Deeply rooted in fundamental research in Mathematics and Computer Science, Cellular Automata are recognized as an intuitive modeling paradigm for Complex Systems. Very basic Cellular Automata, with extremely simple micro dynamics such as the Game of Life, show an almost endless display of complex emergent behavior. By modeling natural or man-made Complex Systems with Cellular Automata we usually dissect the system to it’s most fundamental and minimal properties and interactions, such that the simulated dynamics mimics the emergent behavior of the real Complex System, leading to a true understanding of the fundamental properties of the system under study.

For instance, Cellular Automata models of vehicle traffic are a beautiful example. A few simple rules relating to acceleration, deceleration, and maximum speed of vehicles in a one-dimensional Cellular Automata are sufficient to display all different types of motions that cars on a freeway can have (free flow, stop-and-go, jamming), as well as showing backward traveling density waves in stop-and-go traffic and reproducing the fundamental diagram of car throughput on a freeway as a function of car density.

Vice-versa, Cellular Automata can also be designed to produce a desired emergent behavior, using theoretical methodologies or using e.g. evolutionary techniques to find Cellular Automata rules that produce specified characteristics.

Cellular Automata can also actually reproduce the dynamics of Complex Systems qualitatively. For instance, Lattice Gas Cellular Automata are a class of Cellular Automata that reproduce many of the intricate dynamics in fluids. Likewise, other fundamental physical systems, such as Reaction–Diffusion or Advection–Diffusion can be qualitatively modeled. These Cellular Automata models can actually be used to predict the behavior of Complex Systems under many different circumstances. Nowadays there are many applications of Cellular Automata models in Computational Physics or – Chemistry, but also in for instance Systems Biology (e.g. models for diffusion limited gene regulatory networks).

Over the last decade or so, there has been a tremendous progress in studying Complex Systems with Cellular Automata. They are not only being used within their originating disciplines (say Physics, Computer Science, Mathematics), but are also applied in quite different disciplines such as epidemiology, immunology,
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sociology, and finance. Cellular Automata are quite successful in for instance modeling immune response after HIV infection, both the short term effects, as well as the long term effect that finally lead to the development of AIDS. Cellular Automata are also used to study the dynamics of crowds, for instance in situations where a crowd must escape from a confined space through a small door.

In this context of fast and impressive progress in the field the idea to compose this book emerged. Moreover, another experience convinced us that we should embark on this project that in the end resulted in this book. When teaching Complex Systems Simulations to Master students in the Amsterdam Master program on Computational Science, we always experience the great appeal that Cellular Automata have on the students, and we are always impressed by the deep understanding that our students – but we as well – obtain of a large range of complex systems they try to model and understand using Cellular Automata. These students come from many disciplines, as broad as the application areas of Cellular Automata mentioned earlier.

For us it became evident that an edited book focusing on all aspects of modeling Complex Systems with Cellular Automata was needed, as a welcome overview of the field for its practitioners, as well as a good starting point for detailed study on the graduate and post-graduate level. While Jiří Kroc was a visiting scientist in Amsterdam, in the period September 2007 to September 2008, the idea materialized and the “book project” went into high gear.

The book contains three parts, two major parts on theory and applications, and a smaller part on software. The theory part contains fundamental chapters on how to design and/or apply Cellular Automata for many different areas. This should give the readers a representative overview and strong background on many aspects related to modeling with Cellular Automata. In the applications part a number of representative examples of really using Cellular Automata in a large range of disciplines is presented. By providing a large set of examples, this part should give readers a good idea of the real strength of this kind of modeling and challenge them to apply Cellular Automata in their own field of study. Finally, we included a smaller section on software, to highlight the important work that has been done to create high quality problem solving environments that allow to quickly and relatively easily implement a Cellular Automata model and run simulations, both on the desktop and if needed, on High Performance Computing infrastructures.

We are very proud and happy that many prominent scientists agreed to join this project and prepared a chapter for this book. We are also very pleased to see it materialize in a way as we originally envisioned. We hope that this book will be a source of inspiration to the readers. We certainly challenge students on the graduate and post-graduate level to study this book in detail, learn from it, grasp the fundamental ideas behind modeling Complex Systems with Cellular Automata, and apply it to solve their own problems. For scientists working in many different fields we believe that this book will provide a representative state-of-the-art overview of this field. It not only shows what we can do, it also shows current gaps in our knowledge, open issues and suggestions for further study.
We wish all readers a fruitful time reading this book, and wish they experience the same excitement as we did – and still do – when using Cellular Automata for modeling complex systems.

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