7

The Future of the Science of Complex Systems?

When one considers the science of complex systems, the classical concepts immediately come to mind: algorithmic complexity, genetic algorithms and networks, fitness landscapes, econophysics, allometric scaling, network theory, self-organized criticality, and percolation. All these concepts and directions are about two decades old, or older. Since then, much progress has been made on elucidating and elaborating many of the details of these topics, and the research community has grown from a few dozen to the now hundreds who participate at conferences on complex systems. But what is new? What were the achievements of the past two decades? Or can it be that the science of complex systems was a product of the 1980s that has run out of new ideas and concepts, and is only capable of working out details? If so, is complexity science obsolete and will it be replaced by something new? What are the next steps forward? When we discussed these questions with W. Brian Arthur he offered the following picture:

> The state of complex systems is like a large army that is ready to strike. It is positioned in the countryside and confronts the other army that represents all the unsolved problems in complexity. But our army is stuck. It does not move, it stands still. What is needed is that some sally out at different points, so that the others will follow to attack the massive problems ahead.

The intention of this book was exactly this. To help prepare the way for new progress in a number of directions where we are currently stuck. In particular, we tried to make progress in the following directions:

- Clarifying the origin of scaling laws, in particular for driven non-equilibrium systems.
- Deriving the statistics of driven systems on the basis of understanding their driving and relaxation processes, and their relations.
- Categorizing probabilistic complex systems. Once we know which universality class a particular system belongs to, we know how it behaves statistically, how to identify its relevant parameters, and where its transition and breaking points might be.

Introduction to the Theory of Complex Systems. Stefan Thurner, Rudolf Hanel, and Peter Klimek, Oxford University Press (2018).
DOI: 10.1093/oso/9780198821939.001.0001

- Meaningful generalization of statistical mechanics, and information theory so that they finally become useful for complex systems.
- Unifying the many different approaches to evolution and co-evolution into a single mathematical framework.
- Developing mathematical formalisms for co-evolutionary dynamics of states and interactions.

We believe that pushing these directions will finally help to develop a more coherent theory of complex systems than we currently have. And perhaps more importantly, it will help to finally establish a coherent framework for quantifying, monitoring, and managing systemic risk, resilience, robustness, and efficiency. This might help us see what we can understand in evolution, innovation and creativity, and what we cannot understand. The emerging framework will have to be radically combined with big data sets, otherwise it will not be viable and might not survive the century.

We do not believe that the science of complex systems is obsolete. Never before has it been more urgent to understand complex systems and to be able to manage them. Never before have we been so well prepared for that job. We are entering an era where practically everything that moves on this planet, as well as everything that does not, is monitored by sensors. Quite conceivably, we will eventually record almost everything that happens—we will literally copy the planet into a virtual data world. At the same time we are producing the computational means to handle those data. What is missing are the mathematical tools, concepts, and algorithms to *make sense* of those data in a quantitative and predictive manner. Only then will the management of complex systems be possible.

Will artificial intelligence and machine learning do the job of complexity science? We do not believe that. So far, artificial intelligence and machine learning are fantastic methods for recognizing and learning patterns. But they are not yet making sense of those patterns, and are not linking them with possible underlying mechanisms and causes at various scales. They recognize and use patterns to play chess and games like 'Go', and to translate English into Chinese, but as yet, they do not perform the science of co-evolving systems.

What might happen is that complexity science will not be called 'complexity science' in the future. However, in our opinion the use of mathematics and computer and data science, in combination with a disciplinary understanding of systems, will continue to be a fascinating challenge until we understand what can be learned about complexity and what can not. The bottleneck in our opinion is the current state of the available mathematical framework and concepts. With progress in data availability and computing power, the lack of appropriate algorithms and of ways to create true understanding from data will become increasingly clear. Problems associated with complexity will keep following us for a while. Practically all systems evolve depending on their context and the context changes with the evolution of the systems. We see more and more of this in fantastically comprehensive data sets. However, our human mind is still 'bad' at understanding co-evolutionary dynamics—we need to keep sharpening our tools.

ST Vienna January 2018