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Welcome to Sanya

The workshop of "**Structured Matrix Computations with Applications**" is held during March 14-18, 2016 at Tsinghua Sanya International Mathematics Forum (TSIMF). It aims at bringing together International and Chinese researchers, scientists and graduate students to exchange and stimulate ideas in structured matrix computations and their applications.

The facilities of TSIMF are built on a 140-acre land surrounded by pristine environment at Phoenix Hill of Phoenix Township. The total square footage of all the facilities is over 28,000 square meter that includes state-of-the-art conference facilities (over 9,000 square meter) to hold two international workshops simultaneously, a large library, a guest house (over 10,000 square meter) and the associated catering facilities, a large swimming pool, two tennis courts and other recreational facilities.

Yau Mathematical Sciences Center (YMSC) of Tsinghua University, assisted by TSIMF's International Advisory Committee and Scientific Committee, will take charge of the academic and administrative operation of TSIMF. The mission of TSIMF is to become a base for scientific innovations, and for nurturing of innovative human resource; through the interaction between leading mathematicians and core research groups in pure mathematics, applied mathematics, statistics, theoretical physics, applied physics, theoretical biology and other relating disciplines, TSIMF will provide a platform for exploring new directions, developing new methods, nurturing mathematical talents, and working to raise the level of mathematical research in China.

Organizing Committee

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Invited Speakers

David Bindel	Cornell University, USA
Dario Bini	University of Pisa, USA
Matthias Bolten	University of Kassel, Germany
Stefano Serra-Capizzano	University of Insubria, Italy
Hua Dai	Nanjing University of Aeronautics and Astronautics, China
Xiao-Xia Guo	Ocean University of China, China
Xue-Ping Guo	East China Normal University, China
Michiel Hochstenbach	TU Eindhoven, Netherlands
Daniel Kressner	EPF Lausanne, Switzerland
Fu-Rong Lin	Shantou University, China
Nicola Mastronardi	Institute for the applications of calculus - CNR, Italy
James G. Nagy	Emory University, USA
Michael K Ng	Hong Kong Baptist University, HongKong
Ivan Oseledets	Skolkovo Institute of Science and Technology, Russia
Jian-Yu Pan	East China Normal University, China
Bor Plestenjak	IMFM and Department of Mathematics, University of Ljubljana, Slovenia
Zhi-Ru Ren	Central University of Finance and Economics, China
Hendrik Speleers	University of Tor Vergata, Italy
Eugene Tyrtyshnikov	Institute of Numerical Mathematics, Russian Academy of Sciences
Raf Vandebril	KU Leuven, Belgium
Paris Vassalos	Athens University, Greece
Zheng-Sheng Wang	Nanjing University of Aeronautics and Astronautics, China
Rui-Ping Wen	Taiyuan Normal University, China
Xi Yang	Nanjing University of Aeronautics and Astronautics, China
Jun-Feng Yin	Tongji University, China

Invited Poster Presenters

Davide Bianchi	Alessandro Buccini	Guo-Yan Meng	Vanni Noferini
Yu-Hong Ran	Leonardo Robol	Wei-Wei Xu	Li-Li Zhang
Xiang Zhang			

Program-at-a-glance

Time	Mar 14 (Mon)	Mar 15 (Tue)	Mar 16 (Wed)	Mar 17 (Thu)	Mar 18 (Fri)
Chair	Raymond Chan	Zhong-Zhi Bai	Jian-Lin Xia	Hua Dai	Marco Donatelli
08:45-09:00	Opening & Group Photo				
09:00-09:40	Eugene Tyrtyshnikov	Dario Bini	Hua Dai	James Nagy	Michael Ng
09:40-10:20	Jian-Yu Pan	Bor Plestenjak	Michiel Hochstenbach	Zheng-Sheng Wang	Rui-Ping Wen
10:20-10:50	Coffee Break	Coffee Break	Coffee Break	Coffee Break	Coffee Break
10:50-11:30	Ivan Oseledets	David Bindel	Xiao-Xia Guo	Zhi-Ru Ren	Jun-Feng Yin
11:30-12:10	Zhong-Zhi Bai	Marco Donatelli	Raymond Chan	Stefano Serra-Capizzano	Jian-Lin Xia
12:10-14:00	Lunch	Lunch	Lunch (12:10-13:00)	Lunch	Lunch
Chair	Eugene Tyrtyshnikov	Dario Bini	Excursion (13:00-18:30)	James Nagy	Michael Ng
14:00-14:40	Matthias Bolten	Fu-Rong Lin		Nicola Mastronardi	**Conclusion Session**
14:40-15:20	Raf Vandebril	Paris Vassalos		Xi Yang	
15:20-16:00	Hendrik Speleers	Xue-Ping Guo		Daniel Kressner	
16:00-16:30	Coffee Break	Beach		Coffee Break	Beach & Souvenirs
16:30-18:00	**Discussion 1**			**Discussion 2**	
18:00-19:00	Dinner	Dinner		Dinner	Dinner
19:00-21:30	Beach	**Poster Session**	Banquet	Beach	

Schedule

March 14, Monday

Session Chair	**Raymond Chan**
08:45-09:00	Opening Ceremony & Group Photo
09:00-09:40	Eugene Tyrtyshnikov Cross Approximations of Tensors and Matrices (P. 19)
09:40-10:20	Jian-Yu Pan Shifted Power Method for Computing H-eigenpairs of Symmetric Tensors (P. 18)
10:20-10:50	Coffee Break
10:50-11:30	Ivan Oseledets Astronomically large structured linear systems: what are the challenges? (P. 17)
11:30-12:10	Zhong-Zhi Bai Rotated Block Two-by-Two Preconditioners Based on PMHSS (P. 9)
12:10-14:00	Lunch
Session Chair	**Eugene Tyrtyshnikov**
14:00-14:40	Matthias Bolten Advanced smoothers in multigrid methods for circulant and Toeplitz matrices (P. 10)
14:40-15:20	Raf Vandebril A framework for structured linearizations of matrix polynomials in various bases (P. 20)
15:20-16:00	Hendrik Speleers Symbol-based multigrid methods for isogeometric analysis (P. 19)
16:00-16:30	Coffee Break
16:30-18:00	Discussion 1
18:00-19:00	Dinner
19:00-21:30	Outing (Beach)

