

# Membrane Computing An Introduction Natural Computing Series

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Computing with Cells and Atoms  
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## Pervasive Computing and the Networked World

Formal Languages and Applications provides a comprehensive study-aid and self-tutorial for graduates students and researchers. The main results and techniques are presented in an readily accessible manner and accompanied by many references and directions for further research. This carefully edited monograph is intended to be the gateway to formal language theory and its applications, so it is very useful as a review and reference source of information in formal language theory.

## Computing with Cells and Atoms

The present volume is based on papers presented at the 6th Workshop on Membrane Computing, WMC6, which took place in Vienna, Austria, in the period July 18-21, 2005. The first three workshops were organized in Curtea de Argeș, Romania - they took place in August 2000 (with the proceedings published in Lecture Notes in Computer Science, volume 2235), in August 2001 (with a selection of papers published as a special issue of Fundamenta Informaticae, volume 49, numbers 1-3, 2002), and in August 2002 (with the proceedings published in Lecture Notes in Computer Science, volume 2597). The fourth and the fifth workshops were organized in Tarragona, Spain, in July 2003, and in Milan, Italy, in June 2004, with the proceedings published as volumes 2933 and 3365, respectively, of Lecture Notes in Computer Science. The pre-proceedings of WMC6 were published

by the Institute for Computer Languages of the Vienna University of Technology, and they were available during the workshop. Conforming with tradition, this workshop, too, was a lively scientific event, with many questions and engaged discussions following presentations of papers.

The current volume is based on a selection of papers from the pre-proceedings. These papers were significantly modified according to the discussions that took place during the workshop, and all these selected papers were additionally refereed.

## **Enjoying Natural Computing**

This book constitutes the refereed proceedings of the 10th Conference on Computability in Europe, CiE 2014, held in Budapest, Hungary, in June 2014. The 42 revised papers presented were carefully reviewed and selected from 78 submissions and included together with 15 invited papers in this proceedings. The conference had six special sessions: computational linguistics, bio-inspired computation, history and philosophy of computing, computability theory, online algorithms and complexity in automata theory.

## **Beyond Artificial Intelligence**

Biological and other natural processes have always been a source of inspiration for computer science and information technology. Many emerging problem solving techniques integrate advanced evolution and cooperation strategies, encompassing a range of spatio-temporal scales for visionary conceptualization of evolutionary computation. The previous editions of NCSO were held in Granada, Spain (2006), Acireale, Italy (2007), Tenerife, Spain (2008), and again in Granada in 2010. NCSO evolved to be one of the most interesting and profiled workshops in nature inspired computing. NCSO 2011 has offered an inspiring environment for debating the state of the art ideas and techniques in nature inspired cooperative strategies and a comprehensive image on recent applications of these ideas and techniques. The topics covered by this volume include Swarm Intelligence (such as Ant and Bee Colony Optimization), Genetic Algorithms, Multiagent Systems, Coevolution and Cooperation strategies, Adversarial Models, Synergic Building Blocks, Complex Networks, Social Impact Models, Evolutionary Design, Self Organized Criticality, Evolving Systems, Cellular Automata, Hybrid Algorithms, and Membrane Computing (P-Systems).

## **Applications of Membrane Computing**

This book constitutes the refereed proceedings of the 9th Conference on Computability in Europe, CiE 2013, held in Milan, Italy, in July 2013. The 48 revised papers presented together with 1 invited lecture and 2 tutorials were carefully reviewed and selected with an acceptance rate of under 31,7%. Both the conference series and the association promote the development of computability-related science, ranging over mathematics, computer science and applications in various natural and engineering sciences such as physics and biology, and also including the promotion of related non-scientific fields such as philosophy and history of computing.

## **Membrane Filtration**

### **Membrane Computing**

Products of modern artificial intelligence (AI) have mostly been formed by the views, opinions and goals of the “insiders”, i.e. people usually with engineering background who are driven by the force that can be metaphorically described as the pursuit of the craft of Hephaestus. However, since the present-day technology allows for tighter and tighter mergence of the “natural” everyday human life with machines of immense complexity, the responsible reaction of the scientific community should be based on cautious reflection of what really lies beyond AI, i.e. on the frontiers where the tumultuous ever-growing and ever-changing cloud of AI touches the rest of the world. The chapters of this boo are based on the selected subset of the presentations that were delivered by their respective authors at the conference “Beyond AI: Interdisciplinary Aspects of Artificial Intelligence” held in Pilsen in December 2011. From its very definition, the reflection of the phenomena that lie beyond AI must be inherently interdisciplinary. And so is this book: all the authors took part in a mutual transdisciplinary dialogue after explaining their views on AI not only to a narrow selection of their usual close peers with the same specialisation, but to a much broader audience of various experts from AI engineering, natural sciences, humanities and philosophy. The chapters of this book thus reflect results of such a dialogue.

