Springer Handbook of Computational Intelligence

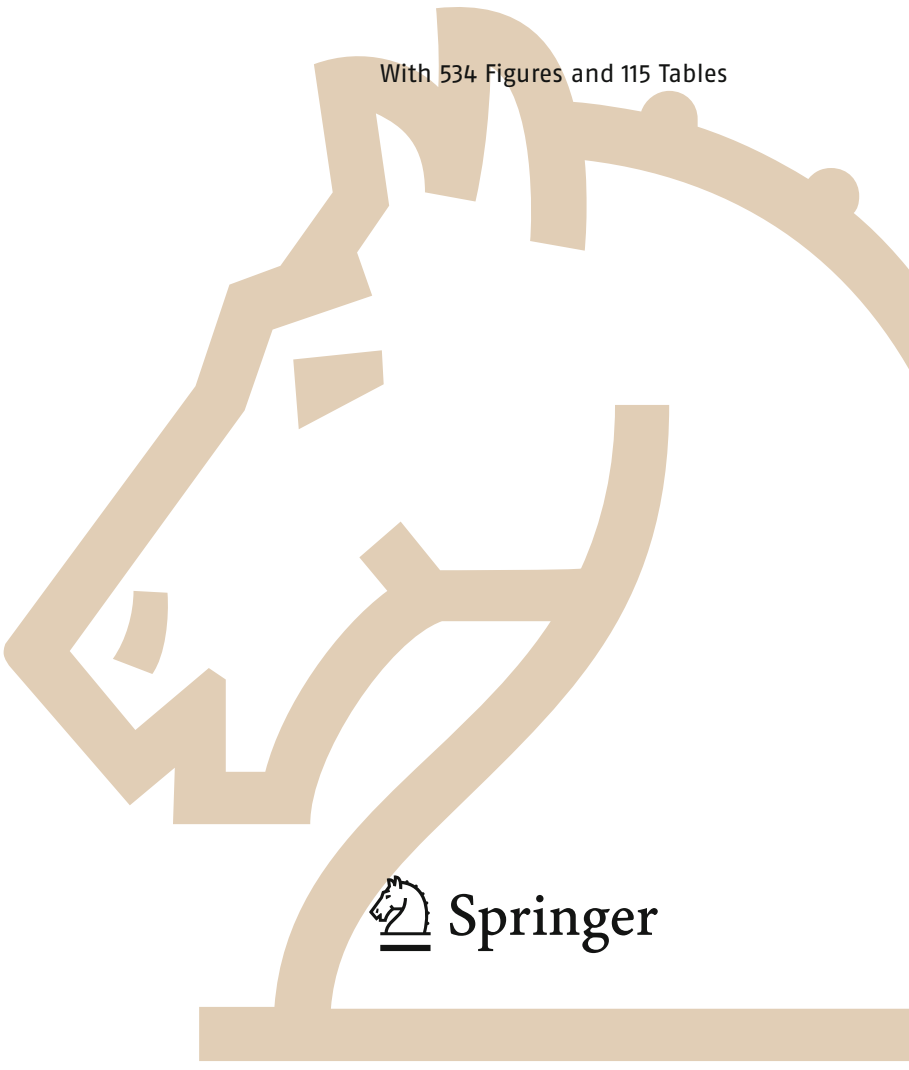
Springer Handbooks provide a concise compilation of approved key information on methods of research, general principles, and functional relationships in physical and applied sciences. The world's leading experts in the fields of physics and engineering will be assigned by one or several renowned editors to write the chapters comprising each volume. The content is selected by these experts from Springer sources (books, journals, online content) and other systematic and approved recent publications of scientific and technical information.

The volumes are designed to be useful as readable desk reference book to give a fast and comprehensive overview and easy retrieval of essential reliable key information, including tables, graphs, and bibliographies. References to extensive sources are provided.

Springer Handbook of Computational Intelligence

Janusz Kacprzyk, Witold Pedrycz (Eds.)

With 534 Figures and 115 Tables



Springer

Editors
Janusz Kacprzyk
Polish Academy of Sciences
Systems Research Inst.
ul. Newelska 6
01-447 Warsaw, Poland
kacprzyk@ibspan.waw.pl

Witold Pedrycz
University of Alberta
Dep. Electrical and Computer Engineering
116 Street 9107
T6J 2V4, Edmonton, Alberta, Canada
wpedrycz@ualberta.ca

ISBN: 978-3-662-43504-5 e-ISBN: 978-3-662-43505-2
DOI 10.1007/978-3-662-43505-2
Springer Dordrecht Heidelberg London New York

Library of Congress Control Number: 2015936335

© Springer-Verlag Berlin Heidelberg 2015
This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer. Violations are liable to prosecution under the German Copyright Law.
The use of general descriptive names, registered names, trademarks, 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.

Production and typesetting: le-tex publishing services GmbH, Leipzig
Senior Manager Springer Handbook: Dr. W. Skolaut, Heidelberg
Typography and layout: schreiberVIS, Seeheim
Illustrations: Hippmann GbR, Schwarzenbruck
Cover design: eStudio Calamar Steinen, Barcelona
Cover production: WMXDesign GmbH, Heidelberg
Printing and binding: Printer Trento s.r.l., Trento

Printed on acid free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

We are honored and happy to be able to make available this *Springer Handbook of Computational Intelligence*, a large and comprehensive account of both the state-of-the-art of the research discipline, complemented with some historical remarks, main challenges, and perspectives of the future. To follow a predominant tradition, we have divided this Springer Handbook into parts that correspond to main fields that are meant to constitute the area of computational intelligence, that is, fuzzy sets theory and fuzzy logic, rough sets, evolutionary computation, neural networks, hybrid approaches and systems, all of them complemented with a thorough coverage of some foundational issues, methodologies, tools, and techniques.

We hope that the handbook will serve as an indispensable and useful source of information for all readers interested in both the theory and various applications of computational intelligence. The formula of the Springer Handbook as a convenient single-volume publication project should help the potential readers find a proper tool or technique for solving their problems just by simply browsing through a clearly composed and well-indexed contents. The authors of the particular chapters, who are the best known specialists in their respective fields worldwide, are the best assurance for the handbook to serve as an excellent and timely reference.

On behalf of the entire computational intelligence community, we wish to express sincere thanks, first of all, to the Part Editors responsible for the scope, authors, and composition of the particular parts for their great job to arrange the most appropriate topics, their coverage, and identify expert authors. Second, we wish to thank all the authors for their great contributions in the sense of clarity, comprehensiveness, novelty, vision, and – above all – understanding of the real needs of readers of diverse interests.

All that efforts would not end up with the success without a total and multifaceted publisher's dedication and support. We wish to thank very much Dr. Werner Skolaut, Ms. Constanze Ober, and their collaborators from Springer, Heidelberg, and le-tex publishing GmbH, Leipzig, respectively, for their extremely effective and efficient handling of this huge and difficult project.

September 2014

Janusz Kacprzyk — Warsaw

Witold Pedrycz — Edmonton

About the Editors

Janusz Kacprzyk graduated from the Department of Electronics, Warsaw University of Technology, Poland with an MSc in Automatic Control, a PhD in Systems Analysis and a DSc (*Habilitation*) in Computer Science from the Polish Academy of Sciences. He is Professor of Computer Science at the Systems Research Institute, Polish Academy of Sciences, Professor of Computerized Management Systems at WIT – Warsaw School of Information Technology, and Professor of Automatic Control at PIAP – Industrial Institute of Automation and Measurements, in Warsaw, Poland, and Department of Electrical and Computer Engineering, Cracow University of Technology, Poland. He is the author of 5 books, (co)editor of ca. 70 volumes, (co)author of ca. 500 papers. He is Editor-in-Chief of 6 book series and of 2 journals, and on the Editorial Boards of more than 40 journals.

Witold Pedrycz is a Professor and Canada Research Chair (CRC) in Computational Intelligence in the Department of Electrical and Computer Engineering, University of Alberta, Edmonton, Canada. He is also with the Systems Research Institute of the Polish Academy of Sciences, Warsaw. He also holds an appointment of special professorship in the School of Computer Science, University of Nottingham, UK. His main research directions involve computational intelligence, fuzzy modeling and granular computing, knowledge discovery and data mining, fuzzy control, pattern recognition, knowledge-based neural networks, relational computing, and software engineering. He has published numerous papers and is the author of 15 research monographs covering various aspects of computational intelligence, data mining, and software engineering. He currently serves as an Associate Editor of IEEE Transactions on Fuzzy Systems and is a member of a number of Editorial Boards of other international journals.

About the Part Editors

Cesare Alippi

Politecnico di Milano
Dip. Elettronica, Informazione e Ingegneria
20133 Milano, Italy
alippi@elet.polimi.it

Part D

Cesare Alippi received his PhD in 1995 from Politecnico di Milano, Italy. Currently, he is Professor at the same institution. He has been a visiting researcher at UCL (UK), MIT (USA), ESPCI (F), CASIA (RC), USI (CH). Alippi is an IEEE Fellow, Vice-President Education of the IEEE Computational Intelligence Society, Associate Editor of the IEEE Computational Intelligence Magazine, Past Editor of the IEEE-TIM and IEEE-TNN(LS). In 2004 he received the IEEE Instrumentation and Measurement Society Young Engineer Award and in 2013 the IBM Faculty Award. His current research focuses on learning in non-stationary environments and intelligence for embedded systems. He holds 5 patents, has published 1 monograph book, 6 edited books and about 200 papers in international journals and conference proceedings.

Thomas Bartz-Beielstein

Cologne University of Applied Sciences
Faculty of Computer Science and Engineering Science
51643 Gummersbach, Germany
thomas.bartz-beielstein@fh-koeln.de

Part E

Thomas Bartz-Beielstein is a Professor of Applied Mathematics at Cologne University of Applied Sciences (CUAS). His expertise lies in optimization, simulation, and statistical analysis of complex real-world problems. He has more than 100 publications on computational intelligence, optimization, simulation, and experimental research. He has been on the program committees of several international conferences and organizes the prestigious track *Evolutionary Computation in Practice* at GECCO. His books on experimental research are considered as milestones in this emerging field. He is speaker of the research center *Computational Intelligence plus* at CUAS and head of the SPOTSeven team.

Christian Blum

University of the Basque Country
Dep. Computer Science and Artificial Intelligence
20018 San Sebastian, Spain
christian.blum@ehu.es

Part F

Christian Blum holds a Master's Degree in Mathematics (1998) from the University of Kaiserslautern, Germany, and a PhD degree in Applied Sciencies (2004) from the Free University of Brussels, Belgium. He currently occupies a permanent post as Ikerbasque Research Professor at the University of the Basque Country, San Sebastian, Spain. His research interests include the development of swarm intelligence techniques and the combination of metaheuristics with exact approaches for solving difficult optimization problems. So far he has co-authored about 150 research papers.

Oscar Castillo

Tijuana Institute of Technology
22379 Tijuana, Mexico
ocastillo@tectijuana.mx

Part G

Oscar Castillo holds the Doctor in Science degree in Computer Science from the Polish Academy of Sciences. He is a Professor of Computer Science in the Graduate Division, Tijuana Institute of Technology, Tijuana, Mexico. In addition, he serves as Research Director of Computer Science. Currently, he is Vice-President of HAFSA (Hispanic American Fuzzy Systems Association) and served as President of IFSA (International Fuzzy Systems Association). He belongs to the Mexican Research System with level II and is also a member of NAFIPS, IFSA, and IEEE. His research interests are in type-2 fuzzy logic, fuzzy control, and neuro-fuzzy and genetic-fuzzy hybrid approaches.

Carlos A. Coello Coello

CINVESTAV-IPN
Dep. Computación
D.F. 07300, México, Mexico
ccoello@cs.cinvestav.mx

Part E

Carlos A. Coello Coello received a PhD in Computer Science from Tulane University in 1996. He has made pioneering contributions to the research area currently known as evolutionary multi-objective optimization, mainly regarding the development of new algorithms. He is currently Professor at the Computer Science Department of CINVESTAV-IPN (Mexico City, México). He has co-authored more than 350 publications (his h-index is 62). He is Associate Editor of several journals, including *IEEE Transactions on Evolutionary Computation* and *Evolutionary Computation*. He has received Mexico's National Medal of Science in *Exact Sciences* and the IEEE Kiyo Tomiyasu Award. He is also an IEEE Fellow.

Bernard De Baets

Ghent University
Dep. Mathematical Modelling, Statistics and Bioinformatics
9000 Ghent, Belgium
bernard.debaets@ugent.be

Part A

Bernard De Baets (1966) holds an MSc degree in Mathematics, a postgraduate degree in Knowledge Technology, and a PhD degree in Mathematics. He is a full professor at UGent (Belgium), where he leads KERMIT, an interdisciplinary team in mathematical modeling, having delivered 50 PhD graduates to date. His bibliography comprises nearly 400 journal papers, 60 book chapters, and 300 conference contributions. He acts as Co-Editor-in-Chief (2007) of Fuzzy Sets and Systems. He is a recipient of a Government of Canada Award, Honorary Professor of Budapest Tech (Hungary), Fellow of the International Fuzzy Systems Association, and has been nominated for the Ghent University Prometheus Award for Research.

Roderich Groß

University of Sheffield
Dep. Automatic Control and Systems Engineering
Sheffield, S1 3JD, UK
r.gross@sheffield.ac.uk

Part F

Roderich Groß received a Diploma degree in Computer Science from TU Dortmund University in 2001 and a PhD degree in Engineering Sciences from the Université libre de Bruxelles in 2007. From 2005 to 2009 he was a fellow of the Japan Society for the Promotion of Science, a Research Associate at the University of Bristol, a Marie Curie Fellow at Unilever, and a Marie Curie Fellow at EPFL. Since 2010 he has been with the Department of Automatic Control and Systems Engineering at the University of Sheffield, where he is currently Senior Lecturer. His research interests include evolutionary and distributed robotics. He has authored over 60 publications on these topics. He is a Senior Member of the IEEE.

Enrique Herrera Viedma

University of Granada
Dep. Computer Science and Artificial Intelligence
18003 Granada, Spain
viedma@decsai.ugr.es

Part B

Enrique Herrera-Viedma received his PhD degree in Computer Science from Granada University in 1996. He is Professor at Granada University in the Depaartment of Computer Science and Artificial Intelligence and a member of the BoG in IEEE SMC. His interest topics are computing with words, fuzzy decision making, consensus, aggregation, social media, recommender systems, libraries, and bibliometrics. His h-index is 44 and presents over 7000 citations (WoS). In 2014 he was identified as Highly Cited Researcher by Thomson Reuters and Top Author in Computer Science according to Microsoft Academic Search.