March 15, Tuesday

Session Chair	Zhong-Zhi Bai
09:00-09:40	Dario Bini Generalization of the Brauer theorem to matrix polynomials and matrix Laurent series with applications (P. 9)
09:40-10:20	Bor Plestenjak Roots of bivariate polynomial systems via determinantal representations (P. 18)
10:20-10:50	Coffee Break
10:50-11:30	David Bindel Rank-Structured PDE Solvers (P. 9)
11:30-12:10	Donatelli Spectral analysis and structure preserving preconditioners for fractional diffusion equations (P. 13)
12:10-14:00	Lunch
Session Chair	**Dario Bini**
14:00-14:40	Fu-Rong Lin Fast algorithms for high accurate solution of convolution type linear integral equations (P. 15)
14:40-15:20	Paris Vassalos Asymptotic results on the condition number of FD matrices approximating semi-elliptic PDEs (P. 21)
15:20-16:00	Xue-Ping Guo Nonlinear solvers for some PDE problems (P. 14)
16:00-18:00	Outing (Beach)
18:00-19:00	Dinner
19:00-21:30	Poster Session

March 16, Wednesday

Session Chair	Jian-Lin Xia
09:00-09:40	Hua Dai Structured Matrix Pencil Nearness Problem in Structural Model Updating (P. 12)
09:40-10:20	Michiel Hochstenbach Some recent progress in generalized Krylov methods (P. 14)
10:20-10:50	Coffee Break

10:50-11:30	Xiao-Xia Guo Real iterative algorithms for a common solution to the complex conjugate matrix equation system (P. 14)
11:30-12:10	Raymond Chan Point-spread function reconstruction in ground-based astronomy (P.12)
12:10-13:00	Lunch
13:00-18:30	Excursion
19:00-21:30	Banquet

March 17, Thursday

Session Chair	**Hua Dai**
09:00-09:40	James Nagy SVD approximations for large-scale structured matrices (P. 16)
09:40-10:20	Zheng-Sheng Wang On the Pseudospectra of Matrices (P. 21)
10:20-10:50	Coffee Break
10:50-11:30	Zhi-Ru Ren A simplified HSS preconditioner for generalized saddle point problems (P. 19)
11:30-12:10	Stefano Serra-Capizzano The GLT class as a Generalized Fourier Analysis and applications (P. 11)
12:10-14:00	Lunch
Session Chair	**James Nagy**
14:00-14:40	Nicola Mastronardi Computing the Jordan structure of an eigenvalue (P. 16)
14:40-15:20	Xi Yang A parallel method for unsteady Stokes equations (P. 22)
15:20-16:00	Daniel Kressner Low multilinear approximation of antisymmetric tensors (P. 15)
16:00-16:30	Coffee Break
16:30-18:00	Discussion 2
18:00-19:00	Dinner
19:00-21:30	Beach

March 18, Friday

Session Chair	**Marco Donatelli**
09:00-09:40	Michael Ng Fast Iterative Solvers for Linear Systems Arising from Time-Dependent Space-Fractional Diffusion Equations (P. 17)
09:40-10:20	Rui-Ping Wen The generalized HSS method with a flexible shift-parameter for non-Hermitian positive definite linear systems (P. 21)
10:20-10:50	Coffee Break
10:50-11:30	Jun-Feng Yin Modulus-Type Inner Outer Iteration Method for Nonnegative and Box Constrained Least Squares Problems (P. 23)
11:30-12:10	Jian-Lin Xia On the stability and accuracy of structured direct solvers (P. 22)
12:10-14:00	Lunch
Session Chair	**Michael Ng**
14:00-16:00	Conclusion Session
16:00-18:00	Outing (Beach/Gift)
18:00-19:00	Dinner

ORAL PRESENTATIONS

Rotated Block Two-by-Two Preconditioners Based on PMHSS

Zhong-Zhi Bai
State Key Laboratory of Scientific/Engineering Computing, Institute of Computational Mathematics
Scientific/Engineering Computing, Academy of Mathematics and Systems Science, Chinese Academy of Sciences

Abstract
Motivated by the HSS iteration method, to solve the distributed control problem we have proposed modified HSS (MHSS) as well as preconditioned and modified HSS (PMHSS) iteration methods. Theoretical analyses and numerical experiments have shown the effectiveness of these iteration methods when used either as linear solvers or as matrix preconditioners for Krylov subspace methods. Moreover, we have developed the PMHSS iteration method to block two-by-two matrices of non-Hermitian sub-blocks, resulting in the additive-type and the rotated block triangular preconditioners.
Spectral analyses and numerical computations have shown that these preconditioners can significantly accelerate the convergence rates of the Krylov subspace iteration methods when they are used to solve the block two-by-two linear systems, and the inexact variants these preconditioners are as effective and robust as the corresponding exact ones.

Rank-Structured PDE Solvers

David Bindel
Cornell University, USA

Abstract
We describe a “superfast” Cholesky code based on CHOLMOD, organized around level 3 BLAS for speed. We combine sparsity and low-rank structure and directly factor low-rank blocks using randomized algorithms. For a nearly-incompressible elasticity problem, CG with our rank-structured Cholesky converges faster than with incomplete Cholesky and the ML multigrid preconditioner, both in iteration counts and in run time. At 10 6 degrees of freedom, we use 3 GB of memory; exact factorization takes 30 GB.

Generalization of the Brauer theorem to matrix polynomials and matrix Laurent series with applications

D.A. Bini and B. Meini

Dipartimento di Matematica, Università di Pisa

Abstract

Brauer's theorem [2] shows how to modify one eigenvalue of a square matrix A via a rank-one perturbation, without changing any of the remaining eigenvalues. We reformulate Brauer's theorem in functional form and provide extensions to matrix polynomials and to matrix Laurent series s $A(z)$ together with generalizations to modifying a set of eigenvalues. Assuming s $A(z)$ has a canonical factorization factorization $A(z) = L(z)U(z)$, we provide conditions under which the modified function $\tilde{A}$ has a canonical factorization $\tilde{A}(z) = \tilde{U}(z)\tilde{L}(z^{-1})$ and determine explicit expressions relating the factors $\tilde{U}(z)$ and $\tilde{L}(z)$ to the factors $L(z)$ and $U(z)$. Similar conditions and expressions are given for the factorization of $A(z^{-1})$ and $\tilde{A}(z^{-1})$. More details can be found in [1].

