VOLUME 85 NUMBER 297 JANUARY 2016

MATHEMATICS OF COMPUTATION

AMERICAN MATHEMATICAL SOCIETY

EDITED BY

Remi Abgrall
Daniele Boffi
Susanne C. Brenner, *Managing Editor*
Daniela Calvetti
Zhiming Chen
Ronald F. A. Cools
Vivette Girault
Nicholas I. M. Gould
Ivan Graham
Douglas Hardin
Fred J. Hickernell
Gregor Kemper
Boris N. Khoromskij
Stig Larsson
Christian Lubich
Gunter Malle
James McKee
Michael J. Mossinghoff
Stanley Osher
Cheryl E. Praeger
Christoph Schwab
Jie Shen
Zuowei Shen
Igor E. Shparlinski
Chi-Wang Shu
Andrew V. Sutherland
Daniel B. Szyld
Mark van Hoeij
Hans Volkmer
Barbara Wohlmuth
Zhimin Zhang

PROVIDENCE, RHODE ISLAND USA

ISSN 0025-5718 (print)
ISSN 1088-6842 (online)

Available electronically at
www.ams.org/mcom/

Mathematics of Computation

This journal is devoted to research articles of the highest quality in computational mathematics. Areas covered include numerical analysis, computational discrete mathematics, including number theory, algebra and combinatorics, and related fields such as stochastic numerical methods. Articles must be of significant computational interest and contain original and substantial mathematical analysis or development of computational methodology. Reviews of books in areas related to computational mathematics are also included.

Submission information. See **Information for Authors** at the end of this issue.

Publication on the AMS website. Articles are published on the AMS website individually after proof is returned from authors and before appearing in an issue.

Subscription information. *Mathematics of Computation* is published bimonthly and is also accessible electronically from `www.ams.org/journals/`. Subscription prices for Volume 85 (2016) are as follows: for paper delivery, US$720.00 list, US$576.00 institutional member, US$648.00 corporate member; US$432.00 individual member; for electronic delivery, US$633.00 list, US$506.40 institutional member, US$569.70 corporate member, US$379.80 individual member. Upon request, subscribers to paper delivery of this journal are also entitled to receive electronic delivery. If ordering the paper version, add US$5 for delivery within the United States; US$35 for delivery outside the United States. Subscription renewals are subject to late fees. See `www.ams.org/help-faq` for more journal subscription information.

Back number information. For back issues see the `www.ams.org/backvols`.

Subscriptions and orders should be addressed to the American Mathematical Society, P.O. Box 845904, Boston, MA 02284-5904 USA. *All orders must be accompanied by payment.* Other correspondence should be addressed to 201 Charles Street, Providence, RI 02904-2294 USA.

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 is permitted only under license from the American Mathematical Society. Permissions to reuse portions of AMS publication content are handled by Copyright Clearance Center's RightsLink® service. For more information, visit: `www.ams.org/rightslink`.

Translation rights and licensed reprint requests should be sent to: `reprint-permission@ams.org`.

Excluded from these provisions is material for which the author holds copyright. In such cases, requests for permission to reuse or reprint material should be addressed directly to the author(s). Copyright ownership is indicated in the notice in the lower right-hand corner of the first page of each article.

Mathematics of Computation (ISSN 0025-5718 (print); ISSN 1088-6842 (online)) is published bimonthly by the American Mathematical Society at 201 Charles Street, Providence, RI 02904-2294 USA. Periodicals postage is paid at Providence, Rhode Island. Postmaster: Send address changes to Mathematics of Computation, American Mathematical Society, 201 Charles Street, Providence, RI 02904-2294 USA.

© 2016 by the American Mathematical Society. All rights reserved.

This journal is indexed in *Mathematical Reviews*, *Zentralblatt MATH*, *Science Citation Index®*, *Science Citation Index™–Expanded*, *ISI Alerting Services℠*, *CompuMath Citation Index®*, and *Current Contents®/Physical, Chemical & Earth Sciences*. This journal is archived in *Portico* and in *CLOCKSS*.

♾ The paper used in this book is acid-free and falls within the guidelines established to ensure permanence and durability.

