Birkhäuser

Autonomic Systems

Series Editors:
Frances M.T. Brazier (TU Delft, Delft, The Netherlands)
Omer F. Rana (Cardiff University, Cardiff, UK)
John C. Strassner (POSTECH, Pohang, South Korea)

Editorial Board
Richard Anthony (University of Greenwich, UK)
Vinny Cahill (Trinity College Dublin, Ireland)
Monique Calisti (Martel GmbH, Switzerland)
Simon Dobson (University of St. Andrews, UK)
Joel Fleck (Hewlett-Packard, Palo Alto, USA)
José Fortes (University of Florida, USA)
Salim Hariri (University of Arizona, USA)
Jeff Kephart (IBM Thomas J. Watson Research Center, Hawthorne, USA)
Manish Parashar (Rutgers University, New Jersey, USA)
Katia Sycara (Carnegie Mellon University, Pittsburgh, USA)
Sven van der Meer (Waterford Institute of Technology, Ireland)
James Won-Ki Hong (Pohang University, South Korea)

The Autonomic Systems series aims at creating a platform of communication between universities and industry by publishing research monographs, outstanding PhD theses, and peer reviewed compiled contributions on the latest developments in the field. It covers a broad range of topics from the theory of autonomic systems that are researched by academia and industry. Hence, cutting-edge research, prototypical case studies, as well as industrial applications are in the focus of this series. Fast reviewing provides a most convenient way to publish latest results in this rapid moving research area.

More information about this series at http://www.springer.com/series/8123

Christian Müller-Schloer • Sven Tomforde

Organic Computing – Technical Systems for Survival in the Real World

Birkhäuser

Christian Müller-Schloer
Institute of Systems Engineering
Leibniz Universität Hannover
Hannover
Germany

Sven Tomforde
Intelligent Embedded Systems Group
Universität Kassel
Kassel
Germany

Autonomic Systems
ISBN 978-3-319-68476-5 ISBN 978-3-319-68477-2 (eBook)
https://doi.org/10.1007/978-3-319-68477-2

Library of Congress Control Number: 2017955542

© Springer International Publishing AG 2017
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Printed on acid-free paper

This book is published under the trade name Birkhäuser, www.birkhauser-science.com
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Verum quia factum
Giambattista Vico
1668–1774

Foreword

The world is experiencing a fundamental transformation due to the tremendous development of information and communication technologies. As almost every area of our society and our economy gets affected by "digitalisation", the digital infrastructure is considered meanwhile to be one of our critical assets which are key to societal and economic competitiveness and well-being. Anticipating this development, industrial and research communities worldwide have initiated research and development programmes in order to be able to cope with new challenges arising from the technical innovation. In particular, at the beginning of this century, the Community of Computer Engineering within the German Informatics Society identified the need for new system architectures and computational methods in order to deal with the emerging multitude of interacting intelligent devices which will have to provide essential functionality in various technical application areas. This resulted in the national research programme on "Organic Computing" funded by the German Research Foundation from 2005 to 2011 as one of its priority programmes. While further closely related initiatives such as "Cyber-physical Systems" or "Industrie 4.0" emphasise the influence of information and communication technologies on classical engineering of technical application systems, the Organic Computing Initiative focuses on the need for system architectures and methodologies that enable the combined presence of autonomy and controlled self-organisation, allowing for an "organic" adaptation of the system behaviour to changing requirements of its operating environment while providing appropriate interfaces for potentially necessary controlled interaction with human users or other entities on higher system levels.

It has been a privilege to have been able to shape this fascinating new branch of science in close cooperation with many colleagues. After major results of the priority programme have been published as a large compendium on *Organic Computing—A Paradigm Shift for Complex Systems*, the present book on *Organic Computing—Technical Systems for Survival in the Real World* combines the content of courses at the universities of Augsburg, Hannover, and Kassel into a comprehensive textbook, providing an excellent introduction into system technologies that are of highest relevance for coping with the inherent technological challenges of digitalisation.

Karlsruhe, Germany Hartmut Schmeck
July 2017

Preface

So far, Organic Computing (OC) literature has been published with the OC researcher in mind. Although the existing books have tried to follow a didactical concept, they remain collections of scientific papers. A comprehensive and systematic account of the OC achievements in the form of a textbook, which lends itself to the newcomer in this field, has been missing so far. When we conceived this book we had primarily our master students in mind. The content has been compiled from several lectures in Organic Computing held at the Leibniz Universität Hannover, the University of Augsburg, and the University of Kassel.