Luis Magdalena

European Centre for Soft Computing
33600 Mieres, Spain
luis.magdalena@softcomputing.es

Part B

Luis Magdalena received the MS and PhD degrees in Telecommunication Engineering from the Technical University of Madrid, Spain, in 1988 and 1994. He has been Assistant (1990–1995) and Associate Professor (1995–2006) in Computer Science at the Technical University of Madrid. Since 2006 he has been Director General of the European Center for Soft Computing. His research interests include soft computing and its application. He has authored over 150 publications in the field. He has been President of the *European Society for Fuzzy Logic and Technologies* (2001–2005), Vice-President of the International Fuzzy Systems Association (2007–2011), and member of the IEEE Computational Intelligence Society AdCom (2011–2013).

Jörn Mehnen

Cranfield University
Manufacturing Dep.
Cranfield, MK43 0AL, UK
j.mehnen@cranfield.ac.uk

Part E

Dr Jörn Mehnen is Reader in Computational Manufacturing at Cranfield University, UK and Privatdozent at TU Dortmund, Germany. He is also Deputy Director of the EPSRC Centre in Through-life Engineering Services at Cranfield University. His research activities are in real-world applications of computer sciences in mechanical engineering with special focus on evolutionary optimization, cloud manufacturing, and additive manufacturing.

Patricia Melin

Tijuana Institute of Technology
Dep. Computer Science
Chula Vista, CA 91909, USA
pmelin@tectijuana.mx

Part G

Patricia Melin holds the Doctor in Science degree in Computer Science from the Polish Academy of Sciences. She has been a Professor of Computer Science in the Graduate Division, Tijuana Institute of Technology, Tijuana, Mexico since 1998. She serves as Director of Graduate Studies in Computer Science. Currently, she is Vice President of HAFSA (Hispanic American Fuzzy Systems Association). She is the founding Chair of the Mexican Chapter of the IEEE Computational Intelligence Society. She is member of NAFIPS, IFSA, and IEEE and belongs to the Mexican Research System with level III. Her research interests are in type-2 fuzzy logic, modular neural networks, pattern recognition, fuzzy control, and neuro-fuzzy and genetic-fuzzy hybrid approaches. She has published over 200 journal papers, 6 authored books, 20 edited books, and 200 papers in conference proceedings.

Peter Merz

University of Applied Sciences and Arts, Hannover
Dep. Business Administration and Computer Science
30459 Hannover, Germany
peter.merz@hs-hannover.de

Part E

Peter Merz received his PhD degree in Computer Science from the University of Siegen, Germany in 2000. Since 2009, he has been Professor at the University of Applied Sciences and Arts in Hannover. He is a well-known scientist in the field of evolutionary computation and meta-heuristics. His research interests center on fitness landscapes of combinatorial optimization problems and their analysis.

Radko Mesiar

STU in Bratislava
Dep. Mathematics and Descriptive Geometry
813 68 Bratislava, Slovakia
radko.mesiar@stuba.sk

Part A

Radko Mesiar received his PhD from Comenius University, Faculty of Mathematics and Physics, in 1979. He has been a member of the Department of Mathematics in the Faculty of Civil Engineering, STU Bratislava since 1978. He received his DSc in 1996 from the Czech Academy of Sciences. He has been a full professor since 1998. He is a fellow member of the Institute of Information and Automation at the Czech Academy of Sciences and of IRAFM, University of Ostrava (Czech Republic). He is co-author of two scientific monographs and five edited volumes. He is the author of more than 200 papers in WOS in leading journals. He is the co-founder of conferences AGOP, FSTA, ABLAT, and ISCAMI.

Frank Neumann

The University of Adelaide
School of Computer Science
Adelaide, SA 5005, Australia
frank.neumann@adelaide.edu.au

Part E

Frank Neumann received his diploma and PhD from the University of Kiel in 2002 and 2006, respectively. Currently, he is an Associate Professor and leader of the Optimisation and Logistics Group at the School of Computer Science, The University of Adelaide, Australia. He is the General Chair of ACM GECCO 2016. He is Vice-Chair of the IEEE Task Force on Theoretical Foundations of Bio-Inspired Computation, and Chair of the IEEE Task Force on Evolutionary Scheduling and Combinatorial Optimization. In his work, he considers algorithmic approaches and focuses on theoretical aspects of evolutionary computation as well as high impact applications in the areas of renewable energy, logistics, and sports.

Marios Polycarpou

University of Cyprus
Dep. Electrical and Computer Engineering and KIOS Research Center for Intelligent Systems and Networks
1678 Nicosia, Cyprus
mpolycar@ucy.ac.cy

Part D

Marios Polycarpou is Professor of Electrical and Computer Engineering and the Director of the KIOS Research Center for Intelligent Systems and Networks at the University of Cyprus. His research expertise is in the areas of intelligent systems and control, computational intelligence, fault diagnosis, cooperative and adaptive control, and distributed agents. He is a Fellow of the IEEE. He has participated in more than 60 research projects/grants, funded by several agencies and industries in Europe and the United States. In 2011, he was awarded the prestigious European Research Council (ERC) Advanced Grant.

Günther Raidl

Vienna University of Technology
Inst. Computer Graphics and Algorithms
1040 Vienna, Austria
raidl@ads.tuwien.ac.at

Part E

Günther Raidl is Professor at the Vienna University of Technology, Austria, and heads the Algorithms and Data Structures Group. He received his PhD in 1994 and completed his Habilitation in Practical Computer Science in 2003. In 2005 he received a professorship position for combinatorial optimization. His research interests include algorithms and data structures in general and combinatorial optimization in particular, with a specific focus on metaheuristics, mathematical programming, and hybrid optimization approaches.

Oliver Schütze

CINVESTAV-IPN
Dep. Computación
D.F. 07300, México, Mexico
schuetze@cs.cinvestav.mx

Part E

Oliver Schütze received a PhD in Mathematics from the University of Paderborn, Germany in 2004. He is currently Professor at Cinvestav-IPN in Mexico City (Mexico). His research interests focus on numerical and evolutionary optimization where he addresses scalar and multi-objective optimization problems. He has co-edited 5 books and is co-author of more than 90 papers. He is a co-founder of SON (Set Oriented Numerics) and founder of the NEO (Numerical and Evolutionary Optimization) workshop series.

Roman Słowiński

Poznań University of Technology
Inst. Computing Science
60-965 Poznań, Poland
Roman.Slowinski@cs.put.poznan.pl

Part C

Roman Słowiński is Professor and Founding Chair of the Laboratory of Intelligent Decision Support Systems at Poznań University of Technology. He is Academician and President of the Poznań Branch of the Polish Academy of Sciences and a member of Academia Europaea. In his research, he combines operations research and computational intelligence. He is renowned for his seminal research on using rough sets in decision analysis. He was laureate of the EURO Gold Medal (1991) and won the 2005 Prize of the Foundation for Polish Science. He is Doctor *Honoris Causa* of Polytech'Mons (2000), the University Paris Dauphine (2001), and the Technical University of Crete (2008).

Carsten Witt

Technical University of Denmark
DTU Compute, Algorithms, Logic and Graphs
2800 Kgs., Lyngby, Denmark
cawi@imm.dtu.dk

Part E

Carsten Witt is Associate Professor at the Technical University of Denmark. He received his PhD in Computer Science from the Technical University of Dortmund in 2004. His main research interests are the theoretical aspects of nature-inspired algorithms, in particular evolutionary algorithms, ant colony optimization and particle swarm optimization. He is a member of the Editorial Boards of Evolutionary Computation and Theoretical Computer Science and has co-authored a textbook.

Yiyu Yao

University of Regina
Dep. Computer Science
Regina, Saskatchewan, S4S 0A2, Canada
yyao@cs.uregina.ca

Part C

Yiyu Yao is Professor of Computer Science in the Department of Computer Science, the University of Regina, Canada. His research interests include three-way decisions, rough sets, fuzzy sets, interval sets, granular computing, information retrieval, Web intelligence, and data mining. He is currently working on a triarchic theory of granular computing, a theory of three-way decisions and generalized rough sets.

List of Authors

Enrique Alba
Universidad de Malaga
E.T.S.I. Informática
Campus de Teatinos (3.2.12)
29071 Málaga, Spain
e-mail: *eat@lcc.uma.es*

Jose M. Alonso
European Centre for Soft Computing
Cognitive Computing
33600 Mieres, Spain
e-mail: *jose.alonso@softcomputing.es*

Jhon Edgar Amaya
Universidad Nacional Experimental del Táchira
Dep. Electronic Engineering
Av. Universidad. Paramillo
San Cristóbal, Venezuela
e-mail: *jedgar@unet.edu.ve*

Plamen P. Angelov
Lancaster University
School of Computing and Communications
Bailrigg, Lancaster, LA1 4YW, UK
e-mail: *p.angelov@lancaster.ac.uk*

Dirk V. Arnold
Dalhousie University
Faculty of Computer Science
6050 University Avenue
Halifax, Nova Scotia, B3H 4R2, Canada
e-mail: *dirk@cs.dal.ca*

Anne Auger
University Paris-Sud Orsay
CR Inria
LRI (UMR 8623)
91405 Orsay Cedex, France
e-mail: *anne.auger@inria.fr*

Davide Bacciu
Università di Pisa
Dip. Informatica
L.Go B. Pontecorvo, 3
56127 Pisa, Italy
e-mail: *bacciu@di.unipi.it*

Michał Baczynski
University of Silesia
Inst. Mathematics
Bankowa 14
40-007 Katowice, Poland
e-mail: *michal.baczynski@us.edu.pl*

Edurne Barrenechea
Universidad Pública de Navarra
Dep. Automática y Computación
31006 Pamplona (Navarra), Spain
e-mail: *edurne.barrenechea@unavarra.es*

Thomas Bartz-Beielstein
Cologne University of Applied Sciences
Faculty of Computer Science and Engineering
Science
Steinmüllerallee 1
51643 Gummersbach, Germany
e-mail: *thomas.bartz-beielstein@fh-koeln.de*

Lubica Benuskova
University of Otago
Dep. Computer Science
133 Union Street East
9016 Dunedin, New Zealand
e-mail: *lubica@cs.otago.ac.nz*

Dirk Biermann
TU Dortmund University
Dep. Mechanical Engineering
Baroper Str. 303
44227 Dortmund, Germany
e-mail: *biermann@isf.de*

Sašo Blažič
University of Ljubljana
Faculty of Electrical Engineering
Tržaška 25
1000 Ljubljana, Slovenia
e-mail: *saso.blazic@fe.uni-lj.si*

Christian Blum
University of the Basque Country
Dep. Computer Science and Artificial Intelligence
Paseo Manuel Lardizabal 1
20018 San Sebastian, Spain
e-mail: *christian.blum@ehu.es*

Andrea Bobbio
Università del Piemonte Orientale
DiSit – Computer Science Section
Viale Teresa Michel, 11
15121 Alessandria, Italy
e-mail: *andrea.bobbio@unipmn.it*

Josh Bongard
University of Vermont
Dep. Computer Science
33 Colchester Ave.
Burlington, VT 05405, USA
e-mail: *josh.bongard@uvm.edu*

Piero P. Bonissone
Piero P. Bonissone Analytics, LLC
3103 28th Street
San Diego, CA 92104, USA
e-mail: *bonissone@gmail.com*

Dario Bruneo
Universita' di Messina
Dip. Ingegneria Civile, Informatica
Contrada di Dio – S. Agata
98166 Messina, Italy
e-mail: *dbruneo@unime.it*

Alberto Bugarín Diz
University of Santiago de Compostela
Research Centre for Information Technologies
15782 Santiago de Compostela, Spain
e-mail: *alberto.bugarin.diz@usc.es*

Humberto Bustince
Universidad Pública de Navarra
Dep. Automática y Computación
31006 Pamplona (Navarra), Spain
e-mail: *bustince@unavarra.es*

Martin V. Butz
University of Tübingen
Computer Science, Cognitive Modeling
Sand 14
72076 Tübingen, Germany
e-mail: *martin.butz@uni-tuebingen.de*

Alexandre Campo
Université Libre de Bruxelles
Unit of Social Ecology
Boulevard du triomphe,
Campus de la Plaine
1050 Brussels, Belgium
e-mail: *alexandre.campo@ulb.ac.be*

Angelo Cangelosi
Plymouth University
Centre for Robotics and Neural Systems
Drake Circus
Plymouth, PL4 8AA, UK
e-mail: *A.Cangelosi@plymouth.ac.uk*

Robert Carrese
LEAP Australia Pty. Ltd.
Clayton North, Australia
e-mail: *robert.carrese@leapaust.com.au*

Ciro Castiello
University of Bari
Dep. Informatics
via E. Orabona, 4
70125 Bari, Italy
e-mail: *ciro.castiello@uniba.it*

Oscar Castillo
Tijuana Institute of Technology
Calzada Tecnolo-gico s/n
22379 Tijuana, Mexico
e-mail: *ocastillo@tectijuana.mx*

Davide Cerotti
Politecnico di Milano
Dip. Elettronica, Informazione e Bioingegneria
Via Ponzio 34/5
20133 Milano, Italy
e-mail: *davide.cerotti@polimi.it*

Badong Chen
Xi'an Jiaotong University
Inst. Artificial Intelligence and Robotics
710049 Xi'an, China
e-mail: *chenbd@mail.xjtu.edu.cn*

Ke Chen
The University of Manchester
School of Computer Science
G10 Kilburn Building, Oxford Road
Manchester, M13 9PL, UK
e-mail: *chen@cs.manchester.ac.uk*

Davide Ciucci
University of Milano-Bicocca
Dep. Informatics, Systems and Communications
viale Sarca 336/14
20126 Milano, Italy
e-mail: *ciucci@disco.unimib.it*

Carlos A. Coello Coello
CINVESTAV-IPN
Dep. Computación
Av. Instituto Politécnico Nacional No. 2508, Col. San Pedro Zacatenco
D.F. 07300, México, Mexico
e-mail: *ccoello@cs.cinvestav.mx*

Chris Cornelis
Ghent University
Dep. Applied Mathematics and Computer Science
Krijgslaan 281 (S9)
9000 Ghent, Belgium
e-mail: *chriscornelis@ugr.es*

Nikolaus Correll
University of Colorado at Boulder
Dep. Computer Science
Boulder, CO 80309, USA
e-mail: *ncorrell@colorado.edu*

Carlos Cotta Porras
Universidad de Málaga
Dep. Lenguajes y Ciencias de la Computación
Avda Louis Pasteur, 35
29071 Málaga, Spain
e-mail: *ccottap@lcc.uma.es*

