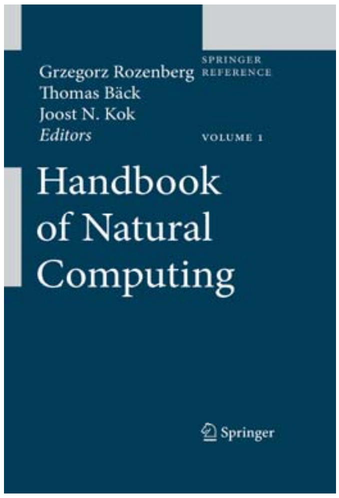
Handbook of Natural Computing



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Overview

Natural Computing is the field of research that investigates both human-designed computing inspired by nature and computing taking place in nature, i.e., it investigates models and computational techniques inspired by nature and also it investigates phenomena taking place in nature in terms of information processing.

Examples of the first strand of research covered by the handbook include neural computation inspired by the functioning of the brain; evolutionary computation inspired by Darwinian evolution of species; cellular automata inspired by intercellular communication; swarm intelligence inspired by the behavior of groups of organisms; artificial immune systems inspired by the natural immune system; artificial life systems inspired by the properties of natural life in general; membrane computing inspired by the compartmentalized ways in which cells process information; and amorphous computing inspired by morphogenesis. Other examples of natural-computing paradigms are molecular computing and quantum computing, where the goal is to replace traditional electronic hardware, e.g., by bioware in molecular computing. In molecular computing, data are encoded as biomolecules and then molecular biology tools are used to transform the data, thus performing computations. In quantum computing, one exploits quantum-mechanical phenomena to perform computations and secure communications more efficiently than classical physics and, hence, traditional hardware allows.

The second strand of research covered by the handbook, computation taking place in nature, is represented by investigations into, among others, the computational nature of self-assembly, which lies at the core of nanoscience, the computational nature of developmental processes, the computational nature of biochemical reactions, the computational nature of bacterial communication, the computational nature of brain processes, and the systems biology approach to bionetworks where cellular processes are treated in terms of communication and interaction, and, hence, in terms of computation.

We are now witnessing exciting interaction between computer science and the natural sciences. While the natural sciences are rapidly absorbing notions, techniques and methodologies intrinsic to information processing, computer science is adapting and extending its traditional notion of computation, and computational techniques, to account for computation taking place in nature around us. Natural Computing is an important catalyst for this two-way interaction, and this handbook is a major record of this important development.

Volume I

Cellular Automata

Area Editor: Jarkko J. Kari (University of Turku, Finland)

Chapters that discuss broad but central topics such as computational universality, cellular automata algorithms, and simulation and modeling of physical systems. There are also chapters on more specific topics such as reversibility and conservation laws, providing a view over the many facets of modern cellular automata research.

- Basic Concepts of Cellular Automata [Jarkko J. Kari]
- Cellular Automata Dynamical Systems [Alberto Dennunzio, Enrico Formenti, Petr Kůrka]
- Algorithmic Tools on Cellular Automata [Marianne Delorme, Jacques Mazoyer]
- Language Recognition by Cellular Automata [Véronique Terrier]
- Computations on Cellular Automata [Jacques Mazoyer, Jean-Baptiste Yunès]
- Universalities in Cellular Automata [Nicolas Ollinger]
- Reversible Cellular Automata [Kenichi Morita]
- Conservation Laws in Cellular Automata [Siamak Taati]
- Cellular Automata and Lattice Boltzmann Modeling of Physical Systems [Bastien Chopard]

Neural Computation

Area Editors: Tom Heskes (Radboud Universiteit Nijmegen, The Netherlands)
Joost N. Kok (LIACS, Leiden University, The Netherlands)

Foundations of neural networks, including feedforward networks, self-organizing maps, support vector machines, kernel methods, and independent components. It also includes applications such as pattern recognition, image analysis, time series analysis, and bioinformatics. The contributions also consider further biological aspects of neural networks, and recent trends such as spiking neural networks.

- Computing with Spiking Neuron Networks [Hélène Paugam-Moisy, Sander Bohte]
- Image Quality Assessment – A Multiscale Geometric Analysis-Based Framework and Examples [Xinbo Gao, Wen Lu, Dacheng Tao, Xuelong Li]
- Nonlinear Process Modelling and Control Using Neurofuzzy Networks [Jie Zhang]
- Independent Component Analysis [Seungjin Choi]
- Neural Networks for Time Series Forecasting [G. Peter Zhang]
- SVM Tutorial – Classification, Regression and Ranking [Hwanjo Yu, Sungchul Kim]
- Fast Construction of Single Hidden-Layer Feedforward Networks [Kang Li, Guang-Bin Huang, Shuzhi Sam Ge]
- Modeling Biological Neural Networks [Joaquín J. Torres, Pablo Varona]
- Neural Networks in Bioinformatics [Ke Chen, Lukasz A. Kurgan]
- Self-organizing Maps [Marc M. Van Hulle]

Evolutionary Computation

Area Editor: Thomas Bäck (LIACS, Leiden University, The Netherlands)

Covers all key instances of evolutionary computation and their basic theoretical results in terms of convergence properties (global convergence and convergence speed). Advanced algorithmic techniques such as multiobjective optimization are examined, as well as the relationship between organic evolution and algorithmic abstraction.

