Management for Professionals

Christoph E. Mandl

Managing Complexity in Social Systems

Leverage Points for Policy and Strategy

Second Edition

Springer

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Foreword to the First Edition

Already before the year 2000 my speeches included the forecast, "Everyone in this audience will see more change over the next 25 years than you have experienced during the past 100." That was a momentous idea for European audiences, given the vast changes in every sphere of their lives since 1900. However, observing the accelerating pace of events as they unfold in 2018, I believe my predictions will be justified. Despite the mounting chaos, we are still only in the very early phases of an exponential change process.

Changes are coming in every aspect of life—political, economic, environmental, technological, and psychological. They are being driven by climate change, automation, migration, debt, the growing reliance on force to resolve disputes, and many other factors. None of us will be able to escape the effects of these forces. But some of us will flounder while others will flourish. The individuals and organizations who are outstandingly successful in the coming decades will not be those who try to predict the future. I believe that is impossible. They will be the ones who try to perceive the underlying sources of change and to manage the dynamics of their interaction with the environment. No one yet knows how to do these things very well. But Christoph Mandl's gives us all a wonderful boost toward mastery. He has been a student, manager, researcher, and teacher. He provides us in an accessible text many of the insights he has gained from over 50 years of professional effort.

His book uses graphics rather than mathematics to explain the causes and consequences of behavior. After an excellent introduction to the basic tools of system dynamics, he describes 11 common system malfunctions. His text is an important contribution to an emerging field of thought.

I have enjoyed and benefitted from reading this text; you will also.

Durham, NH, USA
July 2018

Dennis L. Meadows

Preface to the Second Edition

When I finished writing this book in 2018 the world was still a place with comparatively few surprises around the corner. Sure, events happened in 2018—some positive, some negative—but nothing was totally unexpected. The world's last male northern white rhinoceros died in Kenya, making this species functionally extinct. Heavy wildfires in Greece left 102 dead. The longest total lunar eclipse of the 21st century occurred. An Ebola outbreak began in the Democratic Republic of the Congo—the second-deadliest outbreak of the Ebola virus. Heavy rainfall caused the worst flood in a century to hit the Indian state of Kerala. At the Katowice Climate Change Conference, nearly 200 nations agreed rules on implementing the 2015 Paris agreement, and so on and so forth.

None of those, seemingly fleeting events, was of any significance for this book. That however changed on December 11, 2019.

On that day, the European Commission (2019) published its communication named The European Green Deal. With this deal, all EU Member States committed to turning the EU into the first climate-neutral continent—i.e., no net emissions of greenhouse gases—by 2050. The very notion "climate-neutral" suggests that by 2050 the EU will have made its contribution to stop climate change. This new example of confusing stocks with flows—of stock–flow failure—is not addressed in this book's first edition. Because of its global visibility and relevance, the new climate-neutral policy and its implication for climate change is now included.

On January 23, 2020 the Chinese city Wuhan was quarantined with all scheduled public transport services and intercity flights halted because of the COVID-19 outbreak. The expectation that this was just another fleeting event proved utterly wrong. Triggered by fears of the spreading of COVID-19, on February 27 the Dow Jones Industrial Average plunged by 4.4%, its largest one-day point decline at the time. Then things really started to happen with growing speed. By the end of March 2020 the number of deaths due to COVID-19 doubled every 5 days in the US, doubled every 6 days in Germany, and doubled every 9 days world wide—a growth rate between 10 and 20% per day.

Until then presumably nobody had ever experienced such exponential growth in everyday life. Biologists knew such growth rates from observing microorganisms in Petri dishes, but otherwise the most rapid exponential growth was to be found in computer technology, where the number of transistors per chip had doubled every two years since 1971—a growth rate of approximately 40% per year or 0.09% per day. The human race was experiencing life threatening exponential growth at an, prior to COVID-19 unimaginable growth rate.

Exponential growth—growth with constant doubling time—is not particularly novel to people familiar with self-reinforcing feedback and with system dynamics. As such, it is at the core of this book. Nevertheless, the implications of so far unknown high growth rates for sensitivity analysis, for applying leverage points, and for scenario planning were not incorporated in this book as it was written well before the pandemic started.

