantively lag behind ICT impacts in the developed world.

Part of this difference is a question of investment capacity and national choice (wireless or wired), but an important other aspect is the lack of ability to use the opportunities offered by ICT. Thus, in large parts of Africa, notably, mobile phones are mainly used as a means of telephoning and text messaging, rather than to access the web. This difference in use of ICT is particularly tangible between cities and the countryside, as a result of linguistic and educational differences. According to a report to the European Parliament (STOA 2015), the economic and social returns of ICT in developed and developing countries alike are high, as telecommunications allow a mitigation of the negative effects of dysfunctional markets. Countries with good information technology (IT) infrastructures and abundant IT-skilled labor forces benefit most from the ICT revolution in terms of increased national production, export, domestic and foreign investment, and new employment opportunities.

However, there seems to be insufficient evidence that such wealth creation is contributing to poverty reduction. Here, technical, political, educational, and cultural factors seem to play a role. For one, as long as mobile phone use is limited to communication, it does not necessarily move people out of poverty (STOA 2015). Access to the mobile Internet, on the other hand, does make a difference. Evidence shows that high penetration of modern ICT is an effective driver of socioeconomic development, but this is only the case in a very limited number of countries (e.g., Tunisia, South Africa). Moreover, Africa has the largest number of worst performing countries in terms of establishing regulatory frameworks for ICTs and often has slow, unreliable, insufficient, and expensive telecommunication services.

Basic computer literacy is still not part of the primary education curriculum in most developing countries. The development of local content and of applications designed to address the needs of the poor has also progressed relatively slowly. The nature of ownership of ICT is relevant as it makes developing countries that own their ICT infrastructure more active in introducing technologies that are tailored to the needs of their populations. Notably, as far as internet service providers remain in developed countries, the benefits of ICT to developing countries are limited, because this creates a divide between producers and users of technologies to the advantage of the former. Most of the ICT potential thus remains to be fully exploited, especially for the advantage of lowest income groups. There are of course exceptions, in particular in developing countries where ICT is not owned by corporations in developed nations, and in sectors such as finance, insurance, agriculture, and health, where they do indeed rapidly remove barriers.

To conclude, penetration of ICT can in theory be seen as an unprecedented opportunity to reshape the political and institutional landscape of many developing countries, promising to improve accountability and transparency of governmental actions, and to increase participation in political decisions. But in reality the processes involved in democratic participation are so complex, and driven by societal dynamics of which communication is only a – poorly understood – part, that much more needs to happen. And in view of the prevalent regimes, one has to be aware of the fact that in many countries, for the time being, there is at best the kind of hybrid democratic regime that "keeps the trappings of democracy, including seemingly free elections, while leaders control the election process, the media and the scope of permissible debate by electronic means" (Edsall 2017).

Big Data and Individuation

I will now return to the novel capability to collect, store, and process "big data" that is one of the major technical transitions in information processing. First of all, it has led to huge concentrations of information, and processing tools, in the hands of a very small number of corporations, such as (notably) Tencent, Weibo, Apple, Facebook, Google, Amazon, Ebay, and Yahoo. These corporations were the first to see the huge advantages, both for their prospective clients and for themselves, of facilitating information access and collecting vast amounts of behavioral information from their customers. For a few years, there was a lag in tools to process such information, but the number of tools to do so is currently (2019) exploding. They enable, for example, the identification and analysis of patterns that have thus far been difficult to observe because the statistical samples that could be collected and analyzed were too small. Such analyses have led to customized web-mediated advertising, highly efficient mobilization of relevant voters in elections, automated scrutiny of job applications, monitoring of billions of communications in the search for terrorists, and many more applications, too many to list here. Manikya et al. mapped this process as early as 2011, and their guide, while quickly outdated in terms of details, remains relevant in terms of its general description of the dynamic. Somewhat more forward-looking is a collective work published by the BBVA Foundation in 2013, and to keep abreast of these developments one can rely on magazines such as *Wired*. As an overall trend, the capacity for processing huge amounts of information in great detail is transforming many aspects of our lives – wherever until now calculations were based on generalization from (limited) statistical samples – because we now have the capacity to enhance resolution to deal with each individual entity directly and separately. This not only impacts the insurance industry, but also medicine in its trend toward individualized diagnosing and treatment, and elections in the way one can now determine individual voting patterns by means of big data analysis, etc. Ultimately this development may well have an effect on economics by enabling the use of much more detailed data in its models, or even agriculture by enabling such detailed spatial analysis that techniques of exploitation can be better suited to local circumstance. The examples are plentiful, but they all share the fact that drilling down to the level of the individual, the smallest possible spatial or temporal entity, the individual instance of a phenomenon or process, will improve our understanding of societal and environmental phenomena at the cost of hugely (exponentially?) increasing the need for processing power. This is one of the major trends driving the computer industry toward high-performance computing (aggregating computer power to deliver much higher performance). To give the reader a sense of how quickly this trend is growing, I cite the French newspaper Le Monde (June 7, 2017): "the [European] data economy (from e-commerce to traffic management to personalized medicine) was worth 272 billion euros in 2015, and could increase to more than 640 billion by 2020."

We should never forget that this trend enables a major concentration of information processing, and thus political and financial power, in the hands of a very small elite, aided by sophisticated software and major computerized information processing capacity. The fact that these corporations use these data in completely opaque ways has favored a backlash in the domain of privacy protection, prompting the European Commission to adopt in 2018 a completely new legal and institutional framework, the General Regulation of Data Protection, intended to create full transparency and thus reestablish trust. Its efficiency remains to be demonstrated.

Mass data treatment also stimulates the development of the capability to automate many structured, repetitive tasks, from the very simple ones, such as maintaining bank accounts, to more complicated ones, such as the work of paralegals in lawyers' offices (routine document production and processing). As usual, this novel capability can serve constructive as well as deconstructive purposes, depending on the slant that the users of such information desire to give to their interpretations. Friedman (2016) gives both constructive and deconstructive examples of "big data" processing as resource. O'Neill (2016) gives numerous examples of socially deconstructive uses, in particular when automated, algorithm-based data analysis uses criteria that exclude parts of society (for example from jobs).

Much attention has recently been drawn to the consequences that these (and subsequent) innovations might have for employment, as automated information processing and manufacturing reduce the need for certain kinds of labor (Brynjolfsson & McAfee 2011; Purdy & Daugherty 2014; White House 2014; The Economist 2016).

Automation and Artificial Intelligence

Robots have long been a favorite science-fiction topic, as in the work of Isaac Asimov (1950) and others. But the last sixty years have seen such advances in information processing that increasingly complex mechanical tasks in industry are being automated to reduce labor costs, for example in car manufacture. As long as information-processing capacity was limited, these robots were very specifically designed to perform relatively simple, monotonously repetitive tasks. But that, too, is changing, notably by means of the introduction of machine learning in automation.

Artificial intelligence has been another dream, this time of informatics enthusiasts, for at least fifty years, but over much of that period computing power was still insufficient to instantiate it in a meaningful way. Over a period of just a few years, in the early 2010s, that situation changed dramatically as a consequence of developments just mentioned, and in particular the "cloud." Yet there was little success until an intellectual change in perspective made a fundamental contribution. Most early work, for example on languages and on chess, programmed sets of rules derived from expert opinions, according to which meanings and moves were to be construed. This worked to a reasonable extent for chess. Language, however, is too flexible and fluid, as well as complex, to assign meaning based on such rules. Contemporary artificial intelligence (AI) is based on one or other form of machine learning, which requires the computer to learn from the ways in which language is used by analyzing very large numbers of texts in ways that resemble "fuzzy set" approaches – in which initial approximations of meaning are refined many times until they come close to correct understanding (Zadeh 1965, 1975). This is the approach that transformed Google Translator from being a crutch to a more or less efficient and smooth translation machine (the story behind this is nicely told by Friedman 2016). It is reasonable to expect that this breakthrough – reflexive learning based on analysis of very large datasets – will enable computers to conquer important other domains of information processing, including sophisticated moving robots capable of nonroutine tasks, many relatively complex analytical tasks, etc. A summary of developments leading to the current state of AI and some ideas about its future impact can be found in a report recently issued under the Obama administration by the (US) White House Office for Science and Technology (2016a).[4]

In thinking about the future of AI it is important to distinguish between different ways of applying its basic principles. On the one hand, one can distinguish between narrow and general AI. The former is increasingly widely available now, and is used to address specific application areas, such as playing strategic games, language translation, self-driving vehicles, and image recognition. Narrow AI also underpins many commercial services, such as trip planning, shopper recommendation systems, and advertisement targeting, and is finding important applications in medical diagnosis, education, and scientific research. Narrow AI is not a single technical approach, but rather a set of solutions for discrete problems that relies on a toolkit of specific methods along with problem-specific algorithms.

The White House report (OST 2016a) defines as general AI systems that exhibit apparently intelligent behavior at least as advanced as a human being across a full range of cognitive tasks. It argues that it will be at least several decades before this can be achieved. The diversity of narrow AI problems and solutions, and the apparent need to develop specific methods for each narrow AI application, has made it unfeasible to "generalize" a single narrow AI solution to produce intelligent behavior of general applicability. Hence, attempts to reach general AI by expanding narrow AI solutions have made little headway over many decades of research.

In considering the societal impact of AI it is also important to distinguish between the three different roles that AI can (and does) play: (1) automation, (2) autonomy, and (3) human–machine teaming, which have different impacts on society. Automation occurs when a machine does work that might previously have been done by a person. The term relates to both physical work and mental or cognitive work that might be replaced by AI. This is a long-standing trend that has already permeated very many economic and social activities in our societies. Autonomy refers to the ability of a system to operate and adapt to changing circumstances with reduced or even without human control. An autonomous car, for example, can drive itself to its destination without detailed human control. Autonomy is, of course, a more recent trend that is in many ways still under development.

In contrast to automation and autonomy, human–machine teaming refers to cases in which a machine complements human work. In many cases, a human–machine team can be more effective than either one alone, using the strengths of one to compensate for the weaknesses of the other. This is a particularly important recent development that opens the road to employment opportunities that are not likely to disappear in the next few years. But filling these slots requires a focus on training people who have the specific skills to deal with electronic information processing and the capability to fully use their broad spectrum human information processing capacity.

From Production to Distribution

In the current economic system, the focus is on a production economy that derives its profitability from the gap between cost of production and perceived value of the product in the eyes of the consumer. This drove the European colonial trading system and its sequel, large-scale agricultural and industrial production in the colonies profiting from very low wages. It has also driven the search for ever-cheaper production methods worldwide over the last century or so, adopting ever more efficiency in all aspects of production: human, financial, logistical, technological, organizational, etc.

Yet a potentially important horizon is looming: worldwide limits to cheap labor enabling large-scale industrial production. Although there remain pockets of relatively low labor cost (Bangladesh, India, Indonesia, Africa), the wage advantage is globally eroding. The profitability of the traditional production economy, and thereby its existence under the current market-based regime, may well come under increasing stress. Major industries are beginning to see that this will affect them in the future, especially if they have to weigh the cost of labor against the risk of social instability, corruption, investment, etc.

Automation will no doubt mitigate some of this as robotics and AI replace human activities. Whereas until now human thinking directed machine information processing, machines can increasingly associate information into patterns, which enables them to figure out an appropriate response to changing circumstances. Hence, the use of information is now increasingly becoming external to human beings, rather than internal, and this will lead to yet another quantum jump in information processing in which many more – economic and other – activities are managed by computers.

Economist and technologist Arthur (2017) has summarized his view of what this might do to the economy as follows. Once it is possible to produce enough goods and services for everyone by automated means (if we can do so in environmentally sustainable ways], we are about to witness a major shift from an economy in which production is the bottleneck to one in which the next challenge is to ensure general access to what can be produced. Arthur argues that this will bring about the following major changes:

- The criteria for developing and evaluating policies will change. Gross domestic product and productivity are relatively good measures of the physical economy, but are much less effective in measuring the virtual economy;
- The free-market philosophy will be less suitable to the new situation because the focus shifts to more or less equitable distribution of value, away from the idea that the more is produced, the better it is;
- The new era will not be an economic, but a political one. The paradigm of society at the service of the economy, which has increasingly dominated since the 1840s and 1850s, will have to be inverted (again) to place the economy at the service of society, at least if we are to avoid major societal upheaval.

The transition to the distribution economy is likely to cause a period of major upheaval, in which a number of social questions need to be answered. How will we find meaning in a society where jobs no longer provide it? How will we deal with privacy in a society where every bit of information about everyone is concentrated in databases? Will we abdicate individual learning in favor of computer data and algorithms? The changes and the upheaval, Arthur concludes, will be as important as those that accompanied the Industrial Revolution, and may well take as long. Who knows?

Our Perception of the World

One of the intriguing aspects of the ICT revolution is how it changes our perception of the world. In dealing with that topic, we have to distinguish two different, almost contradictory, trends: complexification and simplification.

In the pursuit of knowledge, the mass of new data and the development of AI enable us to scrutinize in much greater detail many of the dynamics that we have thus far only been able to perceive in relatively general terms. In that sense, the ICT revolution will in many ways have the same kind of effect as the discovery of lenses in the second half of the seventeenth century, which enabled scientists to begin studying the world of the very small and that of the very distant.

Current developments enable us to develop ever finer scales of measurement, from the subatomic on the one hand to distant galaxies on the other, but also to focus on relationships rather than entities, and take a much wider set of contextual dimensions into account. The recent emergence of network approaches is one result of that, and so is the emergence of modeling as a technique to explore dynamics in a wide range of domains, from the environmental to the societal and the extraterrestrial. These developments have been fundamental in enabling the emergence of complex systems thinking as a practicable approach to conceiving the dynamics of the world around us. But they have, for example, also contributed vastly to our understanding and intervention in biological phenomena, whether through microsurgery or genomics. Such developments are in the process of changing our scientific and scholarly worldview from static to systemic and dynamic. In the natural and life sciences that perspective is now generally accepted, but in many of the social sciences and humanities this is not yet the case.

A second impact of the ICT revolution has been, and continues to be, the global unlocking of very large stores of data in all kinds of domains to research that is happening in all parts of the world. This creates a kind of transparency in science that is novel in many domains, but also allows for stretching the timeframes studied, for example through the opening of archival and archaeological data.

Third, the ICT revolution has fundamentally changed the ways in which we practice science and scholarship, enabling us to do so collectively across wide distances in space and time, and moving us from individual science and scholarship to collective, team-based, and interactive approaches to discovery and understanding, This has vastly accelerated the development of new knowledge by mobilizing more brain power and more tools for thought and action on specific challenges, but also by making it much easier to delve into the global store of knowledge across as many disciplines as is desirable. Hence, collective science is now mobilizing hundreds or thousands of scientists around the main themes, for example climate change and its interactions with our societies. No discoveries are nowadays accepted unless corroborated by several independent teams working on the data concerned.

When we look at the reverse of this trend, the increase in simplification that is directly linked to mass consumption of information, one is struck by the huge, and rapidly increasing, gap between the scientific understanding of very complex phenomena that the new methods are facilitating and the oversimplification of such phenomena that is ultimately communicated to the general public. This is clearly related to Debord's spectacularization and the mediatization of our perceptions of the world that I discussed in Chapter 17, as well as to the growing discrepancy between those who have been trained to understand the complexity involved and those who do no more than consume the images and simplified narratives that they have been presented with in the media. In a world that is increasingly divided into "information bubbles," it raises the question whether scientific endeavor will not, at some point, simply be drowned out by other perspectives. In that context, it is ominous to note that in December 2017 the US administration forbade the Centers for Disease Control and Prevention from using the terms "science-based" and "evidence-based" in any budget justification.

How These Trends Are Developing

How will these developments impact our daily lives? That is hard to know in the long run, but every day brings news that is relevant to this question in the form of large or small changes that have to do with ICT. Among the major changes that are now being discussed everywhere are of course "alternative truths," the hacking by foreign nations and others of databases and websites to steal information, or the use of social media to plant it. Other news concerns the evolution of the capabilities of IA, such as the battle between one of IBM's machines and the top player of the game of Go (Koch 2016). But there are many more, seemingly innocuous, changes that illustrate some of these recent developments in information technology. I will briefly refer to some papers I noted recently (January 11–15, 2017). The first of these (Reuters, January 15, 2017 by Suzanne Barleyn) summarizes how insurers are beginning to collect microdata (for the moment on a voluntary basis) of individuals' daily habits, such as the length of time they brush their teeth, the things they buy at the grocery store (and presumably eat), their daily exercise regime, their driving, and much more, all presented as an opportunity to reduce the cost of their insurance. But underlying such efforts is ultimately the opportunity to charge certain individuals much more for their insurance if they do not behave "appropriately." In this manner, the information revolution is destroying the statistical basis of insurance thinking – that one person's good fortune compensates for another's misfortune in what is essentially a collective approach.

The second example is less visible, but certainly of great importance. It is raised in an article in the *Japan Times* of January 14, 2017 by David Howell, and concerns the fact that development of the digital economy since the 1980s has on the one hand caused the emergence of millions of small companies, with the result that traditional measures of the economy are no longer adequate, while on the other hand the large information giants can no longer be controlled because they are essentially global, so that no government has the capacity to constrain them. As a result, the traditional ways to steer an economy are becoming less and less effective. The same incapacity to apply the results of opinion polls to the management of the political process is currently hampering any top-down governance because the samples on which these polls were based are too narrow to reflect opinions in an interactive digital society. Howell concludes: "and where data and facts about the world become either unreliable and misleading or unascertainable, a new phenomenon steps into the vacuum. Enter the age of fake facts, bogus statistics and dud forecasts…"

The third case, by Noah Barkin, also published by Reuters (January 15, 2017), concerns the fact that the top leaders of the developed and developing worlds, congregated in Davos in early 2017, were thrown into disarray by the unexpected political developments of 2016, including the UK vote to leave the EU, the US election of Donald Trump as president, the unreliability of elections owing to cyberwarfare, etc. Barkin cites Moises Naim of the Carnegie Endowment for International Peace: "There is a consensus that something huge is going on, global and in many respects unprecedented. But we don't know what the causes are, nor how to deal with it."

This seems a prime example of a crisis due to an accumulation of unintended consequences that creates a groundswell in favor of change.

In an opinion page in the *New York Times* a few days earlier (January 11, 2017), Friedman summarizes the situation as he sees it:

> "And so it came to pass that in the winter of 2016 the world hit a tipping point that was revealed by the most unlikely collection of actors: Vladimir Putin, Jeff Bezos, Donald Trump, Mark Zuckerberg and the Macy's department store. Who'd have thunk [*sic*] it? And what was this tipping point? It was the moment when we realized that a critical mass of our lives and work had shifted away from the terrestrial world to a realm known as "cyberspace." That is to say, a critical mass of our interactions had moved to a realm where we're all connected but no one's in charge.

In explaining the tipping point, he cites Alan S. Cohen, chief commercial officer of the cyber security firm Illumio, saying that:

> …the reason this tipping point tipped now was because so many companies, governments, universities, political parties and individuals have concentrated a critical mass of their data in enterprise data centers and cloud computing environments. […] As more creative tools like big data and artificial intelligence get "weaponized" this will become an even bigger problem. It's a huge legal, moral and strategic problem, […] and it will require a new social compact to defuse.

His conclusion is all the more important because in our current and future world, policies, whether economic, political or social, will be more and more decided on the basis of information in the major databases that are emerging in the cloud.

Conclusion

In this chapter I have presented some among the many examples of how ICT is impacting on our societies and their information processing. A more complete overview, which is nevertheless compact (but of course already out of date), is found in Hanna (2010). My aim is to drive home the fact that in considering ways to meet some of our sustainability challenges, we must take the present and future impact of ICT into account. What we nowadays call the ICT revolution is the continuation of a number of trends in our global societies that have caused these challenges, but it is adding new, important, and unintended consequences to the predicament in which we find ourselves.