Damien Coyle
University of Ulster
Intelligent Systems Research Centre
Northland Rd
Derry, Northern Ireland, BT48 7JL, UK
e-mail: *dh.coyle@ulster.ac.uk*

Guy De Tré
Ghent University
Dep. Telecommunications and Information Processing
Sint-Pietersnieuwstraat 41
9000 Ghent, Belgium
e-mail: *guy.detre@ugent.be*

Kalyanmoy Deb
Michigan State University
Dep. Electrical and Computer Engineering
428 S. Shaw Lane
East Lansing, MI 48824, USA
e-mail: *kdeb@egr.msu.edu*

Clarisse Dhaenens
University of Lille
CRIStAL laboratory
M3 building – Cité scientifique
59655 Villeneuve d'Ascq Cedex, France
e-mail: *clarisse.dhaenens@univ-lille1.fr*

Luca Di Gaspero
Università degli Studi di Udine
Dip. Ingegneria Elettrica, Gestionale e Meccanica
via delle Scienze 208
33100 Udine, Italy
e-mail: *luca.digaspero@uniud.it*

Didier Dubois
Université Paul Sabatier
IRIT – Equipe ADRIA
118 route de Narbonne
31062 Toulouse Cedex 9, France
e-mail: *dubois@irit.fr*

Antonio J. Fernández Leiva
Universidad de Málaga
Dep. Lenguajes y Ciencias de la Computación
Avda Louis Pasteur, 35
29071 Málaga, Spain
e-mail: *afdez@lcc.uma.es*

Javier Fernández
Universidad Pública de Navarra
Dep. Automática y Computación
31006 Pamplona (Navarra), Spain
e-mail: *fcojavier.fernandez@unavarra.es*

Martin H. Fischer
University of Potsdam
Psychology Dep.
Karl-Liebknecht-Str. 24/25
14476 Potsdam OT Golm, Germany
e-mail: *martinf@uni-potsdam.de*

János C. Fodor
Óbuda University
Dep. Applied Mathematics
Bécsi út 96/b
1034 Budapest, Hungary
e-mail: *fodor@uni-obuda.hu*

Jairo Alonso Giraldo
Universidad de los Andes
Dep. Electrical and Electronics Engineering
Cra 1Este # 19A-40
111711 Bogotá, Colombia
e-mail: *ja.giraldo908@uniandes.edu.co*

Siegfried Gottwald
Leipzig University
Inst. Philosophy
Beethovenstr. 15
04107 Leipzig, Germany
e-mail: *gottwald@uni-leipzig.de*

Salvatore Greco
University of Catania
Dep. Economics and Business
Corso Italia 55
95129 Catania, Italy
e-mail: *salgreco@unict.it*

Marco Gribaudo
Politecnico di Milano
Dip. Elettronica, Informazione e Bioingegneria
Via Ponzio 34/5
20133 Milano, Italy
e-mail: *marco.gribaudo@polimi.it*

Roderich Groß
University of Sheffield
Dep. Automatic Control and Systems Engineering
Mappin Street
Sheffield, S1 3JD, UK
e-mail: *r.gross@sheffield.ac.uk*

Jerzy W. Grzymala-Busse
University of Kansas
Dep. Electrical Engineering and Computer Science
3014 Eaton Hall, 1520 W. 15th St.
Lawrence, KS 66045-7621, USA
e-mail: *jerzygb@ku.edu*

Hani Hagras
University of Essex
The Computational Intelligence Centre
Wivenhoe Park
Colchester, C04 3SQ, UK
e-mail: *hani@essex.ac.uk*

Heiko Hamann
Universtity of Paderborn
Dep. Computer Science
Zukunftsmeile 1
33102 Paderborn, Germany
e-mail: *heiko.hamann@uni-paderborn.de*

Thomas Hammerl
Westbahnstraße 25/1/7
1070 Vienna, Austria
e-mail: *thomas.hammerl@gmail.com*

Julie Hamon
Ingenomix
Dep. Research and Development
Pole de Lanaud
87220 Boisseuil, France
e-mail: *julie.hamon@ingenomix.fr*

Nikolaus Hansen
Universitè Paris-Sud
Machine Learning and Optimization Group (TAO)
Rue Noetzlin
91405 Orsay Cedex, France
e-mail: *hansen@lri.fr*

Mark W. Hauschild
University of Missouri–St. Louis
Dep. Mathematics and Computer Science
1 University Blvd
St. Louis, MO 314-972-2419, USA
e-mail: *markhauschild@gmail.com*

Sebastien Hélie
Purdue University
Dep. Psychological Sciences
703 Third Street
West Lafayette, IN 47907-2081, USA
e-mail: *shelie@purdue.edu*

Jano I. van Hemert
Optos
Queensferry House, Carnegie Business Park
Dunfermline, KY11 8GR, UK
e-mail: *jano@vanhemert.co.uk*

Holger H. Hoos
University of British Columbia
Dep. Computer Science
2366 Main Mall
Vancouver, BC V6T 1Z4, Canada
e-mail: *hoos@cs.ubc.ca*

Tania Iglesias
University of Oviedo
Dep. Statistics and O.R.
3360 Oviedo, Spain
e-mail: *iglesiasctania@uniovi.es*

Giacomo Indiveri
University of Zurich and ETH Zurich
Inst. Neuroinformatics
Zurich, Switzerland
e-mail: *giacomo@ini.uzh.ch*

Masahiro Inuiguchi
Osaka University
Dep. Systems Innovation, Graduate School of Engineering Science
1-3 Machikaneyama-cho
560-8531 Toyonaka, Osaka, Japan
e-mail: *inuiguti@sys.es.osaka-u.ac.jp*

Hisao Ishibuchi
Osaka Prefecture University
Dep. Computer Science and Intelligent Systems, Graduate School of Engineering
1-1 Gakuen-Cho, Sakai
599-8531 Osaka, Japan
e-mail: *hisaoi@cs.osakafu-u.ac.jp*

Emiliano Iuliano
CIRA, Italian Aerospace Research Center
Fluid Dynamics Lab.
Via Maiorise
81043 Capua (CE), Italy
e-mail: *e.iuliano@cira.it*

Julie Jacques
Alicante LAB
50, rue Philippe de Girard
59113 Seclin, France
e-mail: *julie.jacques@alicante.fr*

Andrzej Jankowski
Knowledge Technology Foundation
Nowogrodzka 31
00-511 Warsaw, Poland
e-mail: *andrzej.adgam@gmail.com*

Balasubramaniam Jayaram
Indian Institute of Technology Hyderabad
Dep. Mathematics
ODF Estate, Yeddumailaram
502 205 Hyderabad, India
e-mail: *jbala@iith.ac.in*

Laetitia Jourdan
University of Lille 1
INRIA/UFR IEEA/laboratory CRIStAL/CNRS
59655 Lille, France
e-mail: *laetitia.jourdan@univ-lille1.fr*

Nikola Kasabov
Auckland University of Technology
KEDRI – Knowledge Engineering and Discovery Research Inst.
120 Mayoral Drive
Auckland, New Zealand
e-mail: *nkasabov@aut.ac.nz*

Petra Kersting
TU Dortmund University
Dep. Mechanical Engineering
Baroper Str. 303
44227 Dortmund, Germany
e-mail: *pkersting@isf.de*

Erich P. Klement
Johannes Kepler University
Dep. Knowledge-Based Mathematical Systems
Altenberger Strasse 69
4040 Linz, Austria
e-mail: *ep.klement@jku.at*

Anna Kolesárová
Slovak University of Technology in Bratislava
Faculty of Chemical and Food Technology
Radlinského 9
812 37 Bratislava, Slovakia
e-mail: *anna.kolesarova@stuba.sk*

Magda Komorníková
Slovak University of Technology
Dep. Mathematics
Radlinského 11
813 68 Bratislava, Slovakia
e-mail: *magda@math.sk*

Mark Kotanchek
Evolved Analytics LLC
3411 Valley Drive
Midland, MI 48640, USA
e-mail: *mark@evolved-analytics.com*

Robert Kozma
University of Memphis
Dep. Mathematical Sciences
Memphis, TN 38152, USA
e-mail: *rkozma@memphis.edu*

Tomáš Kroupa
Institute of Information Theory and Automation
Dep. Decision-Making Theory
Pod Vodárenskou věží 4
182 08 Prague, Czech Republic
e-mail: *kroupa@utia.cas.cz*

Rudolf Kruse
University of Magdeburg
Faculty of Computer Science
Universitätsplatz 2
39114 Magdeburg, Germany
e-mail: *kruse@iws.cs.uni-magdeburg.de*

Tufan Kumbasar
Istanbul Technical University
Control Engineering Dep.
34469 Maslak, Istanbul, Turkey
e-mail: *kumbasart@itu.edu.tr*

James T. Kwok
Hong Kong University of Science and Technology
Dep. Computer Science and Engineering
Clear Water Bay
Hong Kong, Hong Kong
e-mail: *jamesk@cse.ust.edu.hk*

Rhyd Lewis
Cardiff University
School of Mathematics
Cardiff, CF10 4AG, UK
e-mail: *lewisR9@cf.ac.uk*

Xiaodong Li
RMIT University
School of Computer Science and
Information Technology
Melbourne, 3001, Australia
e-mail: *xiaodong.li@rmit.edu.au*

Paulo J.G. Lisboa
Liverpool John Moores University
Dep. Mathematics & Statistics
Byrom St
Liverpool, L3 3AF, UK
e-mail: *p.j.lisboa@ljmu.ac.uk*

Weifeng Liu
Jump Trading
600 W. Chicago Ave.
Chicago, IL 60654, USA
e-mail: *weifeng@ieee.org*

Fernando G. Lobo
Universidade do Algarve
Dep. Engenharia Electrónica e Informática
Campus de Gambelas
8005-139 Faro, Portugal
e-mail: *fernando.lobo@gmail.com*

Antonio López Jaimes
CINVESTAV-IPN
Dep. Computación
Av. Instituto Politécnico Nacional No. 2508, Col.
San Pedro Zacatenco
D.F. 07300, México, Mexico
e-mail: *tonio.jaimes@gmail.com*

Francisco Luna
Centro Universitario de Mérida
Santa Teresa de Jornet 38
06800 Mérida, Spain
e-mail: *fluna@unex.es*

Luis Magdalena
European Centre for Soft Computing
Gonzalo Gutiérrez Quirós s/n
33600 Mieres, Spain
e-mail: *luis.magdalena@softcomputing.es*

Sebastia Massanet
University of the Balearic Islands
Dep. Mathematics and Computer Science
Crta. Valldemossa km. 7,5
07122 Palma de Mallorca, Spain
e-mail: *s.massanet@uib.es*

Benedetto Matarazzo
University of Catania
Dep. Economics and Business
Corso Italia 55
95129 Catania, Italy
e-mail: *matarazz@unict.it*

Sergi Mateo Bellido
Polytechnic University of Catalonia
Dep. Computer Architecture
08034 Barcelona, Spain
e-mail: *sergim@ac.upc.edu*

James McDermott
University College Dublin
Lochlann Quinn School of Business
Belfield
Dublin 4, Ireland
e-mail: *jmmcd@jmmcd.net*

Patricia Melin
Tijuana Institute of Technology
Dep. Computer Science
Chula Vista, CA 91909, USA
e-mail: *pmelin@tectijuana.mx*

Corrado Mencar
University of Bari
Dep. Informatics
via E. Orabona, 4
70125 Bari, Italy
e-mail: *corrado.mencar@uniba.it*

Radko Mesiar
STU in Bratislava
Dep. Mathematics and Descriptive Geometry
Radlinskeho 11
813 68 Bratislava, Slovakia
e-mail: *radko.mesiar@stuba.sk*

Ralf Mikut
Karlsruhe Institute of Technology (KIT)
Inst. Applied Computer Science
Hermann-von-Helmholtz-Platz 1
76344 Eggenstein-Leopoldshafen, Germany
e-mail: *ralf.mikut@kit.edu*

Ali A. Minai
University of Cincinnati
School of Electronic & Computing Systems
2600 Clifton Ave.
Cincinnati, OH 45221-0030, USA
e-mail: *ali.minai@uc.edu*

Sadaaki Miyamoto
University of Tsukuba
Risk Engineering
1-1-1 Tennodai
305-8573 Tsukuba, Japan
e-mail: *miyamoto@risk.tsukuba.ac.jp*

Christian Moewes
University of Magdeburg
Faculty of Computer Science
Universitätsplatz 2
39114 Magdeburg, Germany
e-mail: *cmoewes@ovgu.de*

Javier Montero
Complutense University, Madrid
Dep. Statistics and Operational Research
Plaza de las Ciências, 3
28040 Madrid, Spain
e-mail: *monty@mat.ucm.es*

Ignacio Montes
University of Oviedo
Dep. Statistics and O.R.
3360 Oviedo, Spain
e-mail: *imontes@uniovi.es*

Susana Montes
University of Oviedo
Dep. Statistics and O.R.
3360 Oviedo, Spain
e-mail: *montes@uniovi.es*

Oscar H. Montiel Ross
Av. del Parque No. 131º
B.C. 22414, Mesa de Otay, Tijuana, Mexico
e-mail: *oross@citedi.mx*

Manuel Mucientes
University of Santiago de Compostela
Research Centre for Information Technologies
15782 Santiago de Compostela, Spain
e-mail: *manuel.mucientes@usc.es*

Nysret Musliu
Vienna University of Technology
Inst. Information Systems
Favoritenstraße 9
1000 Vienna, Austria
e-mail: *musliu@dbai.tuwien.ac.at*

Yusuke Nojima
Osaka Prefecture University
Dep. Computer Science and Intelligent Systems,
Graduate School of Engineering
1-1 Gakuen-Cho, Sakai
599-8531 Osaka, Japan
e-mail: *nojima@cs.osakafu-u.ac.jp*

Stefano Nolfi
Consiglio Nazionale delle Ricerche (CNR-ISTC)
Inst. Cognitive Sciences and Technologies
Via S. Martino della Battaglia, 44
00185 Roma, Italy
e-mail: *stefano.nolfi@istc.cnr.it*

Una-May O'Reilly
Massachusetts Institute of Technology
Computer Science and Artificial Intelligence Lab.
32 Vassar St.
Cambridge, MA 02139, USA
e-mail: *unamay@csail.mit.edu*

Miguel Pagola
Universidad Pública de Navarra
Dep. Automática y Computación
31006 Pamplona (Navarra), Spain
e-mail: *miguel.pagola@unavarra.es*

