## Mathematics of Computation



EDITED BY
James H. Bramble, Managing Editor
Carl de Boor
Todd Dupont
Walter Gautschi
Donald Goldfarb
Eugene Isaacson
Heinz-Otto Kreiss
Yudell L. Luke
James N. Lyness
Morris Newman
John E. Osborn
Beresford Parlett
Philip Rabinowitz
John R. Rice
Daniel Shanks
Charles C. Sims
Hans J. Stetter
Vidar C. Thomee
Hugh C. Williams
John W. Wrench, Jr.
July 1981
Volume 37, Number 155, Pages 1-242
Published by the American Mathematical Society
Providence, Rhode Island USA

## Editorial Committee

JAMES H. BRAMBLE, Chairman. Dept. of Mathematics, White Hall, Cornell Univ., Ithaca, NY 14853
CARL DE BOOR, Mathematics Research Center, Univ. of Wisconsin, Madison, WI 53706
MORRIS NEWMAN, Dept. of Mathematics, Univ. of California, Santa Barbara, CA 93106
DANIEL SHANKS, Dept. of Mathematics, Univ. of Maryland, College Park, MD 20742
Technical Editor
ANITA WAHLBIN, Dept. of Mathematics, White Hall, Cornell Univ., Ithaca, NY 14853

## Board of Associate Editors

TODD DUPONT, Dept. of Mathematics, Univ. of Chicago, Chicago, IL 69637
WALTER GAUTSCi II, Computer Sciences Dept., Purdue Univ., West Lafayette, IN 47907
DONALD GOLDFARB, Dept. of Computer Sciences, School of Engineering, The City College of the City Univ. of New York, 139th Street \& Convent Avenue, New York, NY 10031
EUGENE ISAACSON, Courant Institute of Mathematical Sciences, New York Univ., 251 Mercer Street, New York, NY 10012
HEINZ-OTTO KREISS, Dept. of Applied Mathematics, California Inst. of Technology, Pasadena, CA 91125
YUDELL L. LUKE, Dept. of Mathematics, Univ. of Missouri at Kansas City, Kansas City, MO 64110
JAMES N. LYNESS, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439
JOHN E. OSBORN, Dept. of Mathematics, Univ. of Maryland, College Park, MD 20742
BERESFORD PARLETT, Dept. of Computer Science, Univ. of California, Berkeley, CA 94720
PHILIP RABINOWITZ, Dept. of Applied Mathematics; The Weizmann Institute of Science, Rehovot, Israel
JOHN R. RICE, Division of Mathematical Sciences, Purdue Univ., Lafayette, IN 47907
CHARLES C. SIMS, Dept. of Mathematics, Rutgers Univ., New Brunswick, NJ 08903
HANS J. STETTER, Institut für Numerische Mathematik, Technische Universität Wien, Karlsplatz 13, A-1040, Wien, Austria
VIDAR C. THOMEE, Mathematics Dept., Chalmers Univ. of Technology, Göteborg, Sweden
HUGH C. WILLIAMS, Dept. of Computer Science, Univ. of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2
JOHN W. WRENCH, JR., 6310 Jefferson Blvd., Frederick, MD 21701
SUBSCRIPTION INFORMATION: MATHEMATICS OF COMPUTATION is published quarterly, with issues numbered serially since Volume 1, Number 1. Subscription prices for Volumes 36 and 37 (1981) are $\$ 65.00$ list; $\$ 45.00$ institutional member; $\$ 35.00$ member of CBMS organizations; $\$ 25.00$ individual AMS member. Combination paper and microform (microfiche or microfilm) subscription prices are $\$ 87.00$ list; $\$ 60.00$ institutional member; $\$ 47.00$ member of CBMS organizations; $\$ 33.00$ individual AMS member. Microfiche of each issue will be mailed the fastest way before the camera copy is sent to the printer.

