Graphs and Algorithms

Proceedings of a Summer Research Conference held
June 28–July 4, 1987
Titles in This Series

Volume

1 Markov random fields and their applications, Ross Kindermann and J. Laurie Snell
2 Proceedings of the conference on integration, topology, and geometry in linear spaces, William H. Graves, Editor
3 The closed graph and P-closed graph properties in general topology, T. R. Hamlett and L. L. Herrington
4 Problems of elastic stability and vibrations, Vadim Komkov, Editor
5 Rational constructions of modules for simple Lie algebras, George B. Seligman
6 Umbral calculus and Hopf algebras, Robert Morris, Editor
7 Complex contour integral representation of cardinal spline functions, Walter Schempp
8 Ordered fields and real algebraic geometry, D. W. Dubois and T. Recio, Editors
9 Papers in algebra, analysis and statistics, R. Lidl, Editor
10 Operator algebras and K-theory, Ronald G. Douglas and Claude Schochet, Editors
11 Plane ellipticity and related problems, Robert P. Gilbert, Editor
12 Symposium on algebraic topology in honor of José Adem, Samuel Gitler, Editor
13 Algebraists’ homage: Papers in ring theory and related topics, S. A. Amitsur, D. J. Saltman, and G. B. Seligman, Editors
14 Lectures on Nielsen fixed point theory, Boju Jiang
15 Advanced analytic number theory. Part I: Ramification theoretic methods, Carlos J. Moreno
16 Complex representations of GL(2, K) for finite fields K, Ilya Piatetski-Shapiro
17 Nonlinear partial differential equations, Joel A. Smoller, Editor
18 Fixed points and nonexpansive mappings, Robert C. Sine, Editor
19 Proceedings of the Northwestern homotopy theory conference, Haynes R. Miller and Stewart B. Priddy, Editors
20 Low dimensional topology, Samuel J. Lomonaco, Jr., Editor
21 Topological methods in nonlinear functional analysis, S. P. Singh, S. Thomeier, and B. Watson, Editors
22 Factorizations of $b^n \pm 1$, $b = 2, 3, 5, 6, 7, 10, 11, 12$ up to high powers, John Brillhart, D. H. Lehmer, J. L. Selfridge, Bryant Tuckerman, and S. S. Wagstaff, Jr.
23 Chapter 9 of Ramanujan’s second notebook—Infinite series identities, transformations, and evaluations, Bruce C. Berndt and Padmini T. Joshi
24 Central extensions, Galois groups, and ideal class groups of number fields, A. Fröhlich
25 Value distribution theory and its applications, Chung-Chun Yang, Editor
26 Conference in modern analysis and probability, Richard Beals, Anatole Beck, Alexandra Bellow, and Arshag Hajian, Editors
27 Microlocal analysis, M. Salah Baouendi, Richard Beals, and Linda Preiss Rothschild, Editors
28 Fluids and plasmas: geometry and dynamics, Jerrold E. Marsden, Editor
29 Automated theorem proving, W. W. Bledsoe and Donald Loveland, Editors
30 Mathematical applications of category theory, J. W. Gray, Editor
31 Axiomatic set theory, James E. Baumgartner, Donald A. Martin, and Saharon Shelah, Editors
32 Proceedings of the conference on Banach algebras and several complex variables, F. Greenleaf and D. Gulick, Editors
33 Contributions to group theory, Kenneth I. Appel, John G. Ratcliffe, and Paul E. Schupp, Editors
34 Combinatorics and algebra, Curtis Greene, Editor
Titles in This Series