OC is a systems science, i.e. it deals with the problem of integrating certain component techniques into a coherent whole. OC is interested in the overall architecture of technical systems able to survive in the real world. Critics might claim that OC is nothing but integration with the component techniques being investigated in the respective special fields. Hence OC—as all the other systems sciences as well—somehow vanishes in between. We are convinced, however, that in addition to the traditional analytical and specialist approach the aspect of integration will become more important as we enter the era of mega-complex systems. A classical divide-and-conquer approach will not suffice when we have to deal with semi-autonomous sub-systems with each of these systems consisting of thousands of sub-systems again. The only system we know of that apparently has solved this problem is life—and the key ability of living systems is embodied in their holonic character. This is why we strive to understand some construction principles of living systems in order to apply it to our technical systems.

In this book, we first try to convey to the reader a feeling of the special character of natural and technical self-organising and adaptive systems through a large number of examples. Then we discuss quantitative aspects of such forms of organisation, and finally, we turn to methods of how to build such systems for practical applications. We realise that the very active area of self-organising adaptive systems is larger than what we could accommodate in this book. We have at least briefly characterised some neighbouring research fields in the chapter on *The Major Context*. In general, the selection of topics followed the didactical concept adopted in our OC lectures.

We do apologise for having left out many relevant ideas and techniques due to space restrictions.

Most of the content of this book has been published before somewhere else. The original literature is referenced in the text, especially in the *Further Reading* section at the end of each chapter. The material has been rearranged for this book, enriched with materials from the lecture slides, and the nomenclature has been unified.

How to Read This Book

The target reader of this book is the master student in Computer Science, Computer Engineering, or Electrical Engineering—or any other newcomer to the field of Organic Computing with some technical or Computer Science background. Readers can seek access to OC ideas from different perspectives: OC can be viewed (1) as a "philosophy" of adaptive and self-organising—life-like—technical systems, (2) as an approach to a more quantitative and formal understanding of such systems, and finally, (3) as a construction method for the practitioner who wants to build such systems. In order to support these different perspectives, reading styles, and depths of penetration, we have preceded the chapters and major sections with "About this chapter" boxes. They are meant as a quick orientation as to "*Why*" this chapter is needed in the context of the book, "*What*" the content is, and "*Who*" is recommended to read it.

Recommendations for *Further Reading* are given at the end of each chapter.

We have decided to list the references at the end of each chapter. While this leads to possibly multiple citations of some papers, it provides more locality and a closer relationship of the references within the context of the single chapters.

Excellence is the result of extensive corrections! We have taken utmost care to eliminate errors, typos, and other mistakes—as far as possible. But there will be, no doubt, more. We appreciate your feedback at cms@sra.uni-hannover.de and stomforde@uni-kassel.de.

Hannover, Germany — Christian Müller-Schloer
Kassel, Germany — Sven Tomforde
August 2017

Acknowledgements

Already in the 1980s, one of the authors (Christian Müller-Schloer) has been exposed to the ideas of system theory (von Bertalanffy), the concept of holons (Arthur Köstler), nature-inspired optimisation, and adaptivity of technical systems. He wants to thank Prof. Dr. Franz Pichler from the Lehrstuhl für Systemtheorie at Johannes Kepler University in Linz, Austria, for first hints and discussions in this direction. A first research grant on “Adaptive Systems” was made possible in 1991 by Prof. Dr. Heinz Schwärtzel, then head of Siemens Corporate Laboratories for software technologies.

We want to explicitly acknowledge the groundbreaking work of Prof. Dr. Hartmut Schmeck (Karlsruhe Institute of Technology), Prof. Dr. Theo Ungerer (University of Augsburg), and Prof. Dr. Wolfgang Reif (University of Augsburg) who, together with the authors of this book, have been key in developing the basic concepts as presented here in this textbook.

Without the long-term financial support of the German Research Foundation (Deutsche Forschungsgemeinschaft—DFG) especially during the Special Priority Programme “Organic Computing” and the follow-up Research Unit OC TRUST, we would not have been able to conduct the research which finally has made possible this book.

We also want to thank all the supporting hands who helped to realise this book: Sebastian Niemann has led the editorial office, Monika Lorenz took care of the references, and Yazhou Wang transferred the raw text into TeX.

Hannover, Germany — Christian Müller-Schloer
Kassel, Germany — Sven Tomforde
August 2017

Contributors

The main part of this book has been written by Christian Müller-Schloer and Sven Tomforde. The authors are specially indebted to invaluable contributions by Ada Diaconescu in the promising field of “Holonic Systems”. The chapters on “Basic Technologies” and “Applications” have been written by contributing authors listed in the following. Bernhard Sick has provided the “Outlook” chapter. We want to thank all the contributors for the smooth cooperation.