Lynne Parker
University of Tennessee
Dep. Electrical Engineering and Computer Science
1520 Middle Drive
Knoxville, TN 37996, USA
e-mail: *leparker@utk.edu*

Kevin M. Passino
The Ohio State University
Dep. Electrical and Computer Engineering
2015 Neil Avenue
Columbus, OH 43210-1272, USA
e-mail: *passino@ece.osu.edu*

Martin Pelikan
1271 Lakeside Dr. #3123
Sunnyvale, CA 94085, USA
e-mail: *martin@martinpelikan.net*

Irina Perfilieva
University of Ostrava
Inst. Research and Applications of Fuzzy Modeling
30. dubna 22
70103 Ostrava, Czech Republic
e-mail: *Irina.Perfilieva@osu.cz*

Henry Prade
Université Paul Sabatier
IRIT – Equipe ADRIA
118 route de Narbonne
31062 Toulouse Cedex 9, France
e-mail: *prade@irit.fr*

Mike Preuss
WWU Münster
Inst. Wirtschaftsinformatik
Leonardo-Campus 3
48149 Münster, Germany
e-mail: *mike.preuss@tu-dortmund.de*

José C. Principe
University of Florida
Dep. Electrical and Computer Engineering
Gainesville, FL 32611, USA
e-mail: *principe@cnel.ufl.edu*

Domenico Quagliarella
CIRA, Italian Aerospace Research Center
Fluid Dynamics Lab.
Via Maiorise
81043 Capua (CE), Italy
e-mail: *d.quagliarella@cira.it*

Nicanor Quijano
Universidad de los Andes
Dep. Electrical and Electronics Engineering
Cra 1Este # 19A-40
111711 Bogotá, Colombia
e-mail: *nquijano@uniandes.edu.co*

Jaroslav Ramík
Silesian University in Opava
Dep. Informatics and Mathematics
University Sq. 1934/3
73340 Karviná, Czech Republic
e-mail: *ramik@opf.slu.cz*

Ismael Rodríguez Fdez
University of Santiago de Compostela
Research Centre for Information Technologies
15782 Santiago de Compostela, Spain
e-mail: *ismael.rodriguez@usc.es*

Franz Rothlauf
Johannes Gutenberg University Mainz
Gutenberg School of Management and Economics
Jakob Welder-Weg 9
55099 Mainz, Germany
e-mail: *rothlauf@uni-mainz.de*

Jonathan E. Rowe
University of Birmingham
School of Computer Science
Birmingham, B15 2TT, UK
e-mail: *J.E.Rowe@cs.bham.ac.uk*

Imre J. Rudas
Óbuda University
Dep. Applied Mathematics
Bécsi út 96/b
1034 Budapest, Hungary
e-mail: *rudas@uni-obuda.hu*

Günter Rudolph
Technische Universität Dortmund
Fak. Informatik
Otto-Hahn-Str. 14
44227 Dortmund, Germany
e-mail: *guenter.rudolph@cs.tu-dortmund.de*

Gabriele Sadowski
Technische Universität Dortmund
Bio- und Chemieingenieurwesen
Emil-Figge-Str. 70
44227 Dortmund, Germany
e-mail: *gabriele.sadowski@bci.tu-dortmund.de*

Marco Scarpa
Universita' di Messina
Dip. Ingegneria Civile, Informatica
Contrada di Dio – S. Agata
98166 Messina, Italy
e-mail: *mscarpag@unime.it*

Werner Schafhauser
XIMES
Hollandstraße 12/12
1020 Vienna, Austria
e-mail: *schafhauser@ximes.com*

Roberto Sepúlveda Cruz
Av. del Parque No. 131º
B.C. 22414, Mesa de Otay, Tijuana, Mexico
e-mail: *rsepulve@citedi.mx*

Jennie Si
Arizona State University
School of Electrical, Computer and
Energy Engineering
Tempe, AZ 85287-5706, USA
e-mail: *si@asu.edu*

Marco Signoretto
Katholieke Universiteit Leuven
Kasteelpark Arenberg 10
3001 Leuven, Belgium
e-mail: *marco.signoretto@esat.kuleuven.be*

Andrzej Skowron
University of Warsaw
Faculty of Mathematics,
Computer Science and Mechanics
Banacha 2
02-097 Warsaw, Poland
e-mail: *skowron@mimuw.edu.pl*

Igor Škrjanc
University of Ljubljana
Faculty of Electrical Engineering
Tržaška 25
1000 Ljubljana, Slovenia
e-mail: *igor.skrjanc@fe.uni-lj.si*

Roman Słowiński
Poznań University of Technology
Inst. Computing Science
Piotrowo 2
60-965 Poznań, Poland
e-mail: *roman.slowinski@cs.put.poznan.pl*

Guido Smits
Dow Benelux BV
Core R&D
Herbert H. Dowweg 5
4542 NM Hoek, The Netherlands
e-mail: *gfsmits@dow.com*

Ronen Sosnik
Holon Institute of Technology (H.I.T.)
Electrical, Electronics and Communication
Engineering
52 Golomb St.
5810201 Holon, Israel
e-mail: *ronens@hit.ac.il*

Alessandro Sperduti
University of Padova
Dep. Pure and Applied Mathematics
Via Trieste, 63
351 21 Padova, Italy
e-mail: *sperduti@math.unipd.it*

Kasper Støy
IT University of Copenhagen
Rued Langgaards Vej 7
2300 Copenhagen S, Denmark
e-mail: *ksty@itu.dk*

Harrison Stratton
Arizona State University & Barrow
Neurological Institute
Phoenix, AZ 85013, USA
e-mail: *Harrison.Stratton@asu.edu*

Thomas Stützle
Université libre de Bruxelles (ULB)
IIRIDIA, CP 194/6
Av. F. Roosevelt 50
1050 Brussels, Belgium
e-mail: *stuetzle@ulb.ac.be*

Dirk Sudholt
University of Sheffield
Dep. Computer Science
211 Portobello
Sheffield, S1 4DP, UK
e-mail: *d.sudholt@sheffield.ac.uk*

Ron Sun
Rensselaer Polytechnic Institute
Cognitive Science Dep.
110 Eighth Street, Carnegie 302A
Troy, NY 12180, USA
e-mail: *rsun@rpi.edu*

Johan A. K. Suykens
Katholieke Universiteit Leuven
Kasteelpark Arenberg 10
3001 Leuven, Belgium
e-mail: *johan.suykens@esat.kuleuven.be*

Roman W. Swiniarski (deceased)

El-Ghazali Talbi
University of Lille
Computer Science CRISTAL
Bat.M3 cité scientifique
59655 Villeneuve d'Ascq, France
e-mail: *el-ghazali.talbi@univ-lille1.fr*

Lothar Thiele
Swiss Federal Institute of Technology Zurich
Computer Engineering and Networks Lab.
Gloriastrasse 35
8092 Zurich, Switzerland
e-mail: *thiele@ethz.ch*

Peter Tino
University of Birmingham
School of Computer Science
Edgbaston
Birmingham, B15 2TT, UK
e-mail: *P.Tino@cs.bham.ac.uk*

Joan Torrens
University of the Balearic Islands
Dep. Mathematics and Computer Science
Crta. Valldemossa km. 7,5
07122 Palma de Mallorca, Spain
e-mail: *jts224@uib.es*

Vito Trianni
Consiglio Nazionale delle Ricerche
Ist. Scienze e Tecnologie della Cognizione
via San Martino della Battaglia 44
00185 Roma, Italy
e-mail: *vito.trianni@istc.cnr.it*

Enric Trillas
European Centre for Soft Computing
Fundamentals of Soft Computing
33600 Mieres, Spain
e-mail: *enric.trillas@softcomputing.es*

Fevrier Valdez
Tijuana Institute of Technology
Calzada del Tecnológico S/N, Tomas Aquino
B.C. 22414, Tijuana, Mexico
e-mail: *fevrier@tectijuana.mx*

Nele Verbiest
Ghent University
Dep. Applied Mathematics,
Computer Science and Statistics
Krijgslaan 281 (S9)
9000 Ghent, Belgium
e-mail: *nele.verbiest@ugent.be*

Thomas Villmann
University of Applied Sciences Mittweida
Dep. Mathematics, Natural and Computer Sciences
Technikumplatz 17
09648 Mittweida, Germany
e-mail: *thomas.villmann@hs-mittweida.de*

Milan Vlach
Charles University
Theoretical Computer Science and Mathematical Logic
Malostranské náměstí 25
118 00 Prague, Czech Republic
e-mail: *Milan.Vlach@mff.cuni.cz*

Ekaterina Vladislavleva
Evolved Analytics Europe BVBA
A. Coppenslaan 27
2300 Turnhout, Belgium
e-mail: *katya@evolved-analytics.com*

Tobias Wagner
TU Dortmund University
Dep. Mechanical Engineering
Baroper Str. 303
44227 Dortmund, Germany
e-mail: *wagner@isf.de*

Jun Wang
The Chinese University of Hong Kong
Dep. Mechanical & Automation Engineering
Shatin, New Territories
Hongkong, Hong Kong
e-mail: *jwang@mae.cuhk.edu.hk*

Simon Wessing
Technische Universität Dortmund
Fak. Informatik
Otto-Hahn-Str. 14
44227 Dortmund, Germany
e-mail: *simon.wessing@tu-dortmund.de*

Wei-Zhi Wu
Zhejiang Ocean University
School of Mathematics, Physics and
Information Science
No.1 Haida South Road, Lincheng District
316022 Zhoushan, Zhejiang, China
e-mail: *wuwz@zjou.edu.cn*

Lei Xu
The Chinese University of Hong Kong
Dep. Computer Science and Engineering
Shatin, New Territories
Hong Kong, Hong Kong
e-mail: *lxu@cse.cuhk.edu.hk*

JingTao Yao
University of Regina
Dep. Computer Science
3737 Wascana Parkway
Regina, Saskatchewan, S4S 0A2, Canada
e-mail: *jtyao@cs.uregina.ca*

Yiyu Yao
University of Regina
Dep. Computer Science
3737 Wascana Parkway
Regina, Saskatchewan, S4S 0A2, Canada
e-mail: *yyao@cs.uregina.ca*

Andreas Zabel
TU Dortmund University
Dep. Mechanical Engineering
Baroper Str. 303
44227 Dortmund, Germany
e-mail: *zabel@isf.de*

Sławomir Zadrożny
Polish Academy of Sciences
Systems Research Inst.
ul. Newelska 6
01-447 Warsaw, Poland
e-mail: *Slawomir.Zadrozny@ibspan.waw.pl*

Zhigang Zeng
Huazhong University of Science and Technology
Dep. Control Science and Engineering
No. 1037, Luoyu Road
430074 Wuhan, China
e-mail: *zgzeng@hust.edu.cn*

Yan Zhang
University of Regina
Dep. Computer Science
3737 Wascana Parkway
Regina, Saskatchewan, S4S 0A2, Canada
e-mail: *zhang83y@cs.uregina.ca*

Zhi-Hua Zhou
Nanjing University
National Key Lab. for Novel Software Technology
210023 Nanjing, China
e-mail: *zhouzh@nju.edu.cn*

Contents

List of Abbreviations XLV

1 **Introduction**
Janusz Kacprzyk, Witold Pedrycz 1
1.1 Details of the Contents 2
1.2 Conclusions and Acknowledgments 4

Part A Foundations

2 **Many-Valued and Fuzzy Logics**
Siegfried Gottwald 7
2.1 Basic Many-Valued Logics 8
2.2 Fuzzy Sets 11
2.3 t-Norm-Based Logics 13
2.4 Particular Fuzzy Logics 16
2.5 Some Generalizations 21
2.6 Extensions with Graded Notions of Inference 23
2.7 Some Complexity Results 25
2.8 Concluding Remarks 27
References 27

3 **Possibility Theory and Its Applications: Where Do We Stand?**
Didier Dubois, Henry Prade 31
3.1 Historical Background 32
3.2 Basic Notions of Possibility Theory 33
3.3 Qualitative Possibility Theory 38
3.4 Quantitative Possibility Theory 45
3.5 Some Applications 49
3.6 Some Current Research Lines 53
References 54

4 **Aggregation Functions on [0,1]**
Radko Mesiar, Anna Kolesárová, Magda Komorníková 61
4.1 Historical and Introductory Remarks 61
4.2 Classification of Aggregation Functions 63
4.3 Properties and Construction Methods 66
4.4 Concluding Remarks 71
References 72

5 **Monotone Measures-Based Integrals**
Erich P. Klement, Radko Mesiar 75
5.1 Preliminaries, Choquet, and Sugeno Integrals 76
5.2 Benvenuti Integral 80

5.3 Universal Integrals 82
5.4 General Integrals Which Are Not Universal 84
5.5 Concluding Remarks, Application Fields 86
References 87

6 **The Origin of Fuzzy Extensions**
Humberto Bustince, Edurne Barrenechea, Javier Fernández, Miguel Pagola, Javier Montero 89
6.1 Considerations Prior to the Concept of Extension of Fuzzy Sets 90
6.2 Origin of the Extensions 93
6.3 Type-2 Fuzzy Sets 94
6.4 Interval-Valued Fuzzy Sets 98
6.5 Atanasssov's Intuitionistic Fuzzy Sets or Bipolar Fuzzy Sets of Type 2 or IF Fuzzy Sets 103
6.6 Atanassov's Interval-Valued Intuitionistic Fuzzy Sets 105
6.7 Links Between the Extensions of Fuzzy Sets 106
6.8 Other Types of Sets 106
6.9 Conclusions 108
References 108

7 ***F*-Transform**
Irina Perfilieva 113
7.1 Fuzzy Modeling 113
7.2 Fuzzy Partitions 114
7.3 Fuzzy Transform 117
7.4 Discrete *F*-Transform 119
7.5 *F*-Transforms of Functions of Two Variables 120
7.6 F^1-Transform 121
7.7 Applications 122
7.8 Conclusions 129
References 129

8 **Fuzzy Linear Programming and Duality**
Jaroslav Ramík, Milan Vlach 131
8.1 Preliminaries 132
8.2 Fuzzy Linear Programming 135
8.3 Duality in Fuzzy Linear Programming 137
8.4 Conclusion 143
References 143

9 **Basic Solutions of Fuzzy Coalitional Games**
Tomáš Kroupa, Milan Vlach 145
9.1 Coalitional Games with Transferable Utility 146
9.2 Coalitional Games with Fuzzy Coalitions 150
9.3 Final Remarks 155
References 156

Part B Fuzzy Logic

10 **Basics of Fuzzy Sets**
János C. Fodor, Imre J. Rudas 159
10.1 Classical Mathematics and Logic 160
10.2 Fuzzy Logic, Membership Functions, and Fuzzy Sets 160
10.3 Connectives in Fuzzy Logic 161
10.4 Concluding Remarks 168
References 168