Volume

35 Four-manifold theory, Cameron Gordon and Robion Kirby, Editors
36 Group actions on manifolds, Reinhard Schultz, Editor
37 Conference on algebraic topology in honor of Peter Hilton, Renzo Piccinini and Denis Sjerve, Editors
38 Topics in complex analysis, Dorothy Browne Shaffer, Editor
39 Errett Bishop: Reflections on him and his research, Murray Rosenblatt, Editor
40 Integral bases for affine Lie algebras and their universal enveloping algebras, David Mitzman
41 Particle systems, random media and large deviations, Richard Durrett, Editor
42 Classical real analysis, Daniel Waterman, Editor
43 Group actions on rings, Susan Montgomery, Editor
44 Combinatorial methods in topology and algebraic geometry, John R. Harper and Richard Mandelbaum, Editors
45 Finite groups—coming of age, John McKay, Editor
46 Structure of the standard modules for the affine Lie algebra $A_1^{(1)}$, James Lepowsky and Mirko Primc
48 Analytic functions of one complex variable, Chung-chun Yang and Chi-tai Chuang, Editors
49 Complex differential geometry and nonlinear differential equations, Yum-Tong Siu, Editor
50 Random matrices and their applications, Joel E. Cohen, Harry Kesten, and Charles M. Newman, Editors
51 Nonlinear problems in geometry, Dennis M. DeTurck, Editor
53 The Selberg trace formula and related topics, Dennis A. Hejhal, Peter Sarnak, and Audrey Anne Terras, Editors
54 Differential analysis and infinite dimensional spaces, Kondagunta Sundaresan and Srinivas Swaminathan, Editors
55 Applications of algebraic K-theory to algebraic geometry and number theory, Spencer J. Bloch, R. Keith Dennis, Eric M. Friedlander, and Michael R. Stein, Editors
56 Multiparameter bifurcation theory, Martin Golubitsky and John Guckenheimer, Editors
57 Combinatorics and ordered sets, Ivan Rival, Editor
58.I The Lefschetz centennial conference. Part I: Proceedings on algebraic geometry, D. Sundararaman, Editor
58.II The Lefschetz centennial conference. Part II: Proceedings on algebraic topology, S. Gitler, Editor
59 Function estimates, J. S. Marron, Editor
60 Nonstrictly hyperbolic conservation laws, Barbara Lee Keyfitz and Herbert C. Kranzer, Editors
61 Residues and traces of differential forms via Hochschild homology, Joseph Lipman
62 Operator algebras and mathematical physics, Palle E. T. Jorgensen and Paul S. Muhly, Editors
63 Integral geometry, Robert L. Bryant, Victor Guillemin, Sigurdur Helgason, and R. O. Wells, Jr., Editors
64 The legacy of Sonya Kovalevskaya, Linda Keen, Editor
65 Logic and combinatorics, Stephen G. Simpson, Editor
66 Free group rings, Narian Gupta
67 Current trends in arithmetical algebraic geometry, Kenneth A. Ribet, Editor
68 Differential geometry: The interface between pure and applied mathematics,
Titles in This Series

Volume

Mladen Luksic, Clyde Martin, and William Shadwick, Editors
69 Methods and applications of mathematical logic, Walter A. Carnielli and Luiz Paulo de Alcantara, Editors
70 Index theory of elliptic operators, foliations, and operator algebras, Jerome Kaminker, Kenneth C. Millett, and Claude Schochet, Editors
71 Mathematics and general relativity, James A. Isenberg, Editor
72 Fixed point theory and its applications, R. F. Brown, Editor
73 Geometry of random motion, Rick Durrett and Mark A. Pinsky, Editors
74 Geometry of group representations, William M. Goldman and Andy R. Magid, Editors
75 The finite calculus associated with Bessel functions, Frank M. Cholewinski
76 The structure of finite algebras, David C. Hobby and Ralph McKenzie
77 Number theory and its applications in China, Wang Yuan, Yang Chung-chun, and Pan Chengbiao, Editors
78 Braids, Joan S. Birman and Anatoly Libgober, Editors
79 Regular differential forms, Ernst Kunz and Rolf Waldi
80 Statistical inference from stochastic processes, N. U. Prabhu, Editor
81 Hamiltonian dynamical systems, Kenneth R. Meyer and Donald G. Saari, Editors
82 Classical groups and related topics, Alexander J. Hahn, Donald G. James, and Zhe-xian Wan, Editors
83 Algebraic K-theory and algebraic number theory, Michael R. Stein and R. Keith Dennis, Editors
84 Partition problems in topology, Stevo Todorcevic
85 Banach space theory, Bor-Luh Lin, Editor
86 Representation theory and number theory in connection with the local Langlands conjecture, J. Ritter, Editor
87 Abelian group theory, Laszlo Fuchs, Rüdiger Göbel, and Phillip Schultz, Editors
88 Invariant theory, R. Fossum, W. Haboush, M. Hochster, and V. Lakshmibai, Editors
89 Graphs and algorithms, R. Bruce Richter, Editor
Graphs and Algorithms
Graphs and Algorithms
Proceedings of the AMS-IMS-SIAM Joint Summer Research Conference held June 28–July 4, 1987 with support from the National Science Foundation

R. Bruce Richter, Editor

AMERICAN MATHEMATICAL SOCIETY
Providence • Rhode Island
The AMS-IMS-SIAM Joint Summer Research Conference in the Mathematical Sciences on
Graphs and Algorithms was held at the University of Colorado, Boulder, Colorado on June 28–July
4, 1987 with support from the National Science Foundation, Grant DMS-8613199.

