

CONTEMPORARY MATHEMATICS

Graphs and Algorithms

Proceedings of a Summer
Research Conference held
June 28–July 4, 1987

AMERICAN MATHEMATICAL SOCIETY

VOLUME 89

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
- 47 Linear algebra and its role in systems theory**, Richard A. Brualdi, David H. Carlson, Biswa Nath Datta, Charles R. Johnson, and Robert J. Plemmons, Editors
- 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
- 52 Geometry of normed linear spaces**, R. G. Bartle, N. T. Peck, A. L. Peressini, and J. J. Uhl, Editors
- 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 Srinivasa 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. Sundaraman, Editor
- 58.II The Lefschetz centennial conference. Part II: Proceedings on algebraic topology**, S. Gitler, Editor
- 58.III The Lefschetz centennial conference. Part III: Proceedings on differential equations**, A. Verjovsky, 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 Lukšić, 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 Todorčević
- 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

CONTEMPORARY MATHEMATICS

Volume 89

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

EDITORIAL BOARD

Daniel M. Burns, Jr., managing editor
Richard W. Beals Sylvain Cappell
David Eisenbud Gerald J. Janusz
Jonathan Goodman Jan Mycielski
Michael E. Taylor

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.

ISBN 0-8218-5095-4 (alk. paper)

1. Graph theory—Congresses. 2. Algorithms—Congresses. 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 publication (including abstracts) is permitted only under license from the American Mathematical Society. Requests for such permission should be addressed to the Manager of Editorial Services, 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. ☺

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
Socorro, New Mexico
and Technology

Larry I. Basenspiller
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

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

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

Jayne L. Szwarcfiter
Universidade Federal do Rio
de Janeiro
Rio de Janeiro, Brazil

William T. Trotter
Arizona State University
Tempe, Arizona

Mirosław 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

ISBN 978-0-8218-5095-4



9 780821 850954

CONM/89