11 **Fuzzy Relations: Past, Present, and Future**
Susana Montes, Ignacio Montes, Tania Iglesias 171
11.1 Fuzzy Relations 172
11.2 Cut Relations 174
11.3 Fuzzy Binary Relations 174
11.4 Particular Cases of Fuzzy Binary Relations 179
11.5 Present and Future of Fuzzy Relations 180
References 180

12 **Fuzzy Implications: Past, Present, and Future**
Michał Baczynski, Balasubramaniam Jayaram, Sebastia Massanet, Joan Torrens 183
12.1 Fuzzy Implications: Examples, Properties, and Classes 184
12.2 Current Research on Fuzzy Implications 187
12.3 Fuzzy Implications in Applications 193
12.4 Future of Fuzzy Implications 198
References 199

13 **Fuzzy Rule-Based Systems**
Luis Magdalena 203
13.1 Components of a Fuzzy Rule Based-System 204
13.2 Types of Fuzzy Rule-Based Systems 209
13.3 Hierarchical Fuzzy Rule-Based Systems 213
13.4 Fuzzy Rule-Based Systems Design 214
13.5 Conclusions 216
References 217

14 **Interpretability of Fuzzy Systems: Current Research Trends and Prospects**
Jose M. Alonso, Ciro Castiello, Corrado Mencar 219
14.1 The Quest for Interpretability 220
14.2 Interpretability Constraints and Criteria 224
14.3 Interpretability Assessment 227
14.4 Designing Interpretable Fuzzy Systems 229
14.5 Interpretable Fuzzy Systems in the Real World 233
14.6 Future Research Trends on Interpretable Fuzzy Systems 234
14.7 Conclusions 234
References 235

15 **Fuzzy Clustering – Basic Ideas and Overview**
Sadaaki Miyamoto 239
15.1 Fuzzy Clustering 239
15.2 Fuzzy *c*-Means 239
15.3 Hierarchical Fuzzy Clustering 245
15.4 Conclusion 246
References 247

16 **An Algebraic Model of Reasoning to Support Zadeh's CWW**
Enric Trillas 249
16.1 A View on Reasoning 249
16.2 Models 250
16.3 Reasoning 251
16.4 Reasoning and Logic 254
16.5 A Possible Scheme for an Algebraic Model of Commonsense Reasoning 255
16.6 Weak and Strong Deduction: Refutations and Conjectures in a BFA (with a Few Restrictions) 260
16.7 Toward a Classification of Conjectures 262
16.8 Last Remarks 264
16.9 Conclusions 265
References 266

17 **Fuzzy Control**
Christian Moewes, Ralf Mikut, Rudolf Kruse 269
17.1 Knowledge-Driven Control 269
17.2 Classical Control Engineering 270
17.3 Using Fuzzy Rules for Control 271
17.4 A Glance at Some Industrial Applications 276
17.5 Automatic Learning of Fuzzy Controllers 279
17.6 Conclusions 281
References 281

18 **Interval Type-2 Fuzzy PID Controllers**
Tufan Kumbasar, Hani Hagras 285
18.1 Fuzzy Control Background 285
18.2 The General Fuzzy PID Controller Structure 286
18.3 Simulation Studies 291
18.4 Conclusion 292
References 293

19 **Soft Computing in Database and Information Management**
Guy De Tré, Sławomir Zadrożny 295
19.1 Challenges for Modern Information Systems 295
19.2 Some Preliminaries 296
19.3 Soft Computing in Information Modeling 298
19.4 Soft Computing in Querying 302
19.5 Conclusions 309
References 309

20 **Application of Fuzzy Techniques to Autonomous Robots**
Ismael Rodríguez Fdez, Manuel Mucientes, Alberto Bugarín Diz 313
20.1 Robotics and Fuzzy Logic 313
20.2 Wall-Following 314
20.3 Navigation 315
20.4 Trajectory Tracking 317
20.5 Moving Target Tracking 318
20.6 Perception 319
20.7 Planning 319
20.8 SLAM 320
20.9 Cooperation 320
20.10 Legged Robots 321
20.11 Exoskeletons and Rehabilitation Robots 322
20.12 Emotional Robots 323
20.13 Fuzzy Modeling 323
20.14 Comments and Conclusions 324
References 325

Part C Rough Sets

21 **Foundations of Rough Sets**
Andrzej Skowron, Andrzej Jankowski, Roman W. Swiniarski 331
21.1 Rough Sets: Comments on Development 331
21.2 Vague Concepts 332
21.3 Rough Set Philosophy 333
21.4 Indiscernibility and Approximation 333
21.5 Decision Systems and Decision Rules 336
21.6 Dependencies 337
21.7 Reduction of Attributes 337
21.8 Rough Membership 338
21.9 Discernibility and Boolean Reasoning 339
21.10 Rough Sets and Induction 340
21.11 Rough Set-Based Generalizations 340
21.12 Rough Sets and Logic 343
21.13 Conclusions 347
References 347

22 **Rough Set Methodology for Decision Aiding**
Roman Słowiński, Salvatore Greco, Benedetto Matarazzo 349
22.1 Data Inconsistency as a Reason for Using Rough Sets 350
22.2 The Need for Replacing the Indiscernibility Relation by the Dominance Relation when Reasoning About Ordinal Data 351
22.3 The Dominance-based Rough Set Approach to Multi-Criteria Classification 353
22.4 The Dominance-based Rough Set Approach to Multi-Criteria Choice and Ranking 361
22.5 Important Extensions of DRSA 366

22.6 DRSA to Operational Research Problems 366
22.7 Concluding Remarks on DRSA Applied to Multi-Criteria Decision Problems 367
References 367

23 **Rule Induction from Rough Approximations**
Jerzy W. Grzymala-Busse 371
23.1 Complete and Consistent Data 371
23.2 Inconsistent Data 375
23.3 Decision Table with Numerical Attributes 377
23.4 Incomplete Data 378
23.5 Conclusions 384
References 384

24 **Probabilistic Rough Sets**
Yiyu Yao, Salvatore Greco, Roman Słowiński 387
24.1 Motivation for Studying Probabilistic Rough Sets 388
24.2 Pawlak Rough Sets 388
24.3 A Basic Model of Probabilistic Rough Sets 390
24.4 Variants of Probabilistic Rough Sets 391
24.5 Three Fundamental Issues of Probabilistic Rough Sets 394
24.6 Dominance-Based Rough Set Approaches 398
24.7 A Basic Model of Dominance-Based Probabilistic Rough Sets 399
24.8 Variants of Probabilistic Dominance-Based Rough Set Approach ... 400
24.9 Three Fundamental Issues of Probabilistic Dominance-Based Rough Sets 403
24.10 Conclusions 409
References 409

25 **Generalized Rough Sets**
JingTao Yao, Davide Ciucci, Yan Zhang 413
25.1 Definition and Approximations of the Models 414
25.2 Theoretical Approaches 420
25.3 Conclusion 422
References 423

26 **Fuzzy-Rough Hybridization**
Masahiro Inuiguchi, Wei-Zhi Wu, Chris Cornelis, Nele Verbiest 425
26.1 Introduction to Fuzzy-Rough Hybridization 425
26.2 Classification- Versus Approximation-Oriented Fuzzy Rough Set Models 427
26.3 Generalized Fuzzy Belief Structures with Application in Fuzzy Information Systems 437
26.4 Applications of Fuzzy Rough Sets 444
References 447

Part D Neural Networks

27 **Artificial Neural Network Models**
Peter Tino, Lubica Benuskova, Alessandro Sperduti 455
27.1 Biological Neurons 455
27.2 Perceptron 456
27.3 Multilayered Feed-Forward ANN Models 458
27.4 Recurrent ANN Models 460
27.5 Radial Basis Function ANN Models 464
27.6 Self-Organizing Maps 465
27.7 Recursive Neural Networks 467
27.8 Conclusion 469
References 470

28 **Deep and Modular Neural Networks**
Ke Chen 473
28.1 Overview 473
28.2 Deep Neural Networks 474
28.3 Modular Neural Networks 484
28.4 Concluding Remarks 492
References 492

29 **Machine Learning**
James T. Kwok, Zhi-Hua Zhou, Lei Xu 495
29.1 Overview 495
29.2 Supervised Learning 497
29.3 Unsupervised Learning 502
29.4 Reinforcement Learning 510
29.5 Semi-Supervised Learning 513
29.6 Ensemble Methods 514
29.7 Feature Selection and Extraction 518
References 519

30 **Theoretical Methods in Machine Learning**
Badong Chen, Weifeng Liu, José C. Principe 523
30.1 Background Overview 524
30.2 Reproducing Kernel Hilbert Spaces 525
30.3 Online Learning with Kernel Adaptive Filters 527
30.4 Illustration Examples 538
30.5 Conclusion 542
References 542

31 **Probabilistic Modeling in Machine Learning**
Davide Bacciu, Paulo J.G. Lisboa, Alessandro Sperduti, Thomas Villmann . 545
31.1 Probabilistic and Information-Theoretic Methods 545
31.2 Graphical Models 552
31.3 Latent Variable Models 560
31.4 Markov Models 565
31.5 Conclusion and Further Reading 572
References 573

32 **Kernel Methods**
Marco Signoretto, Johan A. K. Suykens 577
32.1 Background 578
32.2 Foundations of Statistical Learning 580
32.3 Primal–Dual Methods 586
32.4 Gaussian Processes 593
32.5 Model Selection 596
32.6 More on Kernels 597
32.7 Applications 600
References 601

33 **Neurodynamics**
Robert Kozma, Jun Wang, Zhigang Zeng 607
33.1 Dynamics of Attractor and Analog Networks 607
33.2 Synchrony, Oscillations, and Chaos in Neural Networks 611
33.3 Memristive Neurodynamics 629
33.4 Neurodynamic Optimization 634
References 639

34 **Computational Neuroscience – Biophysical Modeling of Neural Systems**
Harrison Stratton, Jennie Si 649
34.1 Anatomy and Physiology of the Nervous System 649
34.2 Cells and Signaling Among Cells 652
34.3 Modeling Biophysically Realistic Neurons 656
34.4 Reducing Computational Complexity for Large Network Simulations 660
34.5 Conclusions 662
References 662

35 **Computational Models of Cognitive and Motor Control**
Ali A. Minai 665
35.1 Overview 665
35.2 Motor Control 667
35.3 Cognitive Control and Working Memory 670
35.4 Conclusion 674
References 674

36 **Cognitive Architectures and Agents**
Sebastien Hélie, Ron Sun 683
36.1 Background 683
36.2 Adaptive Control of Thought-Rational (ACT-R) 685
36.3 Soar 688
36.4 CLARION 690
36.5 Cognitive Architectures as Models of Multi-Agent Interaction 693
36.6 General Discussion 694
References 695

37 **Embodied Intelligence**
Angelo Cangelosi, Josh Bongard, Martin H. Fischer, Stefano Nolfi 697
37.1 Introduction to Embodied Intelligence 697
37.2 Morphological Computation for Body-Behavior Coadaptation 698
37.3 Sensory–Motor Coordination in Evolving Robots 701
37.4 Developmental Robotics for Higher Order Embodied Cognitive Capabilities 703
37.5 Conclusion 709
References 711

38 **Neuromorphic Engineering**
Giacomo Indiveri 715
38.1 The Origins 715
38.2 Neural and Neuromorphic Computing 716
38.3 The Importance of Fundamental Neuroscience 717
38.4 Temporal Dynamics in Neuromorphic Architectures 718
38.5 Synapse and Neuron Circuits 719
38.6 Spike-Based Multichip Neuromorphic Systems 721
38.7 State-Dependent Computation in Neuromorphic Systems 722
38.8 Conclusions 722
References 723

39 **Neuroengineering**
Damien Coyle, Ronen Sosnik 727
39.1 Overview – Neuroengineering in General 728
39.2 Human Motor Control 732
39.3 Modeling the Motor System – Internal Motor Models 733
39.4 Sensorimotor Learning 736
39.5 MRI and the Motor System – Structure and Function 738
39.6 Electrocorticographic Motor Cortical Surface Potentials 741
39.7 MEG and EEG – Extra Cerebral Magnetic and Electric Fields of the Motor System 745
39.8 Extracellular Recording – Decoding Hand Movements from Spikes and Local Field Potential 748
39.9 Translating Brainwaves into Control Signals – BCIs 754
39.10 Conclusion 762
References 764

40 **Evolving Connectionist Systems: From Neuro-Fuzzy-, to Spiking- and Neuro-Genetic**
Nikola Kasabov 771
40.1 Principles of Evolving Connectionist Systems (ECOS) 771
40.2 Hybrid Systems and Evolving Neuro-Fuzzy Systems 772
40.3 Evolving Spiking Neural Networks (eSNN) 775
40.4 Computational Neuro-Genetic Modeling (CNGM) 778
40.5 Conclusions and Further Directions 779
References 780

41 **Machine Learning Applications**
Piero P. Bonissone 783
41.1 Motivation 784
41.2 Machine Learning (ML) Functions 786
41.3 CI/ML Applications in Industrial Domains: Prognostics and Health Management (PHM) 787
41.4 CI/ML Applications in Financial Domains: Risk Management 797
41.5 Model Ensembles and Fusion 807
41.6 Summary and Future Research Challenges 812
References 817

Part E Evolutionary Computation

42 **Genetic Algorithms**
Jonathan E. Rowe 825
42.1 Algorithmic Framework 826
42.2 Selection Methods 828
42.3 Replacement Methods 831
42.4 Mutation Methods 832
42.5 Selection–Mutation Balance 834
42.6 Crossover Methods 836
42.7 Population Diversity 838
42.8 Parallel Genetic Algorithms 839
42.9 Populations as Solutions 841
42.10 Conclusions 842
References 843

43 **Genetic Programming**
James McDermott, Una-May O'Reilly 845
43.1 Evolutionary Search for Executable Programs 845
43.2 History 846
43.3 Taxonomy of AI and GP 848
43.4 Uses of GP 853
43.5 Research Topics 857
43.6 Practicalities 861
References 862

44 **Evolution Strategies**
Nikolaus Hansen, Dirk V. Arnold, Anne Auger 871
44.1 Overview 871
44.2 Main Principles 873
44.3 Parameter Control 877
44.4 Theory 886
References 895

45 **Estimation of Distribution Algorithms**
Martin Pelikan, Mark W. Hauschild, Fernando G. Lobo 899
45.1 Basic EDA Procedure 900

