

# Mathematics of Computation



## EDITED BY

James H. Bramble  
Bille C. Carlson  
Walter Gautschi, *Managing Editor*  
Donald Goldfarb  
Eugene Isaacson  
Heinz-Otto Kreiss  
James N. Lyness  
Syvert P. Nørsett  
Andrew M. Odlyzko  
Frank W. J. Olver  
John E. Osborn  
Stanley Osher  
Beresford Parlett  
Carl Pomerance  
Philip Rabinowitz  
René Schoof  
Larry L. Schumaker  
Ridgway Scott  
Daniel Shanks  
Frank Stenger  
Hans J. Stetter  
G. W. Stewart  
Vidar Thomée  
Lars B. Wahlbin  
Hugh C. Williams  
John W. Wrench, Jr.

April 1987

Volume 48, Number 178, Pages 449–858

**Published by the American Mathematical Society  
Providence, Rhode Island USA**

ISSN 0025-5718



## Editorial Committee

WALTER GAUTSCHI, Chairman, Dept. of Computer Sciences, Purdue Univ., West Lafayette, IN 47907  
DONALD GOLDFARB, Dept. of Industrial Engineering and Operations Research, Seely W. Mudd Building, Columbia Univ. in the City of New York, New York, NY 10027  
JOHN E. OSBORN, Dept. of Mathematics, Univ. of Maryland, College Park, MD 20742  
HUGH C. WILLIAMS, Dept. of Computer Science, Univ. of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2

## Technical Editor

ERIKA GAUTSCHI, Dept. of Computer Sciences, Purdue Univ., West Lafayette, IN 47907

## Board of Associate Editors

JAMES H. BRAMBLE, Dept. of Mathematics, Cornell Univ., Ithaca, NY 14853  
BILLE C. CARLSON, Dept. of Mathematics, Iowa State Univ., Ames, IA 50011  
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 Institute of Technology, Pasadena, CA 91125  
JAMES N. LYNESS, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439  
SYVERT P. NØRSETT, Div. of Numerical Mathematics, The University of Trondheim and The Norwegian Institute of Technology, Alfred Getz vei 1, N-7034 Trondheim-NTH, Norway  
ANDREW M. ODLYZKO, AT&T Bell Laboratories, 600 Mountain Avenue, Murray Hill, NJ 07974  
FRANK W. J. OLVER, Inst. für Physical Science and Technology, Univ. of Maryland, College Park, MD 20742  
STANLEY OSHER, Dept. of Mathematics, Univ. of California, Los Angeles, CA 90024  
BERESFORD PARLETT, Dept. of Mathematics, Univ. of California, Berkeley, CA 94720  
CARL POMERANCE, Dept. of Mathematics, The Univ. of Georgia, Athens, GA 30602  
PHILIP RABINOWITZ, Dept. of Applied Mathematics, The Weizmann Institute of Science, Rehovot, Israel  
RENÉ SCHOOF, Mathematical Sciences Research Institute, 1000 Centennial Drive, Berkeley, CA 94720  
LARRY L. SCHUMAKER, Center for Approximation Theory, Dept. of Mathematics, Texas A&M Univ., College Station, TX 77843-3368  
RIDGWAY SCOTT, Dept. of Mathematics, Pennsylvania State Univ., University Park, PA 16802  
DANIEL SHANKS, Dept. of Mathematics, Univ. of Maryland, College Park, MD 20742  
FRANK STENGER, Dept. of Mathematics, Univ. of Utah, Salt Lake City, UT 84112  
HANS J. STETTER, Institut für Numerische Mathematik, Technische Universität Wien, Wiedner Hauptstrasse 6-10, A-1040, Wien, Austria  
G. W. STEWART, Dept. of Computer Science, Univ. of Maryland, College Park, MD 20742  
VIDAR THOMÉE, Mathematics Dept., Chalmers Univ. of Technology, S-412 96 Göteborg, Sweden  
LARS B. WAHLBIN, Dept. of Mathematics, Cornell Univ., Ithaca, NY 14853  
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 48 and 49 (1987) are \$174.00 list; \$139.00 institutional member; \$113.00 member of CBMS organizations; \$104.00 individual AMS member. A late charge of 10% of the subscription price will be imposed upon orders received from nonmembers after January 1 of the subscription year. Subscribers outside the United States and India must pay a postage surcharge of \$8.00; subscribers in India must pay a postage surcharge of \$18.00. Combination paper and microfiche subscription prices are \$231.00 list; \$185.00 institutional member. Microfiche of each issue will be mailed the fastest way before the issue is mailed by the printer.