10 9 8 7 6 5 4 3 2 1 21 20 19 18 17 16

MATHEMATICS OF COMPUTATION

CONTENTS

Vol. 85, No. 297 **January 2016**

Gabriel N. Gatica, Ricardo Ruiz-Baier, and Giordano Tierra, A mixed finite element method for Darcy's equations with pressure dependent porosity 1

Claus R. Goetz and Armin Iske, Approximate solutions of generalized Riemann problems for nonlinear systems of hyperbolic conservation laws 35

Waixiang Cao and Zhimin Zhang, Superconvergence of Local Discontinuous Galerkin methods for one-dimensional linear parabolic equations 63

Anne Bouillard, Erwan Faou, and Maxime Zavidovique, Fast weak–KAM integrators for separable Hamiltonian systems 85

Markus Faustmann, Jens Markus Melenk, and Dirk Praetorius, Existence of $\mathcal{H}$-matrix approximants to the inverses of BEM matrices: The simple-layer operator 119

Ji Liu and Stephen J. Wright, An accelerated randomized Kaczmarz algorithm 153

Michael Moeller and Xiaoqun Zhang, Fast sparse reconstruction: Greedy inverse scale space flows 179

Laurent Demanet and Xiangxiong Zhang, Eventual linear convergence of the Douglas-Rachford iteration for basis pursuit 209

Zhitao Fan, Hui Ji, and Zuowei Shen, Dual Gramian analysis: Duality principle and unitary extension principle 239

Yun-Qiu Shen and Tjalling J. Ypma, Rank deficiencies and bifurcation into affine subspaces for separable parameterized equations 271

D. H. Bailey and J. M. Borwein, Computation and structure of character polylogarithms with applications to character Mordell–Tornheim–Witten sums 295

O. Ramaré, An explicit density estimate for Dirichlet L-series 325

Javier Cilleruelo, Florian Luca, and Amalia Pizarro-Madariaga, Carmichael numbers in the sequence $(2^n k + 1)_{n\geq 1}$ 357

Catalina V. Anghel, The self-power map and collecting all residue classes 379

Tomáš Hejda and Edita Pelantová, Spectral properties of cubic complex Pisot units 401

David Krumm, Computing points of bounded height in projective space over a number field 423

Shuhong Gao, Frank Volny IV, and Mingsheng Wang, A new framework for computing Gröbner bases 449

Jürgen Hausen, Simon Keicher, and Antonio Laface, Computing Cox rings 467

Noah Lebowitz-Lockard and Carl Pomerance, Generating random factored Gaussian integers, easily 503

Editorial Information

Information on the backlog for this journal can be found on the AMS website starting from `http://www.ams.org/mcom`.

In an effort to make articles available as quickly as possible, articles are electronically published on the AMS website individually after proof is returned from authors and before appearing in an issue.

A Consent to Publish is required before we can begin processing your paper. After a paper is accepted for publication, the Providence office will send a Consent to Publish and Copyright Agreement to all authors of the paper. By submitting a paper to this journal, authors certify that the results have not been submitted to nor are they under consideration for publication by another journal, conference proceedings, or similar publication.

Information for Authors

Initial submission. All articles submitted to this journal are peer-reviewed. The AMS has a single blind peer-review process in which the reviewers know who the authors of the manscript are, but the authors do not have access to the information on who the peer reviewers are. The AMS uses Centralized Manuscript Processing for initial submission. Authors should submit a PDF file using the Initial Manuscript Submission form found at `www.ams.org/submission/mcom`, or send one copy of the manuscript to the following address: Centralized Manuscript Processing, MATHEMATICS OF COMPUTATION, 201 Charles Street, Providence, RI 02904-2294 USA. If a paper copy is being forwarded to the AMS, indicate that it is for *Mathematics of Computation* and include the name of the corresponding author and contact information, such as an email address or mailing address. The author may suggest an appropriate editor for his or her paper.

The first page must consist of a *descriptive title*, followed by an *abstract* that summarizes the article in language suitable for workers in the general field (algebra, analysis, etc.). The *descriptive title* should be short, but informative; useless or vague phrases such as "some remarks about" or "concerning" should be avoided. The *abstract* must be brief, reasonably self-contained, and not exceed 300 words. Included with the footnotes to the paper should be the 2010 *Mathematics Subject Classification* representing the primary and secondary subjects of the article. The classifications are accessible from `www.ams.org/msc/`. The Mathematics Subject Classification footnote may be followed by a list of *key words and phrases* describing the subject matter of the article and taken from it. Journal abbreviations used in bibliographies are listed in the latest *Mathematical Reviews* annual index. The series abbreviations are also accessible from `www.ams.org/msnhtml/serials.pdf`. To help in preparing and verifying references, the AMS offers MR Lookup, a Reference Tool for Linking, at `www.ams.org/mrlookup/`.

