Lecture Notes in Computer Science 2950

Edited by G. Goos, J. Hartmanis, and J. van Leeuwen

Springer
*Berlin*
*Heidelberg*
*New York*
*Hong Kong*
*London*
*Milan*
*Paris*
*Tokyo*

Nataša Jonoska Gheorghe Păun
Grzegorz Rozenberg (Eds.)

# Aspects of Molecular Computing

Essays Dedicated to Tom Head
on the Occasion of His 70th Birthday

Springer

Series Editors

Gerhard Goos, Karlsruhe University, Germany
Juris Hartmanis, Cornell University, NY, USA
Jan van Leeuwen, Utrecht University, The Netherlands

Volume Editors

Nataša Jonoska
University of South Florida, Department of Mathematics
4202 e. Fowler Av. PHY114, Tampa, FL 33620-5700, USA
E-mail: jonoska@math.usf.edu

Gheorghe Păun
Institute of Mathematics of the Romanian Academy
P.O. Box 1-764, 70700 Bucharest, Romania
and
Rovira i Virgili University
Pl. Imperial Tàrraco 1, 43005 Tarragona, Spain
E-mail: gp@astor.urv.es

Grzegorz Rozenberg
Leiden University, Leiden Institute for Advanced Computer Science
Niels Bohrweg 1, 2333 CA Leiden, The Netherlands
and
University of Colorado, Department of Computer Science
Boulder, CO 80309-0347, USA
E-mail: rozenber@liacs.nl

Cataloging-in-Publication Data applied for

A catalog record for this book is available from the Library of Congress.

Bibliographic information published by Die Deutsche Bibliothek
Die Deutsche Bibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data is available in the Internet at <http://dnb.ddb.de>.