It was thus a very welcome offer by Springer Nature to adapt this book to unexpected experiences made and insights gained since its first edition and incorporate these insights into this second edition.

The most important change concerns the classification of dynamic phenomena or—as I now call them—systems archetypes. In the first edition, I consider all systems archetypes alike as far as how difficult it is to find and apply leverage points. However, even though all systems archetypes are difficult to manage it became clear that some are more difficult than others. Horst Rittel and Melvin Webber (1973) proposed to differentiate between tame and wicked problems in policy. Kelly Levin et al. (2012) further differentiated between wicked and super wicked problems. Thus in the second edition I adopt their classification. Three classes of systems archetypes—tame, wicked, and super wicked—replace the differentiation between intraorganizational and trans-organizational.

"Part III: Managing Intra-Organizational Phenomena" is now "Part III: *Managing Tame Systems Archetypes*", "Part IV: Managing Trans-Organizational Phenomena" is now "Part IV: *Managing Wicked Systems Archetypes*", and "Part V: *Managing Super Wicked Systems Archetypes*" is newly added. In this new structure the chapter "Sensitivity and Uncertainty: Locust Plagues and Price Dynamics of Commodities" fits much better into Part III instead of Part II being entitled "Deterministic Chaos: Locust Plagues and Price Dynamics of Commodities".

To explain the three classes of systems archetypes the chapter "Generic Structures, Systems Archetypes and Theories" is replaced by the chapter entitled "Tame, Wicked, and Super Wicked Systems Archetypes".

Triggered by the notion of climate neutrality, the chapter entitled "Confusing Stocks with Flows: The Carbon Credit Fallacy" is revised and changed to "Stock–Flow Failure: The Case of Climate Neutrality".

The experiences and insights from the pandemic required a complete revision of two chapters. "Chapter 3 Homeostasis, Complexity, Emergence and Purposeful Behavior" is now "Chap. 3 Equilibrium, Resilience, and Emergence", and "Chapter 4 Decision and Forecast: The Cassandra Paradox" is now "Chap. 4 Prediction, Butterfly Effect, and Decision Making".

The experience with COVID-19 showed how important it is to deal with the butterfly effect when analyzing dynamics of social systems. Though Edward Lorenz (1963) discovered that the dynamics of even simple systems may be highly sensitive to initial conditions—the butterfly effect—modelers of COVID-19 dynamics ignored this insight. Thus in chapters of Part III, Part IV, and Part V, I newly address the question how sensitive a systems archetype reacts to small changes of initial conditions and discuss its consequences for applying leverage points.

The pandemic also brought forward how extremely difficult it is to derive effective policies for nonpharmaceutical interventions particularly when the growth rate of the number of infectious people is 10% or more—per day! The new chapter entitled “Epidemics: Out of Control” explains traps and limits of controlling extremely rapid spreads of infections.

In light of all these changes and enhancements, the final chapter “Managing Complexity” needed a substantial overhaul, incorporating and summarizing all the insights from the forgoing Part I up to Part V. As the focus shifted somewhat from strategies to policies this revised chapter is now entitled “Conclusion: Governance and Management in the 21st Century”.

Unfortunately, there are some errors in the first edition even though I tried hard to avoid them. The bright side of this failure of mine was that some of my students at the University of Natural Resources and Life Sciences, Vienna detected them and contacted me. For their vigilance, I am very grateful. This second edition gives me the chance to get rid of all these errors.

A dwarf perched on the shoulders of giants—that is what I was when I wrote this book and what I still am with its second edition. As such, I am grateful for all the giants I mention in “Chap. 1 Preface: Scientific Journey into a Strange Paradigm”. However, I feel obliged to add three more philosophy of science giants who were not essential to me back then in 2018 but became bright stars during a pandemic which brought epidemiology and computer simulation to the brink of scientific misconduct: Karl Popper (1959) for his *The Logic of Scientific Discovery*, Daniel Kahneman (2011) for his *Thinking, Fast and Slow*, and Immanuel Kant (1798) for his *An Answer to the Question: ‘What is Enlightenment?’*

Enjoy and, please, let me know your experience with this second edition!

