

Studies in Computational Intelligence

For further volumes:
<http://www.springer.com/series/7092>

Hidefumi Sawai
Editor

Biological Functions for Information and Communication Technologies

Theory and Inspiration

Editor

Hidefumi Sawai
Kobe Research Laboratories
National Institute of Information and Communications Technology
588-2, Iwaoka, Nishi-ku
Kobe, 651-2492
Japan
e-mail: sawai@nict.go.jp

ISSN 1860-949X

e-ISSN 1860-9503

ISBN 978-3-642-15101-9

e-ISBN 978-3-642-15102-6

DOI 10.1007/978-3-642-15102-6

Springer Heidelberg Dordrecht London New York

Translation from the original Japanese language edition: Seimei to Jouhou Tsuushin, edited and written by Hidefumi Sawai, © 2009 by Hidefumi Sawai, Published by Ohmsha Ltd., 3-1 Kanda Nishikicho, Chiyodaku, Tokyo, Japan. All rights reserved.

© Springer-Verlag Berlin Heidelberg 2011

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the right 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.

Cover design: Scientific Publishing Services Pvt Ltd

Printed on acid-free paper

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

Prologue

In a sense, designing and constructing information communication systems inspired by life will establish a new paradigm in the history of science and technology. Given the 4 billion-years required to evolve intelligent life with the superb structures and functions of human and animal brains, it is clear we have much to gain by studying, with an open mind, the deep, sophisticated structures and functions of life forms, as well as the mechanisms of the evolution of life.

This book introduces trends in research on information and communications technologies inspired by life, current trends in research on molecular communication technologies, and future prospects for research in these areas. [Chapter 1](#): “Reconsidering information and communications technologies from life”, [Chap. 2](#): “Molecular communication as a Biological ICT”, [Chap. 3](#): “Artificial chemistry and molecular networks”, [Chap. 4](#): “Signal transduction in biological systems and its possible uses in computation and communication systems”, and [Chap. 5](#): “For deeper understanding”. I will also present relevant research currently underway.

[Chapter 1](#) aiming at the connections between life and ICT, focuses on information processing research modeled on the brain, on the various theories of evolution, on the early evolution of cells, or inspired by the evolution of life itself. [Chapter 2](#) introduces molecular communication technologies as bio-ICTs and describes biosystem molecular communication, molecular communication architecture, and molecular communication design, which represent molecular communication technologies within the scope of biological information and communications technologies. [Chapter 3](#) focuses on research on a network-type computing machine based on intermolecular interactions, describing control flow clusters as active machines, network connection switching rules based on energy minimization, self-organizing network configurations based on programming of active nodes, molecular agents, and program-flow computing, with the goal of creating new algorithms based on molecular theory. [Chapter 4](#) discusses biosystem signal transmission and potential applications to computation and communication systems, drawing on cellular signal transmission networks and formal models, dynamic analysis of signal transmission networks, and error correction codes for cellular signaling pathways. [Chapter 5](#), for deeper understanding, introduces

briefly the original thoughts aiming at and studying on life, and explains the solutions for real-world problems by complex networks which are currently attracting attention.

These topics will help present the argument that designing information processing models inspired by the superb design and function of life forms will lead to the design of various information processing systems and information communication systems capable of solving real-world problems. They also introduce the topic of using the functions of life forms at the molecular level to construct information communication systems based on molecules. Some of these technologies have already entered practical use, while others are expected to find practical applications in the near future.

Hidefumi Sawai

Acknowledgements

I wish to express my deep gratitude to all those who have provided support and cooperation at various stages of this research and publication, especially to Dr. Hideo Miyahara, President of NICT, for his continuous support, Dr. Claus E. Ascheron, Executive Editor of Springer Verlag, Germany, Mr. Osami Takeo, President of Ohmsha Co. Ltd. Japan, Ms. Motomi Sato, Mr. Masayuki Ishida, and Ms. Mizuki Ishikawa of Ohmsha Co. Ltd. Japan, for their support to smoothly proceed this publication. Also, I wish to express my deep gratitude to all authors who have written each chapter, the reference books and papers to which I refer when I edit and write this book, because without these great achievements, this book would not be formed.