CR Subject Classification (1998): F.1, J.3, G.2, F.4.3

ISSN 0302-9743
ISBN 3-540-20781-3 Springer-Verlag Berlin Heidelberg New York

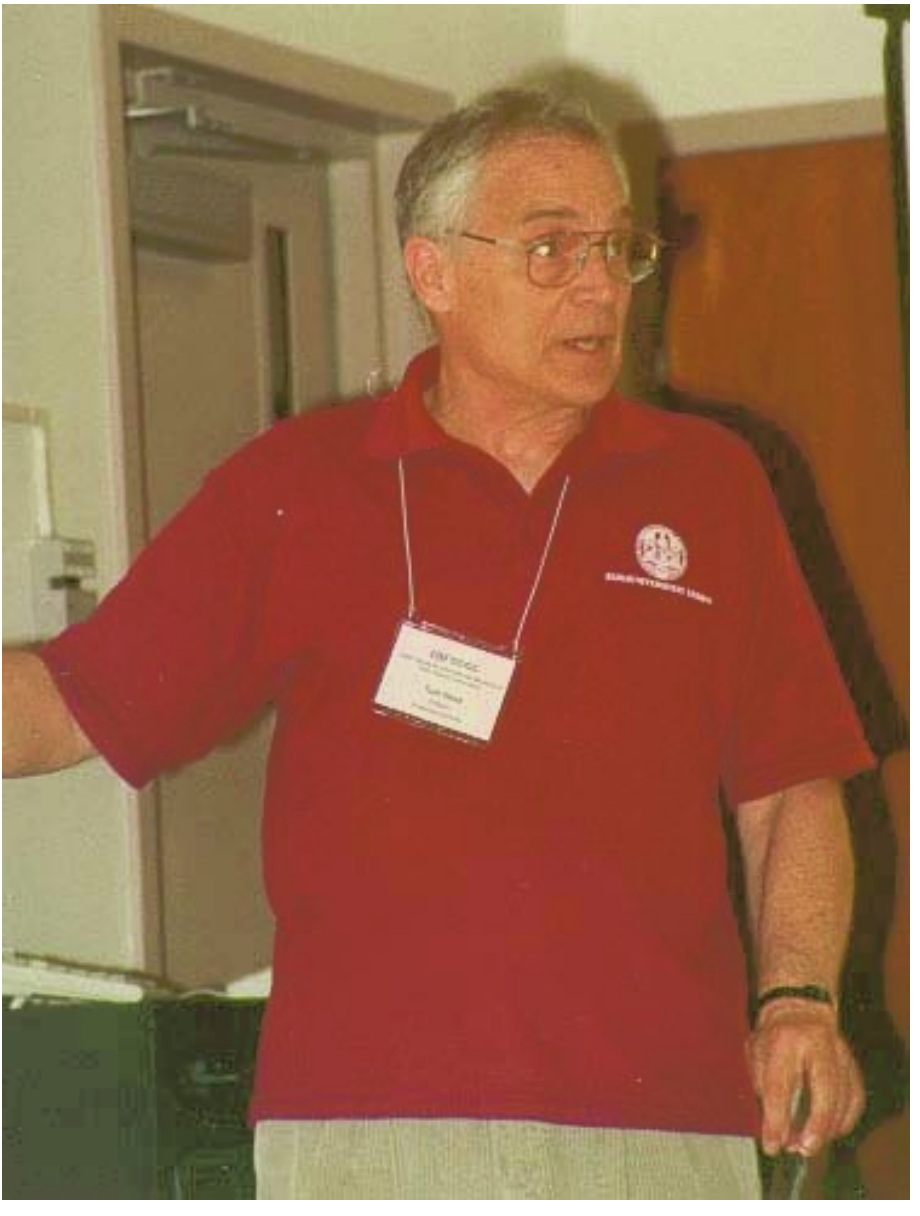


Springer-Verlag is a part of Springer Science+Business Media

springeronline.com


Printed in Germany

Typesetting: Camera-ready by author, data conversion by Boller Mediendesign
Printed on acid-free paper SPIN: 10976616 06/3142 5 4 3 2 1 0



**Thomas J. Head**

# Preface

Molecular Computing is a fast-emerging area of Natural Computing. On the one hand, it is concerned with the use of (bio)molecules for the purpose of computing while on the other hand it tries to understand the computational nature of the molecular processes going on in living cells.

The paper "Molecular computation of solutions to combinatorial problems" by L. Adleman, which describes a laboratory experiment and was published in *Science* in November 1994, was an important milestone for the area of molecular computing, as it provided a "proof-of-principle" that one can indeed perform computations in a biolab using biomolecules and their processing using biomolecular operations. However, research concerning the computational nature of biomolecular operations dates back to before 1994. In particular, a pioneering work concerning the mathematical theory of biooperations is the paper "Formal language theory and DNA: an analysis of the generative capacity of specific recombinant behaviors," authored by Tom Head in 1987, which appeared in the *Bulletin of Mathematical Biology*. The paper uses the framework of formal language theory to formulate and investigate the computational effects of biomolecular operations carried out by restriction enzymes. This paper has influenced research in both molecular computing and formal language theory. In molecular computing it has led to a clear computational understanding of important biomolecular operations occurring in nature, and it has also stimulated the design of a number of laboratory experiments utilizing Tom's ideas for the purpose of human-designed DNA computing. In formal language theory it has led to a novel, interesting and challenging research area, originally called "splicing systems" and then renamed "H systems" in honor of Tom ("H" stands for "Head"). Many papers stimulated by the pioneering ideas presented by Tom in his seminal paper were written by researchers from all over the world.

Adleman's paper was a great event in Tom's life: it has confirmed his conviction that biooperations can be used for the purpose of computing, but more importantly it has stimulated his interest in experimental research. One can safely say that since 1994 most of Tom's research has been focused on the design of experiments related to DNA computing. Also on this research path he remained highly innovative and original, combining his great talent for modeling with a passsion for experimental biology. A good manifestation of this line of Tom's research is aqueous computing – a really elegant but also experimentally feasible model of molecular computing invented by him.

An example of the recognition of Tom's research within the molecular computing community is the "DNA Scientist of the Year" award that Tom received in 2003.

Tom's multidisciplinary talents and interests become even more evident when one realizes that his original training and passion was mathematics, and in particular algebra. He moved from there to formal language theory. It is also im-

portant to keep in mind that his work on formal models for biology started long before his 1987 paper, as he was a very active and productive researcher in the area of Lindenmayer systems that model the development of simple multicellular organisms, not on the molecular but rather on the cellular level.