Vienna, Austria, E.U. Christoph E. Mandl
February 2023

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Praise for *Managing Complexity in Social Systems*

"Managing complexity in social systems is a challenge for both professionals and academicians. The main obstacle is time: learning by experience is only possible if the time interval between cause and effect is short, but if cause and effects are in a circular relationship, feedbacks are delayed then control is not obvious at all—it's a "complex task". Understanding these phenomena form the topic of this book written in, what the author calls, "semasiographic" language for both educated managers and students of business analytics. The system behavior casted in stock and flows diagram provides an intuitive interface between qualitative and quantitative reasoning about dynamics by using "archetypical" stylized models. Learning takes place while you think about intervening in such a system what is by far a nontrivial task—this book helps to find your way!"

—Hans-Jakob Lüthi, *Professor Emeritus, ETH Zurich*

"This book clearly tells the story how to deal with system's complexity in social systems by using the smart language of stock and flow diagrams. Weak spots and leverage points in the development of society and economy are addressed. The reader is supplied by a number of clear and easy to follow archetypes which constitute the basis of so many dynamic systems."

—Manfred Gronalt, *Professor, University of Natural Resources and Life Sciences Vienna*

"This book looks at the world from a different, yet very effective vantage point: the systemic perspective. Anyone needs to and can improve his or her understanding of systems—social, ecological, economic, etc., and will benefit from the systemic approach. The main question here is: "What are the structures that generate the behavior of the system in focus?" The author delivers a perfect introduction to systemic thinking—unorthodox, insightful and practical."

—Markus Schwaninger, *University of St. Gallen, Switzerland*

"A most inspiring approach to simulate the complex socioeconomic dynamics of managerial systems successfully applying Forrester's Stock and Flow concept."

—Hugo Tschirky, *Professor Emeritus, ETH Zurich*

"No areas of human life are more in need of the tools of system modeling and complexity science than business, government and social services, in general. In this stunning volume, Christoph Mandl offers a world-class introduction to what these tools actually are and how they can be used to address questions and problems of everyday life. The best part is that Mandl takes the academic mystery out of system science, presenting the field in a form and style that is accessible to just about everyone. Read it!"

—John Casti, *Founder, X-Event Dynamics, San Jose, California*

"Given the rapidly changing complexity of societal systems and the common thread of organizations 'doing more of the same with less effect' in a resource-scarce environment, this book is not just timely, but necessary. A book of this nature, with topics such as strategic behavior and operational challenges that a decision maker who is resource-stricken while striving for sustainable development can relate to, is an opportune and worthwhile endeavor."

—Christian Stary, *Professor, Johannes Kepler University Linz*

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About the Author

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1 Preface: Scientific Journey into a Strange Paradigm

Much as I dislike the idea of ages, I think a good case can be made that science has now moved from an Age of Reductionism to an Age of Emergence, a time when the ultimate causes of things shift from the behavior of the parts to the behavior of the collective. Robert Laughlin (2005)

Dynamics—the study of motion—was always that part of natural science and, after graduation, the area of social science that fascinated me most. Of course, statics—the science about systems in equilibrium—was a prerequisite, but dynamics really caught my attention. This might be why music is more interesting to me than painting, why I enjoy skiing more than yoga, and why I prefer to read and analyze strategies rather than balance sheets.

My first encounter with the science of dynamics was in high school when I read the book by Wiener (1961) on cybernetics. I devoured it at least as far as I could grasp it because not everything was written in plain language. The parts expressed in the language of math were beyond me, so I decided to study technical mathematics. Given my predilection for dynamics, calculus caught my attention, particularly its use in mechanics. Of all the books of that time the one I liked best—and I still have it on my bookshelf—is one by Parkus (1966) called *Mechanik der festen Körper* (Mechanics of Solid Bodies).

Besides wanting to learn mathematics, there was another reason to choose technical mathematics: it was the only program at that time at an Austrian university where I could learn computer language—programming codes like ALGOL and FORTRAN that are now as nearly extinct as Sumerian or Egyptian. While mathematics was the perfect tool to study systems in equilibrium, a rather frustrating insight was that solutions to problems of dynamics often could not be expressed as mathematical equations but required computational efforts using algorithms. Starting from an initial input, an algorithm describes a computation that proceeds through a finite number of well-defined successive states, eventually producing output and terminating at an end state. Therefore, I learned to design algorithms,

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translate them into computer language, and find answers to questions of dynamics. My undergraduate thesis, for instance, dealt with the question how a pendulum behaves when it is excited at random (Mandl 1970)—a question that could not be answered without an algorithm and computers.