45.2 Taxonomy of EDA Models 903
45.3 Overview of EDAs 908
45.4 EDA Theory 916
45.5 Efficiency Enhancement Techniques for EDAs 917
45.6 Starting Points for Obtaining Additional Information 920
45.7 Summary and Conclusions 921
References 921

46 **Parallel Evolutionary Algorithms**
Dirk Sudholt 929
46.1 Parallel Models 931
46.2 Effects of Parallelization 935
46.3 On the Spread of Information in Parallel EAs 938
46.4 Examples Where Parallel EAs Excel 943
46.5 Speedups by Parallelization 949
46.6 Conclusions 956
References 957

47 **Learning Classifier Systems**
Martin V. Butz 961
47.1 Background 962
47.2 XCS 965
47.3 XCSF 970
47.4 Data Mining 972
47.5 Behavioral Learning 973
47.6 Conclusions 977
47.7 Books and Source Code 978
References 979

48 **Indicator-Based Selection**
Lothar Thiele 983
48.1 Motivation 983
48.2 Basic Concepts 984
48.3 Selection Schemes 987
48.4 Preference-Based Selection 990
48.5 Concluding Remarks 992
References 993

49 **Multi-Objective Evolutionary Algorithms**
Kalyanmoy Deb 995
49.1 Preamble 995
49.2 Evolutionary Multi-Objective Optimization (EMO) 996
49.3 A Brief Timeline for the Development of EMO Methodologies 999
49.4 Elitist EMO: NSGA-II 1000
49.5 Applications of EMO 1002
49.6 Recent Developments in EMO 1004
49.7 Conclusions 1010
References 1011

50 **Parallel Multiobjective Evolutionary Algorithms**
Francisco Luna, Enrique Alba 1017
50.1 Multiobjective Optimization and Parallelism 1017
50.2 Parallel Models for Evolutionary Multi-Objective Algorithms 1018
50.3 An Updated Review of the Literature 1020
50.4 Conclusions and Future Works 1026
References 1027

51 **Many-Objective Problems: Challenges and Methods**
Antonio López Jaimes, Carlos A. Coello Coello 1033
51.1 Background 1033
51.2 Basic Concepts and Notation 1034
51.3 Sources of Difficulty to Solve Many-Objective Optimization Problems 1036
51.4 Current Approaches to Deal with Many-Objective Problems 1038
51.5 Recombination Operators and Mating Restrictions 1042
51.6 Scalarization Methods 1043
51.7 Conclusions and Research Paths 1043
References 1044

52 **Memetic and Hybrid Evolutionary Algorithms**
Jhon Edgar Amaya, Carlos Cotta Porras, Antonio J. Fernández Leiva 1047
52.1 Overview 1047
52.2 A Bird's View of Evolutionary Algorithms 1049
52.3 From Hybrid Metaheuristics to Hybrid EAs 1050
52.4 Memetic Algorithms 1052
52.5 Cooperative Optimization Models 1055
52.6 Conclusions 1056
References 1056

53 **Design of Representations and Search Operators**
Franz Rothlauf 1061
53.1 Representations 1061
53.2 Search Operators 1065
53.3 Problem-Specific Design of Representations and Search Operators 1071
53.4 Summary and Conclusions 1079
References 1080

54 **Stochastic Local Search Algorithms: An Overview**
Holger H. Hoos, Thomas Stützle 1085
54.1 The Nature and Concept of SLS 1086
54.2 Greedy Construction Heuristics and Iterative Improvement 1089
54.3 *Simple* SLS Methods 1091
54.4 Hybrid SLS Methods 1094
54.5 Population-Based SLS Methods 1095
54.6 Recent Research Directions 1097
References 1100

55 **Parallel Evolutionary Combinatorial Optimization**
El-Ghazali Talbi 1107
55.1 Motivation 1107
55.2 Parallel Design of EAs 1108
55.3 Parallel Implementation of EAs 1113
55.4 Parallel EAs Under ParadisEO 1122
55.5 Conclusions and Perspectives 1123
References 1124

56 **How to Create Generalizable Results**
Thomas Bartz-Beielstein 1127
56.1 Test Problems in Computational Intelligence 1127
56.2 Features of Optimization Problems 1128
56.3 Algorithm Features 1130
56.4 Objective Functions 1131
56.5 Case Studies 1133
56.6 Summary and Outlook 1141
References 1142

57 **Computational Intelligence in Industrial Applications**
Ekaterina Vladislavleva, Guido Smits, Mark Kotanchek 1143
57.1 Intelligence and Computation 1143
57.2 Computational Modeling for Predictive Analytics 1144
57.3 Methods 1147
57.4 Workflows 1149
57.5 Examples 1150
57.6 Conclusions 1155
References 1156

58 **Solving Phase Equilibrium Problems by Means of Avoidance-Based Multiobjectivization**
Mike Preuss, Simon Wessing, Günter Rudolph, Gabriele Sadowski 1159
58.1 Coping with Real-World Optimization Problems 1159
58.2 The Phase-Equilibrium Calculation Problem 1161
58.3 Multiobjectivization-Assisted Multimodal Optimization: MOAMO 1162
58.4 Solving General Phase-Equilibrium Problems 1165
58.5 Conclusions and Outlook 1169
References 1169

59 **Modeling and Optimization of Machining Problems**
Dirk Biermann, Petra Kersting, Tobias Wagner, Andreas Zabel 1173
59.1 Elements of a Machining Process 1174
59.2 Design Optimization 1175
59.3 Computer-Aided Design and Manufacturing 1176
59.4 Modeling and Simulation of the Machining Process 1177
59.5 Optimization of the Process Parameters 1178
59.6 Process Monitoring 1179
59.7 Visualization 1179

59.8 Summary and Outlook 1180
References 1180

60 **Aerodynamic Design with Physics-Based Surrogates**
Emiliano Iuliano, Domenico Quagliarella 1185
60.1 The Aerodynamic Design Problem 1186
60.2 Literature Review of Surrogate-Based Optimization 1187
60.3 POD-Based Surrogates 1190
60.4 Application Example of POD-Based Surrogates 1191
60.5 Strategies for Improving POD Model Quality: Adaptive Sampling 1199
60.6 Aerodynamic Shape Optimization by Surrogate Modeling and Evolutionary Computing 1201
60.7 Conclusions 1207
References 1208

61 **Knowledge Discovery in Bioinformatics**
Julie Hamon, Julie Jacques, Laetitia Jourdan, Clarisse Dhaenens 1211
61.1 Challenges in Bioinformatics 1211
61.2 Association Rules by Evolutionary Algorithm in Bioinformatics 1212
61.3 Feature Selection for Classification and Regression by Evolutionary Algorithm in Bioinformatics 1215
61.4 Clustering by Evolutionary Algorithm in Bioinformatics 1218
61.5 Conclusion 1220
References 1221

62 **Integration of Metaheuristics and Constraint Programming**
Luca Di Gaspero 1225
62.1 Constraint Programming and Metaheuristics 1225
62.2 Constraint Programming Essentials 1226
62.3 Integration of Metaheuristics and CP 1230
62.4 Conclusions 1234
References 1235

63 **Graph Coloring and Recombination**
Rhyd Lewis 1239
63.1 Graph Coloring 1239
63.2 Algorithms for Graph Coloring 1240
63.3 Setup 1244
63.4 Experiment 1 1246
63.5 Experiment 2 1249
63.6 Conclusions and Discussion 1251
References 1252

64 **Metaheuristic Algorithms and Tree Decomposition**
Thomas Hammerl, Nysret Musliu, Werner Schafhauser 1255
64.1 Tree Decompositions 1256
64.2 Generating Tree Decompositions by Metaheuristic Techniques 1258
64.3 Conclusion 1268
References 1269

65 **Evolutionary Computation and Constraint Satisfaction**
Jano I. van Hemert 1271
65.1 Informal Introduction to CSP 1271
65.2 Formal Definitions 1272
65.3 Solving CSP with Evolutionary Algorithms 1273
65.4 Performance Indicators 1275
65.5 Specific Constraint Satisfaction Problems 1277
65.6 Creating Rather than Solving Problems 1283
65.7 Conclusions and Future Directions 1284
References 1284

Part F Swarm Intelligence

66 **Swarm Intelligence in Optimization and Robotics**
Christian Blum, Roderich Groß 1291
66.1 Overview 1291
66.2 SI in Optimization 1292
66.3 SI in Robotics: Swarm Robotics 1296
66.4 Research Challenges 1302
References 1303

67 **Preference-Based Multiobjective Particle Swarm Optimization for Airfoil Design**
Robert Carrese, Xiaodong Li 1311
67.1 Airfoil Design 1311
67.2 Shape Parameterization and Flow Solver 1317
67.3 Optimization Algorithm 1319
67.4 Case Study: Airfoil Shape Optimization 1323
67.5 Conclusion 1329
References 1329

68 **Ant Colony Optimization for the Minimum-Weight Rooted Arborescence Problem**
Christian Blum, Sergi Mateo Bellido 1333
68.1 Introductiory Remarks 1333
68.2 The Minimum-Weight Rooted Arborescence Problem 1334
68.3 DP-Heur: A Heuristic Approach to the MWRA Problem 1335
68.4 Ant Colony Optimization for the MWRA Problem 1335
68.5 Experimental Evaluation 1337
68.6 Conclusions and Future Work 1343
References 1343

69 **An Intelligent Swarm of Markovian Agents**
Dario Bruneo, Marco Scarpa, Andrea Bobbio, Davide Cerotti, Marco Gribaudo 1345
69.1 Swarm Intelligence: A Modeling Perspective 1345
69.2 Markovian Agent Models 1346
69.3 A Consolidated Example: WSN Routing 1349

69.4 Ant Colony Optimization 1354
69.5 Conclusions 1358
References 1359

70 **Honey Bee Social Foraging Algorithm for Resource Allocation**
Jairo Alonso Giraldo, Nicanor Quijano, Kevin M. Passino 1361
70.1 Honey Bee Foraging Algorithm 1363
70.2 Application in a Multizone Temperature Control Grid 1365
70.3 Results 1371
70.4 Discussion 1373
70.5 Conclusions 1374
References 1374

71 **Fundamental Collective Behaviors in Swarm Robotics**
Vito Trianni, Alexandre Campo 1377
71.1 Designing Swarm Behaviours 1378
71.2 Getting Together: Aggregation 1379
71.3 Acting Together: Synchronization 1381
71.4 Staying Together: Coordinated Motion 1383
71.5 Searching Together: Collective Exploration 1386
71.6 Deciding Together: Collective Decision Making 1388
71.7 Conclusions 1390
References 1391

72 **Collective Manipulation and Construction**
Lynne Parker 1395
72.1 Object Transportation 1395
72.2 Object Sorting and Clustering 1401
72.3 Collective Construction and Wall Building 1402
72.4 Conclusions 1404
References 1404

73 **Reconfigurable Robots**
Kasper Støy 1407
73.1 Mechatronics System Integration 1409
73.2 Connection Mechanisms 1410
73.3 Energy 1411
73.4 Distributed Control 1412
73.5 Programmability and Debugging 1417
73.6 Perspective 1418
73.7 Further Reading 1419
References 1419

74 **Probabilistic Modeling of Swarming Systems**
Nikolaus Correll, Heiko Hamann 1423
74.1 From Bioligical to Artificial Swarms 1423
74.2 The Master Equation 1424
74.3 Non-Spatial Probabilistic Models 1424

74.4 Spatial Models: Collective Optimization 1428
74.5 Conclusion 1431
References 1431

Part G Hybrid Systems

75 **A Robust Evolving Cloud-Based Controller**
Plamen P. Angelov, Igor Škrjanc, Sašo Blažič 1435
75.1 Overview of Some Adaptive and Evolving Control Approaches 1435
75.2 Structure of the Cloud-Based Controller 1437
75.3 Evolving Methodology for RECCo 1439
75.4 Simulation Study 1442
75.5 Conclusions 1447
References 1448

76 **Evolving Embedded Fuzzy Controllers**
Oscar H. Montiel Ross, Roberto Sepúlveda Cruz 1451
76.1 Overview 1452
76.2 Type-1 and Type-2 Fuzzy Controllers 1454
76.3 Host Technology 1457
76.4 Hardware Implementation Approaches 1458
76.5 Development of a Standalone IT2FC 1461
76.6 Developing of IT2FC Coprocessors 1466
76.7 Implementing a GA in an FPGA 1468
76.8 Evolving Fuzzy Controllers 1470
References 1475

77 **Multiobjective Genetic Fuzzy Systems**
Hisao Ishibuchi, Yusuke Nojima 1479
77.1 Fuzzy System Design 1479
77.2 Accuracy Maximization 1482
77.3 Complexity Minimization 1487
77.4 Single-Objective Approaches 1489
77.5 Evolutionary Multiobjective Approaches 1491
77.6 Conclusion 1494
References 1494

78 **Bio-Inspired Optimization of Type-2 Fuzzy Controllers**
Oscar Castillo 1499
78.1 Related Work in Type-2 Fuzzy Control 1499
78.2 Fuzzy Logic Systems 1500
78.3 Bio-Inspired Optimization Methods 1503
78.4 General Overview of the Area and Future Trends 1505
78.5 Conclusions 1506
References 1506

79 **Pattern Recognition with Modular Neural Networks and Type-2 Fuzzy Logic**
Patricia Melin 1509
79.1 Related Work in the Area 1509
79.2 Overview of Fuzzy Edge Detectors 1510
79.3 Experimental Setup 1512
79.4 Experimental Results 1513
79.5 Conclusions 1515
References 1515

80 **Fuzzy Controllers for Autonomous Mobile Robots**
Patricia Melin, Oscar Castillo 1517
80.1 Fuzzy Control of Mobile Robots 1517
80.2 The Chemical Optimization Paradigm 1518
80.3 The Mobile Robot 1521
80.4 Fuzzy Logic Controller 1522
80.5 Experimental Results 1523
80.6 Conclusions 1530
References 1530

81 **Bio-Inspired Optimization Methods**
Fevrier Valdez 1533
81.1 Bio-Inspired Methods 1533
81.2 Bio-Inspired Optimization Methods 1533
81.3 A Brief History of GPUs 1535
81.4 Experimental Results 1535
81.5 Conclusions 1538
References 1538

Acknowledgements 1539
About the Authors 1543
Detailed Contents 1569
Index 1605

List of Abbreviations

Symbols

1-D	one-dimensional
2-D	two-dimensional
3-CNF-SAT	three variables/clause-conjunctive normal form-satisfiability
3-D	three-dimensional