These consequences are often ambiguous, and can both contribute to sustainability or hinder it. Many of them are not generally taken into account in sustainability-related discussions, and certainly not in the detail and with the knowledge that is required. That is in my opinion one of the major challenges for the sustainability community in the coming years!

In meeting that challenge, we have to remember that the instances of the impact of the ICT revolution that I have given above are only a few of the popularly known ones; every day brings new examples, such as the following I found on October 6, 2017: AI can predict suicidal tendencies in people with 80–90 percent accuracy, much better than trained professionals (Walsh, Ribeiro & Franklin 2017). We are only in the very first stages of the changes the ICT revolution will bring to our societies.

NOTES

1 An interesting, and to my knowledge thus far absent, investigation would look at the acceleration of the collapse of the Soviet Union between 1986 and 1989, which took place after some forty years of stability. Much attention has been paid to the role of the USA in this process, but much less to the internal dynamics that must have been part of the process.

2 It is in that field of tension that Debord and others place the role of artistic creation, as expressed by various artistic currents such as COBRA (post-) surrealism, etc. But in this field of tension one also finds the origins of certain social tensions.

3 I owe a debt to Armin Haas for drawing my attention to these authors' arguments.

4 Downloaded from https://obamawhitehouse.archives.gov/sites/default/files/whitehouse_files/microsites/ostp/NSTC/preparing_for_the_f uture_of_ai.pdf.

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Is There a Way Out?

Ut desint vires, tamen est laudanda voluntas. (Even when the forces are lacking, one must still praise the will.) (A Roman saying)

Introduction

In thinking about ways out of the current sustainability conundrum, we need to acknowledge that there are information-processing dynamics, such as the dominance of past tools for thought and action and the shift in focus toward shorter-term tactical solutions (rather than longer-term strategic ones), under the impact of unintended consequences that have brought us to this point because they are fundamental to human behavior, and therefore difficult to ignore. They have been discussed in Chapters 5 and 16 as major factors behind the path-dependent trajectories of all cultures and worldviews of individuals, groups, and societies. Changing these path-dependent trajectories and their current instantiations is well-nigh impossible in the absence of a set of external values and norms against which we can leverage them. Rather than try to change the values that underpin the current socionatural system in the western world, which are anchored so deeply and have been in existence for such a long time, it might be better to try and redirect them. Instead of initiating change by trying to frontally attack mindsets or worldviews that are closely related to people's and groups' identities, I think we would do better to focus on changing behaviors in the broadest sense; not limiting change to such things as "fly less, save energy," but rethinking all aspects of our behaviors, institutions, and investments from a practical point of view.

How do we change relevant behavior patterns? First of all, it seems that as we have collectively dug ourselves into a huge hole, we have to stop digging. In a literal sense, this effectively means finding ways to redirect the current extraction-to-waste socioeconomic system in time for us to conserve at least part of the Earth's resources and the cultural diversity that humans have built up over many millennia. A crucial part of this is that we must slow down the innovation revolution that is so closely tied to the plentiful availability of energy worldwide, and in particular its information and communications technology (ICT) component, which risks, as we have seen, creating a profound disconnect between the technical developments involved and the societal dynamics to deal with them, as it will result in an acceleration in the emergence of unanticipated and unintended consequences for all aspects of our society. We must thus change behavior simultaneously on a wide range of scales and fronts. In the next few pages, I will look at some of these behavior changes bottom up, from the individual to the group, society, nations, and finally the globe as a whole.

Individuals must Reengage in the Management of our Society

Overall, democratic governance and participation in it seem to be increasing, as new nations open up to it.[1] Yet in a number of developed and developing nations there is a trend toward reduced active participation of the wider population in governance. In developed societies this has recently (since about 1980) manifested itself in the fact that an ever-smaller percentage of the population participates in national elections, and an even lower proportion of people in local, regional, or (in the European case) European elections.[2] This is interpreted as the result of people losing the belief that participation will actually change anything in their everyday lives. In developing nations, but also in some developed ones, the lack of participation may also be the intended result of an absence of freedom of speech, press, and meeting, enforced to varying degrees but generally structured to maintain existing power structures. In other countries, the culture of individual expression on political topics is less widespread, so that voting is not a good barometer of the extent of participation in governance.

Whatever the causes, non-participation in elections has one major effect – people who do not vote are relinquishing control of their destinies. Many of them lead a relatively comfortable life and have not known anything else. They assume that this will more or less continue, and that governance is in the hands of a relatively small group of people who have a solid grip on it. Others think that the people in charge will never improve their lives, and ignore elections because of that.

By not exercising greater control over decision-making in our societies, many of us in the developed countries have, almost imperceptibly, handed such control over to very small groups of people and institutions: large businesses, government bureaucracies, and elected representatives at all levels, from our village or town to our national government. Democratic structures that began as a way to enable a society to achieve necessary and important, societally accepted, goals by according large numbers of people (ideally everyone) a vote in societal decisions, are being transformed into a way in which small minorities can gain control over what happens in the society and bend it to their own advantage. Enabling power has turned into controlling power. Only a few small developed nations such as Switzerland and Sweden have so far escaped this trend.

In this context, I am often reminded of a phrase of Archbishop Desmond Tutu of South Africa: "When white missionaries came to Africa, they brought the bible and we had the land. They said: "let us pray." So we closed our eyes and prayed ... and when we opened our eyes, we had the bible and they had the land ..." (Retrieved August 5, 2017 from: www.brainyquote.com/quotes/quotes/d/desmondtut107531.html)

But elections are only part of the story. If we are to redirect collective behavior in our societies, our starting point should be to reinvest ourselves in the sociopolitical and economic dynamics of our own immediate environments by spending time to familiarize ourselves with the issues and the options facing us and exercise not only our right to vote, but also to actively participate in the management of our communities and environments. If we are to stop digging the hole in which we find ourselves we have to plan a different future – by first asking a question about the kind of future we actually want as a think-outside-the-box-challenge, and then designing a roadmap that may get us there. This needs to be done locally, regionally, and nationally as well as globally. An interesting example of how to organize this is developed by Saijo (2017) and colleagues of Kochi University of Technology for the Japanese towns of Yahaba (Iwate prefecture) and Matsumoto (Nagano prefecture), as well as in both urban (Dhaka) and rural environments in Bangladesh.

Designing a Plausible and Desirable Future

Calling for innovation is not enough if we do not first consider where such innovation should lead us. After all, we must regularly remind ourselves that the last 250 years of unbridled innovation in every direction have led to our supply-driven materialist and consumerist innovation culture and to our current sustainability challenges. If we want to do better, we must also learn to better understand and steer invention and innovation. It may be worth repeating here that we hardly know enough about the dynamics that drive the processes of invention and innovation, mainly because these have to do with the emergence of new ideas (objects, routines, institutions), and emergence is not very easy to study in our traditional reductionist, ex post scientific approach that focuses on providing and proving explanations of currently observed phenomena, and thus inevitably links their present with their past (learning from the past) by means of a cause-and-effect narrative. As a result, we know quite a bit about the conditions under which inventions and innovations flourish and the ways in which they affect the economy, but have much less scientific, procedural knowledge about invention in particular that could help us focus or steer invention and innovation effectively. We must among other things come to understand how invention and innovation dynamics work, and how they affect outcomes. I point to some ideas that might promote such understanding in Chapters 12 and 13.

But more generally, we have to develop ways to promote thinking constructively about the future. One way to do this is by developing the academic discipline of Future Studies. Currently, the development of models, scenarios, and forecasts is widespread among major corporations, governments, and supragovernmental institutions. But there is no independent academic community of a reasonable size that can critically look at the results of such exercises and help develop such efforts. To cite Alan AtKisson: "“Future studies” seems to me a kind of academic ghetto, marginalized from mainstream sustainability studies (and even farther removed from mainstream politics and economics)! (personal communication January 8, 2018)."

Repeating the gist of Chapter 6, if we are to plan our future we must adopt an ex ante perspective, linking learning from the past to learning about the present and to learning for the future. We should more directly focus on the processes that generate new phenomena, on the emergence of phenomena rather than on explaining existing ones.

A major barrier to asking about the kind of future we want seems to be that we often view our current predicament as the result of a quasi-inevitable evolution toward progress. This is a very deep and ancient tradition in our western cultures, but it is also a needless and distorting simplification of the reality of our history. On the contrary, at many times in our history there have been moments in which our societies' trajectory was determined by choice (in the sense of systemic choice) involving the actions of an individual or a small group of individuals. Choice is important, whether systemic, local, or individual!

The situation in Europe in around 1750–1850 which I referred to in Chapter 12 is a case in point. Revolutions (France), near-revolutions (Germany), and war (Europe and North America) show that the structure of European society at the time was approaching a tipping point. Major structural changes occurred as a result of these events, but in particular the harnessing of fossil energy by means of the steam engine and the reorganization of Europe's colonial empires from trade empires to production and marketing empires gave European societies a new lease of life. That said, things could have gone a different way, and European societies could have disintegrated. Choice is important, whether systemic, local or individual. The lesson is that if we are, as we think, at a similar point in our history, facing a tipping point, we must not succumb to an incremental (or worse a passive) perspective, but we must actively stimulate choice by collectively thinking about the kind of future we want, while being fully aware that unanticipated and unintended consequences of past systemic decisions may also limit the extent to which we can influence the future.

A fundamental question at this point is whether we actually struggle to achieve a chosen (more or less distant) ideal, or whether we accept that the future is ontologically uncertain and cannot be determined, so that our main efforts should be to optimize the path that we follow in our everyday actions, choices, and relationships. This dilemma is in some ways reflected in the difference between our western (European/American) approach and the traditional Asian approach to life (Puett & Gross-Loh 2016). Investigating that difference, as is done brilliantly by these authors, highlights a wide range of other differences that one may need to consider, of which in my opinion the most important one is between the western focus on entities (objects, individuals) versus the traditional eastern focus on patterns, relationships, and, in an abstract sense, systems. Do we strive for individual success, in competition, or do we strive for the success of the community? What is success: behaving like an ideal person, as is the case in the Judeo-Christian and Muslim tradition, or behaving like "ordinary" human beings with all their idiosyncrasies?[3] Do we strive for the realization of our individual potential or for that of the group? Ultimately these questions touch on the puzzling question of the existence and role of free will. How independent are individuals and their thoughts and actions from their context? Is the context, and are our relationships with our surroundings (including our social networks), dominant in determining our behavior, or are we as individuals? From the complex systems perspective, contexts and relationships seem to shape decisions and actions to an important extent, but what the role is of individual and collective desires in that process is still an open question. Are such desires fully shaped by contexts and networks, or is there a (genetically or otherwise determined) individual factor that plays a role in them? These are the kinds of questions we need to raise, discuss, and form opinions about as part of our efforts to outline our future actions.

From my perspective, one of the major thrusts should be to strive for an increased multidimensionality of our individual and collective value spaces. I outlined in Chapters 17 and 18 that in my opinion the relative reduction of our value space, individually, nationally, and globally to fewer and fewer dimensions, dominated by the lowest common denominator of wealth, has been a major contributor to the increasing wealth discrepancy we observe in the current world, but also to the destruction of many local, regional, and national social networks, thereby undermining the strength and resilience of communities worldwide, resulting in the urbanization and individuation of our societies. This has in turn facilitated the emergence of growing power over societies on the part of small elites. In the next couple of sections, I will discuss this process in some more detail.

The reduction in the dimensionality of our human experience in the West is also driven by another powerful, and relatively underinvestigated, set of drivers – individual and societal emotional desires. Over the last century, with roots in the works of Freud and his colleagues in different branches of psychiatry, motivational research in advertising has slowly but surely accorded desires a much larger place in human decision-making (see the classic work of Packard 1957). In the last twenty or so years, this has again led to a major development in the scientific study of the role of human desires in decision-making in general, with certain authors according desires a more important role than any kind of scientific or other rational reasoning. It would take me too far from the main subject at hand to summarize this literature, but in the next section I will outline how one might see desires at work in creating narratives that drive our decisions as individuals and societies.

The Role of Narratives

Narratives and memes have in recent years been recognized as important potential agents of change. They can serve multiple functions, some of which are tied to the identity of people or groups. They have been seen to help anchor culture and society around certain basic ideas, myths, or defining moments in history. But it is interesting, in the present context, to drill down into the underlying dynamics.

To that effect, I am adopting the thesis that, in a process of increasing focus on the future in European (and later other western) societies (Girard 1990), our visions of the future have slowly but surely become a major structuring factor in our behavior and decision-making. This process has been going on since the mid-eighteenth century and coincides with the beginnings of the "Great Acceleration."

Beckert (2017) argues that the underlying difference between our current western conception of the future, and that of pre-1750 days is that in medieval and Renaissance times the future was conceived as more of the same, whereas since then it is increasingly viewed as open – subject to uncertainty and unpredictable change. He argues that this has set in motion a (uniquely western) cognitive feedforward loop that creates in our minds "imagined futures" and then develops "fictional expectations" that motivate people toward realizing them. In his words, "expectations of the unforeseeable future inhabit the mind not as foreknowledge but as contingent imaginaries" (Beckert 2017, 9); "they create a world of their own into which actors can (and do) project themselves" (Beckert 2017, 10).

Of course, these fictional expectations are continually adapted to present circumstances. For Beckert, this exchange between imagined futures and present conditions drives our decision-making. "Fictionality, far from being a lamentable but inconsequential moment of the future's fundamental uncertainty, is a constitutive element of capitalist dynamics, including economic crises" (Beckert 2017, 12). He illustrates that in detail for the four main pillars of any economy: money, credit, investments, and innovation.

The implications of the role of such imagined narrative futures stretch far beyond the economy. First, they imply that the cultural, institutional, and social embeddedness of decision-making is based on imagined futures. Decisions reflect the value systems of the people concerned; they are shaped in the interaction networks of these people. Much of our current thinking about the future, for example, is in essence based on a western imagined future that, as part of globalization, has been projected onto other cultures. In other parts of the world, one finds underneath that global projection very different imagined futures. Part of our task is to identify some of these, particularly in parts of the world that might replace the current western-dominated political system.

Secondly, imagined futures are constructed by comparing the present to an imagined future, and they are maintained only as long as there is confidence in that future. In the absence of such confidence, a degradation of people's circumstances or a crisis is experienced. The anticipatory loop can then very rapidly be turned in a negative direction, toward uncertainty, as in the case of recent financial crises. But that is not confined to such crises – it can slowly undermine the totality of our confidence in the future and result in hesitations, contradictory actions, and general loss of self-confidence.

Thirdly, our concern with sustainability can also be seen as the construction of an imagined tipping point for our world. By implication, the current imagined future that drives our present global socioeconomic and environmental system is less solidly anchored and stable than many people currently expect, and in projecting futures for the world we need to take this into account.

Fourthly, we need to consider the relationship between our imagined futures and the real world out there. That interaction is clearly an open-ended one that is not fully controllable, subject as it is to "ontological uncertainty" (Lane & Maxfield 2005). As the imagined futures are confronted with the material and social "real" world, it is impossible to predict the outcome of such confrontations, especially over the longer term, owing to changes in the second order dynamics of the context in which shorter-term decisions are made. That confrontation is a major element in any process of invention and innovation (Lane & Maxfield 2005, 15).

To conclude this section, we need to remember that the driving force of many desires, whether sexual, esthetic, intellectual, or emotional, is a strong and permanent challenge to our current economic, wealth-based, logic. While currently this dominates and is a major factor in globalization, one can envisage a future in which individual and societal desires, as expressed in different cultures, will gain in importance and contribute to the fragmentation of our world.

Reconstructing Communities

Back to the role of information processing. I argued in Chapter 18 that the global and rapid transformation in information processing is further weakening our existing central processing structures and institutions by strengthening horizontal communications worldwide. This clearly has important consequences for our current societal structures and the values that they hold, as it weakens the top-down element in the already fragile equilibrium between people, their institutions, and their governments, as well as the distinction between signal and noise that is dependent on the value space of a group or society.

It does not seem to me that a new social structure can emerge entirely top-down from this weakened power structure. Around the climate change discussions, we have seen that nation-states have major difficulties aligning themselves with a set of goals, and that any attempts to do so cause major friction within and among them. Although idealists have argued for many kinds of international governance, this has remained a very elusive goal; witness the difficulties the European Union (EU) has had to set up and maintain such a governance structure, and the difficulties that the United Nations has in striving to become a strong political player. As we see in Chapter 18, the novel impact of ICT is only making it more difficult to come to some kind of overarching goal in this domain.

I conclude that any fundamental restructuration will be shaped by the intrinsic properties of the complex adaptive system involved. Such a (re) structuration takes time, in the case of the Roman Empire some eight centuries or more. But that is no reason not to think about that process, as we do not currently have a choice. From the perspective of this book, it seems that for a time we will slide further and further into a phase of chaos, but ultimately this phase will generate a new form of societal organization, new values, and new tools for thought and action. Moreover, the ICT revolution may actually help us achieve such reorganization much more rapidly than in the Roman case (see Chapter 20).

How to go about such a restructuration is difficult to outline in a situation in which the ICT revolution is only beginning and is likely to rapidly change. But there are some elements that seem crucial, and the first signs of them are on the way.

One possible trajectory is that of community (re)creation based on the (re)activation of multidimensional value spaces. One example is presented by the transition towns movement that started in the UK. Focused on reducing greenhouse gases, and in the absence of sufficient progress at national level, many towns are taking their own grassroots initiatives, based on collaborations among and between one or more sectors of civil society: local government, business, non-governmental organizations, or less structured groups of citizens. Initiated in Totnes in 2006, in

September 2013 there were 462 officially registered transition settlements in the UK, Ireland, Canada, Australia, New Zealand, the USA , Italy, and Chile. In the USA, transition initiatives have been started in many communities. Their stated national aim is "that every community in the United States will have engaged its collective creativity to unleash an extraordinary and historic transition to a future beyond fossil fuels; a future that is more vibrant, abundant and resilient; one that is ultimately preferable to the present."[4]

Networks established between the transition towns are a resource and catalyst for building resilient communities that are able to withstand severe energy, climate, or economic shocks while creating a better quality of life in the process. They are accomplishing this mission by inspiring, encouraging, supporting, networking, and training individuals and their communities as they consider, adopt, adapt, and implement the transition approach to community empowerment and change, focusing on reducing and cleaning energy use, transportation, food, waste and recycling, economics, and psychology (Hopkins 2008, 2011, 2013).

This kind of community-building activity is also beginning to spread to rural areas. In developed countries, this trend is notably expressed through the organic agriculture and horticulture movements. In China, I am following a related effort in the village of ShiShou in Hubei province, and in Japan I have been able to observe efforts to revitalize rural communities in various parts of the country that have suffered from rural depopulation. Often these efforts are initiated by individuals who have managed successful careers in towns, but want to live in a rural environment and give back to the community of their youth. In Europe, I am involved in studying the efforts of a small community in the Venice lagoon to attain the same, against very heavy odds, in a largely globalized semi-urban society.[5]

Another aspect of the erosion of societal resilience is that such resilience is in large measure derived from the codependency of individuals in groups. Over the last fifty years, many risks that kept people together as communities have been shifted to the level of the city, the province, or the nation, and in some cases the EU – for example, social security, health care, education, and infrastructure. This has helped many people to climb the social ladder but it has also eroded the codependency of people in communities. The real question is therefore how we find a balance. And in order to do that, I think we must have individuals and communities regain a sense of their own risks and how to cope with them.

Rebuilding communities, and in larger cities socially rebuilding neighborhoods, is absolutely fundamental to any effort to deal with the combined impact of the ICT revolution and the closure of our value space on the resilience of our communities, and thus on our overall sustainability. However much the ICT revolution facilitates making contact with everyone, the combined effect of globalization and commodification over the past few decades has so heavily eroded the trust and alignment on specific sets of values in each community that this trust and alignment need to be rebuilt, and this needs to be done face to face and will take considerable amounts of time (see Friedman 2016, chapter 12, for an example in Minnesota). The reopening of our individual and group value spaces that it engenders is fundamental to a successful emergence from our current sustainability challenges.