1980 Mathematics Subject Classification (1985 Revision). Primary 05C, 68M, 68P, 68Q.

Library of Congress Cataloging-in-Publication Data
AMS-IMS-SIAM Joint Summer Research Conference in the Mathematical Sciences on
Graphs and Algorithms (1987: University of Colorado)
Graphs and algorithms: proceedings of the AMS-IMS-SIAM joint summer research
conference held June 28–July 4, 1987 with support from the National Science Foundation
/R. Bruce Richter, editor.
p. cm.-(Contemporary mathematics, ISSN 0271-4132; v. 89)
The AMS-IMS-SIAM Joint Summer Research Conference in the Mathematical Sciences on
Graphs and Algorithms was held at the University of Colorado, Boulder, Colorado-T.p. verso.
Includes bibliographies.
1. Graph theory--Congressess. 2. Algorithms--Congressess. I. Richter, R. Bruce. II. American
Mathematical Society. III. Institute of Mathematical Statistics. IV. Society for Industrial and
Applied Mathematics. V. Title. VI. Series: Contemporary mathematics (American Mathematical
Society); v. 89.
QA166.A47 1987 511'.5--dc19 89-216
CIP

Copying and reprinting. Individual readers of this publication, and nonprofit libraries
acting for them, are permitted to make fair use of the material, such as to copy an article for
use in teaching or research. Permission is granted to quote brief passages from this publication
in reviews, provided the customary acknowledgment of the source is given.
Republication, systematic copying, or multiple reproduction of any material in this pub-
lication (including abstracts) is permitted only under license from the American Mathematical
Society. Requests for such permission should be addressed to the Manager of Editorial Ser-
vices, American Mathematical Society, P.O. Box 6248, Providence, Rhode Island 02940-6248.
The appearance of the code on the first page of an article in this book indicates the
copyright owner's consent for copying beyond that permitted by Sections 107 or 108 of the
U.S. Copyright Law, provided that the fee of $1.00 plus $.25 per page for each copy be paid
directly to the Copyright Clearance Center, Inc., 27 Congress Street, Salem, Massachusetts
01970. This consent does not extend to other kinds of copying, such as copying for general
distribution, for advertising or promotional purposes, for creating new collective works, or for
resale.

Copyright © 1989 by the American Mathematical Society. All rights reserved.
The American Mathematical Society retains all rights except those granted
to the United States Government.
Printed in the United States of America.
This volume was printed directly from author-prepared copy.
The paper used in this book is acid-free and falls within the guidelines
established to ensure permanence and durability.

[Bar code]
CONTENTS

Foreword xi
Organizing Committee xiii
List of Participants xiii
The Robertson-Seymour theorems: A survey of applications
   MICHAEL R. FELLOWS 1
On genus-reducing and planarizing algorithms for embedded graphs
   JOAN P. HUTCHINSON 19
Interval hypergraphs
   ARNOLD L. ROSENBERG 27
Competitive algorithms for on-line problems
   MARK S. MANASSE, LYLE A. McGEOCH,
   and DANIEL D. SLEATOR 45
On recognizability of planar graphs
   LARRY I. BASENSPILER 55
Combinatorial computation of moduli dimension of Nielsen classes
   of covers
   MIKE FRIED 61
Labeled trees and the algebra of differential operators
   ROBERT GROSSMAN and RICHARD G. LARSON 81
Computing edge-toughness and fractional arboricity
   ARTHUR M. HOBBS 89
Directed graphs and the compaction of IC designs
   BRADLEY W. JACKSON 107
Parallelism, preprocessing, and reachability
   PHILIP N. KLEIN 129
A summary of results on pair-connected reliability
   PETER J. SLATER 145
On minimum cuts of cycles and maximum disjoint cycles
JAYME L. SZWARCFITER 153

Graphs and finitely presented groups
ANDREW VINCE 167

Problem corner 187
FOREWORD

The GRAPHS AND ALGORITHMS week of the Joint Summer Research Conference in the Mathematical Sciences took place in Boulder, Colorado, June 28 to July 4, 1987. The co-chairs were Joe Buhler and Phyllis Chinn.

