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Sven A. Brueckner
Giovanna Di Marzo Serugendo
Anthony Karageorgos
Radhika Nagpal (Eds.)

Engineering Self-Organising Systems

Methodologies and Applications

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Series Editors

Jaime G. Carbonell, Carnegie Mellon University, Pittsburgh, PA, USA
Jörg Siekmann, University of Saarland, Saarbrücken, Germany

Volume Editors

Sven A. Brueckner
Altarum Institute
3520 Green Court, Suite 300, Ann Arbor, MI 48105-1579, USA
E-mail: sven.brueckner@altarum.org

Giovanna Di Marzo Serugendo
University of Geneva, Centre Universitaire d'Informatique
24 rue Général-Dufour, 1211 Geneva 4, Switzerland
E-mail: Giovanna.Dimarzo@cui.unige.ch

Anthony Karageorgos
University of Thessaly, Department of Computer and Communication Engineering
37 Glavani - 28th October Str., Deligiorgi Building, 4th floor, room D3/4
382 21 Volos, Greece
E-mail: karageorgos@computer.org

Radhika Nagpal
Harvard University, Division of Engineering and Applied Sciences
Computer Science Dept., 235 Maxwell Dworkin, 33 Oxford Street, Cambridge
MA 02138, USA
E-mail: rad@eecs.harvard.edu

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Preface

The spread of the Internet, mobile communications and the proliferation of new market models, such as e-commerce, has resulted in the whole information infrastructure operating as a global dynamic system. The complexity and the inherent dynamism of the resulting global system require software capable of autonomously changing its structure and functionality to meet dynamic changes in the requirements and the environment without immediate human intervention. In particular, contemporary software applications must provide highly customised services to a huge user population by dynamically adapting to personal requirements. Furthermore, new maintenance approaches need to be followed, for example continuously running software should evolve on run-time to meet ever-changing user requirements. Finally, new ways for handling exceptions and component failure and replacement, as well as changes in the environment are required, for example as is the case in networks including large numbers of smart computing entities, such as ad hoc sensors and MEMs devices. In large interconnected software systems such tasks cannot be achieved by approaches involving direct supervision and centralised management.

A way to meet requirements of this kind is to utilise the emergent properties of distributed interacting software referring to concepts such as self-organisation, self-regulation, self-repair and self-maintenance. However, in artificial systems, environmental pressures and local interactions and control may lead to unpredicted or undesirable behaviour. Understanding how to engineer the correct self-organising behaviour is thus an issue of major concern.

Self-organising applications (SOAs) are able to dynamically change their functionality and structure without direct user intervention to meet changes in requirements and their environment. The overall functionality delivered by SOAs typically changes progressively, mainly in a nonlinear fashion, until it reaches (emerges to) a state where it satisfies the system requirements at the time, and therefore it is termed *self-organising* or *emergent* behaviour. Self-organising behaviour is often the result of the execution of a number of individual application components that locally interact with each other aiming to achieve their local goals, for example systems that are based on agents or distributed objects. The main characteristic of such systems is their ability to achieve complex collective tasks with relatively simple individual behaviours, without central or hierarchical control.

A major open issue is therefore how to engineer desirable self-organising behaviour in SOAs and how to avoid undesirable ones, given the requirements and the application environment. To address this issue, approaches originating from diverse areas such as nonlinear optimisation, knowledge-based programming and constraint problem solving are currently being explored. Furthermore, SOA engineers often take inspiration from the real world, for example from biol-

ogy, chemistry, sociology and the physical world. Typical examples of SOAs are systems that reproduce socially based insect behaviour, such as ant-based systems, artificial life, or robots. Although the results achieved so far are promising, further work is required until the problem is sufficiently addressed.

This book is complementary to a sister volume published in 2003, which aimed at establishing the field of *Engineering Self-organising Systems* and it focused on the foundations of self-organising systems. This year the emphasis is on methodological aspects and on applications of self-organising approaches. The book comprises revised versions of papers presented at the Engineering Self-organising Applications (ESOA 2004) workshop, held during the Autonomous Agents and Multi-agent Systems conference (AAMAS 2004) in New York in July 2004, and selected invited papers from leading contributors in the self-organisation field.

Part I contains three papers related to state of the art of self-organising systems. Wolf and Holvoet review historical definitions of the terms self-organisation and emergence and provide new aggregated definitions of each term supported by examples. Subsequently, Bar Yam demonstrates the limitations of decomposition-based engineering for the development of highly complex systems using multi-scale analysis. Ulieru then discusses the characteristics of adaptive information infrastructures and their role in human/machine and hardware/software integration.

In Part II approaches to designing self-organising systems are presented. d'Inverno and Saunders provide a mathematical formalisation and discuss the advantages of using an agent-based approach to develop biologically plausible models of stem cell systems in the context of a case study. Subsequently, Bour et al. address the issue of the creation of visual ambiences based on the coordinated activity of tiny computing entities distributed randomly on a 2D canvas that can only change their own color and perceive their immediate neighbors. Edmonds argues on the use of adaptive approaches producing reliable self-organised software systems. The argument is supported by defining a class of simple multi-agent systems and showing that it can be evolved to perform simple tasks. Nowostawski et al. then propose an evolutionary computation model based on the theory of hypercycles and autopoiesis. Subsequently, Hales discusses the use of tag dynamics to realize adaptive node behaviour in P2P systems (selfish vs. altruistic) based on results of P2P simulations.

Part III describes applications of self-organisation in self-assembly and robotic systems. Mamei et al. present self-organising spatial shapes in mobile particles with minimal capabilities. Poulton et al. discuss a method for directed self-assembly of 2-dimensional mesoblocks using top-down/bottom-up design. Subsequently, Galstyan et al. present a stochastic model for adaptive task allocation in robots. Finally, White and Helferty discuss the application of division-of-labor principles to achieve emergent team formation in robot soccer.

In Part IV self-organisation models based on the use of stigmergy are discussed. Parunak and Brueckner discuss stigmergic learning for self-organising mobile ad hoc networks (MANETs). Karuna et al. propose a stigmergy-based

approach for emergent forecasting in manufacturing coordination and control. Subsequently, Foukia takes inspiration from natural systems and proposes a self-organising approach for intrusion detction and response in networks. Along a similar line, Armetta et al. describe a self-organising model for managing dynamic flow in production chains.

Part V concludes the book with industrial applications of self-organising systems. Lauterbach et al. describe self-organisation and fault-tolerance issues in a wired peer-to-peer sensor network for textile applications. Subsequently, Brueckner and Gerth discuss the application of distributed adaptive optimisation techniques to digital car-body development. Finally, Graupner et al. propose adaptive service placement algorithms for autonomous service networks.

We are grateful to the Programme Committee of the ESOA 2004 workshop for their timely reviews, and their useful suggestions on improving the workshop. All papers submitted to the workshop were reviewed by three members of the Programme Committee.

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Sven Brueckner, Giovanna Di Marzo Serugendo
Anthony Karageorgos, Radhika Nagpal

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