These results find application to determine the explicit solutions of matrix difference equations, by relying on the theory of standard triples of [4]. In fact, if the matrix polynomial $A(z)$, associated with the matrix difference equation, has some multiple eigenvalues, the tool of standard triple cannot be always applied. However, we can replace $A(z)$ by a new matrix polynomial $\tilde{A}(z)$having pairwise different eigenvalues. The new matrix difference equation associated with $\tilde{A}(z)$ can be solved with the tool of standard triples and we can easily reconstruct the solution of the original matrix difference equation, associated with $A(z)$, from the solution of the equation associated with $\tilde{A}(z)$.

This fact enable us to provide formal solutions to the Poisson problem for QBD Markov chains [3] also in the important case of null-recurrent processes.

[1] D.A. Bini, B. Meini. Generalization of the Brauer Theorem to Matrix Polynomials and Matrix Laurent Series, arXiv:1512.07118v1.

[2] A. Brauer. Limits for the characteristic roots of a matrix. IV. Applications to stochastic matrices. *Duke Math. J.*, 19:75–91, 1952.

[3] S. Dendievel, G. Latouche, and Y. Liu. Poisson's equation for discrete-time quasi-birth-and-death processes. *Performance Evaluation*, 2013.

[4] I. Gohberg, P. Lancaster, and L. Rodman. *Matrix Polynomials*. Academic Press Inc., New York, 1982.

Advanced smoothers in multigrid methods for circulant and Toeplitz matrices

Matthias Bolten

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Abstract

Circulant matrices and Toeplitz matrices arise in a variety of applications including signal processing and partial differential equations. For banded multi-level matrices multigrid methods have been developed, e.g., in [2] for Toeplitz matrices and in [3] for multilevel circulant matrices. A detailed analysis for the matrix algebra case can be found in [1]. Most of the analysis focusses on Richardson iterations as smoother. This

is sufficient from a theoretical viewpoint, nevertheless a different choice of the smoother can significantly speed up the resulting methods.
Richardson corresponds to approximating the inverse by a constant. The natural extension are higher order polynomials that come at the cost of higher bandwidth of the smoothers' iteration matrices. Besides these, possible choices for smoothers include multicolor-SOR or block smoothers, where instead of relaxing single unknowns small blocks are inverted.
We will present a framework that allows for the description of multicolor-SOR, block smoothers and similar methods. For the theoretical analysis proper decompositions of the system matrices are used that allow for a detailed analysis of the resulting method. The analysis tools fit in the established framework that is used to analyze multigrid methods for Toeplitz and circulant matrices.

[1] A. Aricò and M. Donatelli. A V-cycle Multigrid for multilevel matrix algebras: proof of optimality. *Numer. Math.*, 105:511-547, 2007.
[2] G. Fiorentino and S. Serra. Multigrid methods for Toeplitz matrices. *Calcolo*, 28:238-305, 1991.
[3] S. Serra-Capizzano and C. Tablino-Possio. Multigrid methods for multi-level circulant matrices. *SIAM J. Sci. Comput.*, 26(1):55-85, 2004.

The GLT class as a Generalized Fourier Analysis and applications

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Department of Information Technology, Uppsala University, Box 337, SE-751 05 Uppsala, Sweden

Abstract
Recently, the class of Generalized Locally Toeplitz (GLT) sequences has been introduced as a generalization both of classical Toeplitz sequences and of variable coeffcient differential operators and, for every sequence of the class, it has been demonstrated that it is possible to give a rigorous description of the asymptotic spectrum in terms of a function (the symbol) that can be easily identified. This generalizes the notion of a symbol for differential operators (dis- crete and continuous) or for Toeplitz sequences for which it is identified through the Fourier coefficients and is related to the classical Fourier Analysis. The GLT class has nice algebraic properties and indeed it has been proven that it is stable under linear combinations, products, and inversion when the sequence which is inverted shows a sparsely vanishing symbol (sparsely vanishing symbol = a symbol which vanishes at most in a set of zero Lebesgue measure). Furthermore, the GLT class virtually includes any approximation of partial differential equations (PDEs) by local meth- ods (Finite Difference, Finite Element, Isogeometric Analysis etc) and, based on this, we demonstrate that our results on GLT sequences can be used in a PDE setting in various directions:

1. as a generalized Fourier Analysis for the design and for the study of preconditioned iterative and semi-iterative methods, when deal- ing with variable coefficients, non rectangular domains, non uniform gridding or triangulations,

2. for a multigrid analysis of convergence and for providing spectral in- formation on large preconditioned systems in the variable coefficient case,
3. in order to provide a tool for the stability analysis of PDE numerical schemes (e.g. a necessary von Neumann criterium for variable coefficient systems of PDEs is obtained, uniformly with respect to the boundary conditions), etc. We will discuss specifically problems 1) and 2), with special attention to the IgA setting, and other possible directions in which the GLT analysis can be conveniently employed; see below for a recent bibliography on the subject.

Point-spread function reconstruction in ground-based astronomy

Raymond H. Chan
Department of Mathematics,
The Chinese University of Hong Kong,
Shatin, Hong Kong

Abstract

Because of atmospheric turbulence, images of objects in outer space acquired via ground based telescopes are usually blurry. One way to estimate the blurring kernel or point spread function (PSF) is to make use of the aberration of wavefronts received at the telescope, i.e., the phase. However only the low-resolution wavefront gradients can be collected by wavefront sensors. In this talk, I will introduce the necessary background first and then discuss how to use regularization methods to reconstruct high-resolution phase gradients and then use them to recover the phase and the PSF in high accuracy.

Structured Matrix Pencil Nearness Problem in Structural Model Updating

Hua Dai
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Abstract

Highly accurate models are required to analyze and predict the dynamic behavior of complex structures during design and analysis. The most commonly used modelling technique is the finite element method. However, it is well known that the finite element model rarely matches the actual structure due to the complexity of structures. Updating a finite element model to match experimental data has been a important task for engineers. Mathematically, the model-updating problem is closely related to structured matrix pencil approximation problem subject to some constraints. The problem has received much attention over the years and many methods have been presented. However, the updated model with the methods does not preserve the properties of the structure. In this talk, Desired matrix properties including satisfaction of the characteristic equation, symmetry, positive semidefiniteness, and sparsity are

imposed as side constraints to form the optimal matrix pencil approximation problem. Conditions ensuring the feasible region of the structured matrix pencil nearness problem are analyzed by QR decomposition. Some numerical methods for solving the problem are provided.