Leaving mechanics behind, I then ventured into new territory, the dynamics of economic systems. Meanwhile, computer languages became more sophisticated but also more problem-specific. Computer simulation emerged to analyze the dynamics of sociotechnical systems that benefit traffic patterns, manufacturing and distribution systems, as well as economic systems at large. One of these computer simulation languages that caught my attention was DYNAMO by Pugh (1963). While SIMSCRIPT was ideal to study concrete dynamical issues of sociotechnical systems, DYNAMO was perfect to analyze the dynamics of economic systems. Inspired by the book *Principles of Systems* by Forrester (1968) and the *Lectures on the Mathematical Method in Analytical Economics* by Schwartz (1961), I ventured into writing a textbook on the use of computer simulation in business and economics, which Springer gladly accepted—see Mandl (1977).

Although *The Limits to Growth*—Meadows et al. (1972)—was extremely enlightening, I confess my interest in the use of DYNAMO faded so much that when I was a visiting scientist for a year at the MIT Operations Research Center I never thought of contacting Forrester—an oversight which I still regret.

I departed from science and entered the world of business and management. The day-to-day issues of strategic planning in a corporation at first and managing a software start-up afterward left no room for thinking about dynamics in business, or so I thought. I became heavily involved in the computer-integrated manufacturing (CIM) movement. To understand CIM's relevance and its relationship with organizational knowledge on a deeper level, the book *The Tree of Knowledge* by Maturana and Varela (1987) was another highly enlightening read, resulting in Mandl (1988) "Eine systemtheoretische Betrachtung von Computer-Integration".

In (1989), Dietrich Dörner and his experiments about the logic of failure conveyed how easy it is to make inappropriate management decisions when delays between cause and effect are involved. Dörner was the first to show experimentally how thin the line is between doing too little and overreacting and how easily managers can be triggered to react excessively. Dörner's book initiated Mandl (1993).

In 1990, the Web did not yet exist. It was therefore not easy to be up to date in Austria about new publications in the USA. Personal messengers were indispensable. Markus Hauser, a good friend, was such a messenger. At that time, he studied at the California Institute of Integral Studies in San Francisco. From him I learned about a then-recently published book called *The Fifth Discipline* by Senge (1990). This book immediately caught my attention. It was the first book that plausibly demonstrated how systems thinking—Senge called it "fifth discipline"—could be used to make better management decisions. The gap between system dynamics as a way of modeling social systems and making appropriate management decisions was bridged. The immediate use I made of Senge's book was to introduce the Beer Distribution Game to management trainings together with my friend and colleague Hans-Jakob Lüthi, a professor at ETH Zurich. The Beer Distribution Game is an experiential learning game where participants manage a supply chain of beer—and more often than not fail. Observing a group of senior managers utterly overreacting in the Beer Distribution Game thus causing the bullwhip effect—see Forrester (1961)—reconfirmed the relevance of systems thinking for management.

That was my state of mind when I stumbled over a scientist whose name I had not heard before: Gregory Bateson. Immersing into Bateson's (1972) *Steps to an Ecology of Mind* and then Bateson's (1979) *Mind and Nature: A Necessary Unity* and then Bateson's (1987) *Angels Fear*: *Towards an Epistemology of the Sacred* made me aware that systems thinking is not just a method but also a very different way of seeing and understanding the world. Kuhn (1962) called it a paradigm shift:

> When Aristotle and Galileo looked at swinging stones, the first saw constraint fall, the second a pendulum. … Though the world does not change with a change of paradigm, the scientist afterward works in a different world.

Along those lines, Bateson lectured in his typical somewhat ironic style as shown in the wonderful documentary by Bateson (2010):

> It is inculcated by our great universities that the world is made of separable items of knowledge in which if you were a student you could be examined by a series of disconnected questions called true or false quizzes. And the first point I want to get over to you is that the world is not like that at all or to put it more politely the world in which I live is not like that at all and as to you it's your business to live in whatever world you want to.