Electronically prepared manuscripts. Manuscripts should be electronically prepared in $\mathcal{A}\mathcal{M}\mathcal{S}$-LaTeX. To this end, the Society has prepared $\mathcal{A}\mathcal{M}\mathcal{S}$-LaTeX author packages for each AMS publication. Author packages include instructions for preparing electronic manuscripts, samples, and a style file that generates the particular design specifications of that publication series. Articles properly prepared using the $\mathcal{A}\mathcal{M}\mathcal{S}$-LaTeX style file and the \label and \ref commands automatically enable extensive intra-document linking to the bibliography and other elements of the article for searching electronically on the Web.

Authors may retrieve an author package for *Mathematics of Computation* from `www.ams.org/mcom/mcomauthorpac.html` or via FTP to `ftp.ams.org` (login as `anonymous`, enter your complete email address as password, and type `cd pub/author-info`). The *AMS Author Handbook* and the *Instruction Manual* are available in PDF format from the author package link. The author package can also be obtained free of charge by sending email to `tech-support@ams.org` or from the Publication Division, American Mathematical Society, 201 Charles Street, Providence, RI 02904-2294 USA. When requesting an author package, please specify the publication in which your paper will appear. Please be sure to include your complete email address.

After acceptance. The source files for the final version of the electronic manuscript should be sent to the Providence office immediately after the paper has been accepted for publication. The author should also submit a PDF of the final version of the paper to the Managing Editor, who will forward a copy to the Providence office. Accepted electronically prepared manuscripts can be submitted via the web at `www.ams.org/submit-book-journal/`, sent via email to `pub-submit@ams.org`, or sent on CD to the Electronic Prepress Department, American Mathematical Society, 201 Charles Street, Providence, RI 02904-2294 USA. When sending a manuscript electronically via email or CD, please be sure to include a message indicating in which publication the paper has been accepted. Complete instructions on how to send files are included in the author package.

Electronic graphics. Comprehensive instructions on preparing graphics are available starting from `www.ams.org/authors/journals.html`. A few of the major requirements are given here.

Submit files for graphics as EPS (Encapsulated PostScript) files. This includes graphics originated via a graphics application as well as scanned photographs or other computer-generated images. If this is not possible, TIFF files are acceptable as long as they can be opened in Adobe Photoshop or Illustrator.

Authors using graphics packages for the creation of electronic art should also avoid the use of any lines thinner than 0.5 points in width. Many graphics packages allow the user to specify a "hairline" for a very thin line. Hairlines often look acceptable when proofed on a typical laser printer. However, when produced on a high-resolution laser imagesetter, hairlines become nearly invisible and will be lost entirely in the final printing process.

Screens should be set to values between 15% and 85%. Screens which fall outside of this range are too light or too dark to print correctly. Variations of screens within a graphic should be no less than 10%.

Any graphics created in color will be rendered in grayscale for the printed version unless color printing is authorized by the Managing Editor and the Publisher. In general, color graphics will appear in color in the online version.

AMS policy on making changes to articles after publication. Articles are published on the AMS website individually after proof is returned from authors and before appearing in an issue. To preserve the integrity of electronically published articles, once an article is individually published to the AMS website, changes cannot be made in place in the paper. The AMS does not keep author-related information, such as affiliation, current address, and email address, up to date after a paper is electronically published.

Corrections of critical errors may be made to the paper by submitting an errata article to the Editor. The errata article will be published electronically, will appear in a future print issue, and will link back and forth on the Web with the original article.

Secure manuscript tracking on the Web. Authors can track their manuscripts through the AMS journal production process using the personal AMS ID and Article ID printed in the upper right-hand corner of the Consent to Publish form sent to each author who publishes in AMS journals. Access to the tracking system is available from `www.ams.org/mstrack/`. An explanation of each production step is provided on the web through links from the manuscript tracking screen. Questions can be sent to `mcom-query@ams.org`.

Inquiries. Any inquiries concerning a paper that has been accepted for publication that cannot be answered via the manuscript tracking system mentioned above should be sent to `mcom-query@ams.org` or directly to the Electronic Prepress Department, American Mathematical Society, 201 Charles Street, Providence, RI 02904-2294 USA.