The purpose of the week was to foster communication between computer scientists and mathematicians. Recent work in graph theory and related algorithms has relied on increasingly sophisticated mathematics. Wagner’s Conjecture, self-adjusting data structures, graph isomorphism and various embedding and labelling problems in VLSI are examples. Thus, it is clear that researchers in both computer science and mathematics need to be aware of what the other is doing.

The organizers were pleasantly surprised at the depth and diversity of the work being done. The wide range of talks demonstrated the vitality of the activity in both fields. The common graph-theoretic and algorithmic themes insured sufficient cross-interest so many people profited from discussions with others whose work had led in different directions. We hope the papers included here capture some of the diversity and excitement of the conference.

The organizing committee would like to thank all those who attended for their participation. We would also like to thank the AMS-IMS-SIAM Committee and the National Science Foundation for their support. We especially appreciate the hard work of Carole Kohanski of the AMS. The University of Colorado at Boulder was an excellent host institution.

The Organizing Committee
ORGANIZING COMMITTEE

co-chairs: Joe P. Buhler (Reed College)
Phyllis Z. Chinn (Humboldt State University)

committee: Jean Larson (University of Florida)
Eugene Luks (University of Oregon)
Bruce Richter (U.S. Naval Academy)
Bruce Rothschild (University of California at Los Angeles)
Robert Tarjan (AT&T Bell Laboratories)

LIST OF PARTICIPANTS

Curtiss Barefoot
New Mexico Institute of Mining and Technology
Socorro, New Mexico

