BIOMEDICAL MATHEMATICS:

Promising Directions in Imaging, Therapy Planning, and Inverse Problems

BIOMEDICAL MATHEMATICS:

Promising Directions in Imaging, Therapy Planning, and Inverse Problems

Yair Censor, Ming Jiang, Ge Wang
Editors

The Huangguoshu International Interdisciplinary Conference on Biomedical Mathematics

The Huangguoshu National Park of China
Guizhou, China

November 3–9, 2008

MEDICAL PHYSICS PUBLISHING
Madison, Wisconsin

Library of Congress Control Number: 2010921431

ISBN: 978-1-930524-48-4

Medical Physics Publishing
4513 Vernon Boulevard
Madison, WI 53705-4964
Phone: 1-800-442-5778, 608-262-4021
Fax: 608-265-2121
Web: www.medicalphysics.org

Printed in the United States of America

Contents

*Corresponding author.

*Corresponding author.

*Corresponding author.

Preface

This book brings together 27 state-of-the-art, refereed and subsequently revised, research and review papers, by leading experts and practitioners in mathematical methods in biomedical imaging, in intensity-modulated radiation therapy (IMRT) and in optimization and inverse problems. The emphasis is on trying to discover relations and connections between these fields that will enhance progress in each of them. As this volume shows, applicable mathematical work in these fields goes hand-in-hand with real-world applications and the mutual "technology transfers" between them leads to further progress.

The topics covered here include mathematical aspects and practical problems in current major and emerging technologies in diagnostic and therapeutic medicine and biology research. The contributed work signifies the interdisciplinary cooperation between mathematicians and scientists from medical physics, engineering, clinical medicine, and biology that leads to mathematically based better solutions of practical problems in biomedical imaging and IMRT.

The Huangguoshu National Park of China, Guizhou, China, under the leadership of Mr. Degang Yuan, President of the Huangguoshu Tourism Group Company, LTD, recognizing the importance of the field and the need for interaction between theoreticians and practitioners, and desiring to create a high-profile cultural activity at the Huangguoshu National Park, provided us with a special grant to organize the "Huangguoshu International Interdisciplinary Conference on Biomedical Mathematics—Promising Directions in Imaging, Therapy Planning, and Inverse Problems." The Conference took place during November 3–9, 2008, in the breathtaking Huangguoshu National Park of China.

The Conference was conducted under the scientific auspices of the Mathematical Center of the Ministry of Education of China at Peking University (PKU) in Beijing, China; the Center for Computational Mathematics and Scientific Computation (CCMSC) at the University of Haifa, Haifa, Israel; the School of Biomedical Engineering & Sciences at the Virginia Polytechnic Institute and State University, Virginia, USA; and the Guizhou University in Guiyang, Guizhou, China.

Experts from around the world were invited and participated. They came from Australia, Canada, Germany, Israel, Italy, Japan, Korea, P.R. China, Spain, Sweden, Switzerland, the United Kingdom, and the United States of America. Most of the papers in this volume originated from the lectures presented at the Conference, while others were written in the wake of discussions held during the Conference.

It is our pleasure to heartily thank Mr. Degang Yuan and the team of the Huangguoshu Tourism Group, Peking University, and Virginia Tech for their devoted and efficient work throughout all phases of the preparations for the conference. In particular we thank Dr. Lingyin Zhao, Zongmin (Tracy) Mao, Haifeng (Mountain) Tong, and Gang (Leo) Xie, from the the Huangguoshu Tourism Group; Prof. Tie Zhou, Dr. Caifang Wang, Dr. Xin Jiang, and Yuanzheng Si, Yu Zhou, Shengkun Shi, from Peking University (PKU); and Deepak Bharkhada, from Wake Forest University, for their cooperation and extraordinary support in organizing and conducting the Conference. Many thanks are due to the referees whose work enhanced the final versions of the papers which appear here. Last but not least, we thank the participants of the Conference and the authors who contributed their work to this volume. We gratefully acknowledge the help of Ms. Betsey Phelps, Managing Editor, Medical Physics Publishing, Madison, WI, USA, for her and her team's work on the production of this volume.

We hope that researchers in applied mathematics, medical physics, biomedical imaging, and intensity-modulated radiation therapy will find this book a useful tool in their current research and development efforts.