With this volume, presenting many aspects of research in (or stimulated by) molecular computing, we celebrate a scientist who has been a source of inspiration to many researchers, and to us a mentor, a scientific collaborator, and a warm and caring friend.

HAPPY BIRTHDAY, Tom!

November 2003

Nataša Jonoska
Gheorghe Păun
Grzegorz Rozenberg

# Table of Contents

Solving Graph Problems by P Systems with Restricted Elementary Active Membranes . . . . . 1
*Artiom Alhazov, Carlos Martín-Vide, Linqiang Pan*

Writing Information into DNA . . . . . 23
*Masanori Arita*

Balance Machines: Computing = Balancing . . . . . 36
*Joshua J. Arulanandham, Cristian S. Calude, Michael J. Dinneen*

Eilenberg P Systems with Symbol-Objects . . . . . 49
*Francesco Bernardini, Marian Gheorghe, Mike Holcombe*

Molecular Tiling and DNA Self-assembly . . . . . 61
*Alessandra Carbone, Nadrian C. Seeman*

On Some Classes of Splicing Languages . . . . . 84
*Rodica Ceterchi, Carlos Martín-Vide, K.G. Subramanian*

The Power of Networks of Watson-Crick D0L Systems . . . . . 106
*Erzsébet Csuhaj-Varjú, Arto Salomaa*

Fixed Point Approach to Commutation of Languages . . . . . 119
*Karel Culik II, Juhani Karhumäki, Petri Salmela*

Remarks on Relativisations and DNA Encodings . . . . . 132
*Claudio Ferretti, Giancarlo Mauri*

Splicing Test Tube Systems and Their Relation to Splicing Membrane Systems . . . . . 139
*Franziska Freund, Rudolf Freund, Marion Oswald*

Digital Information Encoding on DNA . . . . . 152
*Max H. Garzon, Kiranchand V. Bobba, Bryan P. Hyde*

DNA-based Cryptography . . . . . 167
*Ashish Gehani, Thomas LaBean, John Reif*

Splicing to the Limit . . . . . 189
*Elizabeth Goode, Dennis Pixton*

Formal Properties of Gene Assembly: Equivalence Problem for Overlap Graphs . . . . . 202
*Tero Harju, Ion Petre, Grzegorz Rozenberg*

$n$-Insertion on Languages . . . . . 213
*Masami Ito, Ryo Sugiura*

Transducers with Programmable Input by DNA Self-assembly . . . . . 219
*Nataša Jonoska, Shiping Liao, Nadrian C. Seeman*

Methods for Constructing Coded DNA Languages . . . . . 241
*Nataša Jonoska, Kalpana Mahalingam*

On the Universality of P Systems with Minimal Symport/Antiport Rules . . . . . 254
*Lila Kari, Carlos Martín-Vide, Andrei Păun*

An Algorithm for Testing Structure Freeness of Biomolecular Sequences . . . . . 266
*Satoshi Kobayashi, Takashi Yokomori, Yasubumi Sakakibara*

On Languages of Cyclic Words . . . . . 278
*Manfred Kudlek*

A DNA Algorithm for the Hamiltonian Path Problem Using Microfluidic Systems . . . . . 289
*Lucas Ledesma, Juan Pazos, Alfonso Rodríguez-Patón*

Formal Languages Arising from Gene Repeated Duplication . . . . . 297
*Peter Leupold, Victor Mitrana, José M. Sempere*

A Proof of Regularity for Finite Splicing . . . . . 309
*Vincenzo Manca*

The Duality of Patterning in Molecular Genetics . . . . . 318
*Solomon Marcus*

Membrane Computing: Some Non-standard Ideas . . . . . 322
*Gheorghe Păun*

The P Versus NP Problem Through Cellular Computing with Membranes . . . . . 338
*Mario J. Pérez-Jiménez, Alvaro Romero-Jiménez, Fernando Sancho-Caparrini*

Realizing Switching Functions Using Peptide-Antibody Interactions . . . . . 353
*M. Sakthi Balan, Kamala Krithivasan*

Plasmids to Solve #3SAT . . . . . 361
*Rani Siromoney, Bireswar Das*

Communicating Distributed H Systems with Alternating Filters . . . . . 367
*Sergey Verlan*

Publications by Thomas J. Head . . . . . 385

**Author Index** . . . . . 391