- Generalized Evolutionary Algorithms [Kenneth De Jong]
- Genetic Algorithms – A Survey of Models and Methods [Darrell Whitley, Andrew M. Sutton]
- Evolutionary Strategies [Günter Rudolph]
- Evolutionary Programming [Gary B. Fogel]

- Genetic Programming – Introduction, Applications, Theory and Open Issues
  [Leonardo Vanneschi, Riccardo Poli]
- The Dynamical Systems Approach – Progress Measures and Convergence Properties
  [Silja Meyer-Nieberg, Hans-Georg Beyer]
- Computational Complexity of Evolutionary Algorithms [Thomas Jansen]
- Stochastic Convergence [Günter Rudolph]
- Evolutionary Multiobjective Optimization [Eckart Zitzler]
- Memetic Algorithms [Natalio Krasnogor]
- Genetics-Based Machine Learning [Tim Kovacs]
- Coevolutionary Principles [Elena Popovici, Anthony Bucci, R. Paul Wiegand, Edwin D. de Jong]
- Niching in Evolutionary Algorithms [Ofer M. Shir]

Volume II

Molecular Computation

Area Editor: Lila Kari (University of Western Ontario, Canada)

Both theoretical and experimental aspects, both "classical" and very recent trends, and the impact of molecular computation on the theory and the technology of computation as well as on our understanding of the basic mechanisms of bioprocesses.

- DNA Computing – Foundations and Implications [Lila Kari, Shinnosuke Seki, Petr Sosík]
- Molecular Computing Machineries – Computing Models and Wet Implementations
  [Masami Hagiya, Satoshi Kobayashi, Ken Komiya, Fumiaki Tanaka, Takashi Yokomori]
- DNA Computing by Splicing and by Insertion–Deletion [Gheorghe Păun]
- Bacterial Computing and Molecular Communication [Yasubumi Sakakibara, Satoshi Hiyama]
- Computational Nature of Gene Assembly in Ciliates
  [Robert Brijder, Mark Daley, Tero Harju, Nataša Jonoska, Ion Petre, Grzegorz Rozenberg]
- DNA Memory [Masanori Arita, Masami Hagiya, Masahiro Takinoue, Fumiaki Tanaka]
- Engineering Natural Computation by Autonomous DNA-Based Biomolecular Devices
  [John H. Reif, Thomas H. LaBean]
- Membrane Computing [Gheorghe Păun]

Quantum Computation

Area Editor: Mika Hirvensalo (University of Turku, Finland)

Quantum computing is computing realized in a quantum mechanical environment. Such environments are called quantum systems, and information carried by such systems is called quantum information. The contributions examine aspects such as quantum algorithms, quantum information theory, quantum cryptography, and physical realizations.

- Mathematics for Quantum Information Processing [Mika Hirvensalo]
- Bell's Inequalities – Foundations and Quantum Communication
  [Časlav Brukner, Marek Żukowski]
- Algorithms for Quantum Computers [Jamie Smith, Michele Mosca]
- Physical Implementation of Large-Scale Quantum Computation [Kalle-Antti Suominen]
- Quantum Cryptography [Takeshi Koshiba]
- BQP-Complete Problems [Shengyu Zhang]

Broader Perspective

Area Editor: David W. Corne (Heriot-Watt University, UK)

Established techniques and approaches vie for attention with emerging directions, new visions, and alternate perspectives. Here we examine sources of inspiration – examples include artificial life and artificial immune systems – and we examine the field from the viewpoint of application areas such as communications and finance.

Nature-Inspired Algorithms

- An Introduction to Artificial Immune Systems [Mark Read, Paul S. Andrews, Jonathan Timmis]
- Swarm Intelligence [David W. Corne, Alan P. Reynolds, Eric Bonabeau]
- Simulated Annealing [Kathryn A. Dowsland, Jonathan M. Thompson]
- Evolvable Hardware [Lukáš Sekanina]
- Natural Computing in Finance – A Review
  [Anthony Brabazon, Jing Dang, Ian Dempsey, Michael O'Neill, David Edelman]
- Selected Applications of Natural Computing
  [David W. Corne, Kalyanmoy Deb, Joshua Knowles, Xin Yao]

Alternative Models of Computation

- Artificial Life [Wolfgang Banzhaf, Barry McMullin]
- Algorithmic Systems Biology – Computer Science Propels Systems Biology [Corrado Priami]
- Process Calculi, Systems Biology and Artificial Chemistry [Pierpaolo Degano, Andrea Bracciali]
- Reaction–Diffusion Computing [Andrew Adamatzky, Benjamin De Lacy Costello]
- Rough–Fuzzy Computing [Andrzej Skowron]
- Collision-Based Computing [Andrew Adamatzky, Jérôme Durand-Lose]
- Nonclassical Computation – A Dynamical Systems Perspective [Susan Stepney]

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