I also conclude from these examples – and the many others that I could have adduced – that we must as scientists be more humble and shed any pretense of being able to steer the future or innovate to make it happen in one specific way or another. Except in very rare circumstances, such as the Manhattan Project, no scientist of any kind can successfully try to change the world or the transformational trajectory it is on. This is a dangerous, outdated illusion that derives from our linear perspective on science, and is incompatible with a complex systems vision of society. Society changes itself. Scientists can contribute two kinds of things. First, they can tinker experimentally in the margins of the major societal dynamics, and secondly (and maybe more usefully) they can try and alert our societies to the kinds of changes that are coming, so that people can begin to prepare themselves for these changes.

The Future Role and Management of Cities

Cities are a special case, and merit some additional discussion. Their characteristic that concerns us here is the relationship between the communities living in them and the infrastructure in which they are living. The relatively long-term infrastructure in which urban dwellers live in many places complicates making changes to their social and information-processing configuration, and slows them down. This explains why urbanization so far has been the most persistent societal dynamic known to mankind. Individual cities have disappeared, but urbanization as a phenomenon has not disappeared. The fundamental drivers – aggregation and innovation – have remained intact throughout the last 6,000 or 7,000 years.

However, currently the energy–information balance that is at the root of the recent explosion in urbanization has been changing. Energy is becoming rather more expensive than it has been for the last couple of centuries, and information processing is becoming much less expensive, and less location-dependent. Hence one important question is whether the dynamic that drives urbanization – getting more people closer together so that information processing becomes easier at the cost of increasing the need for energy – is actually going to continue. Might the ICT revolution actually offer an opportunity to change an urban dynamic that has led to poverty, crime, and other undesired consequences of aggregating such a large number of people in limited space? Or would the spread of alternative, renewable energies in the longer run reduce the price of energy again? And if so, would that promote the regrowth of urban centers in the presence of the information-processing facilities now available?

Cities are growing faster and faster, and so are innovation and wealth differentials. Members of our communities and societies have increasing difficulties in keeping up with technological change. This means that societal risks have increased. Owing to the concentration of the population one finds there, this phenomenon is particularly important in cities. Hence, I would argue that cities are in the current context very vulnerable systems. They have a very costly infrastructure, they are dependent on a very large footprint, and in view of the dynamics I have just mentioned they are no longer necessarily the most persistent social dynamic that we have known.

Most of the predictions about urbanization, and in particular that we will have about 80 percent of people living in urban situations by 2100, are based on a linear extrapolation of the current dynamics, including political trend analyses. But in the case of urbanization we are actually dealing with a complex system that has many unintended consequences, and such a linear scenario will not necessarily come about. The ICT revolution, which is only beginning and will change the world much more dramatically than anything we have seen before, undermines the need for spatial concentration in innovation and therefore undermines the need to actually build cities. Climate change will exert pressure to increase transport costs and to reduce the use of bulk transportation, so that we may have to develop economies that are more regional, more local. The food/water/energy nexus, I would argue, may well hit us long before the heaviest impact of climate change (Roberts 2009).

Together, these dynamics may constrain the business-as-usual scenario for urban development. ICT may shift the dynamic toward dispersed settlement when information exchange no longer requires proximity. This saves energy and improves resilience because it keeps mutually dependent social groups together that are therefore more resilient. Mega-cities, as a result, may lose some of their predominance, and this will lead to an adjustment of national rank–size curves under globalization. Individual cities may gain in autonomy because the very large national and supra-national units of governance may become more and more difficult to manage. But cities must find effective ways to manage focused change and stability, forcing them to invent novel ways to solve social challenges. But what these are, and how they are implemented, will differ from case to case and cannot in any way be predicted.

Innovation, as it is currently practiced, is putting our societies at risk because of the acceleration that process is undergoing. As mentioned in Chapter 2, when politicians and other people talk about innovating our way out of the sustainability conundrum, I respond that the last two-and-a-half centuries of undirected innovation in every domain of our lives has actually been a major cause of our present predicament. If we want to deal with the problem, we need to rethink the mechanisms that both foster innovation and suppress it. In that process, (mega-)cities, rather than designing change when they think it is necessary, will need to start designing for permanent change so as to accommodate the increased speeds with which urban communities change.

They will have to start integrating top-down and bottom-up codesign. What does that mean for urban architecture? In Haarlemmermeer, a little town just south of Amsterdam in the Netherlands, the Delta Development Group has been implementing the circular economy in buildings.[6] Every building is designed for disassembly and reassembly whenever that may be needed. The "owner" (in actual fact the user, rather than the owner) of the building rents the building materials, and when they are no longer needed he gives them back to their owners. By that point, these materials will have become scarcer and pricier so that the owners of the materials make a profit. Everything is either composted or recycled back into industry. Of course, this requires new business models for architects, builders, and building users, and a new legal, contractual, and possibly institutional framework. But I think this is nevertheless one of the ways forward that we need to start exploring much more effectively.

What about urban planning? In general, action is taken too late owing to slow, multilevel bureaucratic decision-making. Existing and well-known political systems are the standard and determine how we plan the future. People inside the system often become immune to signals from the outside, so that these systems tend to reproduce themselves and become more robust owing to external threats. As a result, urban planning takes longer than the dynamics that are inspiring it, and the actual results of the planning last even longer. To adapt to newly emerging challenges, we have to look further forward in planning, with a horizon of thirty, forty, or even fifty years, and we have to find faster ways to adapt cities.

Swarm Planning, developed by a Dutch urban planner working in Australia, Rob Roggema, might offer a tool to achieve this. Roggema (2013) argues that two things are essential for planning: the spatial characteristics of the area and region concerned, and the availability of extraordinary ideas. When there is a large group of individual elements – people, buildings, connections, high-quality relationships in a network – and enough diversity, one may be able to design several coexisting patterns and coexisting ideas for further development, in which small groups of people will engender creative jumps, and new structures and information will evolve. But rather than focus on one future, multiple scenarios are prepared and multiple pathways are put in place, so that when the city is faced with the need for change, it actually can and does implement such changes much more quickly, much as a swarm of birds can very suddenly change direction based on almost invisible signals.

Dealing with the Acceleration in Information Processing

In this section I want to move from the national level to that of human societies in general, crossing all levels from the individual to the national. A directly ICT-related societal planetary boundary is that of differences within and among societies in the speed of information processing. In Chapter 16 I cited Friedman's idea that ICT technology revolutions occur every five years or so, while societies need between ten and fifteen years to adapt to them. I now want to look at this in more detail to improve our understanding of what it actually means.

I think we need to distinguish between two aspects of this general statement. The first is the fact that the increasingly smaller community that is involved in generating the technical revolutions in ICT is indeed learning and inventing very fast, thus distancing itself increasingly from the wider population. Under current financial and legal circumstances, this contributes to the wealth gap because information is power, is wealth, and there is a substantive lag in enabling others in the population to catch up in information-processing capacity because that involves transfer of knowledge and education, which both need to be organized. The second aspect is that as part of the innovation concerned, our societies have to adapt in the widest sense, changing their behavior, their customs, their policies, and their institutions, and that takes a lot of time because it involves aligning large numbers of people around changes in the value space of which they are part.

Before I try to point to some ways to deal with this growing gap, I'd like to point out that many, if not most, people – whether politicians, business people, or citizens – assume that the ICT revolution must run its course. That is, again, assuming that history is an inevitability that is beyond human control or interference. Throughout this book I have tried to point out that this is not necessarily true – that individual or collective decisions do indeed impact on events and history in many, sometimes decisive, ways. In Chapter 16, I used the arguments of Polanyi and his students to make the point that the "invisible hand" of the market was not inevitable, but was created by the governing institutions of the time; and that when left to proceed on its own, it ultimately leads to societal reactions that can foster protectionism, trade (and possibly other) wars, and the like.

What could we do about the growing information gap? As is often the case, the opportunity to deal with this is also offered by the ICT revolution. In Chapter 18, we see that human mastery in processing information has only just set in motion a major revolution in our social, economic, and environmental organization. We should profit from that unique occasion to transform our society into one that aims for profound and accelerated restructuring. This implies that we need to collectively take a hold of the directions in which the ICT revolution may transform our society. At the moment, this is not the case – the private ICT companies are leading the development, and steering society in ways that are profitable to them. Part of such a reorientation can be achieved through the democratic process, by strengthening the constraints imposed on the companies involved, but much more can be achieved when individuals take responsibility for their own actions, strengthen their communities, and actively strive to focus on common values and goals.[7]

To begin with, we could – and should – slow down current development so that its speed is more closely in tune with what society can deal with. Here is a clear role for government. The current policy to let these developments accelerate is the result of the Red Queen race inherent in the feedback loop between the growth of the aggregates of population, notably in cities, and the need to develop new values in order to integrate them. But this feedback loop is not inevitable – downscaling population aggregates by devolving societal coherence into a multipolar world might well have the desired effect.

On the other hand, we could coherently and structurally improve the integration between general human and electronic information processing, so that most humans are back in control of the overall information-processing system. That is the essence of the book *Whiplash* by Ito and Howe (2016) that I will discuss in the next chapter.[8] This is clearly a process that is ongoing, in which exploiting the capacity of ICT to reach out and create horizontal networks of information processing worldwide can become of major importance to drastically improve the total information-processing capacity of our societies. But to achieve that, we have to direct the restructuring of our societies' information-processing capabilities in a different direction from the current one.

One measure that could in my opinion contribute to accelerating such a restructuring is the introduction of computational thinking everywhere in society by deploying major efforts in education in this domain at all school levels and ages, coupled with the introduction of generalized information society thinking in computer science. As part of that effort, we could be developing the generative (ex ante) approach to science that we think is essential, including in the historical sciences.

Another important contribution would be to replace the existing top-down and bottom-up information architectures with a more interactive approach, including improving continuous real-time communication and reducing response times.

Thirdly, ICT could be developed to enable us to overcome human cognitive limitations and biases. First and foremost, collectively we could try to overcome the limitations of the human short-term working memory. To this effect, we would need to develop more intensive sharing of human mental capabilities by continuing to invent better tools to communicate and work together as humans, but also make widespread use of electronic information-processing tools. As part of this, we would have to develop new ontologies and the software to apply them. In the scientific domain that would entail such things as developing improved transdisciplinary databases, tools for "Synthesis 2.0" (new software that allows larger groups in different locations to work together in real-time based on multi-site mirroring of content), serious, focused games to understand tacit knowledge, improved tools to study decision-making under uncertainty, open-science platforms involving people with non-academic backgrounds by crowd-solving, as well as more and better virtual experiments, in particular when studying societal phenomena. These should be based on much larger samples of data, enabled by high performance computing and "big data" processing, which must be analyzed in the greatest detail.

Our societies should also use the potential of new ICT developments to overcome the limitations of our thinking habits more widely, for example by further developing problem-based, change-focused tools that favor dynamic understanding over static knowledge. This would greatly contribute to the ability to overcome the current cultural and scientific emphasis on linking present and past in order to explain the present, rather than thinking about the future. To achieve this, emphasizing in education as well as in action the ex ante perspective alongside the ex post perspective that is currently dominant is essential, striving to learn from the past about the present, but with an emphasis on learning for the future. This could be initiated at kindergarten level and maintained throughout the whole curriculum, emphasizing the fact that there are always choices (and that such choices have both beneficial and potentially negative consequences), instead of presenting young children with "truths" in the form of cause-and-consequence narratives. So-called serious games may be a major asset to achieve this goal, as they stimulate such ex ante thinking.

But developing such an approach will also require new thinking about the role of computing. Currently, many approaches using the big data revolution are still based on statistics, and therefore on a reductionist approach to distilling information from data, studying past trajectories and present situations. Some such approaches are discovering thus far unobserved patterns and using them to extrapolate toward the immediate future. But if we want to think about the future out of the box, ICT could be developed to move from a limited number of observed dimensions to generate as many other potential dimensions as possible, and then test those out for feasibility by combining forecasting and backcasting. This would in effect contradict Occam's razor by making the assumption that the world is complex and that, therefore, ideas need to embrace that complexity rather than simplify it away. The first, small, steps in this direction are being set by people such as Belnap (e.g., 2003, 2005, 2007) and Fontana (2012). Another interesting move toward such an approach is presented in the AlphaGo approach developed by René Coulom (Coulom 2006, cited in Ito & Howe 2017) that is able to deal with challenges in very high numbers of dimensions, based on machine learning and statistical sampling techniques (the so-called Monte Carlo Tree Search algorithms).

Such efforts could also reduce, and on occasion overcome, the underdetermination of ideas by observations (see Chapter 16). Massive

ICT-based data gathering is an essential step to achieve this, and more will no doubt develop in this field, in particular as sensors rapidly become cheaper and spread to many more domains.

Identifying better ways to deal with the disciplinary and sectoral biases of human decision-making toward theories, ideas, and behavior that are principally based on successful past responses is another major ingredient of such an improved approach. Any such efforts create major challenges for the integration of different kinds of data into the necessary major databases.

But above all, we scientists should organize ourselves as socially and politically engaged individuals to influence, and where necessary control, the direction in which the ICT revolution leads us if we want to avoid a future such as I will try to sketch in Chapter 20, on the basis of the work of Dirk Helbing.

Our Role as Scientists in the Community

Over the past century or so, in some of our western societies science has to some extent lost the most precious gift of all, the trust of the population – without realizing it – owing to the unchecked instrumentation of science by industry and government for purposes of innovation and/or governance. In this process, science was a willing partner and became increasingly dependent on both for funding. In certain regions and certain domains, therefore, science and scientists are either seen as too distant from the concerns of civil society or too much under the influence (if not control) of government and industry – defending interests that are not those of the wider population. The loss of appreciation for, and trust in, science shows in some countries (such as the USA and, to a lesser degree, the UK and European countries) as a reduction in funding for basic science and/or acceptance of scientific ideas. The recent push of the Trump government in the USA to seriously reduce federal funding for research shows that this distrust has reached such proportions that even a government that has thus far used and promoted the role of scientists now bends to the popular view that science, and especially social science, is suspect.

As a result of that development, as I argued in Chapter 3, we must review the relationship between science and society, make it more open and transparent, be more realistic in the expectations we raise, and be more aware of the potential unintended consequences of our actions. We must listen more, think more broadly in terms of alternatives rather than narrow causal explanations, and use what remains of society's trust in science to influence the political debate, as well as rebuild that trust where it has been eroded.

A first essential ingredient in this context is the wider spread of the complex adaptive systems approach and the thinking behind it. The second is humbleness among scientists about their role in determining the directions our society will take. I will deal with each of these in turn.

In Chapter 7, I outlined some of the differences between the complex adaptive systems (CAS) approach and the traditional, linear, scientific cause-and-effect approach, and I have argued the scientific need to think in CAS terms. There are, however, some political and social aspects of that approach which are important in the current context, but which I did not emphasize in that chapter. A major one is that admitting the nonlinear dynamics of most socioenvironmental and economic phenomena, and their ensuing unpredictability, helps reset our position as scientists in the world. It moves us away from projecting ourselves as "experts" who have "solutions" (which in many cases have not worked or have had unintended consequences, and thus have contributed to the loss of trust in science) to admitting that there is much that we do not know. This would also help us think in more appropriate terms about a future that we are not able to anticipate, but in which we can contribute to the many experiments that finding our way as societies will require. Thirdly, it seems to me that the CAS approach contributes to a convergence between the natural and the social sciences because it reintroduces irreversibility and history in the conceptualizations of the former. Both these conceptual tools have always remained integral parts of thinking in the life and social sciences, but have for a considerable time not been part of the (Newtonian) natural science toolkit that is still widespread in science thinking. An interesting fourth aspect to this is the hypothesis that CAS thinking is able to help bridge the gap between western and eastern approaches to understanding the world, as was proposed by Capra (1975) and others at the time. A team in Singapore is working on this issue, led by Sim and Vasbinder (Sim & Vasbinder, unpublished 2015).

How far should scientists refrain from, or actively participate in, societal debates about the way forward? Here, sustainability is a good case in point. If, as scientists, we see a disaster such as a train wreck coming, should we limit ourselves (as many have) to impartially outlining the scientific conclusions, or should we go as far as warning society, or even engage in promoting what we see as necessary measures to avoid the disaster? The scientific community has not been able to develop a consensus on this point, torn between the idea that articulating a specific position in this debate beyond simply presenting "the scientific facts" will weaken trust in science (as expressed by Merton in 1942), and the idea that if you can be sure that two trains are set to collide you have to take action.

In many ways, this debate is about whether a scientist views him- or herself first and foremost as a scientist and only secondarily as a citizen, or the reverse. Clearly, scientists just like any other people are complex systems and parts of wider systems. However, as actors, the way they view themselves and act upon that perspective is relevant to the ecology in which they function as individuals. My personal opinion is that as society pays for our education and our professional activities, we are first and foremost (educated) citizens, and it is therefore our role to choose among pathways for society and to promote our vision with due reference to the scientific underpinnings of our ideas, and clearly acknowledge where the science stops and our personal choices begin. The world has become so complicated and complex that the overwhelming majority of citizens can no longer identify ongoing dynamics clearly. As educated scientists, we must therefore accept our role in an intelligent manner.

A special aspect of this position is our attitude with respect to education. As I have argued earlier, if our societies (or their successors) are to survive as such, an emphasis on improving the education of our children and ourselves is fundamental. As scientists, we have a huge responsibility in that domain, but because, while we are paid by society to educate, our career structures are predominantly determined by research, that is not always sufficiently acknowledged. Reevaluating our role in this respect is part of what needs to be done.

NOTES

1 At a global level, democratic participation seems to be on the increase: (www.idea.int/gsod/files/IDEA-GSOD-2017CHAPTER-1-EN.pdf. (consulted January 10, 2018)

2 The data for national (and European) elections in many developed countries are available at www.idea.int/data-tools/data/voter-turnout (consulted January 10, 2018). Although there are always major fluctuations that are related to the issues at stake in any election, these data point to a decrease.

3 It is interesting in this respect to compare the classical Greek approach to the Judeo-Christian one. In the former, the gods behave like humans, whereas in the latter, people are striving to behave like gods (Lin Yutang 1998).

4 Wikipedia "transition towns," downloaded December 28, 2016).

5 The Chinese case-study in ShiShou is piloted by the Development Research Center of the State Council of the People's Republic (Yongsheng Zhang, PI), together with Hong Kong University of Technology and Arizona State University; the Japanese project is led by Professor Abe Kenishi of the Research Institute for Humanity and Nature in Kyoto; the Venice project is part of the GREEN-WIN project funded by the EU, led by Jochen Hinkel of the Global Climate Forum in Berlin.

6 See www.deltadevelopment.eu/en/.

7 For example, if under the current threat of companies misusing our personal data, the majority of participants in social networks would decide to cancel their memberships, a couple of major information technology (IT) companies would be in very serious difficulties, and non-IT-based social relationships would again flourish.

8 I am greatly indebted to Dean Christopher Boone of ASU for drawing my attention to this highly stimulating proximate vision of the ICT revolution.

20

"Green Growth"?

Introduction

In this chapter, I want to give some examples of a few of the many long-term visions for the future of humanity and its societies that are emerging. I choose not to go into those that could be labeled science fiction, nor is it my aim to present a coherent overview of the literature. I will limit myself to visions that are likely either to have or have had scientific or political impact: the Steady-State Economy movement, the Sustainable Development Goals adopted by the United Nations (UN), Farewell to Growth, a more politicized version of the steady-state argument, and two visions on the long-term impact that information and communications technology (ICT) will have on our societies, one theoretical, the other more practical.

