ATHEMATICS OF COMPUTATION USEN 1088-6842 (online)

A M E R I C A N M A T H E M A T I C A L S O C I E T Y

EDITED BY

Paola F. Antonietti

Markus Bachmayr

Jennifer Balakrishnan

Ernesto G. Birgin

Susanne C. Brenner, Managing Editor

Martin Burger

Coralia Cartis

Ronald F. A. Cools

Alan Demlow

Bruno Despres

Alicia Dickenstein

Jan Draisma

Qiang Du

Bettina Eick

Howard C. Elman

Kevin Hare

Ralf Hiptmair

Frances Kuo

Buyang Li

Christian Lubich

Andrei Martínez-Finkelshtein

Jens Markus Melenk

Michael J. Mossinghoff

Michael J. Neilan

Fabio Nobile

Houman Owhadi

Daniel Peterseim

Robert Scheichl

Igor E. Shparlinski

Chi-Wang Shu

Andrew V. Sutherland

Daniel B. Szyld



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.

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/.

Individual subscription prices for Volume 92 (2023) are as follows. For electronic only: non-member, US\$766, member, US\$459.60. For paper delivery: non-member, US\$871, member, US\$522.60. Add US\$6 for delivery within the United States; US\$31 for surface delivery outside the United States. Upon request, subscribers to paper delivery of this journal are also entitled to receive electronic delivery. For information on institutional pricing, please visit https://www.ams.org/publications/journals/subscriberinfo. Subscription renewals are subject to late fees. See www.ams.org/journal-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 02904-2213 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. Requests for permission to reuse portions of AMS publication content are handled by the Copyright Clearance Center. For more information, please visit www.ams.org/publications/pubpermissions.

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 02904-2213 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 02904-2213 USA.

© 2023 by the American Mathematical Society. All rights reserved. This journal is indexed in Mathematical Reviews, Zentralblatt MATH, Science Citation Index®, Science Citation Index TM —Expanded, ISI Alerting Services SM , CompuMath Citation Index®, and Current Contents®/Physical, Chemical & Earth Sciences. This journal is archived in Portico and in CLOCKSS.

 \otimes The paper used in this book is a cid-free and falls within the guidelines established to ensure per manence and durability.

10 9 8 7 6 5 4 3 2 1 28 27 26 25 24 23

MATHEMATICS OF COMPUTATION CONTENTS

Vol. 92, No. 340 March 2	2023
Nicola R. Franco, Andrea Manzoni, and Paolo Zunino, A deep learning approach to Reduced Order Modelling of parameter dependent partial differential equations	483
Keegan L. A. Kirk, Tamás L. Horváth, and Sander Rhebergen, Analysis of an exactly mass conserving space-time hybridized discontinuous Galerkin method for the time-dependent Navier–Stokes equations	525
Yongbin Han, Yanren Hou, and Min Zhang, Analysis of divergence-	0_0
free H^1 conforming FEM with IMEX-SAV scheme for the Navier-Stokes	
equations at high Reynolds number	557
Philip L. Lederer and Rolf Stenberg, Energy norm analysis of exactly	
symmetric mixed finite elements for linear elasticity	583
Qingguo Hong, Johannes Kraus, Maria Lymbery, and Fadi Philo, A	
new practical framework for the stability analysis of perturbed saddle-	
point problems and applications	607
Nathalie Ayi, Maxime Herda, Hélène Hivert, and Isabelle Tristani,	
On a structure-preserving numerical method for fractional Fokker-	
Planck equations	635
David M. Ambrose, Michael Siegel, and Keyang Zhang, Convergence of the boundary integral method for interfacial Stokes flow	695
Angelo A. Casulli and Igor Simunec, Computation of generalized matrix	
functions with rational Krylov methods	749
Hui Zhang, Lu Zhang, and Hao-Xing Yang, Revisiting linearized	
Bregman iterations under Lipschitz-like convexity condition	779
Zexin Pan and Art B. Owen, Super-polynomial accuracy of one	
dimensional randomized nets using the median of means	805
Bernhard Reinke, Dierk Schleicher, and Michael Stoll, The	
Weierstrass–Durand–Kerner root finder is not generally convergent	839
Jing Gao and Arieh Iserles, On an extended Filon method for highly	
oscillatory integrals over a simplex	867
Francesc Bars, Mohamed Kamel, and Andreas Schweizer, Bielliptic	00=
quotient modular curves of $X_0(N)$	895
Nathan Ilten and Yoav Len, Tropical tangents for complete intersection	001
curves	931