**BACK NUMBER INFORMATION:** Back number prices *per volume* are for Volumes 1-21, \$80.00 list, \$64.00 member; for Volumes 22-33, \$120.00 list, \$96.00 institutional member; for Volumes 34-43, \$80.00 list, \$64.00 institutional member; Volumes 44-45, \$113.00 list, \$90.00 institutional member; Volumes 46-47, \$123.00 list, \$98.00 institutional member. Back volumes may be purchased on microfilm or microfiche from University Microfilms International, 300 North Zeeb Road, Ann Arbor, MI 48106.

**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 Walter Gautschi, Chairman, Editorial Committee, Mathematics of Computation, Department of Computer Sciences, Purdue University, West Lafayette, IN 47907.

Orders for subscriptions and publications of the American Mathematical Society should be addressed to the AMS, P.O. Box 1571, Annex Station, Providence, RI 02901-9930. *All orders must be accompanied by payment.* Other correspondence should be addressed to P.O. Box 6248, Providence, RI 02940.

MATHEMATICS OF COMPUTATION is published quarterly by the American Mathematical Society, 201 Charles Street, Providence, RI 02940. 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.

Copyright © 1987, American Mathematical Society. All rights reserved.  
Printed in the United States of America.

The paper used in this journal is acid-free and falls within the guidelines established to ensure permanence and durability. (∞)



# MATHEMATICS OF COMPUTATION

## TABLE OF CONTENTS

April 1987

<b>T. M. Hagstrom and H. B. Keller</b> , Asymptotic Boundary Conditions and Numerical Methods for Nonlinear Elliptic Problems on Unbounded Domains .....	449
<b>Winfried Auzinger</b> , Defect Corrections for Multigrid Solutions of the Dirichlet Problem in General Domains .....	471
<b>Jukka Saranen</b> , Local Error Estimates for Some Petrov-Galerkin Methods Applied to Strongly Elliptic Equations on Curves .....	485
<b>Moshe Goldberg and Eitan Tadmor</b> , Convenient Stability Criteria for Difference Approximations of Hyperbolic Initial-Boundary Value Problems. II .....	503
<b>M. Crouzeix and V. Thomée</b> , The Stability in $L_p$ and $W_p^1$ of the $L_2$ -Projection onto Finite Element Function Spaces .....	521
<b>R. M. M. Mattheij</b> , On the Computation of Solutions of Boundary Value Problems on Infinite Intervals .....	533
<b>Eugene C. Gartland, Jr.</b> , Uniform High-Order Difference Schemes for a Singularly Perturbed Two-Point Boundary Value Problem .....	551
<b>A. Neubauer</b> , Finite-Dimensional Approximation of Constrained Tikhonov-Regularized Solutions of Ill-Posed Linear Operator Equations .....	565
<b>Sunil Kumar and Ian H. Sloan</b> , A New Collocation-Type Method for Hammerstein Integral Equations .....	585
<b>Kendall Atkinson and Alex Bogomolny</b> , The Discrete Galerkin Method for Integral Equations .....	595
<b>Jean-Paul Berrut and Manfred R. Trummer</b> , Equivalence of Nyström's Method and Fourier Methods for the Numerical Solution of Fredholm Integral Equations .....	617
<b>C. J. Gladwin</b> , An Algorithm for the Construction of Optimal Methods for the Numerical Solution of Volterra Integral Equations of the First Kind .....	625
<b>Maarten de Gee</b> , Linear Multistep Methods for Functional Differential Equations .....	633
<b>Yousef Saad</b> , On the Lanczos Method for Solving Symmetric Linear Systems with Several Right-Hand Sides .....	651
<b>Bahram Nour-Omid, Beresford N. Parlett, Thomas Ericsson, and Paul S. Jensen</b> , How to Implement the Spectral Transformation .....	663
<b>Rong-Qing Jia</b> , $L_\infty$ -Boundedness of $L_2$ -Projections on Splines for a Multiple Geometric Mesh .....	675
<b>Zhongqi Jing and Adly T. Fam</b> , An Algorithm for Computing Continuous Chebyshev Approximations .....	691
<b>C. K. Chui, K. Jetter, and J. D. Ward</b> , Cardinal Interpolation by Multivariate Splines .....	711
<b>Giuliana Criscuolo and Giuseppe Mastroianni</b> , On the Convergence of an Interpolatory Product Rule for Evaluating Cauchy Principal Value Integrals .....	725