	Last name	First name	Email	Affiliation
Section 2.2.5	Brueckner	Sven	sven.brueckner@axonai.com	Axon AI Inc., Harrisonburg USA
	Parunak	Van	van.parunak@gmail.com	ABC Research, LLC, Ann Arbor, USA
Section 3.3	Diaconescu	Ada	ada.diaconescu@telecom-paristech.fr	INFRES—Télécom ParisTech LTCI, IMT
Section 5.3	Diaconescu	Ada	ada.diaconescu@telecom-paristech.fr	INFRES—Télécom ParisTech LTCI, IMT
Section 7.1	Stein	Anthony	anthony.stein@informatik.uni-augsburg.de	Universität Augsburg, Institut für Informatik / OC
Section 7.2	Sick	Bernhard	bsick@uni-kassel.de	Universität Kassel, Intelligent Embedded Systems
	Gruhl	Christian	cgruhl@uni-kassel.de	Universität Kassel, Intelligent Embedded Systems
Section 7.3	Niemann	Sebastian	niemann@sra.uni-hannover.de	Leibniz Universität Hannover, SRA
Section 7.4	Rudolph	Stefan	stefan.rudolph@informatik.uni-augsburg.de	Universität Augsburg, Institut für Informatik / OC
Section 7.5	Edenhofer	Sarah	sarah.edenhofer@informatik.uni-augsburg.de	Universität Augsburg, Institut für Informatik / OC
Section 8.3	Anders	Gerrit	anders@informatik.uni-augsburg.de	Universität Augsburg, ISSE
	Reif	Wolfgang	reif@informatik.uni-augsburg.de	Universität Augsburg, ISSE
Section 8.4	Hähner	Jörg	joerg.haehner@informatik.uni-augsburg.de	Universität Augsburg, Institut für Informatik / OC
Section 8.5	Kantert	Jan	kantert@sra.uni-hannover.de	Leibniz Universität Hannover, SRA
Section 8.6	Niemann	Sebastian	niemann@sra.uni-hannover.de	Leibniz Universität Hannover, SRA
Section 8.7	von Mammen	Sebastian	sebastian.von.mammen@uni-wuerzburg.de	Universität Würzburg/Games Engineering
	Hamann	Heiko	hamann@iti.uni-luebeck.de	Universität zu Lübeck, Service Robotics
Chapter 10	Sick	Bernhard	bsick@uni-kassel.de	Universität Kassel, Intelligent Embedded Systems

Review Team

The first version of the book was looked through and corrected by a team of reviewers familiar with the topic of Organic Computing. We thank all of them for their effort.

	Last name	First name	Affiliation
Dr.	Bellman	Kirstie	The Aerospace Corporation
Prof. Dr.	Hähner	Jörg	Universität Augsburg
Prof. Dr.	Hoffmann	Martin	Fachhochschule Bielefeld
Prof. Dr.	Karl	Wolfgang	KIT Karlsruhe Institute of Technology
Dr.	Landauer	Chris	The Aerospace Corporation
Prof. Dr.	Maehle	Erik	Universität zu Lübeck
Dr.	Seebach	Hella	Universität Augsburg
Prof. Dr.	Sick	Bernhard	Universität Kassel
M. Sc.	Stein	Anthony	Universität Augsburg
Prof. Dr.	Ungerer	Theo	Universität Augsburg
Prof. Dr.	von Mammen	Sebastian	Universität Würzburg
Prof. Dr.	Wacker	Arno	Universität Kassel
Prof. Dr.	Wanka	Rolf	Friedrich-Alexander-Universität Erlangen-Nürnberg
Dr.	Wildermann	Stefan	Friedrich-Alexander-Universität Erlangen-Nürnberg
Dr.	Würtz	Rolf	Ruhr-Universität Bochum

Acronyms

2SND	Two-Stage Novelty Detector
AC	Autonomic Computing
ACL	Agent Communication Language
ADRA	Adaptive Distributed Resource Allocation Scheme
AIC	Algorithmic Information Complexity
AIDA	Asteroid Impact and Deflection Assessment
AL	Active Learning
AVPP	Autonomous Virtual Power Plant
BBA	Bucket Brigade Algorithm
BDI	Belief-Desire-Intention
BOINC	Berkeley Open Infrastructure for Network Computing
BURP	Big and Ugly Rendering Project
CA	Cellular Automaton
CAS	Collective Adaptive System
CCM	CORBA Component Model
CCN	Cooperating Camera Networks
CCW	Counter-clockwise
CFP	Call for Proposals
CM	Control Mechanism
CMA-ES	Covariance Matrix Adaptation Evolution Strategy
CMM	Classifier based on a Gaussian Mixture Model
CNLS	Center for Non-Linear Studies
COS	Component-Oriented Software
CW	Clockwise
DCOP	Distributed Constraint Optimisation Problem
DER	Distributed energy resource
DFG	Deutsche Forschungsgemeinschaft, German Science Foundation
DMCtrac	Distributed Multi-Camera Tracking
DoS	Denial of Service
DPSS	Decentralised Progressive Signal System
DRG	Dynamic Route Guidance

