Preface

It has been 60 years since the first time that a system was termed “self-organizing” in modern scientific literature.[1] During this time, the concept of self-organization developed in many directions and affected diverse fields, ranging from biology to physics to social sciences. For example, in his seminal book “At home in the Universe”, Stuart Kauffman argued that natural selection and self-organization are two complementary forces necessary for evolution: “If biologists have ignored self-organization, it is not because self-ordering is not pervasive and profound. It is because we biologists have yet to understand how to think about systems governed simultaneously by two sources of order ... if ever we are to attain a final theory in biology, we will surely, surely have to understand the commingling of self-organization and selection”.[2] A similar dilemma can be re-phrased for various fields of engineering: If engineers have ignored self-organization, it is not because self-ordering is not pervasive and profound. It is because we engineers have yet to understand how to think about systems governed simultaneously by two sources of order: traditional design and self-organization.

Without claiming an undue comprehensiveness, this book presents state-of-the-practice of self-organizing systems, and suggests a high-level breakdown of applications into two general areas:

- Distributed Management and Control;
- Self-organizing Computation.

Each of these areas is exemplified with a selection of invited contributions, written and peer-reviewed by international experts in their respective fields, convincingly demonstrating achievements of self-organizing systems. The overall selection balances many aspects: modelling vs simulation vs deployment, as well as macro- vs micro-scale.

[1] Ashby, W. R. (1947). Principles of the self-organizing dynamic system. *Journal of General Psychology*, *37*, 125–128.

[2] Kauffman, S. (1995). *At home in the Universe* (p. 112). London: Oxford University Press.

We begin with more established fields of traffic management, sensor networks, and structural health monitoring, building up towards robotic teams, solving challenging tasks and deployed in tough environments. These scenarios mostly belong to macro-level, where multiple agents (e.g, robots) themselves may contain complicated components. Nevertheless, the main topic is self-organization within a multi-agent system, brought about by interactions among the agents. The second half of the book follows with a deeper look into the micro-level, and considers local interactions between agents such as particles, cells, and neurons. These interactions lead towards self-organizing resource management, scheduling, and visualization, as well as self-modifying digital circuitry, immunocomputing, memristive excitable automata, and eventually to Artificial Life.

We believe that the broad range of scales at which self-organizing systems are applied to real-world problems is one of the most convincing arguments for acceptance of the unifying theme—practical relevance and applicability of self-organization.

The second edition revisits these studies, providing concise summaries of the research during the last 5 years (the chapter "epilogues"), while offering new extensions for several important works. These extensions cover a diverse field, including a distributed thermal protection system for a spacecraft re-entering the atmosphere; self-configuring analog (Songline) processors; ad-hoc multi-robot systems with decentralized control; memristive cellular automata applicable to spintronic devices, neuromorphic circuits, and programmable electronics.

The progress demonstrated by the applied self-organizing systems that were developed in the last years is encouraging. An important general trend that emerged in the area since the first edition is *Guided Self-Organization* (GSO): an approach leveraging the strengths of self-organization while directing the outcome of the self-organizing process towards some specific goals. The approach builds up on earlier ideas of "design for emergence" and "emergent functionality" (as Luc Steels called it in late 1980s), aiming to provide a formal framework for studying and designing GSO systems. Equipped with such a unifying framework, designers may hope not only to produce the systems quicker and more reliably, but also to precisely verify and validate eventual performance of the outcomes—the key prerequisite to a wide-range adoption of self-organizing applications.

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April 2007 (first edition)
January 2013 (second edition)

http://www.springer.com/978-1-4471-5112-8

Advances in Applied Self-Organizing Systems
Prokopenko, M. (Ed.)
2013, X, 426 p., Hardcover
ISBN: 978-1-4471-5112-8