Yair Censor, Ming Jiang and Ge Wang
Haifa, Beijing, and Blacksburg, VA, respectively
January 31, 2010

Contributing Authors

Numbers in brackets refer to the chapter numbers authored or co-authored by the contributors.

Francesca Albertini [1]
Centre for Proton Radiation Therapy
Paul Scherrer Institute
5232 Villigen PSI
Switzerland

Ashok R. Amin* [2]
Carilion Clinic
101 Elm Avenue, 4th Floor
Roanoke, VA 24013
and Virginia Tech Biomedical & Engineering Sciences
Blacksburg, VA 24061

Simon R. Arridge* [19*, 21]
Department of Computer Science
University College London
Gower Street
London WC1E 6BT
United Kingdom

Guillaume Bal* [3]
Department of Applied Physics and Applied Mathematics
Columbia University
New York, NY 10027

Vladimir Bashkirov [17]
Department of Radiation Medicine
Loma Linda University Medical Center
Loma Linda, CA 92354

Heinz H. Bauschke* [4]
Department of Mathematics
Irving K. Barber School
UBC Okanagan
Kelowna, BC V1V 1V7
Canada

Martin Bech [18]
Department of Physics (E17)
Technical University of Munich
85748 Garching
Germany

Adi Ben-Israel* [5]
Rutgers Center for Operations Research
Rutgers University
640 Bartholomew Road
Piscataway, NJ 08854-8003

Thomas Bortfeld [23]
Department of Radiation Oncology
Massachusetts General Hospital *and*
Harvard Medical School
30 Fruit Street
Boston, MA 02114

Matthias Bosshardt [1]
Centre for Proton Radiation Therapy
Paul Scherrer Institute
5232 Villigen PSI
Switzerland

*Corresponding author.

Alberto Bravin [18]
European Synchrotron Radiation Facility
B.P. 220
38043 Grenoble Cedex
France

James A. Brink, M.D. [6]
Yale University School of Medicine
333 Cedar Street
New Haven, CT 06510

Oliver Bunk [18]
Paul Scherrer Institut
5232 Villigen PSI
Switzerland

Yair Censor* [17, 20*]
Department of Mathematics
University of Haifa
Mt. Carmel, Haifa 31905
Israel

Noah C. Choi [23]
Department of Radiation Oncology
Massachusetts General Hospital *and*
Harvard Medical School
30 Fruit Street
Boston, MA 02114

Peter Cloetens [18]
European Synchrotron Radiation Facility
B.P. 220
38043 Grenoble Cedex
France

Rinaldo Cubeddu [21]
IIT, CNR-INFM, and CNR-IFN
Department of Physics
Politecnico de Milano
Piazza Leonardo da Vinci 32
20133 Milan
Italy

Cosimo D'Andrea [21]
IIT, CNR-INFM, and CNR-IFN
Department of Physics
Politecnico de Milano
Piazza Leonardo da Vinci 32
20133 Milan
Italy

Christian David [18]
Paul Scherrer Institut
5232 Villigen PSI
Switzerland

Bruno De Man* [7]
CT and X-ray Systems and Applications Laboratory
GE Global Research – KWC1307
1 Research Circle
Niskayuna, NY 12309

Tilman Donath [18]
Paul Scherrer Institut
5232 Villigen PSI
Switzerland

Eric D. Ehler [8]
Departments of Human Oncology and Medical Physics
University of Wisconsin
K4/334-3684 Clinical Science Center
600 Highland Avenue
Madison, WI 53792-3684

Tommy Elfving* [9]
Department of Mathematics
Linköping University
SE-581 83 Linköping
Sweden

Jeffrey A. Fessler [7]
EECS Department
University of Michigan
1301 Beal Avenue
Ann Arbor, MI 48109-2122

*Corresponding author.