Until I read Bateson my worldview on systems thinking was firmly rooted in Forrester's and his scholars' work. Bateson writings were like switching from seeing a film in Academy ratio to widescreen. Bateson (1972) made me aware of the historical perspective of systems thinking:

> I was privileged to be a member of the famous Macy Conferences on Cybernetics. My debt to Warren McCulloch, Norbert Wiener, John von Neumann, Evelyn Hutchinson, and other members of these conferences is evident in everything that I have written since World War II.

While Forrester (1971) stated that social systems belong to the class called multiloop nonlinear feedback systems, Bateson clarified for me the immense and radical consequences of Forrester's bold premise.

Then another far-reaching idea emerged that neither Bateson nor Forrester anticipated: complexity. Having invited John Casti (1979) for a series of lectures at the Institute for Advanced Studies in Vienna, I became familiar with catastrophe theory, a branch in the study of dynamical systems where small changes in certain parameters can lead to large and sudden changes of the behavior. However, to me it seemed like an interesting new mathematical branch with little practical relevance. Then came chaos theory, see James Gleick (1987).

While catastrophe theory was mostly for enlightened mathematicians, chaos theory and its relevance for understanding dynamics caught the attention of the interested public particularly due to the bestseller *Chaos: Making a New Science*. Chaos theory is a branch of mathematics that deals with dynamical systems that are highly sensitive to slight changes in initial conditions. Small differences in initial conditions yield widely diverging outcomes, rendering long-term prediction of their behavior impossible. System dynamics and systems thinking did not account for that.

A scientific revolution occurs, according to Kuhn (1962), when scientists encounter anomalies that cannot be explained by the universally accepted paradigm within which scientific progress has been made. This anomaly in systems science was deepened when chaos theory led to the science of complexity as described in the bestseller by Mitchell Waldrop (1992), *Complexity: The Emerging Science at the Edge of Order and Chaos*. Systems thinking and complexity seemed at odds with each other. Curious with anything dealing with dynamics, I delved into the work of W. Brian Arthur as well as of Kauffman (1995). Particularly Arthur's (1994) book and Arthur's (1996) article revealed a very new perspective on dynamics of social systems:

> Outcomes were not predictable, problems might have more than one solution, and chance events might determine the future rather than be averaged away. The key to this work lay in the fact that these were processes driven by some form of self-reinforcement, or positive feedback.

The works of Forrester (1961) and Arthur (1994) were for the first time reconciled in Sterman (2000) in the chapter entitled "Path Dependence and Positive Feedback". Sterman's book not only helped me integrate Forrester's and Arthur's ideas, but also it was a very good starting point for a new course on "Systems Thinking and Modeling" at the University of Vienna. Until 2000, I experimented with various course formats to acquaint students with organizational learning, innovation management, and supply chain management, all of which require an understanding of system dynamics. Although I tried hard, Senge (1990)—the best book at that time on systems thinking in business—did not appeal to students as much as it did to me. Sterman's book, however, changed all that. Students readily adopted it. This new course focused on supply chain management and the Beer Distribution Game as well as on dynamics of innovation—developing the former course further toward systems thinking.

Time was ripe to offer a seminar on systems thinking for managers and policymakers. Together with Hans-Jakob Lüthi and Markus Schwaninger, a professor at the University of St. Gallen, we devised it, emphasizing the work of Kim (1992) on systems archetypes as well as of Arthur (1996) on increasing returns. "Managing Complexity with System Dynamics" was the seminar title.

Meanwhile, I dealt with a large consulting project, which started as an IT diagnosis and strategy process. Surprisingly it turned out to be a full-blown tragedy of the commons—a situation in a shared-resource system where individual users act independently according to their own self-interest, behaving contrary to the common good by depleting or spoiling that resource through their collective action. I could only successfully complete the project by applying systems thinking. This experience and the collaboration with Lüthi and Schwaninger led me to orient the "Systems Thinking and Modeling" course more toward systems archetypes while maintaining Sterman's approach toward systems modeling.