Contents

1	Reconsidering Information and Communications Technology from Life	1
1.1	Connection Between Life and ICT	2
1.1.1	Proximate Factor and Ultimate Factor	2
1.1.2	Nature's Hierarchy	2
1.2	Hints from Brain Function	5
1.2.1	Brain Structures and Their Functions.	5
1.2.2	Neural Networks Modeling Brain Function	6
1.2.3	Time-Delay Neural Networks Suitable for Processing Sequential Information and Their Expansion	9
1.2.4	Expansion of Time-Delay Neural Networks to Rotation-Invariant Pattern Recognition	13
1.3	Theory of Evolution and Information Processing Model.	15
1.3.1	Parameter-Free Genetic Algorithms Based on Disparity Theory of Evolution	17
1.3.2	Expansion of Parameter-Free Genetic Algorithm to Parallel Distributed Processing Techniques.	22
1.3.3	Information Processing Model Based on Gene Duplication	25
1.3.4	Information Processing Model Based on Sexual Selection.	28
1.4	Information Processing Based on the Modeling of Cells in Early Stage of Evolution	34
1.4.1	Chemical Genetic Algorithm	34
1.4.2	Chemical Genetic Programming	42
	References	47
2	Molecular Communication Technology as a Biological ICT	49
2.1	Introduction	50
2.2	Molecular Communication in Biological Systems	53
2.2.1	Passive Transport-Based Molecular Communication	53

2.2.2	Active Transport-Based Molecular Communication	55
2.3	Molecular Communication Architecture	58
2.3.1	Generic Representation of Molecular Communication	59
2.3.2	Molecular Communication Processes	59
2.3.3	Characteristics of Molecular Communication	61
2.4	Engineered Molecular Communication	66
2.4.1	Engineering of Sender and Receiver Nanomachines	66
2.5	Engineering of Transport Mechanisms	71
2.5.1	Engineered Passive Transport Mechanisms	71
2.5.2	Engineered Active Transport Mechanisms	74
2.6	Engineering of Communication Mechanisms	76
2.7	Summary	83
	References	84
3	Artificial Chemistry and Molecular Network	87
3.1	Introduction	88
3.2	Artificial Chemistry	89
3.2.1	Basic Elements of Design in Artificial Chemistry	89
3.2.2	Requirements for Artificial Chemistry System's Design—From the Perspective of Evolution and Emergence	90
3.3	Topological Properties of Intermolecular Interactions	99
3.3.1	Intermolecular Forces and Chemical Reaction Velocity Theory	100
3.3.2	Topological Conditions on Molecular Movement	107
3.3.3	Intermolecular Distance and the Molecular Network	108
3.3.4	Topological Properties of the Molecular Network	109
3.4	Evaluating Artificial Chemistry Systems	116
3.5	Network Artificial Chemistry	124
3.5.1	Basic Concept	124
3.5.2	Control Flow Cluster as Active Machine	125
3.5.3	Passive Rewiring Rule Based on Energy Minimization	133
3.5.4	Organization of Network Structure by Active Node Program	140
3.6	Modified Network Artificial Chemistry	146
3.6.1	Concept	146
3.6.2	Formation and Splitting of Hydrophilic Cluster by Molecular Agents	147
3.7	Future Prospects	152
3.7.1	Application to the Graph Coloring Problem	154
3.7.2	Application to Neural Network Modeling	154
	References	156

4	Signal Transduction in Biological Systems and its Possible Uses in Computation and Communication Systems	163
4.1	Introduction	163
4.2	Cellular Signal Transduction Networks and Their Formal Model	165
4.2.1	Some Preliminaries of the Biochemistry of Signal Transduction.	166
4.2.2	Graphic Representation for Signal Transduction	167
4.2.3	Example of Pathway: The MAPK Cascade	170
4.3	Dynamical Analysis of Signal Transduction Networks	172
4.3.1	Temporal Dynamics of Signal Transduction Networks	172
4.3.2	Fixed Point for Pathways with Feedbacks	173
4.3.3	Robustness	177
4.4	Error-Correcting Codes for Cellular Signaling Pathways	183
4.4.1	Molecular Coding for Molecular Communication	185
4.4.2	LDPC Coding for Pathways	186
4.5	Summary	190
	References	191
5	For Deeper Understanding	193
5.1	Paradigm Shifts in Scientific and Technological Revolution	193
5.1.1	Darwin’s Theory of Evolution Still Surviving Today.	198
5.1.2	3.8 Billion Years’ Stream of Life	200
5.2	Solution by Complex Networks Toward the Problems in the Real World	203
5.2.1	What are Complex Networks?	204
5.2.2	Application Fields of Complex Networks.	208
5.2.3	Trends of Social Network-Associated Fields	212
5.3	Summary	216
	References	216
	Epilogue	219
	Index	221