BACK NUMBER INFORMATION: Back number prices per volume are for Volumes 1-27, $\$ 36.00$ list, $\$ 27.00$ member; for Volumes $28-29, \$ 54.00$ list, $\$ 40.50$ member; for Volume 30, $\$ 72.00$ list, $\$ 54.00$ member; for Volumes 31-33, $\$ 84.00$ list, $\$ 63.00$ member; for Volumes 34-35, $\$ 49.00$ list, $\$ 36.75$ member. Beginning with Volume 32, back volumes are also available on 16 mm positive or negative microfilm or on microfiche; Volumes 1-31 are available on microfilm only, not microfiche. The microfilm may be mounted on spools or in Kodak or 3M cartridges. Only current subscribers are eligible to purchase back volumes on microform. Write to the AMS for a detailed price list.

UNPUBLISHED MATHEMATICAL TABLES: The editorial office of the journal maintains a repository of Unpublished Mathematical Tables (UMT). When a table is deposited in the UMT repository a brief summary of its contents is published in the section Reviews and Descriptions of Tables and Books. Upon request, the chairman of the editorial committee will supply copies of any table for a nominal cost per page. All tables and correspondence concerning the UMT should be sent to James H. Bramble, Chairman, Department of Mathematics, White Hall, Cornell University, Ithaca, NY 14853.

Orders for subscriptions and publications of the American Mathematical Society should be addressed to the AMS, P. O. Box 1571, Annex Station, Providence, R.I. 02901. All orders must be accompanied by payment. Other correspondence should be addressed to P. O. Box 6248, Providence, R.I. 02940.

MATHEMATICS OF COMPUTATION is published quarterly by the American Mathematical Society, 201 Charles Street, Providence, RI 02904. Second-class postage is paid at Providence, Rhode Island, and additional mailing offices. Postmaster: Send address changes to Mathematics of Computation, American Mathematical Society, P. O. Box 6248, Providence, RI 02940.

# Mathematics of Computation 

EDITED BY<br>James H. Bramble, Managing Editor<br>Carl de Boor<br>Todd Dupont<br>Walter Gautschi<br>Donald Goldfarb<br>Eugene Isaacson<br>Heinz-Otto Kreiss<br>Yudell L. Luke<br>James N. Lyness<br>Morris Newman<br>John E. Osborn<br>Beresford Parlett<br>Philip Rabinowitz<br>John R. Rice<br>Daniel Shanks<br>Charles C. Sims<br>Hans J. Stetter<br>Vidar C. Thomée<br>Hugh C. Williams<br>John W. Wrench, Jr.

## Information for Contributors

Manuscripts should be typewritten double-spaced in the format used by the journal. For journal abbreviations, see the latest Mathematical Reviews volume index. An author should submit the original and two copies of the manuscript and retain one copy. The author may suggest an appropriate editor for his paper. It is recommended that the author acquaint himself with the pertinent material contained in "A Manual for Authors of Mathematical Papers," which is available from the American Mathematical Society. All contributions intended for publication and all books for review should be addressed to James H. Bramble, Chairman, Editorial Committee, Mathematics of Computation, Department of Mathematics, White Hall, Cornell University, Ithaca, New York 14853. Institutions sponsoring research reported in the journal are assessed page and microfiche charges.

Each article submitted for publication must be accompanied by a brief and reasonably self-contained abstract, and by 1980 Mathematics Subject Classification numbers. If a list of key words and phrases is included, it will be printed as a footnote on the first page. A list of the classification numbers may be found in the 1978 Subject Index to Mathematical Reviews.

The research journals of the American Mathematical Society carry a page charge of $\$ 40.00$ per page to help defray the cost of publication. This amount is charged to the institution or to a contract supporting the research reported in the published paper. The publication charge policy of the United State Federal Council for Science and Technology (FCST) is reported on page 112 of the February, 1975 issue of the NOTICES of the American Mathematical Society. In no case is the author personally responsible for paying the page charge, nor is acceptance of the author's paper for publication dependent upon payment of the page charge.

## 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 acknowledgement 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 Executive Director, American Mathematical Society, Box 6248, Providence, Rhode Island 02940.