DVR	Distance Vector Routing
EA	Evolutionary Algorithm
EML	Evolutionary Machine Learning
ES	Evolutionary Strategy
ESA	European Space Agency
eTC	Explicit Trust Community
FIPA	Foundation for Intelligent Physical Agents
FOV	Field of view
FPGA	Field Programmable Gate Array
GA	Genetic Algorithm
GBML	Genetics-based Machine Learning
GMM	Gaussian Mixture Model
GNC	Guidance Navigation and Control
GoT	Goal-oriented Thing
GoTT	Goal-oriented Thing of Things
GPS	Global Positioning System
GTOC	Global Trajectory Optimisation Competition
HC	Hill Climbing
HDR	High-Density Region
HPSS	Hierarchical Progressive Signal System
IC	Integrated Circuit
ICT	Information and Communication Technology
IDS	Intrusion Detection System
IOT	Internet-of-Things
IP	Internet Protocol
ISO	International Organisation for Standardisation
iTC	Implicit Trust Community
JPL	NASA Jet Propulsion Laboratory
KB	Knowledge Base
KQML	Knowledge Query and Manipulation Language
LCS	Learning Classifier System
LDR	Low-Density Region
LSR	Link State Routing
MAC	Media Access Control
MAD	Mean Absolute Deviation
MAM	Moyenne Adaptive Modifiée
MANet	Mobile Ad-hoc Network
MAS	Multi-agent System
MDP	Markov Decision Process
MLOC	Multi-layer Organic Computing
NASA	National Aeronautics and Space Administration
NEB	Negative Emergent Behaviour
NM	Norm Manager
nTC	Normative Trust Community
O/C	Observer/Controller

OBR	Ordered Bound Representation
OC	Organic Computing
OC-MDP	Organic Computing Meta Design Process
ODE	Ordinary Differential Equation
ODS	Open Distributed Systems
OF	Objective Function
ONC	Organic Network Control
OOP	Object-Oriented Programming
OTC	Organic Traffic Control
P2P	Peer-to-Peer
PA	Prediction Array
PAC	Proactive Computing
PAL	Pool-based Active Learning
PC	Pervasive Computing
PDR	Packet Delivery Rate
PKM	Parallel Kinematic Mechanism
PM	Problem Manager
POMDP	Partially Observable Markov Decision Process
PSO	Particle Swarm Optimisation
PSS	Progressive Signal System
PTZ	Pan/Tilt/Zoom
R-BCast	Reliable Broadcast
RC	Routing Component
RFC	Request for Comments
RM	Regional Manager
RPL	Routing Protocol for Lossy and Low Power Networks
RTL	Register transfer level
SA	Simulated Annealing
SAL	Stream-based Active Learning
SAOS	Self-Optimisation in Autonomic and Organic Computing Systems
SASO	Self-Adaptive and Self-Organising Systems
SAT	Boolean SATisfiability Problem
SC	Smart Camera
SO	Self-organisation
SOA	Service-Oriented Architecture
SOC	Self-organised criticality
SOTL	Self-organising Traffic Lights
SuOC	System under Observation and Control
TC	Trust Community
TCM	Trust Community Manager
TCP	Transmission Control Protocol
TDG	Trusted Desktop Grid
TLC	Traffic Light Controller
TRB	Terminating Reliable Broadcast
TS	Tabu Search

TSP	Travelling Salesman Problem
TTL	TimeToLive-value
UBR	Unordered Bound Representation
UC	Ubiquitous Computing
URL	Unified Resource Locators
VMS	Variable Message Sign
VPP	Virtual Power Plant
WB	Well-behaving
WSN	Wireless Sensor Networks
XCS	eXtended Classifier System
XCSF	Extended Classifier System for Function Approximation
XCS-O/C	Extended Classifier System integrated into the Observer/Controller architecture
XCSR	Extended Classifier System for Real Valued Input
ZCS	Zeroth-level Classifier System

Contents