A

A2A	all-to-all
AaaS	analytics-as-a-service
AANN	auto-associative neural network
ABC	artificial bee colony
ACC	anterior cingulate cortex
ACO	ant colony optimization
ACP	active categorical perception
ACS	action-centered subsystem
ACS	ant colony system
ACT-R	adaptive control of thought-rational
AD	anomaly detection
ADC	analog digital converter
ADF	additively decomposable function
ADF	automatically defined function
ADGLIB	adaptive genetic algorithm optimization library
AER	address event representation
AFPGA	adaptive full POD genetic algorithm
AFSA	artificial fish swarm algorithm
AI	anomaly identification
AI	artificial intelligence
AIC	Akaike information criterion
AICOMP	comparable based AI model
AIGEN	generative AI model
ALCS	anticipatory learning classifier system
ALD	approximate linear dependency
ALM	asset–liability management
ALU	arithmetic logic unit
ALU	arithmetic unit
AM	amplitude modulation
amBOA	adaptive variant of mBOA
AMPGA	adaptive mixed-flow POD genetic algorithm
AMS	anticipated mean shift
AMT	active media technology
ANN	artificial neural network
ANOVA	analysis of variance
ANYA	Angelov–Yager
AP	alternating-position crossover
AP	automatic programming
APA	affine projection algorithm
API	application programming interface
APS	aggregation pheromone system
APSD	auto power spectral density
AR	approximate reasoning
AR	average ranking
ARD	automatic relevance determination
ARGOT	adaptive representation genetic optimization technique
ARMOGA	adaptive range MOGA
ASIC	application-specific integrated circuit
ASP	answer-set programming
ATP	adenosine triphosphate
AUC	area under curve
AUC	area under ROC curve
AVITEWRITE	adaptive vector integration to endpoint handwriting

B

BBB	blood brain barrier
BCI	brain–computer interface
BCO	bee colony optimization
BDAS	Berkeley data analytics stack
BER	bit error rate
BeRoSH	behavior-based multiple robot system with host for object manipulation
BFA	basic fuzzy algebra
BG	basal ganglia
BIC	Bayesian information criterion
BINCSP	binary constraint satisfaction problem
BioHEL	bioinformatics-oriented hierarchical evolutionary learning
BKS	Bandler–Kohout subproduct
BLB	bag of little bootstrap
BMA	Bayes model averaging
BMDA	bivariate marginal distribution algorithm
BMF	binary matrix factorization
BMI	brain–machine interface
BnB	branch and bound
BOA	Bayesian optimization algorithm
BP	bereitschafts potential

BP	back-propagation
BPTT	back-propagation through time
BSB	base system builder
BSD	bipolar satisfaction degree
BSS	blind source separation
BYY	Bayesian Yin-Yang

C

c-granule	complex granule
CA	cellular automata
CA	classification accuracy
CA	complete F-transform-based fusion algorithm
CAD	computer-aided design
CAE	contrastive auto-encoder
CAM	computer-assisted manufacturing
CART	classification analysis and regression tree
CBLS	constraint-based local search
CBR	case-based reasoner
CBR	case-based reasoning
CC	coherence criterion
CCF	cross correlation function
CCG	controlling crossed genes
CD	contrastive divergence
CEA	cellular evolutionary algorithm
CEBOT	cellular robot
CF	collaborative filtering
CF	compact flash
cf	convergence factor
CFD	computational fluid dynamics
CFG	context-free grammar
CFS	correlation feature selection
CG	center of gravity
CG	Cohen–Grossberg
cGA	compact genetic algorithm
CGP	Cartesian GP
CI	computational intelligence
CIP	cross information potential
CIS	Computational Intelligence Society
CLB	configurable logic block
clk	clock
CLM	component level model
CMA	cingulate motor area
CMA	covariance matrix adaptation
CML	coupled map lattice
cMOEA	cellular MOEA
CMOS	complementary metal-oxide-semiconductor
CNF	conjunctive normal form
CNGM	computational neuro-genetic modeling
CNN	cellular neural network
CNS	central nervous system
COA	center of area
COG	center of gravity
COGIN	coverage-based genetic induction
COP	cluster of processors
COP	constrained optimization problem
CORE	Computing Research and Education
cos	center of set
COW	cluster of workstations
CP	constraint programming
CP	contrapositive symmetry
CP net	conditional preference network
CPF	centralized Pareto front
CPG	central pattern generator
CPSD	cross power spectral density
CPT	cummulative prospect theory
CPU	central processing unit
CR	commonsense reasoning
CR	control register
CRA	chemical reaction algorithm
CRI	compositional rule of inference
CS	cell saving
CS1	cognitive system
CSA	contractual service agreement
CSA	cumulative step-size adaptation
CSM	covariate shift minimization
CSP	common spatial pattern
CSP	constraint satisfaction problem
CST	class-shape transformation
CST	corticospinal tract
CTMC	continuous-time finite Markov chain
CUDA	compute unified device architecture
CW	computing with words
CW	control word
CWW	computing with words
CX	cycle crossover

D

DA	dopamine
DACE	design and analysis of computer experiments
DAE	denoising auto-encoder
DAG	directed acyclic graph
DAL	logic for data analysis
DB	database
DBN	deep belief network
dBOA	decision-graph BOA

DC	direct current
DC/AD	change/activate-deactivate
DCA	de-correlated component analysis
DE	differential evolution
dEA	distributed evolutionary algorithm
DENFIS	dynamic neuro-fuzzy inference system
deSNN	dynamic eSNN
DEUM	density estimation using Markov random fields algorithm
DEUM	distribution estimation using Markov random fields
DGA	direct genetic algorithm
DIC	deviance information criterion
DL	deep learning
DLPFC	dorsolateral prefrontal cortex
DLR	German Aerospace Center
DLS	dynamic local search
DM	displacement mutation operator
DM	decision maker
DMA	direct memory access
dMOEA	distributed MOEA
DNA	deoxyribonucleic acid
DNF	disjunctive normal form
DNN	deep neural network
DOE	design of experiment
DOF	degree of freedom
DP	dynamic programming
DPF	distributed Pareto front
DPLL	Davis–Putnam–Logemann–Loveland
DPR	dynamic partial reconfiguration
DRC	domain relational calculus
DREAM	distributed resource evolutionary algorithm machine
DRRS	dynamically reconfigurable robotic system
DRS	dominance resistant solution
DRSA	dominance-based rough set approach
DSA	data space adaptation
DSMGA	dependency-structure matrix genetic algorithm
DSP	digital signal processing
DSP	digital signal processor
DSS	decision support system
dtEDA	dependency-tree EDA
DTI	diffusion tensor imaging
DTLZ	Deb–Thiele–Laumanns–Zitzler
DTRS	decision-theoretic rough set
DW	data word

E

EA	evolutionary algorithm
EAPR	early access partial reconfiguration
EBNA	estimation of Bayesian network algorithm
EC	embodied cognition
EC	evolutionary computation
EC	evolutionary computing
ECGA	extended compact genetic algorithm
ECGP	extended compact genetic programming
ECJ	Java evolutionary computation
ECoG	electrocorticography
ECOS	evolving connectionist system
EDA	estimation of distribution algorithm
EDP	estimation of distribution programming
EEG	electroencephalogram
EEG	electroencephalography
EFRBS	evolutionary FRBS
EFuNN	evolving fuzzy neural network
EGA	equilibrium genetic algorithm
EGNA	estimation of Gaussian networks algorithm
EGO	efficient global optimization
EHBSA	edge histogram based sampling algorithm
EHM	edge histogram matrix
EI	expected improvement
EKM	enhanced KM
EKMANI	enhanced Karnik–Mendel algorithm with new initialization
ELSA	evolutionary local selection algorithm
EM	exchange mutation operator
EM	expectation maximization
EMG	electromyography
EMNA	estimation of multivariate normal algorithm
EMO	evolutionary multiobjective optimization
EMOA	evolutionary multiobjective algorithm
EMSE	excess mean square error
EODS	enhanced opposite directions searching
EP	evolutionary programming
EP	exchange property
EPTV	extended possibilistic truth value
ER	edge recombination
ERA	epigenetic robotics architecture
ERA	Excellence in Research for Australia
ERD	event-related desynchronization
ERM	empirical risk minimization
ERS	event-related synchronization
ES	embedding system
ES	evolution strategy

ESA	enhanced simple algorithm
ESN	echo state network
eSNN	evolving spiking neural network
ESOM	evolving self-organized map
ETS	evolving Takagi–Sugeno system
EV	extreme value
EvoStar	Main European Events on Evolutionary Computation
EvoWorkshops	European Workshops on Applications of Evolutionary Computation
EW-KRLS	exponentially weighted KRLS
EX-KRLS	extended kernel recursive least square

F

FA	factor analysis
FA	firefly algorithm
FA	fractional anisotropy
FA-DP	fitness assignment and diversity preservation
FATI	first aggregation then inference
FB-KRLS	fixed-budget KRLS
FCA	formal concept analysis
FCM	fuzzy *c*-means algorithm
FDA	factorized distribution algorithm
FDRC	fuzzy domain relational calculus
FDT	fuzzy decision tree
FEMO	fair evolutionary multi-objective optimizer
FGA	fuzzy generic algorithm
FIM	fuzzy inference mechanism
FIM	fuzzy instance based model
FIR	finite impulse response
FIS	fuzzy inference system
FIS1	type-1 fuzzy inference system
FIS2	type-2 fuzzy inference system
FITA	first inference then aggregation
FL	fuzzy logic
FLC	fuzzy logic controller
FlexCo	flexible coprocessor
FLP	fuzzy linear programming
FLS	fuzzy logic system
FM	fuzzy modeling
FMG	full multi-grid
FMM	finite mixture model
FMM	fuzzy mathematical morphology
fMRI	functional magneto-resonance imaging
FNN	fuzzy neural network
FNN	fuzzy nearest neighbor
FOM	full-order model
FOU	footprint of uncertainty
FPGA	field programmable gate array
FPGA	full POD genetic algorithm
FPID	fuzzy PID
FPM	fractal prediction machine
FPSO	fuzzy particle swarm optimization
FPU	floating point unit
FQL	fuzzy query language
FRB	fuzzy rule-based
FRBCS	fuzzy rule-based classification systems
FRBS	fuzzy rule-based system
FRC	fuzzy-rule based classifier
FRI	fuzzy relational inference
FS	fuzzy set
FS	fuzzy system
FSVM	fuzzy support vector machine
FTR	F-transform image compression
FURIA	unordered fuzzy rule induction algorithm
FX	foreign exchange

G

GA	general achievement
GA	genetic algorithm
GABA	gamma-aminobutyric acid
GACV	generalized approximate cross-validation
GAGRAD	genetic algorithm gradient
GAOT	genetic algorithm optimization toolbox
GC	granular computing
GCP	graph coloring problem
GE	grammatical evolution
GECCO	Genetic and Evolutionary Computation Conference
GEFRED	generalized fuzzy relational database
GFP	green fluorescent protein
GFS	genetic fuzzy system
GGA	grouping genetic algorithm
GGP	grammar-based genetic programming
GM	gray matter
GMP	generalized modus ponens
GMPE	grammar model-based program evolution
GP	genetic algorithm
GP	genetic programming
GP	Gaussian process
GPCR	g-protein coupled receptor
GPGPU	general-purpose GPU
GPi	globus pallidus
GPIO	general-purpose input/output interface
GPS	genetic pattern search
GPU	graphics processing unit

GPX	greedy partition crossover
GRASP	greedy randomized adaptive search procedure
GRBM	Gaussian RBM
GRN	gene/protein regulatory network
GRN	gene regulatory network
GT2	generalized T2FS
GWAS	genome-wide association studies
GWT	global workspace theory

H

H-PIPE	hierarchical probabilistic incremental program evolution
hBOA	hierarchical BOA
HCF	hyper-cube framework
HCwL	hill climbing with learning
HDL	hardware description language
HFB	higher frequency band
HH	Hodgkin–Huxley
HM	health management
HMM	hidden Markov model
HPC	high-performance computing
HS	Hilbert space
HSS	heuristic space search
HT	Hough transform
HW	hardware
HWICAP	hardware internal configuration access point

I

i.i.d.	independent, identically distributed
IASC	iterative algorithm with stop condition
IB	indicator based
IBEA	indicator-based evolutionary algorithm
iBOA	incremental Bayesian optimization algorithm
IC	intelligent controller
IC	interrupt controller
ICA	independent component analysis
ICAP	internal configuration access point
ICE	induced chromosome element exchanger
ICML	International Conference on Machine Learning
IDA	intelligent distribution agent
IDEA	iterated density estimation evolutionary algorithm
IE	inference engine
IEEE	Institute of Electrical and Electronics Engineers
IF	intuitionistic fuzzy
IFA	independent factor analysis
IFVS	interval valued fuzzy set
IG	iterated greedy
IGR	interactive granular computing
IHA	iterative heuristic algorithm
ILS	iterated local search
IN	interneuron
INCF	International Neuroinformatics Coordinating Facility
IO-HMM	input/output hidden Markov model
IOB	input/output block
IoT	internet of things
IP	identity principle
IP	inductive programming
IP	intellectual property
IPIF	intellectual property interface
IPL	inferior parietal lobe
IPOP	increasing population size
IRGC	interactive rough granular computing
IRLS	iteratively re-weighted least squares
IRSA	indiscernibility-based rough set approach
ISE	Integrated Synthesis Environment
ISI	inter-spike interval
ISM	insertion mutation operator
IT2	interval type-2
IT2FC	interval T2FC
IT2FS	interval T2FS
ITAE	integral time absolute error
ITL	information theoretic learning
IUMDA	incremental univariate marginal distribution algorithm
IVM	inversion mutation operator

J

JDEAL	Java distributed evolutionary algorithms library
JEGA	John Eddy genetic algorithm
JMAF	java multi-criteria and multi-attribute analysis framework

K

KAF	kernel adaptive filter
KAPA	kernel affine projection algorithm
KB	knowledge base
KDD	knowledge discovery and data mining

KGA	Kriging-driven genetic algorithm
KKT	Karush–Kuhn–Tucker
KL	Kullback–Leibler
KLMS	kernel least mean square
KM	Karnik–Mendel
KMC	kernel Maximum Correntropy
KNN	*k* nearest neighbor
KPCA	kernel principal component analysis
KRLS	kernel recursive least square
KUR	Kurswae