Editorial Committee

SUSANNE C. BRENNER, Chair, Center for Computation & Technology and Department of Mathematics, Louisiana State University, Baton Rouge, LA 70803 USA; *E-mail*: mathcomp@math.lsu.edu

RONALD F. A. COOLS, Department of Computer Science, Katholieke Universiteit Leuven, Celestijnenlaan 200A, B-3001 Heverlee, Belgium; *E-mail*: ronald.cools@cs.kuleuven.ac.be

IGOR E. SHPARLINSKI, Department of Pure Mathematics, University of New South Wales, Sydney, NSW 2052, Australia; *E-mail*: igor.shparlinski@unsw.edu.au

CHI-WANG SHU, Applied Mathematics Division, Brown University, P.O. Box F, 182 George St., Providence, RI 02912-0001 USA; *E-mail*: mathcomp@dam.brown.edu

Board of Associate Editors

RÉMI ABGRALL, Institut für Mathematik, Universität Zürich, Winterthurerstrasse 190, CH-8057 Zürich; *E-mail*: remi.abgrall@math.uzh.ch

DANIELE BOFFI, Department of Mathematics, University di Pavia, Via Ferrata 1, 27100 Pavia PV, Italy; *E-mail*: daniele.boffi@unipv.it

DANIELA CALVETTI, Department of Mathematics, Case Western Reserve University, Yost Hall, 10900 Euclid Avenue., Cleveland, OH 44106 USA; *E-mail*: daniela.calvetti@case.edu

ZHIMING CHEN, LSEC Institute of Computational Mathematics, Chinese Academy of Sciences, Beijing 100190, China; *E-mail*: zmchen@lsec.cc.ac.cn

VIVETTE GIRAULT, Laboratoire Jacques-Louis Lions, Boite courrier 187, Université de Pierre et Marie Curie, 4, place Jussieu, 75252 Paris Cedex 05, France; *E-mail*: girault@ann.jussieu.fr

NICHOLAS I. M. GOULD, Department of Scientific Computing, G59, R18 STFC-Rutherford Appleton Laboratory, Chilton, Oxon OX11 0QX England; *E-mail*: nick.gould@stfc.ac.uk

IVAN G. GRAHAM, Department of Mathematical Sciences, University of Bath, Bath BA2 7AY, United Kingdom; *E-mail*: i.g.graham@bath.ac.uk

DOUGLAS HARDIN, Vanderbilt University, Department of Mathematics, 1326 Stevenson Center, Nashville, TN 37240 USA; *E-mail*: doug.hardin@vanderbilt.edu

FRED J. HICKERNELL, Department of Applied Mathematics, Illinois Institute of Technology, E1 Building, Room 208, 10 W. 32nd Street, Chicago, IL 60616-3793 USA; *E-mail*: hickernell@iit.edu

GREGOR KEMPER, Technische Universität München, Zentrum Mathematik M 11, Boltzmannstr 3, 85748 Garching, Germany; *E-mail*: kemper@ma.tum.de

BORIS N. KHOROMSKIJ, Max Planck Institute for Mathematics in the Sciences, Inselstr. 22-26, D-04103 Leipzig, Germany; *E-mail*: bokh@mis.mpg.de

STIG LARSSON, Department of Mathematical Sciences, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden; *E-mail*: stig@chalmers.se

CHRISTIAN LUBICH, Universität Tübingen, Mathematik, Auf der Morgenstelle 10, 72076 Tübengen, Germany; *E-mail*: lubich@na.uni-tuebingen.de

GUNTER MALLE, Fachbereich Mathematik, Universität Kaiserslautern, Postfach 3049, 67653 Kaiserslautern, Germany; *E-mail*: malle@mathematik.uni-kl.de

JAMES McKEE, Department of Mathematics, Royal Holloway University of London, Egham Hill, Egham TW20 0EX, United Kingdom; *E-mail*: james.mckee@rhul.ac.uk

MICHAEL J. MOSSINGHOFF, Department of Mathematics, Davidson College, Box 6996, Davidson, NC 28035-6996 USA; *E-mail*: mimossinghoff@davidson.edu

STANLEY OSHER, Department of Mathematics, University of California, P.O. Box 951555, Los Angeles, CA 90095-1555 USA; *E-mail*: sjo@math.ucla.edu

CHERYL E. PRAEGER, School of Mathematics and Statistics, M019, University of Western Australia, 35 Stirling Highway, Crawley 6009, Western Australia, Australia; *E-mail*: praeger@maths.uwa.edu.au