In my opinion no one can make realistic assessments of where our world will be in 2050, let alone 2100. What follows are summaries of some current visions, simply meant to indicate some of the issues involved.

Why choose the label green growth for this chapter? What do I understand by this phrase? It is defined by Wikipedia (https://en.wikipedia.org/wiki/Green_growth, consulted June 5, 2019) as a path of economic growth that uses natural resources in a sustainable manner. It is used globally to provide an alternative concept to typical industrial economic growth. A number of national and international institutions have adopted this approach or a closely similar one (e.g., the United Nations Economic and Social Commission for Asia and the Pacific, the Organisation for Economic Co-operation and Development, the World Bank, and the Global Green Growth Institute). Most of these see green growth as a way forward with respect to the current sustainability predicament, but within the current socioeconomic free market paradigm.

The reasons for my choices are in part theoretical, in part practical. I am convinced that the climate change debate has from the start been formulated by the scientific community in a way that has precluded general acceptance and consensus – as a threat to our societies, rather than as an opportunity for change. Hence it came to be associated with burden sharing, with limits to growth, and thus with regression; with a way back rather than with a way forward (AtKisson 2010).

The concept of green growth was first introduced under pressure from the business community to make the concept of growth compatible with environmental challenges, as growth is essential for profit in the current capitalist system. It has been adopted more widely as a term that emphasizes transformation rather than regression or danger and accepts that growth is necessary to improve the lot of billions of people in the developing world.

As was the case with its predecessors, sustainability and resilience, the term green growth is ill defined. For me, it implies in effect a profound restructuring of global society that will, in the long run, change the roles and ways of each and every one of us as individuals, as well as the design and functioning of our customs, institutions, and laws, much as earlier structural changes in society (sedentism, urbanization, and the Industrial Revolution) did in the now distant past. As part of that, it is expected to substantively reduce the human use of environmental resources, waste production, and the differences in wealth and wellbeing between north and south, as well as between and within individual countries. But it will, if successful, go beyond that and affect many aspects and sectors of our societies worldwide. Of course, it is impossible to envisage how this will play out – but we need to think seriously about the kinds of dynamics that we should set in motion, why, and how. This is what I would like to consider in this chapter by looking, in the first instance, at some of the futures that others in the sustainability business have (or have had) in mind. In presenting these, I also raise a question about whether growth and its cousin progress have a place in the kind of fundamental change that is required to deal with our sustainability conundrum.

Steady-State Economics

To initiate this topic, I want to go back to a groundbreaking book published many years ago. Herman Daly (1973) is one of the earliest to envisage a world that goes no further down the path of progress and growth. He was of course not the first to mention that human development may ultimately hit limits. Antecedents of Daly's ideas are found in Smith (1776), Malthus (1798), Ricardo (1817), Mill (1848), and Keynes (1930), to mention but a few. Moreover, Daly's book is part of a cluster of works on the same theme that were published at more or less the same time, including Boulding (1966), Georgescu-Roegen (1971), Meadows et al. (1972), Schumacher (1973), and others. But no one has argued the case of a steady-state economics as convincingly (and untechnically) as Daly.

In evaluating his very strong and in some places emotional plea, the reader is reminded that it was written at a time that information, information processing, and complex systems did not yet figure in our arsenal of intellectual tools. His work is therefore entirely based on energy- and matter-related arguments, and does not in any way consider societies as complex systems. His solution of a steady state still characterizes a linear cause-to-effect kind of thinking.

Yet there are still some interesting lessons for us in his analysis. I present them here in the form of a set of questions meant to promote a critical consideration of the fundamental societal choices that are to be faced in an era in which our global environmental footprint (Wackernagel et al. 1998) far exceeds the sustainable.

Daly's critique of the idea of progress and its role in the world is essentially value-based, in the absence of the ideas that are the foundation of this book, concerning information processing as part of the driving feedback loop that pushes our societies to include ever more people, more technology, more wealth, more power, and better health for (part of) the world population. Thus, he grounds his argument in the western value system, stating: "Once we have replaced the basic premise [*sic*] of 'more is better' with 'enough is best',[1] the social and technical problems of moving to a steady state become solvable, perhaps even trivial" (1973, 2). He thus brings the argument back from economics to political and social philosophy, where it started in the nineteenth century with Malthus, Marx, and many others: "Only by returning to its moral and biophysical foundations and shoring them up, will economic thinking be able to avoid a permanent commitment to misplaced concreteness and crackpot rigor."[2]

For Daly, therefore, "the challenge is to develop a political economics that recognizes both ecological and existential scarcity and develops its propositions at a low to intermediate level of abstraction, understandable by the layman or average citizen…" That is indeed the kind of narrative that needs to be, and in part has been, developed to promote the change in mindset that is necessary to achieve sustainability.

Underpinning all this is a particularly critical vision of the role of science and technology in our societies, which is worth thinking about in view of what is happening in the early twenty-first century. He cites a phrase from the 1933 Chicago World's Fair Guidebook: "Science discovers, industry applies, and man adapts himself to, or is molded by, new things … Individuals, groups, entire races of men fall into step with Science and Industry" (cited in Dubos 1974–1975, 8). In other words, in how far have we, the scientists, contributed to the spiraling out of control of society's relationship with the environment? Whether we see technology as shaped by the economy or the other way around (Arthur 2009), this is certainly worth thinking about. I raised this issue in a related form in Chapter 3 and in the last section of Chapter 18.

To what extent has the free market ideology, with its "invisible hand" inversion of the relative roles of society and the economy (Polanyi 1944; Chapter 18), and the ensuing systemic acceleration of innovation sucked science and technology into its vortex? If this is indeed the case, can society regain control over the runaway dynamics thus triggered? Daly's kind of steady-state economics would channel technical progress in the socially benign directions of small-scale decentralization, increased durability of products, and increased long-term efficiency in the use of scarce resources. It would thus respond (at least in part) to the issue raised in Chapter 12 – that scientists must better understand invention so that they can focus it on the most important needs of society, rather than let it continue to run rampant in every conceivable direction (as has happened so far).

All this also raises another important issue that has not received enough attention: demographics. In principle, this is the part of the information processing–knowledge acquisition–population growth feedback loop driving our present predicament that we could indeed individually control. Yet in the sustainability debate the issue plays the role of the, often invisible, elephant in the room, being avoided in discussions for two reasons: the western ethic about life being sacrosanct (which does not necessarily apply to the same extent in other cultures), and the ample evidence that in the current system it is impossible to achieve economic growth without population growth.

But the latter may be about to change, as a result of automation. If automation and artificial intelligence (AI), as predicted, cause widespread unemployment, the question of demographic growth is reduced to an (essentially western) ethical issue: the inviolability of human life and the desire to improve health and lengthen individuals' lives. We need to urgently question whether this value set is compatible with the sustainability of our societies, and if so how we will deal with the resultant increase in the global population, which has thus far in many places been accepted in an almost axiomatic way (except in China and India). Daly states:

> Growth of the human household within a finite physical environment is eventually bound to result in both a food crisis and an energy crisis and in increasingly severe problems of resource depletion and pollution [...] Technological adaptation has been the dominant reaction [...] We need, however, to shift the emphasis toward ecological adaptation, that is to accept the natural limits to the size and dominion of the human household. To concentrate on moral growth and qualitative improvement [...] (Daly 1973, 12)

By implication, we should be "back-casting," working from a future in which those environmental and resource limits apply, toward a roadmap that can achieve the necessary changes, rather than taking the present as a starting point and forecasting from there into the future to create our roadmap.

In this process, as the human mind, as well as the coherence of society, require ever more information processing and acquisition of knowledge, we have to turn to the realm of the mind and the spirit for satisfying that need, rather than to the material and energetic realms. We need to enrich, rather than impoverish, the dimensionality of our value systems by developing the mental, normative, and ethical dimensions that have (in part at least) been jettisoned as part of (one-dimensional, wealth-directed) globalization (see Chapters 14 and 16).

Daly thus initiated a movement toward no growth (steady-state) economics. I want to briefly present and discuss some of the core ideas of this movement as I am not sure it offers a realistic solution to our predicament. A compact treatment of the subject, which places it in its historical context, is found on Wikipedia (https://en.wikipedia.org/wiki/Steady-state_economy, consulted April 28, 2017). First, to avoid a frequent misunderstanding, it is worth pointing out that a steady-state economy (or a degrowth economy) is not the same as a stagnant economy. Whereas the latter is an (undesired) regressive phase in a growth economy, the former is a deliberately politically motivated and implemented economy that is geared to the absence of growth. Critics of the steady-state economy usually object to it by arguing that resource decoupling, technological development, and the unrestrained operation of market mechanisms are fully capable of overcoming any resource scarcity, any rampant pollution, or any overpopulation ever to be encountered. It will be clear to the reader that I do not agree with that thesis unless it encompasses major societal changes, some of which will be discussed in a later section of this chapter. A core driver toward a steady-state economy should be that invention and innovation are, as far as possible by stimuli, by legal means, and a better understanding of the process of invention and innovation itself, directed toward achieving such a goal, while all efforts should be focused on stopping further digging the hole we are in; i.e., slowing down the feedback loop that is responsible for the current acceleration of information processing and its material and environmental consequences. That in turn requires us to review the role of economy and technology as drivers of society and to consider reinventing that relationship by reengineering societal control over the economy. As I mentioned in Chapter 12, our current predicament is due to 250 years of unbridled and undirected invention and innovation, and as Einstein (n.d.) famously said: "We cannot solve our problems with the same thinking we used when we created them."

Proponents of the steady-state economy, on the other hand, argue that these objections remain insubstantial and mistaken – and that the case for a steady-state economy is gaining leverage every day with the power of new technologies and, in particular, ICT. In my opinion, this is not really a better solution as long as we have large proportions of the global population living in abject poverty and lacking even the basic resources that are available to the developed world. Not only is this ethically unacceptable, but it triggers major societal disruptions both within and between nations, of the kind currently manifest in the Near East.

Sustainable Development Goals

One recent attempt to address the current global inequality, while remaining within a safe planetary operating space from an environmental perspective by adopting limited and directed growth, is the UN effort to promote Sustainable Development Goals (SDGs). These goals are – from a political perspective correctly, if from a scientific point of view maybe too sectorally – formulated in terms of seventeen practical challenges to solve in the near future (Figure 19.1). In this section I will briefly present them, and the way in which a major, global project (The World in 2050) is trying to concretize them.[3] My reason for doing this is that the SDG

FIGURE 20.1 The UN's Sustainable Development Goals (open source by permission of the UN)

movement is the most recent global attempt to move in the opposite direction from the steady-state and degrowth economy movements.

The SDGs are defined in a UN resolution that was adopted in 2015, aiming at, in summary, the following (a more extensive description is found in Wikipedia at https://en.wikipedia.org/wiki/Sustainable_Development_Goals, consulted June 6, 2019):

- To end poverty and hunger, in all their forms and dimensions, and to ensure that all human beings can fulfill their potential in dignity and equality and in a healthy environment.
- To protect the planet from degradation, including through sustainable consumption and production, sustainably managing its natural resources and taking urgent action on climate change, so that it can support the needs of present and future generations.
- To ensure that all human beings can enjoy prosperous and fulfilling lives and that economic, social, and technological progress occurs in harmony with nature.
- To foster peaceful, just, and inclusive societies that are free from fear and violence. There can be no sustainable development without peace and no peace without sustainable development.
- To mobilize the means required to implement this agenda through a revitalized Global Partnership for Sustainable Development, based on a spirit of strengthened global solidarity, focused in particular on the needs of the poorest and most vulnerable and with the participation of all countries, all stakeholders, and all people.

The approach reflects Ban Ki-moon's statement that "We don't have [a] plan B because there is no planet B" (https://news.un.org/en/story/2014/09/477962-feature-no-plan-b-climate-action-there-no-planet-b-says-un-chief, consulted June 6, 2019). Though adopted by all the nations represented in the General Assembly of the UN as "Transforming Our World: The 2030 Agenda for Sustainable Development," the approach represents a very specific perspective on the future of Earth and its societies, which is dominated by the idea of progress – the assumption that things will on the whole always tend to become (or should be made) better (whatever that may mean) (https://en.wikipedia.org/wiki/Idea_of_progress, consulted April 14, 2017).

The approach is heavily goal oriented, and attempts to define 168 specific improvements in the seventeen domains, such as: "By 2030, ensure that all girls and boys complete free, equitable and quality primary and secondary education leading to relevant and [...] effective learning outcomes." But most importantly, the SDGs seem to adopt at the global level a more or less linear projection into a future based on current trends, focused on achieving a state of "no one left behind" for the whole of the world's population by attaining a modicum of material comfort for all.[4] As such, it clearly goes against the grain of traditional western liberal capitalism, while adopting the western idea of progress.

As it concerns goals for a possibly foreseeable – but certainly not predictable – future, achieving them could easily be derailed, because of the fundamental uncertainties inherent in the long-term projections of the multidimensional dynamics involved, or because of newly emerging scientific, economic, or political issues.

Moreover, we are all aware of the difficulties and limitations of current social science and humanities research on the topic of global change. While there is considerable scientific knowledge concerning the physical dynamics of the Earth's system, there is much less knowledge of the societal dynamics involved, and little insight into the second order dynamics involved in socioenvironmental coevolution. A major effort in this domain is essential, especially if one views the sustainability challenge as a socioenvironmental rather than an environmental one.

Another question is whether, or to what extent, the linear progress approach is one that all communities involved can subscribe to. Clearly, the SDGs have been negotiated between national representatives principally belonging to their countries' elites, who have, to a certain extent, been brought up with the western ideas involved. It is not clear to what degree the populations of the world would ultimately subscribe to these ideas or be prepared for the effort needed to implement them. Here, again, Polanyi's, Graeber's, and Munck's warnings (Chapter 18) seem relevant; i.e., that the more forcefully one attempts to make large, culturally different, populations converge, the greater the risk that such a trend gives rise to identity challenges and defensive tensions in the societies concerned. Current developments in Europe and the USA seem to point in that direction, not to mention trends in the world of Islam.

I would therefore argue that the top-down approach developed by the UN is an important step forward as it gives researchers, politicians, and others a mandate to search for various paths forward; but that it is also risky. From the complex systems perspective, it would be wiser to develop a wider plurality of futures and trajectories rather than just progress-based ones, taking different contextual developments and different worldviews into account,[5] in different locations, experienced by different societies that think fundamentally differently, have different cultures, different values, and live in different environmental circumstances.

Alongside the very important efforts currently under way to use advanced modeling techniques to try and define a number of trajectories to attain a sustainable SDG future, such as is being undertaken by the World in 2050 project,[6] there are therefore very good reasons to study a much wider set of potential scenarios for our various futures by adopting a complex systems approach and engaging different societies in discussions about which kind of environment and what kind of society they might want to strive for. It would more realistically represent the true nature of the challenge ahead, something that is not fully done justice to in the UN's linear, compromise-driven, approach.

Such an effort could begin by collecting a wide array of narratives about the future of the Earth from different perspectives and different parts of the world. It would improve our understanding of global and regional socioenvironmental dynamics, would yield a number of alternative pathways for the future, including those that will help us achieve the SDGs and others that might offer different futures for our planet and our societies, and would allow a wider global participation in the discussions about the future of our societies; one that is more representative of the cultural diversity of our planet's population.[7]

In summary, contrasting the SDG goals with the arguments of the steady-state and degrowth movements highlights the fact that we are on the one hand urged (top-down) to live within our environmental means, and on the other hand see the need to generate novel kinds of resource use and economic development across the world so that all of the world's populations may share in basic human comforts. That kind of innovation is inevitably to a large extent local and bottom-up.

The question we are faced with is therefore how we can sail between Scylla and Charybdis, between unsustainable resource use and continued imbalances in development, and at the same time between top-down steering of world development and bottom-up encouragement and development of networks of local communities. In Chapter 19, I mentioned various movements and experiments striving to do just that, which have emerged in recent years. But much more remains to be done.

Toward a Mindset Change

As an example of the more recent degrowth version of Daly's general argument, I will take the work of Serge Latouche. In his book Farewell to Growth (2007), in language that is no less emotional than Daly's but much more political, he emphasizes and treats in more detail what it takes to abandon the unidimensional growth and progress ideology that drives the current world system, and focuses on the mindset change that this requires. His goal is to: "build a society in which we can live better lives whilst working less and consuming less. That is an essential proposition if we are to open up a space for the inventiveness and creativity of the imagination, which has been blocked by economistic, developmentalist and progressive totalitarianism." (2007, 9)

In striving for that goal, Latouche delves deeply into the political economy that is responsible for the current situation. Thus, he clearly distances himself from sustainability and sustainable development:

> Sustainable development has now found the perfect way to square the circle: "clean development mechanisms" [*sic*].[8] The expression refers to technologies that save energy or carbon and that are described as being eco-efficient. This is more verbal diplomacy. The undeniable and desirable advances that have been made in technology do nothing to challenge the suicidal logic of development. This is another way of patching things up so as to avoid having to change them. (2007, 11)

Instead, he builds on the tradition of the social sciences that is exemplified by such scholars as Emile Durkheim, Marcel Mauss, Karl Polanyi, Marshall Sahlins, Erich Fromm, and Gregory Bateson, who maintain that the economy is to serve society instead of the other way around (Chapter 16). As pointed out by Georgescu-Roegen (1971[2014]), in adopting a Newtonian paradigm that ignores the second law of thermodynamics and the inevitability of entropy, neoclassical economics creates a formally elegant, closed system model that has little relation to a real world economy that is embedded in an open physical, chemical, and biological as well as social world. It can therefore only be realistically dealt with in a complex flow structure approach, as applied here.

The main aim of Latouche's book is thus to exchange the current extraction-to-waste economy for a (novel) economy of opportunity creation, in which innovation is necessity-driven (Chapter 13; van der Leeuw & Zhang 2014).

In the context of the earlier discussion about demography, it is interesting to see that for Latouche a reduction in the population is a lazy solution that is not realistic. It would not in itself transform the dynamic driving our economies, and would thus at best cause a temporary slowdown. In his vision only a profound dematerialization of our hypergrowth-driven developed and developing societies will have the desired effect, and the main issue is then how the reduced quantities of resources are to be spread across the world. He tends here toward the kind of distribution economy also proffered by Arthur (Chapter 18).

The desired restructuring of our societies, Latouche argues (2007, 33), can be synthesized into a virtuous circle of eight Rs: reevaluate, reconceptualize, restructure, redistribute, relocalize, reduce, reuse, and recycle. These eight interdependent goals, he argues, can together trigger a process of degrowth that will be serene, convivial, and sustainable. It is of necessity a local, bottom-up process that aims for a renewed focus on community, equity, sobriety, taking less and giving more, and using local resources:

> The pleasure of leisure and the ethos of play should replace the obsession with work. The importance of social life should take precedence over endless consumerism, the local over the global, autonomy over heteronomy, an appreciation of good craftsmanship over productivist efficiency, the rational over the material, and so on. A concern for truth, a sense of justice, responsibility, respect for democracy, the celebration of differences, the duty of solidarity and the life of the mind: these are the values we must win back at all cost, as it is those values that will allow us to flourish and to safeguard our future. (Latouche 2007, 34)

In invoking the need to move in this direction, he clearly converges with many moral philosophers (such as John Dewey, see Stanford Encyclopedia of Philosophy (https://plato.stanford.edu/entries/dewey-political/, consulted July 27, 2017), environmentalists such as Gilles Clément (Clément et al. 2007; Clément 2015), and a very large number of Christian ecologists for whom the eleventh commandment is "Respect nature because it is God's creation."

I do not have the space here to go into the eight processes that Latouche argues for in detail. Among them, he sees a strategic role for reevaluation, reduction, and relocalization. The process to achieve these is a bottom-up one, in which local ecological democracies are created that satisfy needs for identity and control over everyday life. Though he does not cite her, his ideas are in this respect very close to Ostrom's (1990). One of the interesting things in his work is that he refers to many ongoing local initiatives that are effectively moving in this direction, striving for environmental and economic autonomy (including but not limited to renewable energy, locally valid vouchers instead of national currencies, and organic, small-scale agriculture), focusing on the management of local and regional common-pool resources that, importantly, involve active citizen participation in the governance process.