L

LAN	local network
LASSO	least absolute shrinkage and selection operator
LB	logic block
LCS	learning classifier system
LDA	latent Dirichlet allocation
LDA	linear discriminant analysis
LDS	limited discrepancy search
LED	light emitting diode
LEM	learning from examples module
LERS	learning from examples using rough sets
LFA	local factor analysis
LFB	lower frequency band
LFDA	learning FDA
LFM	linguistic fuzzy modeling
LFP	local field potential
LGP	linear GP
LHS	latin hypercube sampling
LI	law of importation
LIFM	leaky integrate-and-fire
LLE	liquid–liquid equilibrium
LMI	linear matrix inequalities
LMS	least mean square
LNS	large neighborhood search
LO	leading one
LOCVAL	locational value
LOO	leave-one-out
LOOCV	leave-one-out cross-validation
LOTZ	leading ones trailing zeroes
LP	logic programming
LQR	linear-quadratic regulator
LR	logistic regression
LRP	lateralized readiness potential
LS	least square
LS	local search
LSM	liquid state machine
LSTM	long short term memory
LT	linguistic term
LUT	look-up table
LV	linguistic variable
LVT	linguistic-variable-term
LWPR	locally-weighted projection regression algorithm
LZ	leading zero

M

M1	motor cortex
M2M	machine-to-machine
MA	Markovian agent
MA	memetic algorithm
MAE	mean of the absolute error
MAFRA	Java mimetic algorithms framework
MAM	Markovian agent model
MAMP	multiple algorithms, multiple problems
MAMS	multiple algorithms and multiple problem instances
MAP	maximum a posteriori
MARS	multivariate adaptive regression splines
MASP	multiple algorithms and one single problem
mBOA	mixed Bayesian optimization algorithm
MCA	minor component analysis
MCDA	multi-criteria decision analysis
MCDA	multiple criteria decision aiding
MCDM	multiple criteria decision-making
MCS	maximum cardinality search
MCS	meta-cognitive subsystem
MDL	minimum description length
MDP	Markov decision process
MDS	multidimensional scaling
MEG	magnetoencephalogram
MEG	magnetoencephalography
MEL	minimal epistemic logic
MF	membership function
MG	Mackey–Glass
MG	morphological gradient
MH	metaheuristic
MIL	multi-instance learning
MIMIC	mutual information maximizing input clustering
MIML	multi-instance, multi-label learning
MISO	multiple inputs-single output
MKL	multiple kernel learning
ML	machine learning
ML	maximum likelihood
MLEM2	modified LEM2 algorithm

MLP	multilayer perceptron
MLR	multiple linear regression
MLR	multi-response linear regression
MM	mathematical morphology
MMA	multimemetic algorithm
MMAS	MAX-MIN ant system
MMEA	model-based multiobjective evolutionary algorithm
MMLD	man–machine learning dilemma
MN-EDA	Markov network EDA
MNN	memristor-based neural network
MNN	modular neural network
MOAMO	multiobjectivization-assisted multimodal optimization
MOE	multiobjective evolutionary
MoE	mixture of experts
MOEA	multiobjective evolutionary algorithm
MOEA/D	multiobjective evolutionary algorithm based on decomposition
MOGA	multiobjective genetic algorithm
MoGFS	multiobjective genetic fuzzy system
MOM	mean of maxima
MOMGA	multi-objective messy GA
MOO	multi-objective optimization
MOP	many-objective optimization problem
MOP	multiobjective problem
MOP	multiobjective optimization problem
MOPSO	multiobjective particle swarm optimization
MOSAIC	modular selection and identification for control
MOSES	meta-optimizing semantic evolutionary search
MOT	movement time
MPE	mean percentage error
MPE	most probable explanation
MPGA	mixed-flow POD genetic algorithm
MPI	message passing interface
MPM	marginal product model
MPP	massively parallel machine
MPS	multiprocessor system
MR	maximum ranking
MRCP	movement-related cortical potentials
MRI	magnetic resonance imaging
mRMR	minimal-redundancy-maximal-relevance
mRNA	messenger RNA
MRNN	memristor-based recurrent neural network
MS	master/slave
MS	motivational subsystem
MSA	minor subspace analysis
MSE	mean square error
MSG	max-set of Gaussian landscape generator
msMOEA	master–slave MOEA
MT	medial temporal
MTFL	multi-task feature learning
MTL	multi-task learning
MV	maximum value
MWRA	minimum-weight rooted arborescence

N

NACS	non-action-centered subsystem
NASA	National Aeronautics and Space Administration
NC	neural computation
NC	novelty criterion
NC	numerical control
NCL	negative correlation learning
NDS	nonlinear dynamical systems
NEAT	neuro-evolution of augmenting topologies
NES	natural evolution strategy
NeuN	neuronal nuclei antibody
NFA	non-Gaussian factor analysis
NFI	neuro-fuzzy inference system
NFL	no free lunch
NHBSA	node histogram based sampling algorithm
NIL	nondeterministic information logic
NIPS	neural information processing system
NLMS	normalized LMS
NLPCA	nonlinear principal components
NMF	negative matrix and tensor factorization
NMF	nonnegative matrix factorization
NN	neural network
NOW	networks of workstation
NP	neutrality principle
NP	nondeterministic polynomial-time
NPV	net present value
NR	noise reduction
NS	negative slope
NSGA	nondominated sorting genetic algorithm
NSPSO	nondominated sorting particle swarm optimization
NURBS	nonuniform rational B-spline

O

ODE	ordinary differential equation
OEM	original equipment manufacturer

OKL	online kernel learning
OLAP	online analytical processing
OM	operational momentum
OMA	ordered modular average
OP	ordering property
OPB	on-chip peripheral bus
OPL	open programming language
OR	operations research
OR	operational research
OS	overshoot
OWA	ordered weighted average
OWMax	ordered weighted maximum
OX1	order crossover
OX2	order-based crossover

P

PAC	probably approximately correct
PAES	Pareto-archived evolution strategy
PAR	place and route
PBC	perception-based computing
PBIL	population-based incremental learning
PbO	programming by optimization
PC	probabilistic computing
PC-SAFT	perturbed chain statistical associating fluid theory
PCA	principal component analysis
PCVM	probabilistic classifier vector machine
PD	Parkinson disease
PD	proportional-differential
PDDL	planning domain definition language
PDE	partial differential equation
pdf	probability density function
PDGP	parallel and distributed GP
PEEL	program evolution with explicit learning
PERT	program evaluation and review technique
PESA	Pareto-envelope based selection algorithm
PET	positron emission tomography
PFC	Pareto front computation
PFC	prefrontal cortex
PFM	precise fuzzy modeling
PHM	prognostics and health management
PIC	peripheral interface controller
PID	proportional-integral-derivative
PII	probabilistic iterative improvement
PIPE	probabilistic incremental program evolution
PLA	programmable logic array
PLB	processor local bus
PLS	partial least square
pLSA	probabilistic latent semantic analysis
PLV	phase lock value
PM	parallel model
PMBGA	probabilistic model-building genetic algorithm
PMC	premotor cortex
PMI	partial mutual information
PMX	partially-mapped crossover
PN	pyramidal neuron
PNS	peripheral nervous system
POD	proper orthogonal decomposition
PoE	product of experts
POR	preference order relation
POS	position-based crossover
PP	parallel platform
PPSN	parallel problem solving in nature
PR	partial reconfiguration
PRAS	polynomial-time randomized approximation scheme
PRM	partially reconfigurable module
PRODIGY	program distribution estimation with grammar model
PRR	partially reconfigurable region
PS	pattern search
PSA	principal subspace analysis
PSCM	problem-space computational model
PSD	power spectral density
PSD	predictive sparse decomposition
PSEA	Pareto sorting evolutionary algorithm
PSNR	peak signal-to-noise ratio
PSO	particle swarm optimization
PSS	problem space search
PSTH	peri-stimulus-time histogram
PTT	pursuit-tracking task
PV	principal value
PVS	persistent vegetative state
PWM	pulse width modulation

Q

Q–Q	quantile–quantile
QAP	quadratic assignment problem
QeSNN	quantum-inspired eSNN
QIP	quadratic information potential
QKLMS	quantized KLMS
QP	quadratic programming

R

r.k.	reproducing kernel
RAF	representable aggregation function
RAM	random access memory
RANS	Reynolds-averaged Navier–Stokes
RB	rule base
RBF	radial basis function
RBM	Boltzmann machine
rBOA	real-coded BOA
RECCo	robust evolving cloud-based controller
RecNN	recursive neural network
REGAL	relational genetic algorithm learner
REML	restricted maximum likelihood estimator
RET	relevancy transformation
RFID	radio frequency identification
RFP	red fluorescent protein
RGB	red-green-blue
RGN	random generation number
RHT	randomized Hough transform
RII	randomized iterative improvement
RISC	reduced intstruction set computer
RKHS	reproducing kernel Hilbert space
RL	reinforcement learning
RLP	randomized linear programming
RLS	randomized local search
RLS	recursive least square
RM-MEDA	regularity model based multiobjective EDA
RMI	remote method invocation
RMSE	root-mean-square error
RMSEP	root-mean-square error of prediction
RMTL	regularized multi-task learning
RN	regularization network
RNA	ribonucleic acid
RNN	recurrent neural network
ROC	receiver operating characteristic
ROI	region of interest
ROM	read only memory
ROM	reduced-order model
ROS	robot operating system
RP	readiness potential
RPC	remote procedure call
RPCL	rival penalized competitive learning
RS	rough set
rst	reset
RT	reaction time
RT	real-time
RTL	register transfer logic
RTRL	real-time recurrent learning
RUL	remaining useful life
RWS	roulette wheel selection

S

S-ACO	simple ant colony optimization
S-bit	section-bit
S3VM	semi-supervised support vector machine
SA	simple F-transform-based fusion algorithm
SA	simulated annealing
SAE	sparse auto-encoder
SAMP	one single algorithm and multiple problems
SARSA	state-action-reward-state-action
SASP	one single algorithm and one single problem
SAT	satisfiability
SBF	subspace-based function
SBO	surrogate-based optimization
SBR	similarity based reasoning
SBS	sequential backward selection
SBSO	surrogate based shape optimization
SBX	simulated binary crossover
SC	soft computing
SC	surprise criterion
SCH	school
SCNG	sparse coding neural gas
SD	structured data
SDE	stochastic differential equation
SDPE	standard deviation percentage error
SEAL	simulated evolution and learning
SEMO	simple evolutionary multi-objective optimizer
SF	scaling factor
SFS	sequential forward selection
SG-GP	stochastic grammar-based genetic programming
SHCLVND	stochastic hill climbing with learning by vectors of normal distribution
SI	swarm intelligence
SIM	simple-inversion mutation operator
SISO	single input single output
SLAM	simultaneous localization and mapping
SLF	superior longitudinal fasciculus
SLS	stochastic local search
SM	scramble mutation operator
SM	surrogate model
SMA	supplementary motor area

SMO	sequential minimum optimization
SMP	symmetric multiprocessor
SMR	sensorimotor rhythm
sMRI	structural magnetic resonance imaging
SMS-EMOA	S-metric selection evolutionary multiobjective algorithm
SNARC	spatial–numerical association of response code
SNE	stochastic neighborhood embedding
SNP	single nucleotide polymorphism
SNR	signal-noise-ratio
SOC	self-organized criticality
SOFM	self-organized feature maps
SOFNN	self-organizing fuzzy neural network
SOGA	single-objective genetic algorithm
SOM	self-organizing map
SPAM	set preference algorithm for multiobjective optimization
SPAN	spike pattern association neuron
SPD	strictly positive definite
SPEA	strength Pareto evolutionary algorithm
SPOT	sequential parameter optimization toolbox
SPR	static partial reconfiguration
SQL	structured query language
SR	stochastic resonance
SR	symbolic regression
SRD	standard reference dataset
SRF	strength raw fitness
SRM	spike response model
SRM	structural risk minimization
SRN	simple recurrent network
SRT	serial reaction time
SSM	state–space model
SSOCF	subset size-oriented common features
SSSP	single-source shortest path problem
StdGP	standard GP
STDP	spike-timing dependent plasticity
STDP	spike-timing dependent learning
STGP	strongly typed GP
SU	single unit
SURE-REACH	sensorimotor, unsupervised, redundancy-resolving control architecture
SUS	stochastic universal sampling
SVaR	simplified value at risk
SVC	support vector classification
SVD	singular value decomposition
SVM	support vector machine
SW	software
SW-KRLS	sliding window KRLS

T

T1	type-1
T1FC	type-1 fuzzy controller
T1FS	type-1 fuzzy set
T2	type-2
T2FC	type-2 fuzzy controller
T2FS	type-2 fuzzy set
T2IC	type-2 intelligent controller
T2MF	type-2 membership function
TAG3P	tree adjoining grammar-guided genetic programming
TD	temporal difference
TDNN	time delay neural network
TET	total experiment time
TFA	temporal factor analysis
TGBF	truncated generalized Bell function
TN	thalamus
TOGA	target objective genetic algorithm
TR	type reducer
TRC	tuple relational calculus
TS	tabu search
TS	time saving
TSK	Takagi–Sugeno–Kang
TSP	traveling salesman problem
TTGA	trainable threshold gate array
TWNFI	transductive weighted neuro-fuzzy inference system

U

UART	universal asynchronous receiver/transmitter
UAV	unmanned aerial vehicle
UCF	user constraint file
UCS	supervised classifier system
UCX	uniform cycle crossover
UMDA	univariate marginal distribution algorithm
UML	universal modeling language
UPMOPSO	user-preference multiobjective PSO
US EPA	United States Environmental Protection Agency
UW	underwriter

V

VB	variational Bayes
VC	Vapnik–Chervonenkis
VC	variable consistency
VCR	variance ratio criterion
VEGA	vector-evaluated GA

VHDL	VHSIC hardware description language
VHS	virtual heading system
VHSIC	very high speed integrated circuit
VLNS	very large neighborhood search
VLPFC	ventrolateral prefrontal cortex
VLSI	very large scale integration
VND	variable neighborhood descent
VNS	variable neighborhood search
VPRSM	variable precision rough set model
VQ	vector quantization
VQRS	vaguely quantified rough set

W

W2T	wisdom web of things
WAN	wide area network
WC	Wilson–Cowan
WEP	weight error power
WFG	walking fish group
WisTech	Wisdom Technology
WM	white matter
WM	working memory
WSN	wireless sensor network
WT	Wu–Tan
WTA	winner-take-all
WWKNN	weighted-weighted nearest neighbor

X

XACS	x-anticipatory classifier system
XB	Xie-Beni cluster validity index
XCS	X classifier system
XCSF	XCS for function approximation
xNES	exponential natural evolution strategy
XPS	Xilinx platform studio
XSG	Xilinx system generator

Z

ZCS	zeroth level classifier system
ZDT	Zitzler–Deb–Thiele
ZEN	Zonal Euler–Navier–Stokes