The appearance of the code on the first page of an article in this journal 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 copier pay the stated per copy fee through the Copyright Clearance Center, Inc., 21 Congress Street, Salem, Massachusetts 01970. This consent does not extend to other kinds of copying, such as copying for general distribution, for advertising or promotion purposes, for creating new collective works, or for resale.
MATHEMATICS OF COMPUTATION
TABLE OF CONTENTS
July 1981
James H. Bramble, The Lagrange Multiplier Method for Dirichlet's Problem. ..... 1
Juhani Pitkäranta, The Finite Element Method With Lagrange Multipliers for Do- mains With Corners. ..... 13
M. Vogelius and I. Babuška, On a Dimensional Reduction Method. I. The Opti- mal Selection of Basis Functions ..... 31
M. Vogelius and I. Babuška, On a Dimensional Reduction Method. II. Some Ap- proximation-Theoretic Results ..... 47
D. L. Hicks, Hydrocode Subcycling Stability ..... 69
Alan E. Berger, Jay M. Solomon and Melvyn Ciment, An Analysis of a Uniformly Accurate Difference Method for a Singular Perturbation Problem ..... 79
Athena Makroglou, A Block-by-Block Method for Volterra Integro-Differential Equations With Weakly-Singular Kernel ..... 95
M. Madalena Martins, Note on Irreducible Diagonally Dominant Matrices and the Convergence of the AOR Iterative Method ..... 101
Y. Saad, Krylov Subspace Methods for Solving Large Unsymmetric Linear Systems.. ..... 105
James A. Pennline, Improving Convergence Rate in the Method of Successive Ap- proximations. ..... 127
C. B. Dunham and Jack Williams, Rate of Convergence of Discretization in Chebyshev Approximation ..... 135
P. Lancaster and K. Salkauskas, Surfaces Generated by Moving Least Squares Methods ..... 141
J. Marshall Ash and Roger L. Jones, Optimal Numerical Differentiation Using Three Function Evaluations ..... 159
Bing-Yuan Ting and Yudell L. Luke, Computation of Integrals With Oscillatory and Singular Integrands ..... 169
B. Mond, On Algorithmic Equivalence in Linear Fractional Programming. ..... 185
John P. Boyd, The Rate of Convergence of Chebyshev Polynomials for Functions Which Have Asymptotic Power Series About One Endpoint ..... 189
J. P. Delahaye, Automatic Selection of Sequence Transformations ..... 197
C. J. Smyth, On the Measure of Totally Real Algebraic Integers. II ..... 205
Rudolf A. Mathon, Kevin T. Phelps and Alexander Rosa, A Class of Steiner Triple Systems of Order 21 and Associated Kirkman Systems ..... 209
A. J. W. Duijvestijn and P. Leeuw, Lowest Order Squared Rectangles and Squares With the Largest Element Not on the Boundary ..... 223
Robert Baillie, G. Cormack and H. C. Williams, The Problem of Sierpiński Concern- ing $k \cdot 2^{n}+1$ ..... 229
Arne Fransén, Addendum and Corrigendum to "High-Precision Values of the Gamma Function and of Some Related Coefficients". ..... 233
Reviews and Descriptions of Tables and Books ..... 237
Shampine and Gordon 12, Brezinski 13, Kennedy and Gentle 14

# SEQUENCE TRANSFORMATIONS AND THEIR APPLICATIONS 

BY JET WIMP
A VOLUME IN THE MATHEMATICS IN SCIENCE AND ENGINEERING SERIES

CHAPTER HEADINGS: Sequences and Series. Linear Transformations. Linear Lozenge Methods. Optimal Methods and Methods Based on Power Series. Nonlinear Lozenges: Iteration Se quences. The Schmidt Transformation: The $\epsilon$-Algorithm. Aitken's $\delta^{2}$-Process and Related Methods. Lozenge Algorithms and the Theory of Continued

Fractions. Other Lozenge Algorithms and Nonlinear Methods. The BrezinskiHåvie Protocol. The Brezinski-Håvie Protocol and Numerical Quadrature. Probabilistic Methods. Multiple Sequences. Appendix. Index.
1981, 288 pp., $\$ 38.50$
ISBN: 0-12-757940-0