Spectral analysis and structure preserving preconditioners for fractional diffusion equations

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Abstract
Fractional partial diffusion equations (FDEs) are a generalization of classical partial differential equations, used to model anomalous diffusion phenomena. In [2] the authors introduced an unconditionally stable method for approximating the FDEs which combines the implicit Euler formula and the shifted Grünwald formula and which leads to a Toeplitz-like matrix-sequence (see [5]).
In the constant diffusion coefficients case such a matrix-sequence reduces to a Toeplitz one, then exploiting well-known results on Toeplitz sequences, we are able to describe its asymptotic eigenvalue distribution. In the case of nonconstant diffusion coefficients, we show that the resulting matrix sequence is a generalized locally Toeplitz (GLT) and then we use the GLT machinery to study its singular value/eigenvalue distribution as the matrix size diverges (see [4]). These new spectral information are employed for analyzing methods of preconditioned Krylov and multigrid type recently appeared in the literature [1, 3], with both positive and negative results and with a look forward to the multidimensional setting.
Finally, we propose two structure preserving preconditioners with minimal bandwidth (and so with efficient computational cost) in combination with CGNR and GMRES methods and show that they are numerically more effective than the recently used circulant preconditioner.

[1] S.-L. Lei, H. W. Sun: "A circulant preconditioner for fractional diffusion equations", *J. Comput. Phys.*, Vol. 242, pp. 715–725, 2013.
[2] M. M. Meerschaert, C. Tadjeran: "Finite difference approximations for two-sided space-fractional partial differential equations", *Appl. Numer. Math.*, Vol. 56-1, pp. 80–90, 2006.
[3] H. Pang, H. Sun: "Multigrid method for fractional diffusion equations", *J. Comput. Phys.*, Vol. 231, pp. 693–703, 2012.
[4] S. Serra-Capizzano: "The GLT class as a generalized Fourier Analysis and applications", *Linear Algebra Appl.* Vol. 419, pp. 180–233, 2006.
[5] H. Wang, K. Wang, T. Sircar: "A direct O(N log2N) finite difference method for fractional diffusion equations", *J. Comput. Phys.*, Vol. 229, pp. 8095–8104, 2010.

Real iterative algorithms for a common solution to the complex conjugate matrix equation system

Xiao-Xia Guo
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Abstract
In this paper, we propose a new algorithm for the computation of the common solution to the complex conjugate matrix equation system $A_iXB_i + C_iXD_i = E_i, i = 1,2,\dots,N$. The algorithms only need finite iteration steps, requiring only real computation. Furthermore, the algorithm can be extended to solve a more general complex matrix equation system. Two numerical examples are given to illustrate the effectiveness of the proposed algorithm.

Nonlinear solvers for some PDE problems

Xue-Ping Guo
East China Normal University, Shanghai, China

Abstract
We consider some effective and robust algorithms for solving large sparse systems of nonlinear equations

$$F(x) = 0,$$

where $F: \mathbb{D} \subset \mathbb{C}^n \to \mathbb{C}^n$ is nonlinear and continuously differentiable. The Jacobian matrix of $F(x)$ is large, sparse, non-Hermitian, positive definite or complex symmetric.

Some recent progress in generalized Krylov methods

Michiel Hochstenbach
TU Eindhoven,Netherlands

Abstract
We will discuss recent progress in the development of generalized Krylov methods. In particular, we will discuss the generalized eigenvalue problem

$$Ax = \lambda Bx\,,$$

and the generalized Tikhonov approach

$$A^*A + \mu B^*B = A^*b.$$

This talk reflects joint work with Lothar Reichel, Xuebo Yu, and Ian Zwaan. Part of this presentation is based on [2, 1]; see also, e.g., [3, 4, 5].

[1] M. E. Hochstenbach, L. Reichel and X. Yu, A Golub–Kahan-type reduction method for matrix pairs, *J. Sci. Comp.* 65(2), pp. 767–789, 2015.
[2] M. E. Hochstenbach, E. Romero, J. E. Roman, Davidson type subspace expansions for the linear eigenvalue problem, *SLEPc report STR*-10, 2012.
[3] R.-C. Li and Q. Ye, A Krylov subspace method for quadratic matrix polynomials with application to constrained least squares problems, *SIAM J. Matrix Anal. Appl.* 25, pp. 405–428, 2003.
[4] L. Reichel, F. Sgallari, and Q. Ye, Tikhonov regularization based on generalized Krylov subspace methods, *Appl. Numer. Math.*, 62, pp. 1215–1228, 2012.

[5] L. Reichel and X. Yu, Tikhonov regularization via flexible Arnoldi reduction, *BIT*, 55(4), pp. 1145–1168, 2015.

Low multilinear approximation of antisymmetric tensors

Daniel Kressner
EPF Lausanne, Switzerland

Abstract

A tensor $\chi \in \mathbb{R}^{n\times\dots\times n}$ of order $d \geq 2$ is called antisymmetric if its entries $\chi_{i_1,i_2,\dots,i_d}$ change sign when permuting pairs of indices. For example, a tensor of order three with entries is antisymmetric if

$$\chi_{i_1,i_2,i_3} = -\chi_{i_2,i_1,i_3} = -\chi_{i_3,i_2,i_1} = -\chi_{i_1,i_3,i_2}, i_1, i_2, i_3 = 1, \dots, N$$

Such tensors arise frequently in quantum mechanics, due to the Pauli exclusion principle. For order two, the notion of antisymmetric tensors coincides with the notion of skew-symmetric matrices.

In this talk, we discuss the multilinear rank of antisymmetric tensors, which exhibits a suprising difference between $d = 2$ and $d > 2$. We discuss algorithms that aim to find the best antisymmetric low multilinear rank approximation to a given antisymmetric tensor. Particular attention is paid to the approximation of lowest nonzero rank.