The difference between familiarizing students with systems thinking was—and still is—strikingly different from teaching the concept to managers and policymakers. Students are primarily interested in understanding system dynamics and show less interest in applying that knowledge. Managers and policymakers, on the other hand, want to learn how to make better decisions and show less interest in time-consuming learning about system dynamics basics. As always, Forrester (2000) was blunt about this:

> Efforts in system dynamics have repeatedly shown the high hurdle to cross in drawing people to the dynamic viewpoint when they were already mature in established, or open-ended, or static views of their surrounding environments. Understanding dynamic behavior comes slowly. … It can take several years for a management to understand and accept the way in which their own policies are creating the problems they are experiencing.

Thus, Senge's (1990) and Kim's (1992) approach was more appealing to managers, while Sterman's (2000) approach was more helpful to students. For some time, the Beer Distribution Game and its debriefing bridged the gap between systems thinking and decision-making.

Then a publication by Meadows (1997) about "Places to intervene in a system" entered my worldview. Its impact on me was profound. It was the first publication that addressed management from a strictly system dynamics point of view. Meadows (1997) gave a vivid account how she conceived this concept:

> One day I was sitting in a meeting about the new global trade regime, NAFTA and GATT and the World Trade Organization. The more I listened, the more I began to simmer inside. "This is a huge new system people are inventing!" I said to myself. "They haven't the slightest idea how it will behave," myself said back to me. "It's cranking the system in the wrong direction—growth, growth at any price!! And the control measures these nice folks are talking about—small parameter adjustments, weak negative feedback loops—are puny!" Suddenly, without quite knowing what was happening, I got up, marched to the flip chart, tossed over a clean page, and wrote: Places to Intervene in a System.

This article and her publication on prediction and choice—Meadows (1999)—changed and inspired my thinking about what it means to manage.

While the inner journey was progressing, I also ventured into new territory. Thanks to my long-time colleague Manfred Gronalt, a professor at the University of Natural Resources and Life Sciences Vienna, I started a course for students in natural resource management. It was fascinating to experience how much easier students with a background in life sciences grasp the idea of circular causality versus students of business administration where Taylorism still lingers. Manfred Gronalt and I also started a seminar "Mastering strategic and environmental challenges with complexity management" for alumni of the University of Natural Resources and Life Sciences Vienna.

Together these seminars and courses made it necessary to overhaul the syllabi. Being a visiting professor at the ETH Zurich Department of Management, Technology and Economics for one term was the perfect opportunity. Fish Banks Ltd. Game developed by Meadows (1996) replaced the Beer Game. After all, scholars of natural resource management were much more interested in tragedy of the commons than in the bullwhip effect. Meadows' (1997) article on leverage points became mandatory reading. To Senge's (1990) systems archetypes I added Rogers' (2003) diffusion of innovations and Arthur's (1994) increasing returns to adoption. What I kept though was Sterman's (2000) rigorous approach to systems modeling.

A good way to notice if students are interested is if they want to do a thesis on the topic. Hurschler (2005) did. Her thesis on the research question if generic drugs are path-dependent exemplified how practical a good theory can be. Besides, her work clarified the close relationship between Arthur's path dependence and Senge's success to the successful.

Addressing systems thinking and complexity in natural resource management substantially broadened the idea of management. In business administration, a person who fulfills managerial tasks is typically seen as someone belonging to the upper or even top part of an organization's hierarchy. After all, the verb "manage" comes from the Italian maneggiare (to handle, especially tools or a horse), which derives from the two Latin words *manus* (hand) and *agere* (to act). Natural resource management, however, deals with managing the way in which organizations and natural resources interact. It brings together land use planning, water management, biodiversity conservation, and the sustainability of agriculture, mining, tourism, fisheries, and forestry. Such a managerial task is not embedded in a hierarchy but in a highly intertwined nonhierarchical network of independent yet, at the same time, interdependent systems. Natural resource managers who behave as if they were hierarchically above stakeholders and natural resources inevitably fail. For that reason I abandoned the pervasive concept of managers as leaders and replaced it with the concept of managers as persons who can change a system's behavior because they know (some of) its sensitive influence points.