### **Membrane Computing**

### **Membrane Computing**

### **Fundamentals of Computation Theory**

Membrane computing is an unconventional model of computation associated with a new computing paradigm. The field of membrane computing was initiated in 1998 by the author of this book; it is a branch of natural computing inspired by the structure and functioning of the living cell and devises distributed parallel computing models in the form of membrane systems. This book is the first monograph surveying the new field in a systematic and coherent way. It presents the central notions and results: the main classes of P systems, the main results about their computational power and efficiency, a complete bibliography, and a series of open problems and research topics.

### **The Nature of Computation: Logic, Algorithms, Applications**

This book is an Up-to-date and authoritative account on physicochemical principles, pharmaceutical and biomedical applications of hydrogels. It consists of eight contributions from different authors highlighting properties and synthesis of hydrogels, their characterization by various instrumental methods of analysis, comprehensive review on stimuli-responsive hydrogels and their diverse

applications, and a special section on self-healing hydrogels. Thus, this book will equip academia and industry with adequate basic and applied principles related to hydrogels.

## **Future Information Technology**

26th European Symposium on Computer Aided Process Engineering contains the papers presented at the 26th European Society of Computer-Aided Process Engineering (ESCAPE) Event held at Portorož Slovenia, from June 12th to June 15th, 2016. Themes discussed at the conference include Process-product Synthesis, Design and Integration, Modelling, Numerical analysis, Simulation and Optimization, Process Operations and Control and Education in CAPE/PSE. Presents findings and discussions from the 26th European Society of Computer-Aided Process Engineering (ESCAPE) Event

## **Advances in Artificial Life**

This book constitutes the refereed proceedings of the 4th International Conference on Unconventional Computation, UC 2005, held in Sevilla, Spain in September 2005. The conference formerly was named Unconventional Models of Computation (UMC). The 19 revised full papers presented together with 5 invited full papers were carefully reviewed and selected for inclusion in the book. All major areas of unconventional computing models are covered in theory as well as in experiments and applications. Topics addressed are: natural computing including quantum, cellular, molecular, neural and evolutionary computing; chaos and dynamical systems based computing; and various proposals for computations that go beyond the Turing model.

## **Formal Languages and Applications**

This book constitutes the thoroughly refereed post-conference proceedings of the 15th International Conference on Membrane Computing, CMC 2014, held in Prague, Czech Republic, in August 2014. The 19 revised selected papers presented together with 5 invited lectures were carefully reviewed and selected from 24 papers presented at the conference. In addition, two papers selected from the 22 papers presented at the regional version of CMC, the Asian Conference on Membrane Computing , ACMC 2014, held in Coimbatore, India, are included. The papers cover a wide range of topics in the area of membrane computing, which is an area of computer science aiming to abstract computing ideas and models from the structure and the functioning of living cells, as well as from the way the cells are organized in tissues or higher order structures.

## **Developments in Language Theory**

This book addresses the fundamentals of CO<sub>2</sub> storage for long-term sequestration in a subsurface geologic formation. In general, membrane gas separation can find a large room of application in flue gas. To achieve the development of this technology on a larger scale than which is possible in the lab we have to use membrane engineering. Consequently, greater emphasis is placed on novel

materials for gas separation. Possible design strategies and role of novel materials are discussed. Additionally, the latest progress in design and preparation of asymmetric membranes for natural gas purification are highlighted. In fact, further development should focus on module and process design in order to bring gas separation membrane technology into commercial application. Therefore, the key issues to propel current research towards industrial application are examined. Besides, the feasibility of implementing polyimide membrane for CO<sub>2</sub> removal under real industrial conditions and its economic viability are highlighted. In order to exhibit excellent film-forming properties, zeolite membrane and cellulose acetate butyrate membrane are addressed. Interestingly, it was found that the most accurate theoretical three-phase model is arguably revised Pal model with average percentage error of 0.74%.