This talk is based on joint work with Erna Begović, University of Zagreb, Croatia.

Fast algorithms for high accurate solution of convolution type linear integral equations

Fu-Rong Lin, Yong-Jie Shi, and Wei-Li Guo
Department of Mathematics, Shantou University
Shantou Guangdong 515063, China

Abstract

In this talk, we introduce fast algorithms for the solution of convolution type linear integral equations

$$x(t) + \int_a^b k(t-s)x(s)ds = g(s), a \leq t \leq b,$$

where the kernel function $k(t)$ is smooth or semi-smooth and assume that $x(t)$ is smooth. If $k(t)$ is smooth, we consider applying composite Gauss-Legendre quadratures or composite Clenshaw-Curtis quadratures to discretize the integral equation. For the case where $k(t)$ is semi-smooth, we consider applying composite Nyström-Clenshaw-Curtis (NCC) quadratures which was proposed in [Math. Comp., 72 (2003), pp. 729–756]. We show that by suitably ordering the unknowns, the coefficient matrix of corresponding linear system has block Toeplitz structure. As a result, the linear system can be solved efficiently by using the preconditioned conjugate gradient method. Numerical results are presented to illustrate the efficiency of the proposed methods.

Computing the Jordan structure of an eigenvalue

Nicola Mastronardi and Paul Van Dooren
Istituto per le Applicazioni del Calcolo "M. Picone", Consiglio Nazionale delle Ricerche, sede di Bari, Italy

Abstract

In this paper we revisit the problem of finding an orthogonal similarity transformation that puts an $n \times n$ matrix A in a block upper-triangular form that reveals its Jordan structure at a particular eigenvalue α. The obtained form in fact reveals the dimensions of the null spaces of $(A - \alpha I)^i$ at that eigenvalue via the sizes of the leading diagonal blocks, and from this the Jordan structure at α is then easily recovered. The method starts from a Hessenberg form that already reveals several properties of the Jordan structure of A. It then updates the Hessenberg form in an efficient way to transform it to a block-triangular form $\mathcal{O}(mn^2)$ floating point operations, where m is the total multiplicity of the eigenvalue. The method only uses orthogonal transformations and is backward stable. We illustrate the method with a number of numerical examples.

SVD approximations for large-scale structured matrices

James Nagy
Emory University, USA

Abstract

The singular value decomposition (SVD) is a fundamental tool for analyzing and solving ill-conditioned linear systems. However, in many applications the matrices are often too large to be able to efficiently compute a full SVD. While iterative methods, such as Lanczos bidiagonalization, or recent randomized matrix algorithm approaches can be used to compute a few singular values and vectors, they often become too expensive if a large number of components need to be computed.

In this talk we describe a general approach to efficiently approximate a large number of singular values and corresponding singular vectors for large scale structured matrices. We apply these methods to solve ill-posed inverse problems in image processing.

Fast Iterative Solvers for Linear Systems Arising from Time-Dependent Space-Fractional Diffusion Equations

Michael Ng
Hong Kong Baptist University, Hong Kong

Abstract

In this talk, we discuss the linear systems arising from the discretization of timedepen-

dent space-fractional diffusion equations. By using a finite difference discretization scheme for the time derivative and a finite volume discretization scheme for the space-fractional derivative, Toeplitz like linear systems are obtained. We propose to use the approximate inverse-circulant preconditioner to deal with such Toeplitz-like matrices, and show that the spectra of the corresponding preconditioned matrices are clustered around 1. Experimental results on time-dependent and space-fractional diffusion equations are presented to demonstrate that the preconditioned Krylov subspace methods converge very fast.

Astronomically large structured linear systems: what are the challenges?

Ivan Oseledets
kolkovo Institute of Science and Technology
Skolkovo Innovation Center, Building 3, Moscow 143026, Russia

Abstract

In this talk I will talk about approximate solution of structured linear systems $\mathrm{Ax} = \mathrm{f}$ with $\mathrm{n} \times \mathrm{n}$ matrices A with $\mathrm{n} = 2\mathrm{d}$ and d being as high as 50 or 100. Tensor structure is the only hope, since even storing the solution is not appropriate. A very efficient tool for several classes of problem is the so-called tensor train (TT) or quantized tensor train (QTT) format, which represents the solution vector x as d-dimensional tensor which is then approximated in the TT-format as

$$\mathrm{X}(\mathrm{i}_1, \dots, \mathrm{i}_\mathrm{d}) = \mathrm{X}_1(i_1)X_2(i_2) \dots X_d(i_d),$$

where $\mathrm{X_k}(i_k)$ is a matrix of size $\mathrm{r_{k-1}} \times r_k$, $\mathrm{r}_0 = r_d = 1$. Several efficient method for computing solution in the TT-format have been proposed, including alternating least squares, alternating minimal energy and Riemannian optimization approaches. They often work in the assumption that the true solution can be well-approximated in the TT-format. Recently it has been shown that for matrices coming from certain PDEs and also for some algebraic classes (like banded Toeplitz matrices) the solution indeed has a low-rank structure. However, for *astronomically large* n matrix A is typically very ill-conditioned, and there is no chance to recover the solution accurately even in double precision arithmetic, even though we know, that it has a good low-rank structure. In this talk I will demonstrate how we can reformulate the original system for matrices coming from PDEs in the form, equivalent in the exact arithmetic, but much more robust in the finite precision, and show numerical experiments for n up to 2^{50}.

Shifted Power Method for Computing H-eigenpairs of Symmetric Tensors

Yin-Bing Lu and Jian-Yu Pan
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Abstract

WeproposeashiftedsymmetrichigherorderpowermethodforcomputingtheH-eigenpairs of a real symmetric even-order tensor. The local convergence of the method is given. In addition, by utilizing the fixed point analysis, we can characterize exactly which H-

eigenpairs can be found and which cannot be found by the method. Numerical examples are presented to illustrate the performance of the method.