Larry I. Basenspiler
Northern Illinois University
DeKalb, Illinois

Fredricka T. Bennett
Skidmore College
Saratoga Springs, New York

David R. Berman
University of North Carolina
Wilmington, North Carolina

Ken D. Blaha
University of Oregon
Eugene, Oregon

Gary M. Brenner
P.O. Box 7114
Boulder, Colorado

Thomas C. Brown
Simon Fraser University
Burnaby, British Columbia

Joe P. Buhler
M.S.R.I. Reed College
Portland, Oregon

Bruce A. Chalmers
Mt. Allison University
Sackville, New Brunswick

Eldon K.W. Chan
San Jose State University
San Jose, California

Phyllis Z. Chinn
Humboldt State University
Arcata, California

Fan R.K. Chung
Bell Communications Research
Morristown, New Jersey
<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karen L. Collins</td>
<td>Wesleyan University</td>
<td>Middletown, Connecticut</td>
</tr>
<tr>
<td>Alice M. Dean</td>
<td>Skidmore College</td>
<td>Saratoga Springs, New York</td>
</tr>
<tr>
<td>Jane W. Di Paola</td>
<td>3580 County Rd. 215</td>
<td>Cheyenne, Wyoming</td>
</tr>
<tr>
<td>Clifton E. Ealy, Jr.</td>
<td>Northern Michigan University</td>
<td>Marquette, Michigan</td>
</tr>
<tr>
<td>Vance Faber</td>
<td>Los Alamos National Laboratory</td>
<td>Los Alamos, New Mexico</td>
</tr>
<tr>
<td>Arthur M. Farley</td>
<td>University of Oregon</td>
<td>Eugene, Oregon</td>
</tr>
<tr>
<td>Joan Feigenbaum</td>
<td>600 Mountain Ave.</td>
<td>Murray Hill, New Jersey</td>
</tr>
<tr>
<td>Mike R. Fellows</td>
<td>University of Idaho</td>
<td>Moscow, Idaho</td>
</tr>
<tr>
<td>Michael D. Fried</td>
<td>University of Florida</td>
<td>Gainesville, Florida</td>
</tr>
<tr>
<td>Mark K. Goldberg</td>
<td>Rensselaer Polytechnic Institute</td>
<td>Troy, New York</td>
</tr>
<tr>
<td>Steven B. Grantham</td>
<td>Boise State University</td>
<td>Boise, Idaho</td>
</tr>
<tr>
<td>Alvin C. Green</td>
<td>State University College at Buffalo</td>
<td>Buffalo, New York</td>
</tr>
<tr>
<td>Charles M. Grinstead</td>
<td>Swarthmore College</td>
<td>Swarthmore, Pennsylvania</td>
</tr>
<tr>
<td>Robert L. Grossman</td>
<td>University of California</td>
<td>Berkeley, California</td>
</tr>
<tr>
<td>Stanley J. Gurak</td>
<td>University of San Diego</td>
<td>San Diego, California</td>
</tr>
<tr>
<td>Eleanor O. Hare</td>
<td>Clemson University</td>
<td>Clemson, South Carolina</td>
</tr>
<tr>
<td>William R. Hare</td>
<td>Clemson University</td>
<td>Clemson, South Carolina</td>
</tr>
<tr>
<td>Sandra M. Hedetniemi</td>
<td>Clemson University</td>
<td>Clemson, South Carolina</td>
</tr>
<tr>
<td>Steven T. Hedetniemi</td>
<td>Clemson University</td>
<td>Clemson, South Carolina</td>
</tr>
<tr>
<td>Kim A.S. Hefner</td>
<td>University of Colorado</td>
<td>Denver, Colorado</td>
</tr>
<tr>
<td>Arthur M. Hobbs</td>
<td>Texas A&amp;M University</td>
<td>College Station, Texas</td>
</tr>
<tr>
<td>Fred Hoffman</td>
<td>Florida Atlantic University</td>
<td>Boca Raton, Florida</td>
</tr>
<tr>
<td>Joan P. Hutchinson</td>
<td>Smith College</td>
<td>Northampton, Massachusetts</td>
</tr>
<tr>
<td>Brad W. Jackson</td>
<td>San Jose State University</td>
<td>San Jose, California</td>
</tr>
<tr>
<td>Kathryn L. Jones</td>
<td>University of Colorado</td>
<td>Denver, Colorado</td>
</tr>
<tr>
<td>Philip N. Klein</td>
<td>Massachusetts Institute of Technology</td>
<td>Cambridge, Massachusetts</td>
</tr>
<tr>
<td>Yueh-Er Kuo</td>
<td>University of Tennessee</td>
<td>Knoxville, Tennessee</td>
</tr>
<tr>
<td>Jean A. Larson</td>
<td>University of Florida</td>
<td>Gainesville, Florida</td>
</tr>
<tr>
<td>Renu Laskar</td>
<td>Clemson University</td>
<td>Clemson, South Carolina</td>
</tr>
<tr>
<td>Sin-Min Lee</td>
<td>San Jose State University</td>
<td>San Jose, California</td>
</tr>
</tbody>
</table>
Eugene M. Luks
University of Oregon
Eugene, Oregon

J. Richard Lundgren
University of Colorado
Denver, Colorado

Mary A. Maher
New Mexico State University
Las Cruces, New Mexico

Peter D. Mark
University of Oregon
Eugene, Oregon

Ursula Martin
RHBNC, University of London
Egham, Surrey

Robert A. Melter
Long Island University
Southampton, New York

Zevi Miller
Miami University
Oxford, Ohio

John A. Mitchem
San Jose State University
San Jose, California

Eric Regener
Concordia University
Montreal, Quebec

R. Bruce Richter
U.S. Naval Academy
Annapolis, Maryland

Arnold L. Rosenberg
University of Massachusetts
Amherst, Massachusetts

Michael E. Saks
Rutgers University
New Brunswick, New Jersey

Peter J. Slater
Clemson University
Clemson, South Carolina

Daniel D. Sleator
Carnegie Mellon University
Pittsburgh, Pennsylvania

Joseph B. Stephen
Northern Illinois University
DeKalb, Illinois

Rebekka R. Struik
University of Colorado
Boulder, Colorado

Jayme L. Szwarcfiter
Universidad Federal do Rio de Janeiro
Rio de Janeiro, Brazil

William T. Trotter
Arizona State University
Tempe, Arizona

Miroslaw Truszczynski
University of Kentucky
Lexington, Kentucky

Donald W. Vandejagt
Grand Valley State College
Allendale, Michigan

Andrew Vince
University of Florida
Gainesville, Florida

Walter D. Wallis
Southern Illinois University
Carbondale, Illinois

Michael Werman
Brown University
Providence, Rhode Island

Indra Wui
San Jose State University
San Jose, California