A detailed discussion of the way this approach might play out in the global south is included, and here Latouche emphasizes that local communities should not be forced or seduced to adopt northern ideas, but helped (or left alone) to define their own futures and develop ways to attain them.

For me, an important contribution here is that this would enlarge our global value space and thereby open new ways for harmonious and appreciative interaction between multidimensional communities. The Development Research Centre (DRC – of the State Council of the People's Republic of China) project in ShiShou in China in which ASU is participating (Chapter 18) is an interesting example, where a local community is being given support to develop from a preindustrial agricultural community to a postindustrial one without transitioning through an industrial stage, and along lines the community itself defines. As part of the project, the community is revived and begins attracting back some of the inhabitants who earlier went to the city.

In contrasting this approach with the SDG initiative discussed in the last section, the difference is not so much in the ultimate goal, a better life and a better local or regional balance between resources and consumption, but in the other dimension of our trip between Scylla and Charybdis – top-down versus bottom-up. The bottom-up choice represented here allows for many more, and very different, ways forward. It enhances the dimensionality of our human experience and favors diversity. And after all, isn't it from the bottom up that humanity has created all forms of durable societal organization, including hierarchies?

Pluri-Polarity

In this context Elinor Ostrom (1990) tackles the problem of finding the most appropriate form of governance to achieve long-term stability. Having undertaken numerous case studies, both in the USA and in many parts of the developing world (Asia and Africa) with a very wide network of excellent scholars, Ostrom comes to the conclusion (1990) that (1) relatively small communities are demonstrably able to find effective long-term solutions to managing their complex environments, and in particular what she calls their "common pool resources"(1990, xiii) such as water, vegetation, herds of animals, but also knowledge and other such resources as are essentially the basis for the maintenance of society; and that (2) above a certain size of community, governance becomes less effective, more subject to various kinds of endogenous vulnerabilities, and in general less stable. She therefore makes the case for a multipolar world in which relatively small-scale societies govern themselves and their environments, in interaction with each other.

From the perspective that has been presented in this book, her work has several noteworthy aspects. The first of these is expressed in Chapter 10, where I try to show the interaction between institutions and individuals: at times individuals undermine institutions, while at other times individuals create novel institutions to deal with issues at hand. The difference between Ostrom's work and mine is that I have been able to look at a much longer period, so that both the successes and the failures of small-scale governance that Ostrom mentions might be interpreted as due to a second order dynamic that accounts both for phases of institutional continuity and for variation and change in the system.

Another element in Ostrom's work that resonates with me is the importance of system size in relation to governance. In an era in which much effort is spent on working toward top-down global governance, I believe that this is an unattainable goal that may seriously threaten the effectiveness of governance. Part of my argument is based on the fact that any optimization of resource use necessarily requires intimate knowledge of the detailed spatial and resource structure of the environment. The modern tendency to mechanize and optimally rely on economies of scale, whatever its merits are, is based on a statistical approach to the environment that ignores considerable relevant detail and can thus never achieve optimal results. And in the domain of societal governance, I would argue that governance systems organize themselves to manage a certain number of potentially discordant sources of information, as we saw in Chapter 11.

Instead of top-down global governance, strengthening global bottom-up awareness and cultural commitment to sustainability may therefore be a better means to achieve our goals.

Possible Future Roles for ICT

As the reader of this chapter will be aware, neither the steady-state and degrowth movements nor the SDGs explicitly take into account a number of potentially very important ongoing dynamics that are related to the rapid pace of the ICT revolution. Might ICT be able eventually to help us set a course between Scylla and Charybdis? In the next few pages, I present two visions of the impact of the ICT revolution on our societies that illustrate some of the issues concerned.

One of the many protagonists of the "ICT society" is Helbing. In his publications, he adopts the point of view that the ICT revolution will lead to a society that will largely depend for its information processing on distributed networks of computers. In Helbing (2015), he first renders plausible the assumption that within the next twenty to thirty years AI based on "big data" and sophisticated machine learning will make it technically possible that most of human behavior will be impacted, if not steered, by electronic information processing. In doing so, he echoes the work of many others, such as Kurzweill (2005) and Brynjolfsson & McAfee (2011), as well as the authors of the two reports published by the White House (Executive Office of the President of the United States 2016a, 2016b) on the advances of AI (Chapter 19).

Helbing then poses that this evolution could proceed either toward top-down control of society by computers (the Hobbes model), or bottom-up free-market development (the Smith model) of a self-organizing society that relies on computing for its information processing. The core question to ask is how will the technological capabilities be used. The central issue in responding to this question is that of the coordination capacity of our systems – by increasing central information processing capability (following the Hobbes model) into a Leviathan (a true, huge and unmanageable top-down organization), our social and life support systems may well become hypercoherent, and therefore increasingly unstable, whereas reducing the centrality of information processing (in the sense of the Smith model) we may find that insufficient coordination creates dysfunctionalities such as climate change or tragedies of the commons, and cannot be relied upon either.

With this dilemma in mind, Helbing first discusses the top-down approach, beginning with a well-documented and rather detailed summary of steps that have already been achieved in collecting and using big data centrally by major corporations such as Google, Facebook, the US Central Intelligence Agency and National Security Administration and others such as the World Health Organization, but also a large number of startups that are beginning to crowd this domain. This summary convinced me that, in principle, it is now possible to know so much (5,000+ attributes of every individual in the USA) about every person on Earth that it would – given enough data storage and treatment capacity – be possible to create various ways to monitor, understand, and to some extent predict and influence certain aspects of the behavior of large numbers of individual people. As this trend is accelerating, and the behavioral models involved improve owing to machine learning based on studying very large datasets, certain individuals and institutions are tempted to infer that it will be possible for a central authority (a wise king or benevolent dictator) to know, regulate, and control social life, and thus socioenvironmental dynamics, globally, creating what Helbing has called the Leviathan approach of top-down regulation.

Helbing then proceeds to argue very effectively why this might be advantageous; for example, if it were possible to avoid major events such as the financial crisis, or improve the efficiency of a wide range of processes. But societal predictions – the basis for such management – would immediately lead to social reactions once they became known. Such reflexivity would make judiciously acting on them extremely difficult, and could all too easily lead to a form of totalitarian technocracy (a Big Brother society) in which the predictive policing that is currently being used in combating crime would be extended. In the process, the fundamental assumption that people are innocent until proven guilty would be abandoned in favor of the opposite.

Alternatively, systematic use could be made of nudging our decisions in certain directions, as is currently done through inserting appropriate advertisements into our cellphones or computers, or even through subliminal messaging. The current worries about foreign interference in elections in Europe and the USA reflect this train of thought. As discussed in Chapter 19, this process is enabled by the blurring of the boundary between noise and signal that is inherent in the ICT revolution, and the resulting fuzziness makes it very difficult to come to clear decisions.

But Helbing concludes – for a number of theoretical as well as practical reasons – that this approach can never achieve its intended goal.

A fundamental barrier to "managing" society is the difficulty of distinguishing good and bad solutions. As we saw in Chapter 10, all solutions ultimately lead to unanticipated problems, and thus to ontological uncertainty. Another challenge is the margin of error in the statistical analyses that leads to decisions.[9] The same challenge would be faced by the use of inappropriate models to separate positive from negative courses of action, which would distort the actual risks involved in certain decisions.

A final and convincing limitation is in my opinion the fact that complex systems such as the ones we are dealing with cannot, as Helbing says, "be driven like a bus" (Helbing & Lämmer 2008, 7). One can never expect to have all the information needed to make the correct decision. As the past to an extent determines both the present and the future, in order to make the right decision, one would need to know the past in detail – an impossibility that seriously limits our decision-making in systems that are subject to the butterfly effect or to some Rayleigh-Bénard effect that structures subsets of society in unpredictable ways.

But over and beyond that, the variability inherent in the behavior of social systems is so great, and their algorithmic complexity so huge, that

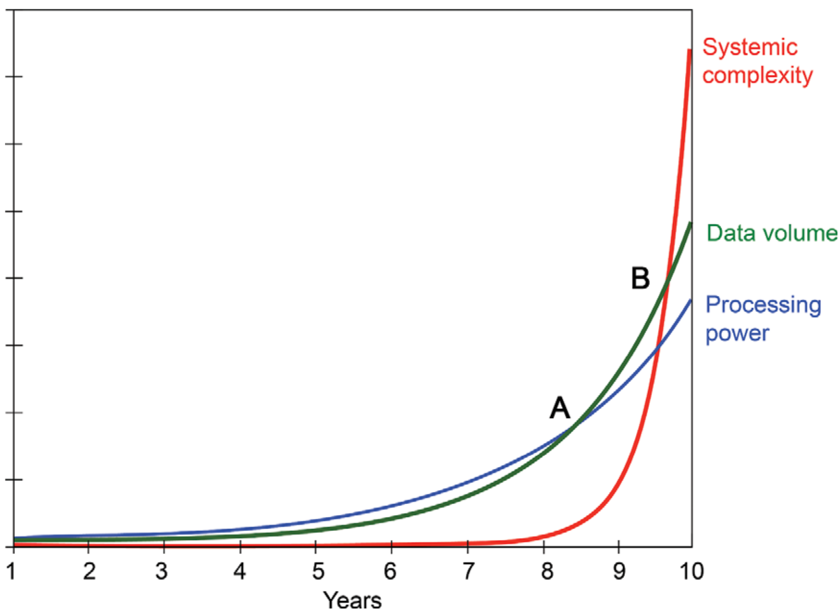

FIGURE 20.2 Relationship between the increase in processing power, data volume, and systemic complexity. (Source: Helbing et al. 2017, Permission Springer)

the computing power needed to deal with the behavior of social systems will always be insufficient.

The reason is that both the data volume generated by our societies and the (combined) system complexity (owing to human intervention in the system, see Chapter 15) are increasing at rates far in excess of the increase in processing power that follows Moore's law (Figure 19.2). Even with the increase in information processing that it predicts, unintended, unknowable consequences would therefore still overwhelm the system.

Helbing therefore argues that instead of a top-down, centrally managed society, a bottom-up, self-organizing society can be developed based on a combination of big data, the Internet of Things, and AI, which will transform the economy, and through it, society.[10]

How would that work? A fundamental change in approach is a necessary part of this process, from a focus on entities and system components to a focus on relations and interactions.[11] Another difference is that rather than force or nudge a system in an a priori determined direction, it would use the fact that forces within a system structure it very efficiently (but in ways not predictable a priori). The resultant dynamic structures tend to be more stable, he argues, than structures shaped from the outside. Our research would thus have to focus primarily on identifying the forces operating dynamically in a system, and on how change is driven by the system itself. And rather than adapt the system to desirable outcomes, we would have to shape desirability around the outcomes of the inherent dynamics. Helbing's core thesis in this respect is that one can, however, let different outcomes emerge by slightly changing the interactions between components (in what he calls "assisted self-organization"). Contrary to the Hobbes approach, these interventions would be local and minimal (involving distributed control). In these circumstances, Helbing argues, such systems would not be totally unpredictable, as they would tend toward a limited number of dynamic attractors, and in many instances would return to them after a disruption. Though formulated in the context of a future under the impact of the ICT revolution, these characteristics are of course inherent in any bottom-up structuring of our future societies.

What is the role of ICT in this context? One would have to be able to identify composite patterns made up of elementary entities by not focusing on improving the condition of individual entities as we commonly do, but on obtaining system-wide benefits. And that would, in Helbing's world, be enabled by the Internet of Things, direct communication between the objects that determine such an important part of our human behavior, allowing them to make their own decisions unimpeded by human beings and to take many dimensions into account that humans cannot at any time relate interactively because of the limitations of their short-term working memory (Chapter 8).

A very interesting conclusion of his dynamic (traffic) modeling studies is that optimization of local collective benefits does not seem to lead to large-scale coordination when the interactions between the system's components are strong. This restates the thesis of Granovetter (1973) that weak ties are more important in structuring a system than strong ones. And that conclusion in turn reinforces the multicentric approach to societal regulation proposed by Ostrom and her students that I discussed in the last section (Ostrom 1990; Ostrom et al. 1994), while at the same time pointing to the instability of hypercoherent systems, and reinforcing the arguments of Polanyi and others (Chapter 18) that reducing the dimensionality of community values too strongly generates strong social instabilities.

This general approach raises the very interesting, and hotly debated, question of humans' tendency to often collectively balance the advantages of the individual and those of the group in favor of the latter. I do not want to enter that debate, but I do want to point out a couple of interesting things about it.

First, it turns out in the simulations that Helbing presents that random interactions in an open space or network, between (1) people favoring cooperation, (2) people avoiding cooperation ("free riders"), (3) people sanctioning the avoiders, and (4) people not sanctioning the avoiders, results rather easily in a tragedy of the commons (individual behavior undermining the collective good), but within a confined space or cluster in a social network, the opposite happens and the common good prevails.

Another interesting result is that when it is possible for individuals to move around between different networks, this leads to cooperative clusters that emerge during the spatial organization of the population, because the behavior of individuals is determined by the behavior in the individuals' surroundings. Thus, when people can move around freely, this promotes cooperation when the individuals can be integrated effectively in groups.

Clearly, these are results of a number of modeling exercises, and as such have yet to be scrutinized and should for the moment be taken as hypotheses. But it is interesting to associate these results with those mentioned in Chapter 11 concerning the emergence of social networks as a function of percolation theory. Together, they seem to indicate that there are limits to the extent of cooperation that can be achieved as a network grows in size.

Based on these results, as well as those of Elinor Ostrom about the management of common pool resources (Ostrom et al. 1994), Helbing comes to the conclusion that bottom-up coordination of self-organizing societies is indeed possible, and (in his eyes) preferable to top-down controlling of such societies, but that when the groups become too large, and interact with too many random participants, there comes a tipping point where cooperation in the group decreases.

In the remainder of his book, Helbing outlines a number of properties and developments that would enhance the stability and scope of such bottom-up cooperative systems. I mentioned those that are in my opinion the most relevant in Chapter 18, based on my own vision rather than Helbing’s. Here, these concern me less than the general conclusion that bottom-up-based self-organizing systems can more realistically integrate ICT-based tools than top-down-based control systems. For our purposes, this means – I cannot repeat this enough – that to achieve some kind of resilient future for our societies we must actively promote bottom-up approaches to gain a more balanced development than is currently under way top-down, driven by the large ICT companies.

The New World: How Might the ICT Revolution Impact on Society?

In 2016 the director of MIT’s Media Lab (Ito) and one of his colleagues (Howe) published what is to my knowledge the first inside story, written for non-technical people like myself, of the fundamental cognitive, intellectual, societal, and practical changes the ICT revolution is currently driving and imposing (Ito & Howe 2016). Clearly, this is done from a perspective that the ICT revolution is unstoppable and that its progress will transform the world. I have argued in Chapter 19 that that is an assumption that in theory need not be either true or positive for our societies. But for the moment their assumption is certainly interesting, and I have therefore decided to end this part of the book with a critical examination of their perspective, following the nine different fields of tension that they expose.

Emergence and Authority

I argued in Chapter 6 that we need to complement an a posteriori, linear perspective on the past and the origins of the present with an a priori one that is focused on the emergence of the present in a multidimensional space. Ito and Howe take this as a starting point of their argument, but add an important element to it: the fact that the linear perspective is anchored in a hierarchical worldview that is, in turn, deeply anchored in our Judeo-Christian tradition: we are supposed to lead a life that is designed and prescribed by a religious authority or, in its modern form, anchored in ethics ultimately derived from that authority. The newly developing approach they are writing about, anchored in – or at least strongly favored by – the ICT revolution, will enable the opinions of the many to complement, and possibly overcome, those of the few that have until now set the ways in which our societies were evolving. From a world driven by the information processing of the few, we are crossing a tipping point and moving into a world of collective information processing that will be able to deal with much larger information loads than our societies have managed thus far. By implication, the transition that is currently going on is seen as a consequence of the fact that our means of collective information processing are inadequate for the rapid rise in the global population of the last half-century. If this development continues, Ito and Howe argue, one can expect humanity to develop into one (or several?) meta-organism(s), which represents a further step in the percolation approach I described in Chapter 11.

Ito and Howe (2016, 37) call this new form of collective information processing "emergent democracy," and expect that it will ultimately replace what we currently call our (representative) democracies. In Chapter 18 I signaled the beginnings of this process: the traditional role of political parties (and representation) is no longer needed in the context of politicians reaching out directly to their electorates. It is based on the fact that no individual or small group has ever been able to fully impose a particular kind of behavior or decision-making by controlling the information that is available to others in a society. In the current information-processing regime this is even less true than it has ever been before. Rather, in such an "emergent democracy" (or maybe better a "democracy of emergence") the behavior of the collective emerges from the interactions of all its members.

Individuals' "power over" is replaced by the collective "power to" of the society as a whole (see Foucault 1983). Such emergent systems presume that every individual within a group possesses unique intelligence that would benefit the group.

In the process of bundling that collective intelligence, a much wider value space and innovation space are opened up. Ito and Howe present the contrast between the *Encyclopedia Britannica* and Wikipedia as a good example of this kind of transition, which is also widely documented in many biological systems. Such information-processing tools as Wikipedia are enabled by the huge reduction in the cost of innovation processing achieved by (almost completely) separating information from its energetic and material substrates.

Pull and Push

Part of our hierarchical (authoritarian) approach to governance and (more widely) instantiation of ideas is the fact that ideas are "pushed down" from the top of a hierarchy to the level where they hit the real world. In Whiplash (2016, chapter 2, 61–81), the authors argue for the importance of "pull"; that is, allowing ideas to emerge from the bottom to the top. On this theme, they substantially draw on the work of John Seely Brown et al. (2012), but give the example of the way in which a worldwide network of people with different skills responded to the Fukushima earthquake much faster and more efficiently than either the business world (in the form of TEPCO, the company responsible for much of the disaster) or the Japanese government.

The essence of this idea derives directly from the last one: the wider world has more ideas than any organization, and mobilizing these ideas is therefore a more effective way of reacting to events than the traditional, hierarchical approach or any other organized one. It is more flexible, demands less investment, can respond to a much wider range of events, and, above all, is not limited to anticipated events and responses, but adapts to the real needs of the moment. It mobilizes resources just in time, only for the time necessary, and relinquishes them as they are no longer needed. I argued (in Chapter 16) that under the impact of the Industrial Revolution and its reduction in the cost of energy our current society has hugely accelerated invention and innovation, and, in the process, also increased the speed with which markets are able to create and meet the need for any innovation. The complex dynamic driving these developments has created our current resource-to-waste societies and the sustainability conundrum. Returning, as Ito and Howe argue, to need-based innovation would in my opinion be a major step forward toward global sustainability.

Another aspect of this change in approach concerns motivation. Although our current western system strongly attaches motivation to financial reward, this is certainly not the only motivation that counts for many people. Much of what has happened in the Internet-based Open Source movement, including Wikipedia, Twitter, and Bitcoin, as well as in the non-governmental organization movement, is based on the fact that people are in search of a personal identity that is satisfied by performance, or in a wider sense making a contribution to a collective goal. In that context, bundling the efforts of many people into a collective achievement, as proposed by "pull over push," is a very strong driver of innovation. This is also demonstrated by the recent emergence of both crowd-funding and crowd-sourcing as major movements strengthening what is happening in cyberspace in terms of innovation. The authors of *Whiplash* conclude:

> As the cost of innovation continues to fall, entire communities that have been sidelined by those in power will be able to organize themselves and become active participants in society and government. The culture of emergent innovation will allow everyone to feel a sense of both ownership and responsibility to each other and to the rest of the world, which will empower them to create more lasting change than the authorities who write policy and the law. (Ito & Howe 2016,71)

And in that process, as Granovetter (1973) mentioned, one's acquaintances often end up playing a more important role than one's friends. But to enable that to happen, one needs to combine creating a network with many such weak ties, and a vision that is reactive to the kinds of occasions that can put such a network to good use.