Roots of bivariate polynomial systems via determinantal representations

Bor Plestenjak
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Abstract
For each monic polynomial $p(x) = p_0 + p_1 + \cdots + p_{n-1}x^{n-1} + x^n$ we can construct a matrix $A \in \mathbb{C}^{n\times n}$ such that $\det(xI - A) = p(x)$ and then numerically compute the roots of p as eigenvalues of A. One of the options for A is the companion matrix.
We show that a similar approach can be applied to a system of two bivariate polynomials

$$p(x,y) := \sum_{i=0}^{n_1}\sum_{j=0}^{n_1-j} p_{ij}x^i y^j = 0,$$

$$q(x,y) := \sum_{i=0}^{n_2}\sum_{j=0}^{n_2-j} q_{ij}x^i y^j = 0,$$

For each polynomial we find a determinantal representation, i.e, matrices A_1, B_1, C_1 of size $m_1 \times m_1$ and A_2, B_2, C_2 of size $m_2 \times m_2$ such that

$$\det(A_1 + xB_1 + yC_1) = p(x,y),$$

$$\det(A_2 + xB_2 + yC_2) = q(x,y).$$

This gives an equivalent singular two-parameter eigenvalue problem

$$(A_1 + xB_1 + yC_1)u_1 = 0,$$

$$(A_2 + xB_2 + yC_2)u_2 = 0,$$

whose finite regular eigenvalues are the roots of p, q.
It is known since Dixon's 1902 result that for each bivariate polynomial of degree n there exists a determinantal representation with $n \times n$ matrices, but up to now there are no efficient constructions. We will present some determinantal representations with small matrices that can be constructed efficiently. The resulting numerical method for the roots of a system of two bivariate polynomials is competitive with some existing methods for polynomials of small degree.

A simplified HSS preconditioner for generalized saddle point problems

Zhi-Ru Ren
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Abstract
For generalized saddle point problems, we propose a simplified Hermitian and skew-Hermitian splitting (SHSS) preconditioner which is much closer to the generalized saddle point matrix than the HSS preconditioner. It is proved that all eigenvalues of the

SHSS preconditioned matrix are real and nonunit eigenvalues are located in a positive interval. We also study the eigenvector distribution and the degree of the minimal polynomial of the preconditioned matrix. Numerical examples of a model Stokes problem show the effectiveness of the SHSS preconditioner.

Symbol-based multigrid methods for isogeometric analysis

Hendrik Speleers
University of Tor Vergata, Italy

Abstract

In this talk we consider the Galerkin and collocation discretization of classical elliptic problems in the context of B-spline isogeometric analysis. By exploiting specific spectral properties compactly described by a symbol, we design efficient multigrid methods for the fast solution of the related linear systems. Despite the theoretical optimality, the convergence rate of two-grid methods with classical stationary smoothers worsens exponentially when the spline degree increases. With the aid of the symbol we provide a theoretical interpretation of this exponential worsening. Moreover, by a proper factorization of the symbol we provide a preconditioned conjugate gradient smoother, in the spirit of the multi-iterative strategy, that allows us to obtain a good convergence rate independent both of the matrix size and of the spline degree. A numerical experimentation confirms the effectiveness of our proposal and the numerical optimality with a uniformly high convergence rate, also for the V-cycle multigrid method and large spline degrees.
This is joint work with Marco Donatelli, Carlo Garoni, Carla Manni and Stefano Serra-Capizzano.

Cross Approximations of Tensors and Matrices

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Lomonosov Moscow State University
Moscow Institute of Science and Technology

Abstract

Numerical data are frequently organized as d-dimensional matrices, also called tensors. However, only small values of d are allowed if we need to keep this data in a computer memory. In the case of many dimensions, special representation formats are crucial and it looks natural to try the so called tensor decompositions. In the recent decade, the known tensor decompostions have been considerably revisited and the two of them appeared and are now recognized as the most adequate and useful tools for numerical analysis. These two are the Tensor-Train and Hierarchical-Tucker decompositions. Both are intrinsically related with low-rank matrices associated with a given tensor.
In the talk, we expound the role of low-rank matrices for the construction of efficient numerical algorithms and consider possible developments of the idea of cross approximation that proved to be very fruitful for matrices and then has been

successfully extended over to tensors. The nice property of the approach is that we construct the approximation using only a small portionof the data.
The idea of cross approximation is substantiated by the maximal volume concept for low-rank approximation of matrices and related with the classic problem of choosing a "good" basis from a given set or vectors. We discuss possible advantages of using "good" frames and what it may give for better work with tensors.

A framework for structured linearizations of matrix polynomials in vairous bases

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‡ Catholic University of Louvain, Dept. of Mathematical Engineering, Louvain-la-Neuve, Belgium

Abstract
We present a framework for the construction of linearizations for scalar and matrix polynomials based on dual bases which, in the case of orthogonal polynomials, can be described by the associated recurrence relations. The framework provides an extension of the classical linearization theory for polynomials expressed in non-monomial bases and allows to represent polynomials expressed in product families, that is as a linear combination of elements of the form $\phi_i(x)\psi_j(x)$, where $\{\phi_i(x)\}$ and $\{\psi_j(x)\}$ can either be polynomial bases or polynomial families which satisfy some mild assumptions.
We show that this general construction can be used for many different purposes. Among them, we show how to linearize sums of polynomials and rational functions expressed in different bases. As an example, this allows to look for intersections of functions interpolated on different nodes without converting them to the same basis.

Asymptotic results on the condition number of FD matrices approximating semi-elliptic PDEs

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Abstract
In this work we study the asymptotical spectral properties of the matrices A_{nn} arising from the discretization of semi-elliptic partial differential of the form

$$-\nabla\left(\begin{pmatrix} a & 0 \\ 0 & b \end{pmatrix}\nabla^T u\right) = f$$

on the square $\Omega = [0,1]^2$, with Dirichlet boundary conditions, where the smooth variable coefficients $a(x,y), b(x,y)$ are nonnegative functions on Ω with zeros. Denoting with α the minimum of the orders of these zeros, we show that if α is happened in a common zero, then the spectral condition number $\kappa(A_{nn})$ of A_{nn} grows as $n^{max\{2,\alpha\}}$. Additionally, when the concrete zeros of $a(x,y), b(x,y)$ are on different points of Ω, then the $\kappa(A_{nn})$ always behaves like $O(n^2)$. Finally, the more complicated case of coefficient functions having curves of roots is considered, and conjectures for future work are given. The presentation is ended with many experiments that numerically confirm the developed theoretical analysis.