## **21st European Symposium on Computer Aided Process Engineering**

This book constitutes the thoroughly refereed post-proceedings of the International Workshop on Membrane Computing, WMC-CdeA 2002, held in Curtea de Arges, Romania, in August 2002. The 29 revised full papers presented were carefully selected during two rounds of reviewing and revision; some were especially solicited for inclusion in the book after the workshop. Most papers address membrane systems and membrane computing from the point of view of theoretical computer science; some papers solve open problems and present new approaches, and others provide mathematical and biological background. All in all, the book presents the state of the art in membrane computing.

## **Fundamenta Informaticae**

Though mathematical ideas underpin the study of neural networks, the author presents the fundamentals without the full mathematical apparatus. All aspects of the field are tackled, including artificial neurons as models of their real counterparts; the geometry of network action in pattern space; gradient descent methods, including back-propagation; associative memory and Hopfield nets; and self-organization and feature maps. The traditionally difficult topic of adaptive resonance theory is clarified within a hierarchical description of its operation. The book also includes several real-world examples to provide a concrete focus. This should enhance its appeal to those involved in the design, construction and management of networks in commercial environments and who wish to improve their understanding of network simulator packages. As a comprehensive and highly accessible introduction to one of the most important topics in cognitive and computer science, this volume should interest a wide range of readers, both students and professionals, in cognitive science, psychology, computer science and electrical engineering.

## **Membrane Technology for CO<sub>2</sub> Sequestration**

## **Membrane Technology and Applications**

This book thoroughly investigates the underlying theoretical basis of membrane computing models, and reveals their latest applications. In addition, to date there have been no illustrative case studies or complex real-life applications that capitalize on the full potential of the sophisticated membrane systems computational apparatus; gaps that this book remedies. By studying various complex applications – including engineering optimization, power systems fault diagnosis, mobile robot controller design, and complex biological systems involving data modeling and process interactions – the book also extends the capabilities of membrane systems models with features such as formal verification techniques, evolutionary approaches, and fuzzy reasoning methods. As such, the book offers a comprehensive and up-to-date guide for all researchers, PhDs and undergraduate students in the fields of computer science, engineering and the bio-sciences who are interested in the applications of natural computing models.

## **Mathematical Foundations of Computer Science 2005**

This book constitutes the thoroughly refereed extended postproceedings of the 5th International Workshop on Membrane Computing, WMC 2004, held in Milan, Italy in June 2004. The 20 revised full papers presented together with 6 invited papers went through two rounds of reviewing and improvement. All current topics in the area of membrane computing are addressed, ranging from mathematics and theoretical computer science to applications in biology, linguistics, and computer graphics. Issues related to computational power and complexity classes, new classes of P systems, fuzzy approaches, and reversibility and energy consumption are dealt with as well.

## **Bio-inspired Computing: Theories and Applications**

Focusing on the application of membranes in an engineering context, this hands-on computational guide makes previously challenging problems routine. It formulates problems as systems of equations solved with MATLAB, encouraging active learning through worked examples and end-of-chapter problems. The detailed treatments of dead-end filtration include novel approaches to constant rate filtration and filtration with a centrifugal pump. The discussion of crossflow microfiltration includes the use of kinetic and force balance models.

Comprehensive coverage of ultrafiltration and diafiltration processes employs both limiting flux and osmotic pressure models. The effect of fluid viscosity on the mass transfer coefficient is explored in detail, the effects of incomplete rejection on the design and analysis of ultrafiltration and diafiltration are analysed, and quantitative treatments of reverse osmosis and nanofiltration process analysis and design are explored. Includes a chapter dedicated to the modelling of membrane fouling.

## **The Oxford Handbook of Membrane Computing**

This book comprises the refereed proceedings of the Workshop on Computation: Theory and Practice (WCTP)-2012, held in Manila, The Philippines, in September 2012. The workshop was organized by the Tokyo Institute of Technology, the Institute of Scientific and Industrial Research-Osaka University, the University of the Philippines Diliman, and De La Salle University-Manila and was devoted to

theoretical and practical approaches to computation. The 22 revised full papers presented in this volume were carefully reviewed. They deal with biologically inspired computational modeling, programming language theory, advanced studies in networking, and empathic computing.