<b>Ben Johnsen and Eldar Straume, Counting Binary Matrices with Given Row and Column Sums</b> .....	737
<b>Péter Kiss and Bui Minh Phong, On a Problem of A. Rotkiewicz</b> .....	751
<b>Martin Seysen, A Probabilistic Factorization Algorithm with Quadratic Forms of Negative Discriminant</b> .....	757
<b>Kurt Girstmair, On Invariant Polynomials and Their Application in Field Theory</b> .....	781
<b>R. V. Moody and J. Patera, Computation of Character Decompositions of Class Functions on Compact Semisimple Lie Groups</b> .....	799
<b>Reviews and Descriptions of Tables and Books</b> .....	829
Fröberg <b>7</b> , Birkhoff and Lynch <b>8</b> , Rice and Boisvert <b>9</b> , Quinney <b>10</b> , Smith <b>11</b> , Brebbia, Editor <b>12</b> , Murman and Abarbanel, Editors <b>13</b> , Grebenikov and Ryabov <b>14</b> , Linz <b>15</b> , Cullum and Willoughby <b>16</b> , Henrici <b>17</b> , Lorentz <b>18</b> , Bracewell <b>19</b> , Odeh, Davenport and Pearson, Editors <b>20</b> , Paddon and Holstein, Editors <b>21</b> , Ascher and Russell, Editors <b>22</b>	
<b>Table Errata</b> .....	851
Philip <b>608</b>	
<b>Corrigenda</b> .....	853
Lewanowicz, Milovanović and Wrigge, Gramain and Weber	
<b>Author Index</b> .....	855
<b>Supplement to “Uniform High-Order Difference Schemes for a Singularly Perturbed Two-Point Boundary Value Problem” by Eugene C. Gartland, Jr.</b> .....	S5
<b>Supplement to “The Discrete Galerkin Method for Integral Equations” by Kendall Atkinson and Alex Bogomolny</b> .....	S11

Information for Contributors and information on Copying and Reprinting  
can be found after the supplements section at the end of this issue.



### Information for Contributors

Authors are encouraged to prepare articles electronically with the AMS-TeX software package in the AMS pre-print style and to provide the article in this electronic form for typesetting. While this procedure may not reduce the interval between submission and publication of an article, generally much more accurate copy will be returned for proofreading. Production time for manuscripts prepared with other systems, even TeX itself without AMS-TeX, currently prevents cost-effective use of the existing electronic form. Before sending an AMS-TeX manuscript for typesetting, contact the AMS Composition Department for details.

Manuscripts prepared by some means other than AMS-TeX should be double-spaced and produced 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 Walter Gautschi, Chairman, Editorial Committee, Mathematics of Computation, Department of Computer Sciences, Purdue University, West Lafayette, Indiana 47907. The date received, which is published with the final version of an accepted paper, is the date received in the office of the Chairman of the Editorial Committee, and it is the responsibility of the author to submit manuscripts directly to this office. 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* (1985 *Revision*) 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 1984 Subject Index to *Mathematical Reviews*.

The research journals of the American Mathematical Society carry a page charge of \$50.00 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 States 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, P. O. 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 fee of \$1.00 plus \$.25 per page for each copy be paid directly to 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.



(Continued from back cover)