Compasses and Maps

Innovation is fundamentally open ended and ontologically uncertain. One never knows what the result will be of the emergence of the new, as that engages in a dynamic with novel attractors and new dimensions of perception and action. Hence, Ito and Howe argue that a precise roadmap is less valuable than a compass that shows one the direction in which one can move, but does not fix the path or the endpoint of an innovative trajectory. In their terms:

> A map implies a detailed knowledge of the terrain, and the existence of a [known] optimum route; the compass is a far more flexible tool and requires the user to employ creativity and autonomy in discovering his or her own path. The decision to forfeit the map in favor of the compass recognizes that in an increasingly unpredictable world moving ever more quickly, a detailed map may lead you deep into the woods at unnecessarily high cost. (Ito & Howe 2016, 89)

In business, as in academia, this distinction is commonly discussed as that between a vision and a plan. A vision is a long-term general idea of where one would like one's effort to lead, whereas a plan is a fixed way of achieving a particular goal. Both have their uses, but when the goal is emergence of novelty and the means is bundling the ideas of many to deal with an uncertain future, the vision is more useful in guiding the effort than the plan because it directly reflects values, which provide a better, more profound, and more flexible compass than the plan.

One can also express this as the distinction between exploration and exploitation. It is essential that a system or a group of people has both capabilities. But at present, in our society, the core is essentially focused on exploitation (even as, in the oil industry, this includes major exploratory efforts that are directed toward creating the possibility to continue exploiting the same resource). Academia, government, and business are essentially (and increasingly) focused on finding new ways to exploit known resources, techniques, values, and knowledge. This is one of the implications of the "closure of our value space," which I mentioned extensively in Chapter 16. It is only in the margins of our societies that true exploration takes place, such as occurs at the Media Lab of MIT, in corporations such as Google for example, and increasingly in many, many small startups. In that context, it is relevant to look at the arts as a major domain of experiment and innovation.

We saw in Chapter 6 that to think about the future we must enhance the number of dimensions we consider. Rather than start reasoning from a fixed end-point (ex post), we should start reasoning ex ante, with the arrow of time and focused on the emergence of novelty.

To imagine the simultaneous interaction between several dimensions is difficult in an oral or written (linear) mode but is much easier by means of images or other forms of art. Therefore, I think art is essential to help scientists develop this kind of emergence perspective.

Moreover, as scientists we have been notoriously bad at communicating our ideas to the nonscientific world. Sustainability science has for thirty years been predicting doomsday, but little collective action has been taken. I think that this is in part because we did not engage the wider public. As scientists we were talking at people, rather than interacting with people. It is now urgent to promote a change of general mindset that can avert disaster. To do so, we need to have a message that is easy to understand. In some cases, this can be a narrative that appeals to underlying values, but in other cases, this is better done with art.

As a consequence of "freeing the animal spirits" (Keynes 1936, 161–162) in the way Ito and Howe propose, our societies would greatly enhance the dimensionality of their value space and thereby enable themselves to change direction in a constructive, environment-conscious way. Without such an increase in dimensionality, that seems impossible because the path dependency of our current system has created a situation of hypercoherence that makes it very difficult to conceive of changing its current direction.

And this brings me back to a point that I raise a number of times in this book: the need to drastically change our education systems by emphasizing learning over teaching. For professional educators, that also includes learning to listen rather than to talk, respecting the opinions of students (and the wider population), rather than imposing their own ideas, etc. To begin with, it also means allowing, or even creating, diversity of opinions in class, and reinforcing the idea that there are always alternatives and different ways to achieve a vision.

One of the core ideas Ito and Howe develop is that computers allow humans to deal with much more complicated ideas and models than the human mind can, whether individually or collectively. That capability further enhances the dimensionality of our societies' value spaces and the range of tools for thought and action that our societies can develop. Rather than functioning as tools that execute human instructions according to a map, computers can become interactive partners with humans in developing new ways forward with the help of a compass. In that light, one can see the (huge) impact of a program such as Scratch, "which, rather than teaching young children to code, leads them to code in order to learn" (Siegel 2016, quoted in Ito & Howe 2016, 106).

Risk and Safety

I argued in Chapter 12 that our current societies have a tendency to assume stability and study or bring about change. Rather than adopt this approach as the only perspective (following Aristotle), I argue that we should complement it with the Heraclitan approach that change is omnipresent in nature, and stability is (temporarily) imposed by human beings. In effect, both approaches are necessary to understand the complex regulatory dynamics that are responsible for all socioenvironmental interaction, as such interactions generally follow a punctuated equilibrium dynamic.

Risk and risk perception play a crucial role in such a shift. Following Atlan (1992), I have attributed the risk-adverse tendency in our societies to limitations of our human cognitive system, which biases human information processing toward underdetermination of ideas by observations and their overdetermination by past experience. Ito and Howe argue that the ICT revolution is changing that. They argue (2016, 116) that different risk calculations are at the root of favoring a perception assuming stability or one assuming change, and that the ICT revolution has changed the risk calculus in our society. Their argument runs like this. With a high cost to bring a novel product to market, for example because a large integrated company has to be geared to making the product, it makes sense to favor safety over risk and thus move more cautiously. But with the huge decrease in the cost of innovation that is triggered by the ICT revolution, it makes more sense not to do so, but to outsource the production by quickly assembling an effective supply chain, and thus beat the competition on speed. Hence the ICT revolution favors rapid change, taking risks, and using or developing very light and often temporary organizations.

Clearly, any risk is dependent on the material and social investment made, as well as on the uncertainty involved, so if the investment is small the risk is too. The greater the investment in a cognitive, social, and/or material structure, the greater the risk taken, and the stronger the tendency toward conservatism. If, on the other hand, the investment is small, so is the risk, and it is easy to favor risk-taking and change. An important implication is that rather than see change as a challenge, we are inverting our perception, accepting change as the norm. Indeed, we are living in a period characterized by rapidly increasing volumes of available information and unbridled, accelerating change. This favors creating an intellectual and organizational climate that allows people to overcome the inertia involved in a relationship between information and knowledge that is underdetermined by observation and overdetermined by routines that were successful in the past. That climate is the most important asset of the Media Lab of MIT.

I accept Ito and Howe's argument about the risk calculus, but I still maintain that for the moment at least – pending huge steps forward in dealing with the big data revolution – Atlan's argument is valid for human societies at large, and that there is thus a long-term bias toward continuing on existing trajectories. That raises a question about whether our societies will at some point need to slow down again, as argued by Daly and others. If so, we would have to deal with stability rather than change as the challenge, finding ways to favor it and to slow down the current, ICT-driven acceleration. In today's neoliberal capitalist system that seems far-fetched, but then the historian in me says "We've seen more drastic changes in history."

Disobedience and Compliance

Ito and Howe begin chapter 5 of their book (2016) with a reference to Kuhn's *Structure of Scientific Revolutions* (1962), and argue with him that fundamental changes in approach (so-called paradigm changes) are due to people not following the rules of their community, whether these are scientific, civil, cultural, or legal. They illustrate this extensively with examples from their domains: business, industry, and research. The ICT revolution has currently indeed put an emphasis on innovation and disruption, and on creating a climate of not following the rules. But interestingly, fifteen years later Kuhn published a volume called *The Essential Tension* (1977), in which, in the form of several essays, he emphasized the complementarity of disobedience and compliance. Neither can exist without the other. There are times when disobedience is fundamental for a society and others when compliance is. The Resilience Alliance's lemniscate (Chapter 5) symbolizes this by pointing to the fact that as the information and energy flows reach a point where they cannot further expand in a socioenvironmental structure, a phase occurs in which the system falls apart into component, much smaller, elements that begin experimenting with different organizational forms. Elsewhere I have linked the transition between an expansive and a fragmenting phase in the resilience cycle to the explosion of unintended consequences that is the result of the system's earlier decisions (Chapter 15). But whichever explanation one favors, over time socioenvironmental systems tend to (re)structure after a phase of exploration and fragmentation and, for a while at least, tend toward stability (see Monod 1971). I presented the history of the Western Netherlands in this light in Chapter 10. Thus, while I agree with Ito and Howe that we currently experience a transition in which disobedience is particularly valued, from the long-term perspective that is mine as an archaeologist and historian, unless the ICT revolution fundamentally changes that pattern I would expect that over time our societies will again find ways to deal with the overwhelming amount of new data and new ways to process information that they are currently encountering, and thus shape a new information-processing structure that is stable for some time. What that will look like is anyone's guess, but it will probably involve a closer integration between human and electronic information processing.

That being said, I agree that at this point in our trajectories, to free up the "animal spirits" is fundamental. Our current education systems in developed as well as many developing countries – apart from exceptions such as Dalton or Montessori that favor learning over teaching – are probably the most important institutional barrier to doing so. In the domain of education, from start to finish – that is from kindergarten to, and including, adult education – we need to make better use of the many other ways of learning that abound in the world. A massive effort is needed to bring human information processing in tune with its electronic counterpart. From their earliest years, our children are brought together in groups with two purposes that are at right angles to each other: socialization and development of learning. Teachers mostly vector these two goals by socializing the children around a set of externally derived values ("truths") that reduce the natural diversity of their thought, favoring conformity above creativity. Once children enter primary schools, tests and exams continue that process of alignment, which is suitable when one lives in a period of relative stability but which is not adapted to the contemporary ICT revolution. Later in life, career structures in most places in developed countries effectively maintain the pressure to conform.

To transform this situation, one should emphasize that in any situation there are always alternatives, and to stimulate learners to explore and compare those before making decisions. Informal learning as it occurs everywhere in the world is a major asset to achieve this, and this is insufficiently recognized by formal educational institutions.[12] A much closer link between formal and informal learning would quickly enrich the experience of millions all over the world, both among those who are now subject to mainly formal education and for those who have had no such training, but have educated themselves in real life. The current KLASICA project (https://klasica.org/about-us/) is an important effort in that direction.

Practice and Theory

Chapter 6 of Ito and Howe (2016) is essentially an argument in favor of learning by doing, rather than learning through theory, by reading or otherwise. "Putting practice over theory means recognizing that in a faster future, in which change has become a new constant, there is often a higher cost to waiting and planning than there is to doing and then improvising" (Ito & Howe 2016,158). Of course, that enhances the chance of failures, but rather than consider them as such one tends nowadays to see failures as learning opportunities, removing the opprobrium that failing used to have and replacing it by learning or experimenting, which both have positive connotations.

This chapter of Ito and Howe (2016) echoes a number of the assumptions I have outlined elsewhere in this book. Referring to Chapter 12, it implies an emphasis on the high-dimensional polyinterpretability of phenomena and things against the reduced dimensionality of theories.

Even at best, learning in theory only relates the mind to a subset of the dimensions of reality, and is thus less effective in gaining insight into the complex patterns of relationships that make up reality.

Their chapter also relates to the section in Chapter 17 that deals with the progressive distancing from the real world that is driven by our media and computer games and, finally, it relates to the core of the cognitive dynamic that drives socioenvironmental coevolution in which reality and practice never completely project onto knowledge, so that knowledge is enhanced by its interaction with practice (Chapter 9).

One very important aspect of learning by doing that I have not emphasized before is that it trains the mind to see relational patterns that place the subject one is learning about in a wider context. Rather than create clarity by excluding all but a small number of observed dimensions of phenomena as "noise" – as happens often in the development of scientific theories – learning by doing trains us to first of all observe the multidimensional patterns of relationships among phenomena as they are manifest in the real world, and then to proceed to build our understanding upon those observations instead of isolating entities in our observations and our thinking as we do in our western scientific approaches. Training the capability to see things as complex relational patterns is precious in the context of the dynamics needed to cope with the ICT revolution. It is that relational perspective that naturally leads us to develop the multidimensional "pull over push" attitude that Ito and Howe emphasize, as well as the emphases on diversity over ability, resilience over strength, and systems over objects that are the subjects of the next paragraphs.

Diversity and Ability

Much of our social structure in science, business, and other domains is currently based on an assessment of people's ability. We give Nobel (and other) prizes to people because they innovated, but we attach to those prizes the label that these people are the most intelligent, the best performers, people able to deal successfully with the most difficult topics, etc. Remuneration is based on ability, and so is social recognition. Hence, the role of individuals is emphasized in many domains in our society – whether in business or in the arts or in academia.

In their chapter 7, Ito and Howe (2016) propose a very different approach. They argue that whatever a person's ideas or capabilities are, in large measure they are determined by the network in which he or she functions.

The difficulty of maintaining secrecy in the Internet society has prompted a debate on the validity of assigning intellectual property rights to individuals or teams without taking into account that the interactions of those people or teams with others, over long periods of time, have contributed to their achievements. According to Ito and Howe, once one adopts a relational perspective, emphasizing teamwork and the contribution of everyone's actions and ideas in the network in which people are functioning, as well as spreading information for collective benefit rather than hoarding information for private benefit, the diversity of the participants in an effort becomes more important than the ability of individuals. This is a direct implication of the fact that the network approach inherently emphasizes a highly multidimensional approach to thinking and acting, which is essential for communities to function well. The basis of this approach is that every individual develops his or her own distinctive ways of thinking, and that bringing these together (bottom-up) is a more effective way to guarantee success than relying on a small number of selected individuals, even if they are considered to have particular abilities. In the ICT community, this approach has led to the successful implementation of crowd-sourcing, for example in scientific domains such as microbiology (see the FoldIt experiment to request participation of the gaming community in solving a challenge that was escaping the scientists and their computers), and in crowd-funding, where many startups now prefer to gather their first funds by soliciting small contributions from numerous participants, rather than depending on venture capitalists and becoming beholden to one or a few individuals or companies.

The ICT revolution has opened the possibility that many individuals can contribute to, and also share in, the results of, collective efforts based on their individual capabilities and wishes. It has proven itself to be a powerful tool to harness ideas, but also to spread wealth rather than allow it to accumulate in the possession of a few individuals. In my opinion this is therefore a very interesting potential antidote to the reduction of our value space to a single lowest common denominator (wealth), which we have identified as the corollary of globalization. It rewards people's identity, stimulates their interest and creativity, and thus adds very different rewards to participation than mere wealth, while maintaining people's independence. It would in all probability also reduce the wealth gap that is hanging over our global societies. It is an excellent example of Granovetter's (1973) theory about the importance of weak ties. As a result, "the best way to match talent to tasks [. . .] is not to assign the fanciest degrees to the toughest jobs, but rather to observe the behavior of thousands of people and identify those who show the greatest aptitude for the cognitive skills that the task requires" (Ito & How 2016, 179).

Resilience and Strength

Chapter 8 of Ito and Howe (2016) argues that opening up the value space of communities is exactly what contributes to their coherence and resilience – the higher the dimensionality of the value space, the wider the range of potential ways to absorb any negative impact on a society and then rebound. Building strong organizations was a very effective way to ensure survival in a relatively stable system, but in the current very rapidly changing system flexibility is a more effective survival strategy. That has been facilitated, argue Ito and Howe, by the important reduction in the outlay required for change that is the result of the ICT revolution, so that rapid changes, even if they entail a loss, can be overcome rather than sinking the enterprise.

This argument clearly resonates closely with the one they present in their chapter 4, risk over safety, but it allows me to draw attention to another aspect of the shift in attitudes that is triggered by the ICT revolution: a shift from building on an a posteriori perspective in dealing with the future of a company, thus striving toward continuity, toward developing a number of potential a priori perspectives by generating multiple future projects (of which a substantive number are sure to fail, but some might succeed). In the process, feedforward (anticipation) and out-of-the-box thinking are given more important roles alongside the omnipresent idea of feedback, and as a result the way is open for change. I placed the importance of this shift in perspective in Chapter 6.

Systems and Objects

Under this heading, Ito and Howe (2016, chapter 9, 214–231) return from a different angle to the distinction between the focused, subject- and entity-directed perspective versus the context- and relation-based perspective that was one of their earlier topics, stressing the importance of gaining from the outset a high-dimensional grasp of complex real life patterns, rather than (as the western empirical tradition does) decomposing that complexity into simpler subsets, and then hoping that the understanding thus gained provides an insight into the overall complex phenomenon.

Here it is not the perspective itself that is discussed, but its consequences. The authors draw attention to some of the issues involved in trying to solve what they call intractable problems – which others have called hairy or wicked problems – where it seems necessary to discover all the building blocks in a complex system (Chapter 2). Very important "is the subtle but incredibly important distinction between inter-disciplinary and anti-disciplinary approaches [...] that requires the reconstruction of the sciences entirely, the creation of new disciplines or pioneering an approach that eschews disciplines altogether" (Ito & Howe 2016, 219). The fundamental trait of such an approach is that it does away with objects of study – that it studies phenomena *in vivo*, focuses on processes rather than products, uses a high-dimensional conceptualization that goes against the reductionist trend of western science, and focuses on the systems studied as part of larger systems.

Ito and Howe illustrate this with the example of designing appropriate street lighting in Detroit, emphasizing that any innovation is bound to change the system in which it is embedded (Ito & Howe 2016, 225), and that therefore we should shift from design to codesign to ensure that any innovation is compatible with the socioenvironmental system of which it is to be part.

Conclusion

In this chapter, selecting specific works of earlier scholars, I have tried to make the argument for the need of a different approach to our common future and to outline various authors' ideas about how to achieve that. The main purpose of the first part of the chapter was to raise the kinds of questions we have to take into account in making decisions about the way forward. My main personal conclusions are that:

a. It is not realistic to expect that we could achieve a zero-growth or degrowth dynamic in the short term. The only way to come to that point would be to slowly but surely redirect our present (and thus our longer-term future) toward green growth – growth of a completely different kind: dematerialized and based on a fundamental change in the structure of our value space.

b. It seems that efforts to further globalize the scale of our economies and/or our governance structure (for example by using ICT) will increasingly butt up against identity and other issues that are related to the difficulty of maintaining for large groups the combination of high-dimensional value systems and the frequency of communication that is necessary for the creation and maintenance of flourishing, highly resilient communities. A tendency toward polycentrism is the result. The top of our governance levels are likely to lose control over many dimensions in favor of lower levels. In the European Union this has been going on under the label of subsidiarity. It is also likely to occur in the USA, with a shift away from federal to state authority, while China will continue to operate a semi-decentralized structure with high autonomy for its regions. This devolution of power might ultimately make (large) cities the most cohesive governance units.
c. Nobody can predict with any certainty how the coevolution of ICT and our societies will evolve and will affect their sustainability. Major transformations in both are a certainty. But one thing becomes clear: there is an important potential for the ICT revolution to help us deal with some of the major issues involved, but that will minimally require (1) gaining more insight in the societal dynamics involved, (2) exercising political and technical control over the ICT development, (3) improving the integration between human and electronic information processing, and (4) undertaking the complete restructuring of our education systems and their curricula, including universities and research organizations, to promote undisciplinarity. That is where some of these developments must, and can, begin.
d. Last but not least, it is the responsibility of the current crop of sustainability scientists to finally acknowledge that our sustainability conundrum is not an environmental one, but a societal one (see Dyer 2009). Social scientists should take the lead in this, and reconceptualize the current approach to sustainability issues accordingly, looking not only at greenhouse gases, but taking the whole of the socio-environmental system dynamics and their coevolution into account.

NOTES

1 Alan AtKisson drew my attention to the fact that, interestingly, Swedish society's values in the industrial era were partly built around this concept: the phrase "lagom är bäst," which can be roughly translated as "sufficient is best." The concept of lagom is relatively unique to Swedish society, and

means "the optimal amount," a balance point between too much and too little.