That shift created a new difficulty. Most of what is described as problematic dynamics has to do with either too many or too few items of something in stock, too much CO_2 in the atmosphere, too little equity, too much plastic waste in oceans, and so on. Jay Forrester highlighted this truism in a plenary session at the 29th International Conference of the System Dynamics Society in Washington, DC. In his matter-of-fact way, he pointed out that if one wants to model a problematic dynamic, one has to start by identifying the problematic stocks rather than by identifying the causal loops. Forrester's small comment on someone's presentation was the singular most insightful information I took away from this conference.

Yet it was—and is—common practice to introduce first circular causality (feedback), adding later the notion of stocks and flows. The underlying assumption is that circular causality is more important and more difficult to understand than the concept of stocks and flows. Again, an important piece of experimental research helped. Booth Sweeney and Sterman (2000) and Sterman (2008) showed in their publications that even well-educated people have great difficulties in distinguishing stocks from flows. These insights were completely in line with my own teaching experience with students, managers, and policymakers alike. The situation was further complicated by the idea that stocks may cause problems, but stocks can never be changed directly. Governing stocks require controlling inflows and outflows.

The more I used the aforementioned literature with students, managers, and policymakers, the more I appreciated the paradigm shift they advocated. Yet it also dawned on me that there was a gap between the different schools of thought about dynamics of social systems. The notion of leverage points was somewhat separated from (computer) models of social systems. Stock and flows were treated separately from circular causality. Management of businesses was seen as different to policymaking and to governance. Segregation, increasing returns, and success to the successful were discussed as different phenomena. Understanding dynamics of systems, creating models of systems, and governing systems were considered as belonging to different domains of knowledge.

Therefore, I decided to write this book. My intention is to integrate the differing schools of thought wonderfully represented by Arthur (1994), Bateson (1979), Meadows (2008), Schelling (1978), Senge (1990), and Sterman (2000) into one single book for policymakers, managers, and students alike.

During the process of writing, I happened to see the movie *Arrival* that at its core is about language and how it informs thinking. In this movie based on *Story of Your Life* by Chiang (2016), aliens arrive in spaceships. The U.S. Army recruits linguist Louise and physicist Gary to communicate with the aliens. In an attempt to learn their language, Louise finds their writing to be chains of semagrams in no linear sequence and semasiographic, having no reference to speech. She discovers that when writing in it, premises and conclusions become interchangeable. She finds herself starting to think in this language and begins to see time as the aliens do.

What fascinated me about this story was the very concept of a semasiographic language and the hypothesis of linguistic relativity—the Sapir–Whorf hypothesis—which holds that linguistic categories and usage influence, thought, and decisions. It struck me that stock and flow diagrams need to be treated not just as a graphical user interface, but also as a unique semasiographic language in its own right that can be used to describe and think about dynamics of systems. This insight gave the book an additional meaning: an introduction to the semasiographic language called stock and flow diagram.

In 1159 John of Salisbury (1955) wrote:

> Bernard of Chartres used to compare us to dwarfs perched on the shoulders of giants. He pointed out that we see more and farther than our predecessors, not because we have keener vision or greater height, but because we are lifted up and borne aloft on their gigantic stature.

A dwarf perched on the shoulders of giants—that is what I am. As such I am grateful beyond words for all the giants I mentioned above—the ones whose writings I absorbed, the ones I was privileged to listen to, the ones who partnered with me to create seminars and who shared their thinking, my wife Hanna who always encouraged me to write this book, my supportive and extremely patient editor Barbara Feß, and all unnamed scholars who attended my classes and from whom I learned enormously through their struggle in understanding what I was trying to get across. Finally yet importantly, I thank Ventana Systems Inc. for generously offering its simulation software Vensim PLE free for educational use.

Enjoy and, please, let me know your experience with this book!

January 2019.

Wien, AT, EU.

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Part I

From Logic to Circular Causality

Logic can often be reversed, but the effect does not precede the cause. … What is the case is that when causal systems become circular, a change in any part of the circle can be regarded as cause for change at a later time in any variable anywhere in the circle. It thus appears that a rise in the temperature of the room can be regarded as the cause of the change in the switch of the thermostat and, alternatively, that the action of the thermostat can be regarded as controlling the temperature of the room.

Gregory Bateson