## ANALYSIS AND COMPUTATION OF FIXED POINTS

EDITED BY STEPHEN M. ROBINSON

The papers published in this book arose primarily from the Symposium on Analysis and Computation of Fixed Points, held at the University of Wisconsin, Madison on May 7 and 8, 1979. CONTENTS: M. J. Todd, Numerical Stability and Sparsity in PiecewiseLinear Algorithms. S. Shamir, Two New Triangulations for Homotopy Fixed Point Algorithms with an Arbitrary Grid Refinement. D. G. Saari and R. Saigal, Some Generic Properties of Paths Generated by Fixed Point Algorithms. T.-Y. Li and J. A. Yorke, A Simple Reliable Numerical Algorithm
for Following Homotopy Paths. M. Kojima, Strongly Stable Stationary Solutions in Nonlinear Programs. H. Jürgens et al., Topological Perturbations in the Numerical Study of Nonlinear Eigenvalue and Bifurcation Problems. J. Whalley and J. Piggott, General Equilibrium Analysis of Taxation Policy. J. G. MacKinnon, Solving Urban General Equilibrium Models by Fixed Point Methods. C. R. Engles, Economic Equilibrium under Deformation of the Economy.
1980, 424 pp., $\$ 22.50$
ISBN: 0-12-590240-9

## INTERVAL MATHEMATICS 1980

EDITED BY KARL L. E. NICKEL

Proceedings of an International Symposium on Interval Mathematics held in Freiburg i. Br./Germany from May 27 to 31, 1980.
INVITED LECTURES: N. Apostolatos and G. Karabatzos, Set Functions and Applications. E. R. Hansen and S. Sengupta, Global Constrained Optimization Using Interval Analysis. P. Henrici, A Model for the Propagation of Rounding Error in Floating Arithmetic. K.-U. Jahn, The Importance of 3-Valued Notions for Interval Mathematics. W. M. Kahan, Interval Arithmetic Options in the Proposed IEEE Floating
Future volumes in the MATHEMATICS IN SCIENCE AND ENGINEERING Series are now available on a Continuation Order basis. Your Continuation Order authorizes us to ship and bill each future

Point Arithmetic Standard. D. Klaua, Interval Components of Non-Archimedean Number Systems. S. Markov, Interval Differential Equations. R. E. Moore, New Results on Nonlinear Systems. H. Ratschek, Optimal Approximations in Interval Analysis. B. Sendov, Some Topics of Segment Analysis. F. Stummel, Rounding Error in Gaussian Elimination of Tridiagonal Linear Systems. Survey of Results. Plus 30 Contributed Lectures.
1980, 554 pp., $\$ 29.50$
ISBN: 0-12-518850-1
volume in the series automatically, immediately upon publication. This order will remain in effect until cancelled. Specify the volume number or title with which your order is to begin.

Prices are in U.S. dollars and are subject to change without notice.

## ACADEMIC PRESS, INC.

## American Mathematical Society



The AMERICAN MATHEMATICAL SOCIETY, founded in 1888, is the oldest society in the United States devoted to promoting the interests of mathematical scholarship and research. The Society serves its membership by publishing books and journals, holding meetings, and providing reviewing, indexing, employment information, and other services useful to the mathematical community.

The membership of the AMS is approximately 20,000 . This includes more than 3,500 members who live outside of North America.

## privileges of membership

The opportunity to present and to hear original research papers at mathematics meetings held throughout the United States and Canada.

Free subscriptions to the NOTICES and the BULLETIN (New Series), journals devoted to the publication of news items, research papers, and announcements of interest to mathematicians.