2 Crackpot rigor exemplified by: "The behavior of a peasant selling a cow was analyzed in terms of the calculus of variations and Lagrangian multipliers" (Daly 1973, 3).

3 The World in 2050 is a project currently undertaken by an important part of the scientific modeling community involved in GEC research, coordinated by the International Institute for Applied Systems Analysis near Vienna in Austria, the Stockholm Resilience Center, and the Earth Institute of Columbia University. For an up-to-date perspective on its efforts see Sachs et al. (2018).

4 Hence the ire of conservatives in the USA, that "sustainability" is an attempt by the UN to uniformize life across the globe. This, however, is an incorrect interpretation, as the implementation of the SDG program leaves ample leeway for different societies to realize their goals in their own way.

5 I can see the logic of focusing on one single future from a political point of view – mobilizing all forces to achieve that. But to my mind the risks of failure owing to societal dynamics are so important that trying to identify different trajectories toward similar goals, which can be implemented depending on different social, cultural, historical, or local circumstances is preferable.

6 See www.iiasa.ac.at/web/home/research/twi/TWI2050_Report_web-071718.pdf. For transparency's sake, I am part of the team, placing its effort in a wider context in chapter 2 of the report, for which I was coordinating author.

7 Such exercises were done in the run-up to Rio+20 in 2012, at a relatively large scale globally. As an anthropologist, I cannot help but wonder whether these have actually been able to reach down below the practical into the fundamental thought patterns of the populations concerned.

8 Latouche here generalizes a term that was originally a strictly technical one related to UN-mediated purchasing of carbon offsets under the Kyoto protocol.

9 Helbing here refers to decisions of "type I and type II." Type I concerns false alarms, and type II the absence of an alarm when one would have been needed. Even very small errors (0.0001 percent) would have major effects with the large numbers of people involved. There is a dilemma here. The populations are too large to be supported by current resources and technology, but innovation is leading to lethal unintended consequences. I don't see how a reduction in population is escapable.

10 In this, Helbing follows the line of argument that places the economy in control of society, contrary to the position adopted in this book, which holds that society should control the economy.

11 Interestingly enough, although he does not seem to be aware of this, this is moving us closer to the Oriental approach to cognition that focuses on cognizing patterns, rather than entities, as is dominant in the West.

12 One of my early teachers, Jan Kalsbeek, a professional potter at the University of Leiden in the Netherlands, essentially saw formal schooling as an attempt to make children unlearn things they naturally and intuitively knew and practiced. I think there is indeed some truth in that.

21

Conclusion

What Is the Message Thus Far?

The main message of this book is that we need to bring together a Complex Systems approach, a focus on Information Theory and the dynamics of information processing, and the long-term study of invention and innovation as seen from an emergent, ex-ante, perspective to study system trajectories from the past to the present, instead of explaining the present by invoking the past. This perspective avoids the trap of much current science, which presents linear arguments about cause and effect in a limited number of dimensions. The dynamic socioenvironmental system of which we humans are a part is in the true sense of the phrase a complex system and should be studied within a theoretical framework that is appropriate for such phenomena. Hence, I have tried throughout this book to emphasize that approach, which enables us to develop a much more intricate, holistic perspective that intellectually fuses information obtained in a wide range of disciplines.

Another important and encompassing message of the book is the fact that our sustainability conundrum is a societal one and not an environmental one. Our societies have created the current degradation of the environment, from CO_2 emissions to waste dispersal around the world. They have defined what they considered their environments, what they thought they could extract from them and dump in them, and later what they saw as their environmental problems. They currently try and find solutions for these challenges by mitigating the impacts they have on that environment, but often (though certainly not always) without a more fundamental analysis of the dynamics involved, so that many solutions remain relatively superficial.

Moreover, the disciplinary and reductionist nature of much of our current science means that we look at the challenges and potential solutions in a disciplinary manner without being able to transcend the different disciplinary approaches and develop a holistic perspective. In particular, sustainability has for a considerable time been predominantly investigated and researched by the natural and life sciences without any contribution from the social sciences. In more recent years, the latter have now been solicited to make a contribution, but in many instances the questions they were asked to respond to were ultimately defined in terms of those natural and life sciences, rather than encouraging the social sciences to develop their own perspective. That is beginning to change, and this book hopes to contribute to that change, in particular by defining sustainability as a societal challenge rather than an environmental one, and thus subject to the societal, political, economic and commercial dynamics occurring globally.

Indeed, once one adopts such a societal perspective on the great acceleration of resource depletion, pollution and destruction of, for example, the world's biodiversity, another great acceleration hits our radar screens – that of the rapid increase in technological innovation that is currently manifesting itself, after two and a half centuries, in the material and energetic domains – notably in the domain of information processing. It is my contention that this acceleration – called the information and communications technology (ICT) revolution throughout this book – will so rapidly and drastically change our current societies and their institutions that it needs to be seen and investigated alongside the environmental challenges we are facing, because the latter will have to be dealt with by future societies very different from our current ones.

In order to put this ICT acceleration in a proper perspective I have argued for combining a number of different, or at least infrequently used, perspectives on the topic. These include a different role for science in the current social and political context, in which science risks losing some of the trust it gained in the middle of the last century. Another part of this novel scientific perspective is using a Complex Adaptive Systems approach that looks at the history of our societies and environments from an a priori perspective, searching for the emergence of change as it occurred and occurs through time, rather than an a posteriori perspective that looks at the origins of the present against the arrow of time.

I have further argued that one must apply a long-term perspective to the evolution of our socioenvironmental systems for three reasons. The first of these is because some of the dynamics, both natural and societal, are very slow and only perceptible over millennia. Secondly, a short-term view of such long-term socioenvironmental processes is like looking at a very ill patient (our Earth system) without any inkling of what the patient looked like when it was healthy. Thirdly and importantly, because without adopting the long-term perspective one is not able to observe the "change of change," the second order change that transforms the first-order dynamics over time. One therefore misses a major set of transformative drivers that play an important role, one that is only observable over many centuries.

Developing a long-term, global, and transdisciplinary complex systems perspective led me to search for ultimate rather than proximate causes for the emergence and decline of a wide range of societal phenomena – formulating a theoretical model that could indeed help me understand the dynamics of change in very different socioenvironmental systems, from past and present small-scale, local hunter-gatherer, and tribal societies to the incredibly complex globe-spanning societies of the present day. I found such an ultimate explanation when I realized that every society on Earth has always been an information society, because information is the only one of the three basic commodities known to humanity that can actually be shared among the members of a society. Neither energy nor matter can be shared because they are subject to the conservation principle.

Hence, I view human societal evolution as a feedback loop of the following kind:

> Problem-solving structures knowledge —> more knowledge increases the information-processing capacity —> that in turn allows the cognition of new problems —> creates new knowledge —> knowledge creation involves more and more people in processing information —> increases the size of the group involved and its degree of aggregation –> creates more problems —> increases need for problem-solving —> problem-solving structures more knowledge . . . etc.

For a major part of human evolution this dynamic was physically constrained by the capacity of the human brain's short-term working memory (STWM) to deal with more than a few sources of information simultaneously. However, around 50,000 BP, roughly speaking, the human brain had evolved to a point where its STWM could deal with 7 ± 2 sources of information, and that set in motion a relatively quick expansion of the complexity of the challenges that humans could deal with, which I have here described as the (relatively rapid, and accelerating) development of tools for thought and action. These tools enabled human societies to organize their thoughts, their social organization, and their environment in ever more complex ways.

Taking this approach a step further, to the development of the relationship of human societies with their environments, I have then adapted Prigogine's concept of dissipative flow structures (1977), defining them as dynamic structures in which a flow of information-processing (organizational) capability outward from a group or society is complemented by an inward flow of matter and energy that enables the society's individuals to physically thrive. In the process, the feedback cycle driving such dissipative flow structures transforms the uncognized environment (chaos) into cognized knowledge (information-processing capacity).

I illustrated this by outlining how one may understand human socioenvironmental evolution on two different timescales, first the long-term of human cognitive and social coevolution over millions, and later tens of thousands, thousands, and hundreds of years, and then in more detail focusing on the succession of social, technical, and economic changes occurring over a couple of millennia in a particular region.

I then shifted back to theory and used simple models to clarify how I saw socioenvironmental evolution as driven by changes in information-processing structure within societies, leading to major institutional transformations. To begin with, I drew heavily on ideas developed by organization scientists about different forms of information-processing control structures: processing under universal control (in anthropology termed egalitarian), processing under partial control (also called hierarchical), and processing without central control (here called market-based). From a long-term perspective, the transitions between these kinds of information-processing systems are of particular interest, and I therefore looked at some of their affordances and limitations, which may have engendered transitions between these general kinds of structures. Initially, I did so from a percolation perspective, looking at communication in growing networks of interacting people. The networks involved are determined by two parameters, connectivity and interactivity (activation). Different proportions of both these parameters give rise to several states of the system, from highly localized and temporary interactions to localized permanent interactions, to a wider, but highly variable, activation of the network beyond the initial localized areas, and finally to the very sudden emergence of a network in which interactions can affect each other over very large areas.

Next, I have argued that this might be a way to look at the transitions between mobile small-scale societies, spatially fixed small-scale societies, a highly variable range of larger societies, and finally very large-scale (clustered) societies. Of course, this model is very abstract, but it merits attention in so far as it leads to further, more detailed, study of information-processing system state transitions that have occurred throughout human history. Within these variously sized societies, one can then observe some of the characteristics of the organization of information processing – and in particular the role of information processing under universal, partial, or no control. Looking at the characteristics of such systems independent of the nature of the nodes or the connections between them, we can outline how combining hierarchical and market-based systems (i.e., systems without overall control, in which actors only have partial knowledge) may have interacted to generate clusters of nodes that one could interpret as networks of towns. One can thus make a coherent argument for considering the major societal transformations that we know from archaeology, history, and anthropology as due to an increase in knowledge and understanding, and thus an increase in the information-processing needs and capabilities of human societies.

It follows from this basic model of information processing that invention and innovation are at the core of what has driven our societies' coevolution between cognition, technology, institutions, economy, and environmental impact. I therefore next elaborated my perspective on invention and innovation, and in particular emphasized that our reductionist science has never really been able to deal with the process of emergence of new phenomena that is the main characteristic of invention and innovation. I have developed the argument that invention is a process of interaction between the realm of ideas (tools for thought and action) and the realm of the physical world and its phenomena. The centrality of my emphasis on information processing leads me to invert the traditional, positivist conception of the relationship between phenomena and ideas: objects are polyinterpretable and ideas give our perceptions of those phenomena temporal continuity and path dependency. The fundamental conceptual structure of tools for thought and action, and thus of ways of doing things, outlives objects and technologies even if in detail they are modified. Ideas determine how we look at things, what we see, and what we do not see. In the field of tension between ideas and phenomena, inventions occur owing to the interaction between both spheres that is fundamental to our basic assumption about the interaction between acquired knowledge and the observations in the real world that resonate with them, between the reality of the world out there and our perception of it, much in the way in which Laubichler and Renn, in their "extended evolution" (2015), outline the interaction between evolutionary control mechanisms and the niches with which they articulate. This is illustrated with an example from (traditional) ceramic manufacture.

One of the implications of this approach for our overall understanding of cultural dynamics is that we also need to change our perspective on change and its absence. Rather than assume stability and explain change, as we regularly do in our current scientific practice, we have to view both change and stability (innovation and its absence) as two states of the same regulatory system, and to understand technical or cultural traditions as circumscribed by the things people have never thought about, rather than defined by the tools for thought and action they have conceived.

To cap the theoretical chapters that I have summarized above, I have elaborated a dynamical model of the different transitions that may have led from a simple, egalitarian, rural, and isolated village society to a (proto-)urban network, with an emphasis on how the temporalities of environmental dynamics have slowly but surely been invaded and overtaken by the faster dynamics of the societies interacting with them. The transitions involved have at different times driven the members of those societies to make clear de facto choices about whether or not to participate in the novel dynamics driven by the spreading of activation nets. This was an occasion to emphasize the importance of the second order dynamics that can be understood if one considers a sufficiently long period of societal change, but that are often not taken into account because our models are confined to a century or two. But it also serves to demonstrate that one can in effect model these kinds of transitions as bifurcations occurring in mathematical models that are themselves content-neutral.

The remainder of the book is devoted to the coevolution of western societies from the Roman Empire to the present, and to the challenges that the present state of that coevolution poses for the continued existence of our current global mode of life, mainly from an information-processing point of view. This begins with a quick and very sketchy summary of the long-term coevolution of European society and its global environment, essentially viewed from the dissipative flow structure perspective, emphasizing that this history was not a continual progressive evolution of society, but a process in which phases of relatively uninterrupted, apparently stable dynamics alternated with clear tipping points at which novel resources, institutions, ideas, and societal dynamics emerged. At each of these tipping points we can identify the end of an era in which the existing mode of living outlived its optimal usefulness in dealing with an environment that had been changed to an important extent by the unintended and unanticipated consequences of its exploitation by a growing population. Whether the tipping point was triggered by environmental or societal dynamics, society had to shift from exploiting existing resources and adopted ways of thinking and doing to exploring novel approaches to interact with its environment and organize itself.

Although in the sustainability and global environmental change communities we have for some time now acknowledged that we are either close to, or at, a major environmental tipping point that threatens the continuity of our current way of life on Earth, we have not very often looked at some of the concomitant societal trends that may be driving our societies to their own tipping points, in the domains of demography, health, food and water, economy, finance, and others. I have tried to present some of these dimensions of our current predicament in an equally summary but poignant manner and attributed all of these so-called crises to one and the same second-order dynamic, the fact that our societal information processing apparatus has been overwhelmed by the unintended consequences of earlier (systemic or societal, unconscious or conscious) decisions.

Looking more closely at our incapacity to process the information necessary to deal with what is going on around us, I developed an argument about the drivers behind the acceleration we are currently living through. It seems to me that the discovery and harnessing of fossil energy during the Industrial Revolution removed the main constraint that had thus far limited the introduction of new inventions in society: the high cost in energy of implementing them. As more (fossil) energy became available, innovation in western societies accelerated. In the process, it affected the fundamental cognitive feedback loop that I have posited as responsible for the coevolution of society, technology, economy, and the exploitation of environmental resources. Early in that process, in the mid-nineteenth century, this acceleration also inverted the balance between our societies and their economies, from one in which the economy (in the form of exchange and trade) served society to one in which society became subservient to the economy, leading to the current free-market, capitalist approach.

Thus far, the speed of information processing in society had been limited by the need for society to adapt to novelty, and as that involved very large numbers of people, and network activation was for most of the nineteenth century limited to face-to-face and written communication, such adaptation was still relatively slow. That changed with the introduction of electrical means of communication (telegraph, telephone, etc.), setting in motion a wide range of inventions that ultimately also included the electronic processing of information, thereby enabling another quantum jump in the speed and efficiency of our societies' information processing capacity and reducing its cost, paving the way for the developments that we now call the ICT revolution, and hugely accelerating invention and innovation in our societies as well as generating an overwhelming quantity of information. Not only did this development change the relationship we have as humans with space and time, but it also accelerated change in a number of societal processes that had been fundamental stabilizers to the existing societal order.

One of the important dynamics set in motion was the total loss of control over information processing, which in the heterarchical mode of communication that prevailed until the middle of the twentieth century, had ensured a degree of alignment of the members of any society around a set of values and ways to think and act. Now, anyone in the world can communicate with everyone. As a result, there is an exponential increase in different perspectives and values that are being transmitted. Hence, the boundary between signal and noise is to an extent disappearing, both nationally and globally. This in turn leads to increasing confusion and undermines the national and international orders among developed nations that, until now, have been based on (1) shared sets of values within each nation, (2) non-interference in internal matters between different nation-states, and (3) balance of power between nations or blocks of nations. We observe this currently in the emergence of alternative truths and international cyber-warfare.

An important aspect of this is the reduction of the dimensionality of our societies' "value spaces" (the totality of the shared dimensions along which a society measures value), under the impact of globalization, to a single dominant dimension – the lowest common denominator shared by different cultures and societies: wealth. This global trend is rapidly accelerating wealth differentials both within and between societies, while at the same time so reducing the diversity of ways in which members of a society can affirm their identity that it is leading to the intra-societal conflicts we witness today with the rise of populist, extremist movements in many countries.

An interesting model of the situation in which we find ourselves as a result of all this is the lemniscate that summarizes the approach of the resilience community (see Chapter 5). After a phase in which both the energy and information flows increased continuously, and thus kept our societies more or less on track, we seem to be approaching a point where these flows no longer grow in tandem, and their growth no longer involves the whole of the members of society, creates fracture lines, and may ultimately be driving societies to the point where the highest levels of global organization may fragment into smaller entities.

To illustrate this fragmentation, I have briefly (and again summarily) described some of the processes that we can observe. First of all, there was the disintegration of the European political order that since the mid-seventeenth century was based on balance of power between nation-states and non-interference in the internal affairs of others. Next, political parties' most important role – connecting people in power to their power base in the population – is usurped by social networks, with important consequences for the functioning of our democratic systems. Third is what I have called "the spectacularization of experience." This process is slowly but surely detaching many people from the experience of reality, initially through increasingly intensive viewing of the media, and more recently by their spending large amounts of time on computer games.

The impact of the "big data" revolution is a fourth case in point. On the one hand, it has led to a huge concentration of power in the hands of a very small number of institutions, most of which are in private hands and can do with the information they gather more or less whatever they wish. But on the other hand, the collection of much more detailed data moves us away from the statistical approach to many domains such as insurance, medicine, agriculture, and others, where economies of scale prevail over detailed, adapted, small-scale information treatment. The issue here is that there is no government control over the use of these data to ensure that they are used to the benefit of all.

And finally, I have devoted some attention to the rapid emergence of automation, artificial intelligence and especially machine learning, which are clearly going to wreak havoc at some time in the future with our labor-based societies, creating important unemployment and annihilating the negotiating power of labor in the relations of production – if we do not in time find solutions to greatly elevate the level of general education in ways that promote human–machine collaborative problem-solving.

The fundamental and accelerating shift in information-processing structures that potentially risks overtaking societies' speed of adaptation makes it likely that we are approaching a fundamental transformation of societal organizations. It seems on a collision course with the existing value space of our western societies and those cultures and nations elsewhere that are following the globalization trajectory. That value space, firmly anchored in the structure of a world that goes back to the Enlightenment, has not really evolved to the point that it can deal with the increase in information processing capacity that we have been seeing since 2000. This trend shall ultimately – and probably quicker that we expect – reach the developing world, where the technology is quickly having a growing impact. But in many parts of it, for example in sub-Saharan Africa, rural Latin America, and Asia, the local modes of human information processing are (fortunately?) still a barrier.

A major issue in thinking about the future is whether we should, or even could, slow down (or stop?) the current acceleration of technological and societal innovation. This would in my opinion either require an external constraint, such as a reduction in the availability of energy or an important increase in its cost, or an internal constraint, such as a move away from the idea that progress underpins all societal developments. Although the former may indeed occur at some unknown time, we cannot currently depend on it to change the course of our trajectory. This leaves us with the option to change both our western conception of the role of human beings and our idea that technological progress is unstoppable. But as this approach is very deeply anchored in our culture, changing it in a relatively short time would seem to be very difficult. Hence, I propose redirecting development in a more practical sense. This is not an original suggestion, far from it. I am here asserting my position in this field, and emphasizing the importance of the work already being done in this direction!

The process begins, in my opinion, with individuals in the developed world reengaging in the everyday dynamics of their societies, instead of leaving the management of these societies to delegates to whom they have essentially relinquished a very large proportion of their societies' decision power. As part of that process, we need individually and collectively to conceive of plausible and desirable futures for our societies, and because of the current speed of societal change, in choosing between such futures we need to shift our attention from assuming stability and explaining change to the inverse: assuming and designing for change and studying how to achieve (temporary) stability.