Sylvain Gaignat [1]
Centre for Proton Radiation Therapy
Paul Scherrer Institute
5232 Villigen PSI
Switzerland

Cornelia Gansemer [23]
Department of Clinical Medicine (Mannheim)
Ruprecht-Karls University
Heidelberg
Germany

Çiğdem Güler [10]
Department of Mathematics
Technical University of Kaiserslautern
Kaiserslautern
Germany

Horst W. Hamacher* [10]
Department of Mathematics
Technical University of Kaiserslautern
Kaiserslautern
Germany

Cem Iyigun [5]
Department of Industrial Engineering
Middle Eastern University
06531 Ankara
Turkey

Torben Jensen [18]
Niels Bohr Institute
University of Copenhagen
2100 Copenhagen
Denmark

Ming Jiang* [11]
LMAM, School of Mathematical Sciences
Peking University
Beijing 100871
China

Alexandre Jollivet [3]
Department of Applied Physics and
Applied Mathematics
Columbia University
New York, NY 10027

Joanne Kang [16]
DKFZ Heidelberg
Department of Medical Physics in
Radiation Therapy
Im Neuenheimer Feld 280
69120 Heidelberg
Germany

Alexander Katsevich [12]
Department of Mathematics
University of Central Florida
Orlando, FL 32816-1364

Geraldine Le Duc [18]
European Synchrotron Radiation Facility
B.P. 220
38043 Grenoble Cedex
France

Antony J. Lomax* [1]
Centre for Proton Radiation Therapy
Paul Scherrer Institute
5232 Villigen PSI
Switzerland

Genaro López [13]
Department of Mathematical Analysis
University of Seville
Apdo. 1160, 41080-Seville
Spain

Victoria Martín-Márquez [13]
Department of Mathematical Analysis
University of Seville
Apdo. 1160, 41080-Seville
Spain

*Corresponding author.

Scott McAllister [17]
Department of Computer Science
and Engineering
California State University San Bernardino
San Bernardino, CA 92407

Atsushi Momose* [14]
Department of Advanced Materials Science
Graduate School of Frontier Sciences
The University of Tokyo
5-1-5 Kashiwanoha, Kashiwa
Chiba 277-8561
Japan

Frank Natterer [15]
Department of Mathematics and
Computer Science
University of Münster
Münster
Germany

Touraj Nikazad [9]
Department of Mathematics
Iran University of Science and Technology
Narmak, Tehran, 16846-13114
Iran

Uwe Oelfke* [16]
DKFZ Heidelberg
Department of Medical Physics
in Radiation Therapy
Im Neuenheimer Feld 280
69120 Heidelberg
Germany

Scott N. Penfold* [17]
Centre for Medical Radiation Physics
University of Wollongong
Wollongong, New South Wales 2522
Australia

Franz Pfeiffer* [18]
Department of Physics (E17)
Technical University of Munich
85748 Garching
Germany

Daniel Pflugfelder [16]
DKFZ Heidelberg
Department of Medical Physics
in Radiation Therapy
Im Neuenheimer Feld 280
69120 Heidelberg
Germany

Constantin Popa [9]
Faculty of Mathematics
and Computer Science
Ovidius University
Constanta Boulevard
Mamaia 124
900527 Constanta
Romania

Nadeem Riaz [24]
Department of Radiation Oncology
Stanford University School of Medicine
Stanford, CA 94305

Anatoly B. Rosenfeld [17]
Centre for Medical Radiation Physics
University of Wollongong
Wollongong, New South Wales, 2522
Australia

Keith E. Schubert [17]
Department of Computer Science
and Engineering
California State University San Bernardino
San Bernardino, CA 92407

*Corresponding author.

Reinhard W. Schulte [17]
Department of Radiation Medicine
Loma Linda University Medical Center
Loma Linda, CA 92354

Martin J. Schweiger [19]
Department of Computer Science
University College London
Gower Street
London WC1E 6BT
United Kingdom

Alexander Segal [20]
Department of Mathematics
University of Haifa
Mt. Carmel, Haifa 31905
Israel

Vadim Y. Soloviev* [21]
Department of Computer Science
University College London
Gower Street
London WC1E 6BT
United Kingdom

George Starkschall [22]
Department of Radiation Physics
The University of Texas M.D. Anderson Cancer Center
1515 Holcombe Boulevard
Houston, TX 77030

Yoshihiro Takeda [14]
Department of Advanced Materials Science
Graduate School of Frontier Sciences
The University of Tokyo
5-1-5 Kashiwanoha, Kashiwa
Chiba 277-8561
Japan

Wolfgang A. Tomé* [8]
University of Wisconsin
School of Medicine and Public Health
Departments of Human Oncology *and* Medical Physics
K4/314 Clinical Science Center
600 Highland Avenue
Madison, WI 53792