A free copy of the COMBINED MEMBERSHIP LIST biennially.
Reduced subscription rates to the following journals published by the AMS:

> ABSTRACTS OF PAPERS PRESENTED TO THE AMS
> CURRENT MATHEMATICAL PUBLICATIONS
> MATHEMATICAL REVIEWS
> MATHEMATICS OF COMPUTATION
> MATHEMATICS OF THE USSR-IZVESTIJA
> MATHEMATICS OF THE USSR-SBORNIK
> MEMOIRS OF THE AMERICAN MATHEMATICAL SOCIETY
> PROCEEDINGS OF THE AMERICAN MATHEMATICAL SOCIETY
> PROCEEDINGS OF THE STEKLOV INSTITUTE OF MATHEMATICS
> SOVIET MATHEMATICS-DOKLADY
> THEORY OF PROBABILITY AND MATHEMATICAL STATISTICS
> TRANSACTIONS OF THE AMERICAN MATHEMATICAL SOCIETY TRANSACTIONS OF THE MOSCOW MATHEMATICAL SOCIETY VESTNIK OF THE LENINGRAD UNIVERSITY (MATHEMATICS)

Fifty percent price reduction to individual members on most of the books published by the Society.

Reduced subscription rates to several non-AMS journals.
Minimum annual dues range from $\$ 10$ to $\$ 48$ based upon employment status.
FOR FURTHER INFORMATION AND MEMBERSHIP APPLICATION
American Mathematical Society
P. O. Box 6248, Providence, Rhode Island 02940
Arne Fransén, Addendum and Corrigendum to "High-Precision Values of theGamma Function and of Some Related Coefficients".233
Reviews and Descriptions of Tables and Books ..... 237Shampine and Gordon 12, Brezinski 13, Kennedy and Gentle 14

## MATHEMATICS OF COMPUTATION <br> TABLE OF CONTENTS

July 1981
James H. Bramble, The Lagrange Multiplier Method for Dirichlet's Problem ..... 1
Juhani Pitkäranta, The Finite Element Method With Lagrange Multipliers for Do- mains With Corners. ..... 13
M. Vogelius and I. Babuška, On a Dimensional Reduction Method. I. The Opti- mal Selection of Basis Functions. ..... 31
M. Vogelius and I. Babuška, On a Dimensional Reduction Method. II. Some Ap- proximation-Theoretic Results. ..... 47
D. L. Hicks, Hydrocode Subcycling Stability ..... 69
Alan E. Berger, Jay M. Solomon and Melvyn Ciment, An Analysis of a Uniformly Accurate Difference Method for a Singular Perturbation Problem ..... 79
Athena Makroglou, A Block-by-Block Method for Volterra Integro-Differential Equations With Weakly-Singular Kernel. ..... 95
M. Madalena Martins, Note on Irreducible Diagonally Dominant Matrices and the Convergence of the AOR Iterative Method ..... 101
Y. Saad, Krylov Subspace Methods for Solving Large Unsymmetric Linear Systems.. ..... 105
James A. Pennline, Improving Convergence Rate in the Method of Successive Ap- proximations ..... 127
C. B. Dunham and Jack Williams, Rate of Convergence of Discretization in Chebyshev Approximation. ..... 135
P. Lancaster and K. Salkauskas, Surfaces Generated by Moving Least Squares Methods. ..... 141
J. Marshall Ash and Roger L. Jones, Optimal Numerical Differentiation Using Three Function Evaluations ..... 159
Bing-Yuan Ting and Yudell L. Luke, Computation of Integrals With Oscillatory and Singular Integrands. ..... 169
B. Mond, On Algorithmic Equivalence in Linear Fractional Programming. ..... 185
John P. Boyd, The Rate of Convergence of Chebyshev Polynomials for Functions Which Have Asymptotic Power Series About One Endpoint. ..... 189
J. P. Delahaye, Automatic Selection of Sequence Transformations ..... 197
C. J. Smyth, On the Measure of Totally Real Algebraic Integers. II. ..... 205
Rudolf A. Mathon, Kevin T. Phelps and Alexander Rosa, A Class of Steiner Triple Systems of Order 21 and Associated Kirkman Systems. ..... 209
A. J. W. Duijvestijn and P. Leeuw, Lowest Order Squared Rectangles and Squares With the Largest Element Not on the Boundary. ..... 223
Robert Baillie, G. Cormack and H. C. Williams, The Problem of Sierpiński Concern- ing $k \cdot 2^{n}+1$ ..... 229