The next level up concerns the rebuilding of local and regional communities that have been deconstructed and individualized by globalization and the concomitant reduction of the dimensionality of our societies' value spaces. As part of that reconstruction, we need to correct the wealth discrepancies that are currently tearing many societies apart. In the case of cities, in which the articulation between the ideas and behavior of societies is constrained by material construction, this may also mean that designing for change takes a larger place in their governance and material structure.

And finally, at the global level, we will have to find ways to harness the added information-processing capacity rather than let it dictate the future of our societies. That can only be achieved by a closer interaction between human and electronic information processing, and by using the power of electronic processing in novel ways, rather than to simply accelerate current, precomputer kinds of procedures. For example, we could move away from the reductionist statistical approach to interpreting massive data and gear our computers to truly predict rather than explain.

All this leaves us with a question about our role as scientists. First of all, I think we have to accept that the trust in science, in many of our societies, has suffered and is declining because of overpromising on the part of scientists, unintended negative consequences of certain inventions, and in a more general sense the harnessing of science by industry (for innovation) and government (to justify unpopular decisions). To counter this, we have to reconsider the institutional context of science, its engagement with civil society, and its presumed – but fake – neutrality. After all, our methods may be objective, but the questions we ask are subjective and culturally determined. We have to shift focus from a posteriori science (focused on origins and ex-post explanations of how we got to this point) to a priori science (focused on emergence of new phenomena in the past, in the present, and in the future), and this entails a shift to Complex Systems Science, with the implications outlined in Chapter 7.

Finally, a last but essential point on this issue. As scientists, we must be ready to engage in society. We are citizens trained in science but citizens above all. Hence, we should play our role in guiding society. Rather than limit ourselves to presenting the conclusions of our analyses in the most balanced detail – for and against – we can, and must, share with society our ideas about possible challenges and solutions to the problems it faces. But we must separate the presentation of our science from that of our conclusions and opinions, so that it is crystal clear what is what.

In Chapter 20, I presented some examples of the very wide range of visions for our future that are extant in the literature. The main purpose of those presentations was to draw the reader's attention to:

1 The challenges and issues involved in trying to stop the frantic race of our society to the destruction of our environment since

developed societies have become subservient to economies, let alone any efforts to turn the clock back on the recent history of our societies.

2 The strong western cultural ("progress") bias involved in such projects as implementing the United Nations' Sustainable Development Goals (SDGs), a bias that might endanger the project itself because by the time (2030 or 2050) that the work is supposed to be done, many major societies in our world possibly will have very different cultural values than those on which the SDG project is based. The SDGs remain framed around traditional conceptions of economic growth, which are in turn embedded in the western economic progress vision, which has been adopted by most of the world's governments. But underlying value conflicts are sure to impede their implementation, and top-down implementation may exacerbate those value conflicts, cause conservative cultural backlashes, etc.

3 The observation that continuing to globalize large parts of the world is in all probability not an effective way to try and master the challenges our socioenvironmental systems are facing, even if it sometimes seems as if the rapid developments in information processing would enable a global government. On the contrary, ICT developments seem to point to a fragmentation of world regulation and governance into a multipolar system, thus avoiding hyper-coherence and introducing a flexibility that takes local circumstances and cultural values into account.

4 A range of innovations in our ways of thinking and organizing ourselves that are the result of intensive interaction between human and electronic means of information processing. One of the interesting things is that these proposed changes, outlined in a recent volume by Ito and Howe (2016), converge substantially with the earlier chapters of the book, which were developed and written before I was alerted to it.

What Are the Chances of Success?

After lectures on the topics at the core of this book, I am often asked whether I am an optimist or a pessimist about the chance that human societies will survive the sustainability challenge. The question can be answered in many different ways. One of the simplest, which I often use after a long meeting, is that I am a long-term optimist as well as a short-term pessimist. The long-term perspective that is mine as an archaeologist shows that, until now, humanity has always been able to change its ways of thinking and acting when it has been forced to do so. But in the process of implementing those changes, there has often been considerable short-term collateral damage (as my US colleagues and friends would put it).

What brings me to this conclusion? If I begin with the short-term pessimism, it is rooted in the extent to which the global market-based system, and more importantly its ideology, ethics, institutions, and attitudes, have rolled over much of the world and are embedded in very powerful social and economic structures. The struggle to reduce CO_2 and other greenhouse gases in the atmosphere, which is only one of the many consequences – rather than a cause – of the sustainability predicament we are in, shows us how difficult it is to change the course of our mammoth current socioeconomic (or should I say econosocial?) thinking and its institutional structure. If we succeed (and there are increasingly many signs pointing in that direction) it will have taken the world some sixty or more years, and yet we have not in any way dealt with the root causes of the problem. These may manifest themselves in a plethora of different crises to come, in virtually any domain we can think of: health pandemics, resource shortages, deterioration of the quantity and quality of the basic necessities of life such as food, clean air, and water, economic and financial crises, political instability, and so on. Unanticipated consequences of the increasingly rapid rate of innovation we have seen since *c.* 1750 in all domains is likely to overwhelm us in each of these – and many other – areas because our current global dynamic flow structure is simply unsustainable. Add to this the completely unpredictable but profound consequences of the ICT revolution, and it is easy to see that our global system has been at the edge of chaos, and is likely to be overwhelmed, if we let it continue on its current trajectory.

We effectively have to move our focus from progress, growth, competition, and individual satisfaction to community building, stimulating social (group) coherence, and multidimensional wellbeing. As expressed by Quinn in his magnificent novel *Ishmael*, we have to move globally from a taking to a leaving philosophy (1995). Many authors, including Daly and Latouche who were extensively discussed in Chapter 20, have been proposing this for some time, ever since Malthus raised the underlying issue – the positive feedback cycle between demography and food production. But we have thus far set hardly any steps in that direction, except at the level of individuals and some small communities.

This move implies breaking the fundamental feedback loop that I have put forward as the driver of human coevolution, linking information, cognition, innovation, energy, and population size. There seem to me at present several ways in which such a break could theoretically occur, but only a few that have a realistic chance to occur during this century. I will look at the potential of each of these in turn.

Breaking the Fundamental Feedback Loop of Coevolution

Now let us look at potential reasons for long-term optimism. Clearly, a voluntary reduction in population increase worldwide is difficult to put in place and has a number of consequences that are contrary to our current western (and increasingly dominant) value systems. Governments in China and India have tried to reduce the rate of population increase, in China forcibly and in India by a mixture of enticement and enforcement, but with mixed results. In both cases the greatest challenge seems to be the emphasis on economic growth, as growing economies generally require demographic growth in order to sustain themselves. The only other road to reduction of population that has been widely discussed is a major increase in per capita wealth in the developing countries, which, according to demographers, would reduce the birthrate in those countries. But one may question whether that would indeed have the desired long-term effect if one looks closely at what has happened in the developed countries, where, over centuries and millennia the population has seen major increases, interrupted by relatively short periods of stagnation or depopulation. Moreover, population reduction is a kind of "sacred cow" in developed countries – a basic infraction on a fundamental individual freedom that is not often publicly discussed. Convincing people to voluntarily reduce the number of their children requires convincing them to fundamentally change many of their values. This leaves involuntary reduction of the population owing to environmental or natural factors, such as pandemics, famines, and similar drastic events, which while deplorable are highly likely to continue. But these are also in disagreement with the philosophy of developed societies and are therefore likely to be resisted (owing to efforts in the domain of health) or mitigated (by means of food transfers). Viewed over the long term, this poses the question whether the wealth accrued by the developed nations will continue to be sufficient to keep successfully fighting off such events. Wealth, we must remind ourselves, that is accrued by exploiting the resources of the developing world.

Another way to interrupt the fundamental positive feedback loop that drives the current socioenvironmental coevolution is by limiting the energy flow through society that, as we have seen, is the inherent counterpart of the information flow. The acceleration of innovation and information flow that was triggered by the discovery and harnessing of fossil energy could conceivably be slowed down or even inverted by a lack of energy. However, one of the consequences of the greenhouse gas debate has been the shift to solar and wind energy that, once complete, ensures the long-term availability of plentiful energy.

This leaves other material flows as potential interruptors of the basic feedback loop. In discussing the topic, we have to distinguish between the availability of the means to meet basic human needs such as food and water and the availability of other raw materials, as used in industry or for shelter. Certain of the latter are, at one point or another, likely to run out: rare earth minerals, such as coltan, etc. But it would seem that human ingenuity and a sufficient investment in research will find solutions for such shortages by substitution.

Potential global shortages of food and water are more difficult to deal with, and until food security has been dealt with as a global challenge we do not know whether human ingenuity and will can solve this. One of the important constraints to increasing the total global quantity of food is the fact that human beings have a limited range of foodstuffs that they digest and use. Shifting the emphasis of production from meat and fish to vegetarian foodstuffs can reduce the risk of global food shortages for a (considerable) time, but some proteins are needed for human health.

Fresh water is another commodity that is basic to human subsistence. It, too, is limited in overall quantity available, especially if climate change leads to a reduction in the amounts of frozen fresh water available worldwide. Although it can be created from salt water (and there is enough of that), this is costly in energy, and there has so far been no major breakthrough in the water–food–energy nexus that I know of. Hence these two commodities may well turn out to limit the fundamental feedback loop unless per capita water use can be drastically reduced, particularly in agriculture (the heaviest consumer of fresh water), or water recycling can be improved and spread to the extent necessary to rely on available water resources. But this again is costly in (renewable) energy.

That leaves only one other potential human-engineered interruption in the basic feedback cycle: the information flow itself. Can we intervene in the data–information–knowledge cycle that is at the core of the flow structure that is driving societal coevolution? In the light of the ICT revolution this seems an intriguing option that we need to consider in some more detail. One major difference with the other elements in the flow structure is that this one is driven by a very small, though growing, number of people worldwide. One question is whether that community could be convinced of the need to redirect its efforts in a different direction, and another whether it is not already too late to do so in a way that will convince others to take up their torch. But convincing a relatively small community seems easier to do than convincing a substantive part of the world population. I argued in Chapter 19 that to redirect the development of ICT away from a very small and powerful component of the world's business community, people in the developed nations need to reassert their individual and collective power to determine their future and control the development of information technology. Is that feasible? Will enough people come to see and accept the changes that this development is imposing on our social lives if nothing is done to wrest the control over it from those who have it at present?

A similar, relatively small but hugely controlling group that could at least theoretically be convinced to steer society in a different direction is the world of finance. The same questions will need to be asked and answered for this group, but at the present time there is more of a reaction to its supremacy than to that of the information technology (IT) community.

The next question is in which directions the current rapid developments in IT and/or finance could be reoriented to have a positive effect. The answer is in part the same: by strengthening public governance, they could be slowed down and then transformed so that large numbers of people across the world are empowered to use them in alternative ways. Widening out our value space with the values of the "developing" or "underdeveloped" world would not only enrich our experience, but also set in motion new dissipative flows, ultimately possibly balancing the existing inward flows of matter and energy, and thus spreading wealth rather than concentrating it.

How might this work? The ICT revolution will continue to impact on our society in very many ways that we can only glimpse at present. We must look at these both from the ICT perspective itself, and from that of its impact on our societies. From the ICT perspective, the technology offers the opportunity to mitigate at least to some extent the main cognitive limitations that we have mentioned earlier as driving societal information processing to date. ICT may improve the integration between human and electronic information processing. This is clearly an ongoing process, in which exploiting the capacity of ICT to reach out and create horizontal networks of information processing worldwide is of major importance if we are to drastically improve the total information processing capacity of our societies. That will no doubt lead to different perspectives on our past, present, and future trajectories and, we may hope, a more realistic assessment of the long-term affordances and constraints of societal development. It will in my opinion also be one of the drivers of the enlargement of our global value space, and therefore an important driver of the transition from a resource-to-waste economy to an economy of opportunity that finds a better balance between "takers" and "leavers" (Quinn 1995).

ICT may also enable us to deal with the bias of human decision-making toward theories, ideas, and behavior that is principally based on successful past responses, owing to the underdetermination of our ideas by our observations. The big data revolution may enhance the role of observations in decision-making and therefore loosen the path dependency of our current societal evolution, paving the way for a very different kind of decision-making. Currently, techniques and methods to deal with that big data revolution are still insufficiently available, but the development of machine leaning is likely to remedy that.

In order to facilitate thinking about the future, ICT may help us develop a kind of informatics that, rather than reducing the dimensionality of big data into simpler concepts, does the reverse: moving from a limited number of observed dimensions to generate as many other dimensions as possible, and then testing those for feasibility, in effect reversing Occam's razor and assuming that the world is complex; and that, therefore, ideas need to embrace that complexity rather than simplify it away.

From a perspective of societal change, at least four different dimensions of the future impact of ICT seem important to me. ICT might (1) substantially increase transaction efficiency and (2) trigger structural changes in the division of labor, including increasing specialization in the functions and tasks fulfilled by individuals, groups, and institutions. As part of that process it may well render large parts of the population unemployed and therefore restless for change. That might in turn (3) change the configuration of our institutions, including firms and markets, as well as their roles and shapes. And, as importantly, (4) the fact that fewer resources might be devoted to maintaining the current structure would free up resources for implementing innovations.

These profound changes may in my opinion offer an occasion to move the long-term dynamics of human development in a different direction.

The ICT revolution is already in the process of leveling information-processing and wealth differentials by enabling the strengthening of horizontal networks, as opposed to the vertical ones that have dominated our human information processing for so many centuries and created the current wealth-centered world and its material imbalances between different strata of the population and between different parts of the Earth.

Rather than accumulation, spreading of information is becoming, and should become much more, the main driver of the economy, and the tool to create wealth in other parts than the current developed world. This trend is the reason for the high current valuations of the social networks, which have discovered a fundamentally different, novel, way to profit from the existing information-processing differentials – rather than increasing them, they are making their profit from decreasing them. This favors an inversion from the current, predominantly extraction-to-waste economy (in terms of raw materials, but also human capital) into an economy of opportunity creation and spreading wealth, and substantively enlarges the total value space of the global community involved.

But, and I cannot emphasize this enough, we need to grasp the opportunities offered by the ICT revolution and not let them slip by uncontrolled. The enlarging of the value space is not going to happen if the spreading of information is used to propagate the current, narrow, material-, gross domestic product-, and consumption-focused western value system across the entirety of the planet. Indeed, we must use this occasion to do the inverse – to enhance the global value space by developing the many other values that are current among non-western societies: actively stimulating the emergence of novel dimensions of value from the embryonic state in which they currently exist, often (but not only) among small-scale societies. Certainly, biodiversity is an important aspect of sustainability, but so is cultural (value) diversity. Without cultural diversity to grow our value system, we will not be able to find ways to durably live peacefully with billions of people on Earth. Only by increasing the information-processing capacity, education, and wealth of the underprivileged can we redirect the current trend so as to approximate a more stable equilibrium.

We can distinguish two main kinds of information processing that currently link the developed and the developing world. The first aims for direct information transfer from the developed to the developing world and does not directly contribute to the expansion of our global value space, even though the confrontation between the ideas spread and local knowledge may generate innovation and new values. The second approach, on the other hand, enables the development of local knowledge and the expansion of local wealth creation. Examples of the first are the facilitation of distant access to information from many different sources that was initiated by the search engines (Yahoo, Google, etc.), and then led to the development of specialized online encyclopedias such as Wikipedia, which not only assemble but also synthesize information. It is now entering a different stage with the emergence of online degrees at many universities and the Massive Open Online Courses (MOOCs) driven by major institutions such as MIT and Stanford. These enable anyone to study free of charge, or at lower cost than is traditional, anywhere in the world. They are spreading as ways are found to return to the educating institution a small percentage of the proceeds ultimately generated by the people thus educated. They are part of the "online revolution," which will in the next thirty years fundamentally transform the worldwide educational and societal landscape at all levels. In addition, there are many e-based tools that, even though they do not deliberately aim to educate, have very important educational components. These range from blogs to social networks to "serious" games that promote certain learning skills. In this domain, we may expect many more innovations that contribute to the transformation of the information-processing landscape.

Examples of the second kind abound, and have been spreading for fifty years under the impact of those non-governmental organizations that saw that providing local populations in poor countries with western knowledge or infrastructure was not always effective in enhancing their happiness, wealth, or autonomy, and did not have as immediate and long-lasting an effect as helping local populations use their existing talents. Developing the local recycling economies of the developing world is a good example. These use materials such as empty oil drums and crates, used tires, and the like to create pipelines, furniture, and baskets. They are a fundamental part of the local economy, providing jobs, spreading or accumulating knowledge, and reducing waste. Giving them access to world markets has been one way to promote them, as in the case of the South African production of decorative baskets from telephone wire. Another example of this kind of promotion of local developments has been the spread of microcredit to provide for the initial investments needed for local enterprises (which are doing things that are not done in the west) to emerge. This has been so successful that more recently microcredit lending has spread to poor areas in the developed world, such as parts of New York City.

This trend is positive, but it would greatly gain in importance if non-western societies would try to move in the direction of implementing their traditional values, directed at leaving in Quinn's sense, rather than western (taking) approaches, increasing their level of education and innovative capability in independent innovative ways. One characteristic of many indigenous leaving societies is that they have not developed an externalized, material-based value system to maintain their coherence, but have, as far as we can see, very intricate and subtle, high-dimensional, internalized, mental value systems. Dematerializing our western value systems might be an interesting way to proceed.

Decentralization, Disruption, and Chaos

Whether as a result of one of the potential top-down reorganizations proposed in the last sections, or as a result of a bottom-up societal change driven by social unrest owing to the tension between globalization and social exclusion (Munck 2004), the changes are likely to trigger major disruptions in our societies. This is where my short-term pessimism comes in again.

It is one of the tenets of the resilience community (Gunderson & Holling 2002) that the kind of longer-term development that we have seen over the last sixty or more years ultimately leads to rapidly increasing vulnerability to shocks. Once such shocks begin to generate cracks in the dynamic structure of the system, novel values and ideas, which could not previously express themselves, emerge. I would argue that that is in effect what we are beginning to see worldwide, as our world fragments from a bipolar into a multipolar one at all levels. This fragmentation is nothing but another manifestation of the fact that people are beginning to assume an increased responsibility for their own actions because they no longer feel comfortable with the current system. As this feeling spreads, their actions will increasingly be based on awareness of different sets of values, and deviate from the kind of "rational decisions" proposed by the free-market economics that only takes a very limited number of value dimensions into account. This is exactly the kind of development that favors the growth of the global value space that I have been arguing for. But in the process it may well dismantle at least the upper part of the current institutional structure that governs our societies, limiting the size of coherent, stable, social entities. The European Union for example, might disintegrate into its constituent nation-states, and the USA might deconstruct much of its federal superstructure and relegate major responsibilities to the individual states. Similar processes could occur in China, an empire that is essentially a conglomerate of regional entities with major social, economic, and cultural differences. How far down such deconstruction would reach in our current societal and governance systems is an interesting question. One of my colleagues argues that it might well go as far as empowering major metropolitan areas at the expense of all larger sociopolitical units.

It is likely that all this would lead to a substantive period of chaos before a next set of more or less stable institutional solutions was identified and implemented. The longer our societies continue on the current trajectory, the more likely it is that in such a chaotic period many people will suffer substantively. The current chaos in the Near East and adjacent areas is a telling example, as is the situation in Africa that is causing the current migration crisis in Europe. Neither is likely to change unless there is a fundamental societal restructuring, and that will take a lot of time.

But that is where my optimism comes in again. At some point in time this restructuring will happen, if only because it is the fundamental nature of human beings to be social and individuals cannot survive alone. That is the lesson of the long-term perspective that archaeology offers, the study of the emergence, flourishing, and disintegration of all kinds of societal structures, from very small to very large, such as the Chinese, Persian, and Roman Empires. That is the reason I can be optimistic about humanity, yet pessimistic about our current way of life.

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