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 02904-2213 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 $\mathcal{A}_{\mathcal{M}}\mathcal{S}$ -IATEX. To this end, the Society has prepared $\mathcal{A}_{\mathcal{M}}\mathcal{S}$ -IATEX 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 $\mathcal{A}_{\mathcal{M}}\mathcal{S}$ -IATEX 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. The *AMS Author Handbook* is 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 02904-2213 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 02904-2213 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 02904-2213 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

MICHAEL J. MOSSINGHOFF, Center for Communications Research, 805 Bunn Dr., Princeton, NJ 08540 USA; *E-mail*: m.mossinghoff@idaccr.org

MICHAEL J. NEILAN, Department of Mathematics, University of Pittsburgh, Pittsburgh, PA 15260 USA; E-mail: neilan@pitt.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

Board of Associate Editors

PAOLA F. ANTONIETTI, Dipartimento di Matematica, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milano, Italy; *E-mail*: paola.antonietti@polimi.it

MARKUS BACHMAYR, Institut für Mathematik, Johannes Gutenberg Universität Mainz, 55128 Mainz, Germany; E-mail: bachmayr@uni-mainz.de

JENNIFER BALAKRISHNAN, Department of Mathematics and Statistics, Boston University, 11 Cummington Mall, Boston, MA 02215 USA; E-mail: jbala@bu.edu

ERNESTO G. BIRGIN, Department of Computer Science, University of São Paulo, Rua de Matão, São Paulo - SP 05508-090, Brazil; E-mail: ebirgin@ime.usp.br

MARTIN BURGER, Department Mathematik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Cauerstrasse 11, 91058 Erlangen, Germany; E-mail: martin.burger@fau.de

CORALIA CARTIS, Mathematical Institute, University of Oxford, Andrew Wiles Building, Woodstock Road, Oxford OX2 6GG, England; *E-mail*: Coralia.Cartis@maths.ox.ac.uk

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

ALAN DEMLOW, Department of Mathematics, Texas A&M University, Mailstop 3368, College Station, TX 77843 USA; *E-mail*: demlow@math.tamu.edu

BRUNO DESPRES, University of Paris VI, Laboratory Jacques-Louis Lions, 175 rue du Chevaleret, 75013 Paris, France; *E-mail*: despres@ljll.math.upmc.fr

ALICIA DICKENSTEIN, Departamento de Matemática, FCEN, University of Beunos Aires, Ciudad Universitaria, Pab. I, C1428EGA Buenos Aires, Argentina; *E-mail*: alidick@dm.uba.ar

JAN DRAISMA, Mathematical Institute, University of Bern, Sidlerstrasse 5, 3012 Bern Switzerland; E-mail: jan.draisma@math.unibe.ch

QIANG DU, Columbia University, 500 W 120th Street, APAM, 200 Mudd, MC 4701, New York, NY 10027 USA; E-mail: qd2125@columbia.edu

BETTINA EICK, Institut Computational Mathematics, University of Braunschweig, 38106 Braunschweig, Germany; E-mail: beick@tu-bs.de

HOWARD C. ELMAN, Department of Computer Science, University of Maryland, College Park, MD 20742 USA; E-mail: elman@cs.umd.edu

KEVIN HARE, Department of Pure Mathematics, University of Waterloo, 200 University Ave. W, Waterloo ON N2L 3G1, Canada; *E-amil*: kghare@uwaterloo.ca

RALF HIPTMAIR, Department of Mathematics, Seminar of Applied Mathematics, ETH Zurich, CH-8092 Zurich, Switzerland. *E-mail*: hiptmair@sam.math.ethz.ch