## **Theory and Practice of Computation**

This Festschrift is in honor of Mario de Jesús Pérez-Jiménez, Professor in the Department of Computer Science of University of Seville, Spain, on the occasion of his 70th birthday. The title of this volume reflects both his main research area, viz., Natural Computing, and the guiding principle of his functioning: "once you choose to do something, enjoy doing it". The respect that Professor Mario de Jesús Pérez-Jiménez enjoys in the scientific community was well demonstrated by the enthusiastic response received to the request to contribute to this book. The contributions by more than 70 authors from 15 countries cover a wide spectrum of research areas and reflect well the broad range of research interests of Professor Mario de Jesús Pérez-Jiménez. The research areas presented in this Festschrift include membrane computing, spiking neural networks, phylogenetic networks, ant colonies optimization, workbench for biocomputing, reaction systems, entropy of computation, rewriting systems, and insertion-deletion systems.

## **An Introduction to Neural Networks**

### **Mathematical Reviews**

This book constitutes the thoroughly refereed extended postproceedings of the 9th International Workshop on Membrane Computing, WMC 2008, held in Edinburgh, UK, in July 2008 under the auspices of the European Molecular Computing Consortium (EMCC) and the Molecular Computing Task Force of IEEE Computational Intelligence Society. The 22 revised full papers presented together with 5 invited papers went through two rounds of reviewing and improvement. The papers in this volume cover all the main directions of research in membrane computing, ranging from theoretical topics in mathematics and computer science to application issues. A special attention was paid to the interaction of membrane computing with biology and computer science, focusing both on the biological roots of membrane computing, on applications of membrane computing in biology and medicine, and on possible electronically based implementations.

### **Membrane Computing**

This book constitutes the refereed post-proceedings of the Joint International Conference on Pervasive Computing and the Networked World, ICPCA-SWS 2012, held in Istanbul, Turkey, in November 2012. This conference is a merger of the 7th International Conference on Pervasive Computing and Applications (ICPCA) and the 4th Symposium on Web Society (SWS). The 53 revised full papers and 26 short papers presented were carefully reviewed and selected from 143 submissions. The papers cover a wide range of topics from different research communities such as computer science, sociology and psychology and explore both theoretical and

practical issues in and around the emerging computing paradigms, e.g., pervasive collaboration, collaborative business, and networked societies. They highlight the unique characteristics of the "everywhere" computing paradigm and promote the awareness of its potential social and psychological consequences.

## **Natural Computing for Simulation and Knowledge Discovery**

The objective is to provide the latest developments in the area of soft computing. These are the cutting edge technologies that have immense application in various fields. All the papers will undergo the peer review process to maintain the quality of work.

## **Emerging Concepts in Analysis and Applications of Hydrogels**

Nature has long provided the inspiration for a variety of scientific discoveries in engineering, biomedicine, and computing, though only recently have these elements of nature been used directly in computational systems. Natural Computing for Simulation and Knowledge Discovery investigates the latest developments in nature-influenced technologies. Within its pages, readers will find an in-depth analysis of such advances as cryptographic solutions based on cell division, the creation and manipulation of biological computers, and particle swarm optimization techniques. Scientists, practitioners, and students in fields such as computing, mathematics, and molecular science will make use of this essential reference to explore current trends in natural computation and advance nature-inspired technologies to the next generation.

## **Proceedings of the International Conference on Soft Computing for Problem Solving (SocProS 2011) December 20-22, 2011**

This book constitutes the refereed proceedings of the 14th International Symposium Fundamentals of Computation Theory, FCT 2003, held in Malmö, Sweden in August 2003. The 36 revised full papers presented together with an invited paper and the abstracts of 2 invited talks were carefully reviewed and selected from 73 submissions. The papers are organized in topical sections on approximability, algorithms, networks and complexity, computational biology, computational geometry, computational models and complexity, structural complexity, formal languages, and logic.

## **Unconventional Computation**

At the turning of the millennium, a switch in computing technology is forecasted and looked for. Two main directions of research, both based on quite unconventional ideas are most promising - quantum computing and molecular computing. In the last few years, both of these methods have been intensely investigated. The present book is the first "friendly" presentation of basic ideas in these exciting areas. The style is rigorous, but without entering into excessive technicalities. Equal attention is paid to the main practical results reported so far and the main theoretical developments. The book is written for the educated layman and is self-contained, including all the necessary facts from mathematics,

computer science, biology and quantum mechanics.

## **Nature Inspired Cooperative Strategies for Optimization (NICSO 2011)**

Membrane Computing studies models of computation (called P systems) inspired by the structure and functioning of a living cell, in particular by the role of membranes in compartmentalization of living cells. This handbook provides the necessary biological and formal background, in a state-of-the-art review of current research.