On the Pseudospectra of Matrices

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Abstract

The pseudospectrum of a matrix is a way to visualize the non-normality of a matrix and the sensitivity of its eigenvalues. In this talk, we briefly introduce the definitions, algebraic properties and computational methods for the pseudospectra of matrices. In addition, we propose an equivalent definition for the pseudospectra of matrices via Rank-Revealing QR (RRQR) factorization. We give the proof of the equivalency between this definition and the classical ones. And an algorithm for computing the pesudospectra based on this equivalent definition is given. Numerical experiments and comparisons are given to illustrate the efficiency of the results. Finally, some challenging problems in this area are commented, such as structured pseudospectra problem and so on.

The generalized HSS method with a flexible shift-parameter for non-Hermitian positive definite linear systems

Rui-Ping Wen
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Abstract

Based on the Hermitian and skew-Hermitian splitting (HSS) (see Z.Z. Bai 2003), we come up with a generalized HSS iteration method with a flexible shift-parameter for solving the non-Hermitian positive definite system of linear equations. This iteration method utilizes the optimization technique to obtain the optimal value of the flexible shift-parameter at iteration process. Both theory and experiment have shown that the new strategy is efficient.

On the stability and accuracy of structured direct solvers

Jian-Lin Xia

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Abstract

Structured direct solvers are known to be very efficient in solving some integral equations and PDEs. Here, we show that they are not only faster than standard direct solvers, but can also have much better stability. In particular, for some hierarchical structured matrices, we first show how the approximation errors can be controlled by the tolerance via either rank-revealing factorization or randomized compression. We further demonstrate the backward stability of the direct solution. In fact, the growth of the numerical error in the direct factorization is significantly slower than that in standard LU factorization with pivoting. The numerical growth factors are derived. This is joint work with Yuanzhe Xi.

A parallel method for unsteady Stokes equations

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Abstract

The unsteady Stokes equations are semi-discretized in space to obtain the systems of the unsteady discrete Stokes equations, i.e., systems of linear time-invariant differential-algebraic equations (DAEs) with saddle-point coefficient matrices. The solution of a system of unsteady discrete Stokes equations is represented as an integral along a smooth curve Γ in the complex plane with singularities of the integrand located on the left of and not too close to the curve Γ. A truncated quadrature rule based on the sinc function is then employed to evaluate the solution of the unsteady discrete Stokes equations. This results in a set of systems of saddle-point linear equations which are the major computational cost and may be solved in parallel.

Modulus-Type Inner Outer Iteration Method for Nonnegative and Box Constrained Least Squares Problems

Ning Zheng* , Ken Hayami† , and Jun-Feng Yin‡

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†National Institute of Informatics, and SOKENDAI, Tokyo
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Abstract

For the solution of large sparse nonnegative constrained least squares (NNLS) problems, a new iterative method is proposed by using conjugate gradient least squares (CGLS) method for inner iterations and the modulus-type iterative method in the outer iterations for the solution of linear complementarity problem (LCP) resulting from Karush-Kuhn-Tucker (KKT) conditions of the NNLS problem. Theoretical convergence analysis including the optimal choice of the parameter matrix is presented for the proposed method. Numerical experiments show the efficiency of the proposed

method compared to projection-type methods with less iteration steps and CPU time. Application to some image restoration problems also show the effectiveness of the proposed methods. If time allows, we will also present a generalization of the method to box constrained least squares problems (BLS), where we employ the generalized SOR method for the inner iterations, and the accelerated modulus iterative method for the outer iterations for the solution of the linear complementarity problem resulting from the KKT condition of the BLS problem. Theoretical convergence analysis is presented. Numerical experiments show the efficiency of the proposed method with less iteration steps and CPU time compared to projection methods. This work was essentially done by my Ph.D. student, Dr. Ning Zheng.

POSTER PRESENTATIONS

Regularization preconditioners for frame-based image deblurring with reduced boundary artifacts

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Abstract

Thresholding iterative methods are recently successfully applied to image deblurring problems. We investigate the modified linearized Bregman algorithm (MLBA) used in image deblurring problems with a proper treatment of the boundary artifacts. We consider two standard approaches: the imposition of boundary conditions and the use of the rectangular blurring matrix.

The fast convergence of the MLBA depends on a regularizing preconditioner that could be computationally expensive and hence it is usually chosen as a block circulant circulant block (BCCB) matrix, diagonalized by discrete Fourier transform. We show that the standard approach based on the BCCB preconditioner could provide low quality restored images and we propose different preconditioning strategies that improve the quality of the restoration and save some computational cost at the same time. Motivated by a recent nonstationary preconditioned iteration, we propose a new algorithm that combines such method with the MLBA. We prove that it is a regularizing and convergent method. A variant with a stationary preconditioner is also considered.

On nonstationary preconditioned iterative regularization methods for image deblurring

Alessandro Buccini and Marco Donatelli
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Abstract

In many applications, such as astronomy and medicine, arises the problem of image deblurring, this inverse problem is ill-conditioned and the inevitable presence of noise make a very difficult task obtaining a good reconstruction of the true image.

In the recent paper (D. Hanke 2013) the authors developed an algorithm for image deblurring which can be seen as an approximated version of the non-stationary iterated Tikhonov method. We call it approximated because we can obtain this method by substituting the true blurring operator, inside the Tikhonov iteration, with another one which is spectral equivalent but that has a structure that let us have very fast computations. Moreover, unlike the classical iterated Tikhonov, this method does not need the estimation of any parameter, which led to a more robust and stable algorithm.

We want to present some extensions of this method, in particular we add the possibility to project the reconstruction at each iteration onto a closed and convex set and to add a regularization operator in order to better preserve the edges.
Recent results (M. Donatelli 2006) have shown that iterative methods of multigrid type are very precise and efficient for regularizing purposes, thus a further extension is to include the proposed method in a multilevel strategy. The algorithm in (M. Donatelli 2012) was developed for Toeplitz matrices, i.e. for the zero boundary conditions, and combines multigrid methods with framelet denoise; the multigrid regularize and solve the problem and the denoise is used for keeping under control the effect of noise going on with the iterations.
Our proposal uses a multi-resolution representation of the point spread function to allow the method to be independent of the structure of the blurring matrix, in order to have the possibility to choose any boundary conditions and not only the zeros. Another important difference from (M. Donatelli 2012) is the smoothing strategy: we propose to combine the previous nonstationary preconditioning and the projection into a closed and convex set.
Finally we compare the results with the different approaches.