Alexei Trofimov* [23]
Department of Radiation Oncology
Massachusetts General Hospital *and* Harvard Medical School
30 Fruit Street
Boston, MA 02114

Gianluca Valentini [21]
IIT, CNR-INFM, and CNR-IFN
Department of Physics
Politecnico de Milano
Piazza Leonardo da Vinci 32
20133 Milan
Italy

Michael W. Vannier, M.D. [24]
Department of Radiology
University of Chicago
5841 S. Maryland Avenue
Chicago, IL 60637

Christian Vrančic [23]
Department of Clinical Medicine (Mannheim)
Ruprecht-Karls University
Heidelberg
Germany

Ge Wang [2, 11, 25, 27]
Virginia Tech Biomedical & Engineering Sciences
1880 Pratt Drive, Suite 2000
Blacksburg, VA 24061

*Corresponding author.

Xianfu Wang [4]
Department of Mathematics
Irving K. Barber School
UBC Okanagan
Kelowna, BC V1V 1V7
Canada

Rodney D. Wiersma* [24]
Department of Radiation and Cellular Oncology
The University of Chicago
5758 S. Maryland Avenue, MC9006
Chicago, IL 60637

Timm Weitkamp [18]
European Synchrotron Radiation Facility
B.P. 220
38043 Grenoble Cedex
France

Jan Jakob Wilkens [16]
Department of Radiation Oncology
Technical University of Munich
Klinikum rechts der Isar
Ismaninger Strasse 22
81675 Munich
Germany

Lei Xing [24]
Department of Radiation Oncology
Stanford University School of Medicine
Stanford, CA 94305

Hong-Kun Xu* [13]
Department of Applied Mathematics
National Sun Yat-sen University
Kaohsiung 80424
Taiwan

Liangjin Yao [4]
Department of Mathematics
Irving K. Barber School
UBC Okanagan
Kelowna, BC V1V 1V7
Canada

Wataru Yashiro [14]
Department of Advanced Materials Science
Graduate School of Frontier Sciences
The University of Tokyo
5-1-5 Kashiwanoha, Kashiwa
Chiba 277-8561
Japan

Yangbo Ye* [25, 27*]
Department of Mathematics
University of Iowa
Iowa City, IA 52242

Adam D. Yock [23]
Department of Radiation Oncology
Massachusetts General Hospital *and*
Harvard Medical School
30 Fruit Street
Boston, MA 02114

Hengyong Yu* [25*, 27]
Biomedical Imaging Division
VT-WFU School of Biomedical Engineering and Science
Virginia Tech
Blacksburg, VA 24061

*Corresponding author.

Furthermore, medical images are used. 1 Fundamentals of Biomedical Image Processing.Â According to the Maxwell laws, accelerated (continuously changing its direction) charge induces electro-magnetic radiation: the electron would lose energy gradually spiraling inwards and collapsing into the nucleus. Within the Bohr model of the atom, there are certain shells where an elec-tron can orbit its nucleus without releasing electromagnetic radiation. BIOMEDICAL MATHEMATICS: PROMISING DIRECTIONS IN IMAGING,THERAPY PLANNING, AND INVERSE PROBLEMS Y. Censor, M. Jiang, G. Wang, Editors Â© 2009 Medical Physics Publishing.All rights reserved. Statistical Iterative Reconstruction for X-Ray Computed Tomography. Bruno De Man.Â Statistical Iterative Reconstruction for X-Ray Computed Tomography. This represents a quest for the most likely image, given the measurements. Applying Bayes rule, using the monotonicity of the logarithm and dropping the constant term, this formulation is equivalent to the following optimization problem: ( ) reconstructed. image. Biomedical Mathematics: Promising Directions in Imaging, Therapy Planning, and Inverse Problems (ed 1). Madison: Medical Physics Pub Corp; 2009. pp. 1â€“18. 5. Smith A, Gillin M, Bues M, Zhu XR, Suzuki K, Mohan R, Woo S, Lee A, Komaki R, Cox J, Hiramoto K, Akiyama H, Ishida T, Sasaki T, Matsuda K. The M. D. Anderson proton therapy system.Â The patient images and segmentation may be shared under UCLA IRB approval of amendment on a case by case base. The 4Ï€ planning package is proprietary due to patent protection but compiled binary code may be available under special agreement. Authorsâ€™ contributions.