## **26th European Symposium on Computer Aided Process Engineering**

This book constitutes the thoroughly refereed extended post-proceedings of the 7th International Workshop on Membrane Computing, WMC 2006, held in Leiden, Netherlands in July 2006. The papers in this volume cover all the main directions of research in membrane computing, ranging from theoretical topics in mathematics and computer science, to application issues. Special attention was paid to the interaction of membrane computing with biology.

## **Real-life Applications with Membrane Computing**

This book constitutes the thoroughly refereed post-proceedings of the International Workshop on Membrane Computing, WMC 2003, held in Tarragona, Spain, in July 2003. The 26 revised full papers presented were carefully selected during two rounds of reviewing and improvement. All current topics in the emerging area of membrane computing are addressed, ranging from issues in mathematics and theoretical computer science to (potential) applications in biology, bioinformatics, sorting, ranking, linguistics, and computer graphics; several implementations and simulations on computers, computer networks, and reconfigurable hardware are presented too.

## **Membrane Computing**

This book constitutes the refereed proceedings of the 7th Conference on Computability in Europe, CiE 2011, held in Sofia, Bulgaria, in June/July 2011. The 22 revised papers presented together with 11 invited lectures were carefully reviewed and selected with an acceptance rate of under 40%. The papers cover the topics computability in analysis, algebra, and geometry; classical computability theory; natural computing; relations between the physical world and formal models of computability; theory of transfinite computations; and computational linguistics.

## **Language, Life, Limits**

The European Symposium on Computer Aided Process Engineering (ESCAPE) series presents the latest innovations and achievements of leading professionals from the industrial and academic communities. The ESCAPE series serves as a forum for engineers, scientists, researchers, managers and students to present and discuss

progress being made in the area of computer aided process engineering (CAPE). European industries large and small are bringing innovations into our lives, whether in the form of new technologies to address environmental problems, new products to make our homes more comfortable and energy efficient or new therapies to improve the health and well being of European citizens. Moreover, the European Industry needs to undertake research and technological initiatives in response to humanity's "Grand Challenges," described in the declaration of Lund, namely, Global Warming, Tightening Supplies of Energy, Water and Food, Ageing Societies, Public Health, Pandemics and Security. Thus, the Technical Theme of ESCAPE 21 will be "Process Systems Approaches for Addressing Grand Challenges in Energy, Environment, Health, Bioprocessing & Nanotechnologies."

## **Membrane Computing**

The new multimedia standards (for example, MPEG-21) facilitate the seamless integration of multiple modalities into interoperable multimedia frameworks, transforming the way people work and interact with multimedia data. These key technologies and multimedia solutions interact and collaborate with each other in increasingly effective ways, contributing to the multimedia revolution and having a significant impact across a wide spectrum of consumer, business, healthcare, education and governmental domains. This book aims to provide a complete coverage of the areas outlined and to bring together the researchers from academic and industry as well as practitioners to share ideas, challenges and solutions relating to the multifaceted aspects of this field.

## **Models of Computation in Context**

This book constitutes the refereed proceedings of the 30th International Symposium on Mathematical Foundations of Computer Science, MFCS 2005, held in Gdansk, Poland in August/September 2005. The 62 revised full papers presented together with full papers or abstracts of 7 invited talks were carefully reviewed and selected from 137 submissions. All current aspects in theoretical computer science are addressed, ranging from quantum computing, approximation, automata, circuits, scheduling, games, languages, discrete mathematics, combinatorial optimization, graph theory, networking, algorithms, and complexity to programming theory, formal methods, and mathematical logic.

## **Membrane Computing**

Membrane computing is a branch of natural computing which investigates computing models abstracted from the structure and functioning of living cells and from their interactions in tissues or higher-order biological structures. The models considered, called membrane systems (P systems), are parallel, distributed computing models, processing multisets of symbols in cell-like compartmental architectures. In many applications membrane systems have considerable advantages - among these are their inherently discrete nature, parallelism, transparency, scalability and nondeterminism. In dedicated chapters, leading experts explain most of the applications of membrane computing reported so far, in biology, computer science, computer graphics and linguistics. The book also

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contains detailed reviews of the software tools used to simulate P systems.

### **Membrane Computing**

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### **Membrane Computing**

This book constitutes the proceedings of the 9th International Conference on Bio-inspired Computing: Theories and Applications, BIC-TA 2014, held in Wuhan, China, in October 2014. The 109 revised full papers presented were carefully reviewed and selected from 204 submissions. The papers focus on four main topics, namely evolutionary computing, neural computing, DNA computing, and membrane computing.

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