CHRISTOPH SCHWAB, Seminar of Applied Mathematics, ETHZ, 8092 Zurich, Switzerland; *E-mail*: christoph.schwab@sam.math.ethz.ch

JIE SHEN, Department of Mathematics, Purdue University, West Lafayette, IN 47907 USA; *E-mail*: shen@math.purdue.edu

ZUOWEI SHEN, Department of Mathematics, National University of Singapore, Block S17 10, Lower Kent Ridge Road, 119076 Singapore; *E-mail*: matzuows@nus.edu.sg

ANDREW V. SUTHERLAND, Department of Mathematics, Massachusetts Institute of Technology, Cambridge, MA 02139 USA; *E-mail*: drew@math.mit.edu

DANIEL B. SZYLD, Department of Mathematics 038-16, Temple University, 638 Wachman, 1805 N. Broad St. Philadelphia, PA 19122-6094 USA; *E-mail*: szyld@temple.edu

MARK VAN HOEIJ, Department of Mathematics, Florida State University, 1017 Academic Way, Tallahassee, FL 32306 USA; *E-mail*: hoeij@math.fsu.edu

HANS VOLKMER, Department of Mathematical Sciences, University of Wisconsin-Milwaukee, P.O. Box 413, Milwaukee, WI 53201-0413 USA; *E-mail*: volkmer@csd.uwm.edu

BARBARA WOHLMUTH, Fakultät für Mathematik, Technische Universität München, Boltzmannstr. 3, 85748 Garching, Germany; *E-mail*: wohlmuth@ma.tum.de

ZHIMIN ZHANG, Department of Mathematics, Wayne State University, Detroit, MI 48202 USA; *E-mail*: zzhang@math.wayne.edu

(*Continued from back cover*)

Shuhong Gao, Frank Volny IV, and Mingsheng Wang, A new framework for computing Gröbner bases 449
Jürgen Hausen, Simon Keicher, and Antonio Laface, Computing Cox rings 467
Noah Lebowitz-Lockard and Carl Pomerance, Generating random factored Gaussian integers, easily 503

MATHEMATICS OF COMPUTATION

CONTENTS

Vol. 85, No. 297 January 2016

Gabriel N. Gatica, Ricardo Ruiz-Baier, and Giordano Tierra, A mixed finite element method for Darcy's equations with pressure dependent porosity 1

Claus R. Goetz and Armin Iske, Approximate solutions of generalized Riemann problems for nonlinear systems of hyperbolic conservation laws 35

Waixiang Cao and Zhimin Zhang, Superconvergence of Local Discontinuous Galerkin methods for one-dimensional linear parabolic equations 63

Anne Bouillard, Erwan Faou, and Maxime Zavidovique, Fast weak–KAM integrators for separable Hamiltonian systems 85

Markus Faustmann, Jens Markus Melenk, and Dirk Praetorius, Existence of $\mathcal{H}$-matrix approximants to the inverses of BEM matrices: The simple-layer operator 119

Ji Liu and Stephen J. Wright, An accelerated randomized Kaczmarz algorithm 153

Michael Moeller and Xiaoqun Zhang, Fast sparse reconstruction: Greedy inverse scale space flows 179

Laurent Demanet and Xiangxiong Zhang, Eventual linear convergence of the Douglas-Rachford iteration for basis pursuit 209

Zhitao Fan, Hui Ji, and Zuowei Shen, Dual Gramian analysis: Duality principle and unitary extension principle 239

Yun-Qiu Shen and Tjalling J. Ypma, Rank deficiencies and bifurcation into affine subspaces for separable parameterized equations 271

D. H. Bailey and J. M. Borwein, Computation and structure of character polylogarithms with applications to character Mordell–Tornheim–Witten sums 295

O. Ramaré, An explicit density estimate for Dirichlet L-series 325

Javier Cilleruelo, Florian Luca, and Amalia Pizarro-Madariaga, Carmichael numbers in the sequence $(2^n k + 1)_{n \geq 1}$ 357

Catalina V. Anghel, The self-power map and collecting all residue classes 379

Tomáš Hejda and Edita Pelantová, Spectral properties of cubic complex Pisot units 401

David Krumm, Computing points of bounded height in projective space over a number field 423

(*Continued on inside back cover*)

0025-5718(201601)85:297;1-M

Mathematics of Computation VOLUME 85 NUMBER 297 PAGES 1–516 JANUARY 2016