<b>Ben Johnsen and Eldar Straume</b> , Counting Binary Matrices with Given Row and Column Sums .....	737
<b>Péter Kiss and Bui Minh Phong</b> , On a Problem of A. Rotkiewicz .....	751
<b>Martin Seysen</b> , A Probabilistic Factorization Algorithm with Quadratic Forms of Negative Discriminant .....	757
<b>Kurt Girstmair</b> , On Invariant Polynomials and Their Application in Field Theory .....	781
<b>R. V. Moody and J. Patera</b> , Computation of Character Decompositions of Class Functions on Compact Semisimple Lie Groups .....	799
<b>Reviews and Descriptions of Tables and Books</b> .....	829
Fröberg <b>7</b> , Birkhoff and Lynch <b>8</b> , Rice and Boisvert <b>9</b> , Quinney <b>10</b> , Smith <b>11</b> , Brebbia, Editor <b>12</b> , Murman and Abarbanel, Editors <b>13</b> , Grebenikov and Ryabov <b>14</b> , Linz <b>15</b> , Cullum and Willoughby <b>16</b> , Henrici <b>17</b> , Lorentz <b>18</b> , Bracewell <b>19</b> , Odeh, Davenport and Pearson, Editors <b>20</b> , Paddon and Holstein, Editors <b>21</b> , Ascher and Russell, Editors <b>22</b>	
<b>Table Errata</b> .....	851
Philip <b>608</b>	
<b>Corrigenda</b> .....	853
Lewanowicz, Milovanović and Wrigge, Gramain and Weber	
<b>Author Index</b> .....	855
<b>Supplement to</b> "Uniform High-Order Difference Schemes for a Singularly Perturbed Two-Point Boundary Value Problem" by <b>Eugene C. Gartland, Jr.</b> .....	S5
<b>Supplement to</b> "The Discrete Galerkin Method for Integral Equations" by <b>Kendall Atkinson and Alex Bogomolny</b> .....	S11

No microfiche supplement in this issue



# MATHEMATICS OF COMPUTATION

## TABLE OF CONTENTS

April 1987

<b>T. M. Hagstrom and H. B. Keller</b> , Asymptotic Boundary Conditions and Numerical Methods for Nonlinear Elliptic Problems on Unbounded Domains .....	449
<b>Winfried Auzinger</b> , Defect Corrections for Multigrid Solutions of the Dirichlet Problem in General Domains .....	471
<b>Jukka Saranen</b> , Local Error Estimates for Some Petrov-Galerkin Methods Applied to Strongly Elliptic Equations on Curves .....	485
<b>Moshe Goldberg and Eitan Tadmor</b> , Convenient Stability Criteria for Difference Approximations of Hyperbolic Initial-Boundary Value Problems. II .....	503
<b>M. Crouzeix and V. Thomée</b> , The Stability in $L_p$ and $W_p^1$ of the $L_2$ -Projection onto Finite Element Function Spaces .....	521
<b>R. M. M. Mattheij</b> , On the Computation of Solutions of Boundary Value Problems on Infinite Intervals .....	533
<b>Eugene C. Gartland, Jr.</b> , Uniform High-Order Difference Schemes for a Singularly Perturbed Two-Point Boundary Value Problem .....	551
<b>A. Neubauer</b> , Finite-Dimensional Approximation of Constrained Tikhonov-Regularized Solutions of Ill-Posed Linear Operator Equations .....	565
<b>Sunil Kumar and Ian H. Sloan</b> , A New Collocation-Type Method for Hammerstein Integral Equations .....	585
<b>Kendall Atkinson and Alex Bogomolny</b> , The Discrete Galerkin Method for Integral Equations .....	595
<b>Jean-Paul Berrut and Manfred R. Trummer</b> , Equivalence of Nyström's Method and Fourier Methods for the Numerical Solution of Fredholm Integral Equations .....	617
<b>C. J. Gladwin</b> , An Algorithm for the Construction of Optimal Methods for the Numerical Solution of Volterra Integral Equations of the First Kind .....	625
<b>Maarten de Gee</b> , Linear Multistep Methods for Functional Differential Equations .....	633
<b>Yousef Saad</b> , On the Lanczos Method for Solving Symmetric Linear Systems with Several Right-Hand Sides .....	651
<b>Bahram Nour-Omid, Beresford N. Parlett, Thomas Ericsson, and Paul S. Jensen</b> , How to Implement the Spectral Transformation .....	663
<b>Rong-Qing Jia</b> , $L_\infty$ -Boundedness of $L_2$ -Projections on Splines for a Multiple Geometric Mesh .....	675
<b>Zhongqi Jing and Adly T. Fam</b> , An Algorithm for Computing Continuous Chebyshev Approximations .....	691
<b>C. K. Chui, K. Jetter, and J. D. Ward</b> , Cardinal Interpolation by Multivariate Splines .....	711
<b>Giuliana Criscuolo and Giuseppe Mastroianni</b> , On the Convergence of an Interpolatory Product Rule for Evaluating Cauchy Principal Value Integrals .....	725

(Continued on inside back cover)