FRANCES KUO, University of New South Wales, School of Mathematics, Sydney NSW 2052, Australia; *E-mail*: f.kuo@unsw.edu.au

BUYANG LI, Department of Applied Mathematics, The Hong Kong Polytechnic University, Hong Kong; *E-mail*: buyang.li@polyu.edu.hk

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

ANDREI MARTÍNEZ-FINKELSHTEIN, Department of Mathematics, Baylor University, Waco, TX 76798 USA; and Department of Mathematics, University of Almeria, 04120 Almeria, Spain; *E-mail*: a_martinez-finkelshtein@baylor.edu

JENS MARKUS MELENK, Institute of Analysis and Scientific Computing, Technische Universität Wien, Wiedner Haupstrasse 8-10, A-1040 Vienna, Austria; *E-mail*: melenk@tuwien.ac.at

FABIO NOBILE, Mathematics Institute of Computational Science and Engineering, École Polytechnique Fédérale de Lausanne, CH 1015 Lausanne, Switzerland; *E-mail*: fabio.nobile@epf1.ch

HOUMAN OWHADI, Department of Computing and Mathematical Sciences, Division of Engineering, California Institute of Technology, 1200 E. California Blvd., Pasadena, CA 91125, USA; *E-mail*: owhadi@caltech.edu

DANIEL PETERSEIM, Institute of Mathematics, University of Augsburg, Universitätsstrasse 12a, 86159 Augsburg, Germany; *E-mail*: daniel.peterseim@math.uni-augsburg.de

ROBERT SCHEICHL, Institute for Applied Mathematics, University of Heidelberg, Im Neuenheimer Feld 205, 69120 Heidelberg, Germany; E-mail: r.scheichl@uni-heidelberg.de

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

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

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

MATHEMATICS OF COMPUTATION CONTENTS

Vol. 92, No. 340 March 2	202
Nicola R. Franco, Andrea Manzoni, and Paolo Zunino, A deep learning approach to Reduced Order Modelling of parameter dependent partial	
differential equations	48
Keegan L. A. Kirk, Tamás L. Horváth, and Sander Rhebergen,	
Analysis of an exactly mass conserving space-time hybridized discontinuous Galerkin method for the time-dependent Navier–Stokes equations	52
Yongbin Han, Yanren Hou, and Min Zhang, Analysis of divergence-	
free H^1 conforming FEM with IMEX-SAV scheme for the Navier-Stokes	
equations at high Reynolds number	55'
Philip L. Lederer and Rolf Stenberg, Energy norm analysis of exactly	
symmetric mixed finite elements for linear elasticity	583
Qingguo Hong, Johannes Kraus, Maria Lymbery, and Fadi Philo, A	
new practical framework for the stability analysis of perturbed saddle-	001
point problems and applications	60'
Nathalie Ayi, Maxime Herda, Hélène Hivert, and Isabelle Tristani, On a structure-preserving numerical method for fractional Fokker-	
Planck equations	63
David M. Ambrose, Michael Siegel, and Keyang Zhang, Convergence	000
of the boundary integral method for interfacial Stokes flow	69
Angelo A. Casulli and Igor Simunec, Computation of generalized matrix	
functions with rational Krylov methods	749
Hui Zhang, Lu Zhang, and Hao-Xing Yang, Revisiting linearized	
Bregman iterations under Lipschitz-like convexity condition	779
Zexin Pan and Art B. Owen, Super-polynomial accuracy of one	
dimensional randomized nets using the median of means	80
Bernhard Reinke, Dierk Schleicher, and Michael Stoll, The	
Weierstrass–Durand–Kerner root finder is not generally convergent	839
Jing Gao and Arieh Iserles, On an extended Filon method for highly	0.00
oscillatory integrals over a simplex	86'
Francesc Bars, Mohamed Kamel, and Andreas Schweizer, Bielliptic	90
quotient modular curves of $X_0(N)$	89
curves	933
Cut vos	00.