A Practical Asymptotical Optimal SOR Method

Guo-Yan Meng
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Abstract
We consider a practical asymptotical optimal successive over-relaxation(SOR) method for solving the large sparse linear system. Based on two optimization models, asymptotically optimal relaxation factors are given, which are computed by solving the low-order polynomial equations in each iteration. The coefficients of the two polynomials are determined by the residual vector and the coefficient matrix A of the real linear system. The numerical examples show that the new methods are more feasible and effective than the classical SOR method.

The structured condition number of a smooth map between matrix manifolds

Vanni Noferini
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Abstract
We study the structured condition number of matrix functions between smooth matrix manifolds, developing a theoretical framework that extends previous results for vector subspaces to any smooth manifold. Automorphism groups associated with a scalar product are analyzed as a special case of smooth matrix manifolds. We argue that the structured and unstructured condition numbers can differ by several orders of magnitude, thus motivating the development of structured algorithms. We also provide numerical comparisons between the structured and unstructured condition numbers of matrix logarithm and matrix square root. We present an efficient estimator for the

structured condition number of f(X), where X is a symplectic or symplectic-orthogonal matrix. Finally, we give the lower and the upper bounds of the structured condition number.
This poster is based on joint work with B. Arslanand F. Tisseur from the University of Manchester.

On HSS-like iteration method for the space fractional coupled nonlinear Schrödinger equations

Yu-Hong Ran
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Abstract
The implicit conservative difference scheme with the fractional centered difference formula, which is unconditionally stable, is employed to discretize the space fractional coupled nonlinear Schrödinger equations. The coefficient matrix of the discretized linear system is equal to the sum of a complex scaled identity matrix which can be written as the imaginary unit times the identity matrix and a symmetric diagonal-plus-Toeplitz matrix. In this paper, the HSS-like iteration method is proposed to solve the discretized linear system. Theoretical analyses shows that the iteration method is unconditionally convergent. Moreover, we derive an upper bound of the contraction factor of the HSS-like iteration. In addition, we present a approximate preconditioner based on the corresponding HSS-like preconditioner for such Toeplitz-like linear system. Numerical examples are presented to illustrate the effectiveness of the HSS-like iteration method and show that Krylov subspace methods such as BiCGSTAB with the proposed preconditioners converge very fast.

Ehrlich–Aberth iteration for rank structured pencils

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Abstract
The Ehrlich–Aberth iteration is an effective method to approximate the roots of scalar polynomials. Recently it has been shown to be a viable solution also for the approximation of eigenvalues of matrix pencils and polynomials.
Motivated by the recent introduction of rank structured pencils, we investigate the applicability of a structured Ehrlich–Aberth iteration for pencils that enjoy low rank structures in a suitable block partitioning. We show that an efficient iteration can be devised for such cases and that this leads to both cheaper algorithms and more accurate approximations.
We give some ideas for estimating good starting points for approximating the roots of sum of polynomials expressed in Newton, Lagrange, and Chebyshev bases, and show convincing experimental results that prove the effectiveness of the approach. We show that a good selection of the initial approximations is vital for the performance of the algorithm.

We also discuss the easy deflation of infinite eigenvalues (even in presence of Jordan chains at infinity) in this framework.

On upper and lower bounds of perturbation of generalized eigenvalues for diagonalizable matrix pairs

Wei-Wei Xu
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Abstract
On generalized eigenvalue perturbation bounds for diagonalizable matrix pairs upper bounds are discussed all the time. In this paper we mainly consider not only upper bounds but also lower bounds of perturbation of generalized eigenvalues for diagonalizable matrix pairs and present the corresponding interval estimates. This paper is concerned with relationships between generalized eigenvalues before and after the disturbance. Upper and lower bounds on perturbation of generalized eigenvalues for diagonalizable matrix pairs are obtained in terms of the distances of two points in Grassmann manifold. Both upper and lower bounds are provided to further narrow the scope of distances between generalized eigenvalues. The theoretical results are also illustrated by numerical examples.

Two-Step Modulus-Based Synchronous Multisplitting Iteration Methods for Linear Complementarity Problems

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Abstract
For large sparse linear complementarity problems, the modulus-based synchronous multisplitting iteration method is an effective algorithm, which is suitable to be implemented parallelly on multiprocessor systems. As the communication among processors is much more time-consuming than the computation, we intend to reduce the communication by making full use of the previous iteration and communication. To this end, we present a two-step modulus-based synchronous multisplitting iteration method and the corresponding symmetric modulus-based multisplitting relaxation methods, which consist of two sweeps at each iteration step. The convergence theorems are established when the system matrix is an H_+-matrix, which improve the existing convergence theory. Numerical results show that the symmetric modulus-based multisplitting relaxation methods are effective to reduce the communication among processors and improve the computing time in actual implementation.

A system of generalized Sylvester quaternion matrix equations and its applications

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Abstract

Let $\mathbb{H}^{m\times n}$ be the set of all $m \times n$ matrices over the real quaternion algebra. We call that $A \in \mathbb{H}^{n\times n}$ is η-Hermitian if $A = -\eta A^{*}\eta, \eta \in \{i, j, k\}$, where $i, j, k$are the quaternion units. Denote $A^{\eta *} = -\eta A^{*}\eta$. In this talk, we derive some necessary and sufficient conditions for the solvability to the system of generalized Sylvester real quaternion matrix equations $A_i X_i + Y_i B_i + C_i Z D_i = E_i, (i = 1,2)$,and give an expression of the general solution to the above mentioned system. As applications, we give some solvability conditions and general solution for the generalized Sylvester real quaternion matrix equation$A_1 X + Y B_1 + C_1 Z D_1 = E_1$, where Z is required to be η-Hermitian. We also present some solvability conditions and general solution for the system of real quaternion matrix equations involving η-Hermicity $A_i X_i + (A_i X_i)^{\eta *} + B_i Y B_i^{\eta *} = C_i, (i = 1,2)$, where Y is required to be η-Hermitian. Our results include the main result of [Q.-W. Wang, Z.-H. He, Automatica 49 (2013) 2713-2719] and other well-known results as special cases.

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