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A parallel algorithm of subspace iterations and its implementation on a multiprocessor with ring architecture

A. V. KNYAZEV

Abstract – A subspace iteration method for solving partial eigenvalue problems is considered. Different algorithms realizing this method are discussed for a computer consisting of several universal processors. An efficient implementation of the method on a multiprocessor computer with ring architecture is suggested. An almost complete utilization of all processors is achieved while the data exchanges between memories of different processors are minimal.

The subspace iteration method (known also as the simultaneous iteration method, the Bauer method, etc.) is widely used. Though lately the Lanzocs method has been rapidly developed the subspace iteration method is not superseded. It is still used for computation of vibrations and stability of structures. The area of its applications is still growing, for instance, it is used for solving problems on criticality of nuclear reactors [3]. The theory of the method (for symmetric eigenvalue problems) is rather well developed [4,5,8] and for one of the algorithms there exists a standard code [9].

In connection with the increasing number of multiprocessor installations it was indicated [2] that subspace iterations evidently allow for a natural 'parallel' implementation. When considering the subject in more detail one can state a problem of choosing the architecture of a multiprocessor computer [1] to minimize the data exchanges between processors. The present paper deals with the solution of this problem.

In Section 1 the partial eigenvalue problem is formulated and the subspace iteration method is described.

Section 2 considers various algorithms implementing the method on a multiprocessor computer without taking into account the type of interprocessor communications.

In Section 3 a scheme of the simultaneous iteration method for a computer with ring architecture is suggested and it is shown that with this scheme an almost complete utilization of all the processors is achieved while the data exchanges between memories of different processors are minimal.

1. SUBSPACE ITERATIONS FOR SOLVING PARTIAL EIGENVALUE PROBLEMS

Let a symmetric positive definite real matrix $A = A^{\mathrm{T}} > 0$ be given. The eigenvectors $u_1, \ldots, u_p$ corresponding to the p largest eigenvalues $\lambda_1 > \ldots > \lambda_p$ of the matrix A can be computed using the subspace iterations

$$U^{n+1} = AU^n, \qquad \dim U^n = p, \qquad n = 0, 1, \ldots \tag{1.1}$$

starting from a given (and almost arbitrary) initial guess U^0. As is known [2,4,5] the subspaces U^n converge

$$U^n \to U = \operatorname{span}\{u_1, \ldots u_p\}, \qquad n \to \infty \tag{1.2}$$

Numerical Analysis Of Eigenvalue Algorithms Based On Subspace Iterations

P.-A. Absil,R. Mahony,Rodolphe Sepulchre

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Numerical Analysis of Eigenvalue Algorithms Based on Subspace Iterations Paul Smit,1997 *Numerical Analysis: Historical Developments in the 20th Century* C. Brezinski,L. Wuytack,2012-12-02 Numerical analysis has witnessed many significant developments in the 20th century This book brings together 16 papers dealing with historical developments survey papers and papers on recent trends in selected areas of numerical analysis such as approximation and interpolation solution of linear systems and eigenvalue problems iterative methods quadrature rules solution of ordinary partial and integral equations The papers are reprinted from the 7 volume project of the Journal of Computational and Applied Mathematics on homepage sac cam na2000 index htmlNumerical Analysis 2000 An introductory survey paper deals with the history of the first courses on numerical analysis in several countries and with the landmarks in the development of important algorithms and concepts in the field *Optimization Algorithms on Matrix Manifolds* P.-A. Absil,R. Mahony,Rodolphe Sepulchre,2009-04-11 Many problems in the sciences and engineering can be rephrased as optimization problems on matrix search spaces endowed with a so called manifold structure This book shows how to exploit the special structure of such problems to develop efficient numerical algorithms It places careful emphasis on both the numerical formulation of the algorithm and its differential geometric abstraction illustrating how good algorithms draw equally from the insights of differential geometry optimization and numerical analysis Two more theoretical chapters provide readers with the background in differential geometry necessary to algorithmic development In the other chapters several well known optimization methods such as steepest descent and conjugate gradients are generalized to abstract manifolds The book provides a generic development of each of these methods building upon the material of the geometric chapters It then guides readers through the calculations that turn these geometrically formulated methods into concrete numerical algorithms The state of the art algorithms given as examples are competitive with the best existing algorithms for a selection of eigenspace problems in numerical linear algebra Optimization Algorithms on Matrix Manifolds offers techniques with broad applications in linear algebra signal processing data mining computer vision and statistical analysis It can serve as a graduate level textbook and will be of interest to applied mathematicians engineers and computer scientists Numerical Methods for Large Eigenvalue Problems Yousef Saad,2011-01-01 This revised edition discusses numerical methods for computing eigenvalues and eigenvectors of large sparse matrices It provides an in depth view of the numerical methods that are applicable for solving matrix eigenvalue problems that arise in various engineering and scientific applications Each chapter was updated by shortening or deleting outdated topics adding topics of more recent interest and adapting the Notes and References section Significant changes have been made to Chapters 6 through 8 which describe algorithms and their implementations and now include topics such as the implicit restart techniques the Jacobi Davidson method and automatic multilevel substructuring **Numerical Mathematics And Advanced Applications: 3rd European Conf, Jul 99,**

Finland Pekka Neittaanmaki,Pasi Tarvainen,Timo Tiihonen,2000-09-05 This volume contains major lectures given at ENUMATH 99 the 3rd European Conference on Numerical Mathematics and Advanced Applications The ENUMATH conferences were established in 1995 to provide a forum for discussing current topics in numerical mathematics They convene leading experts and young scientists with special emphasis on contributions from Europe Recent results and new trends are discussed in the analysis of numerical algorithms as well as their application to challenging scientific and industrial problems The topics of ENUMATH 99 included finite element methods a posteriori error control and adaptive mesh design non matching grids least squares methods for partial differential equations boundary element methods and optimization in partial differential equations Apart from theoretical aspects a major part of the conference was devoted to numerical methods in interdisciplinary applications such as problems in computational fluid electrodynamics telecommunications software as well as visualization Eigenvalue Problems in Power Systems Federico Milano,Ioannis Dassios,Muyang Liu,Georgios Tzounas,2020-12-22 The book provides a comprehensive taxonomy of non symmetrical eigenvalues problems as applied to power systems The book bases all formulations on mathematical concept of matrix pencils MPs and considers both regular and singular MPs for the eigenvalue problems Each eigenvalue problem is illustrated with a variety of examples based on electrical circuits and or power system models and controllers and related data are provided in the appendices of the book Numerical methods for the solution of all considered eigenvalue problems are discussed The focus is on large scale problems and hence attention is dedicated to the performance and scalability of the methods The target of the book are researchers and graduated students in Electrical Computer Science Engineering both taught and research Master programmes as well as PhD programmes and it explains eigenvalue problems applied into electrical power systems explains numerical examples on applying the mathematical methods into studying small signal stability problems of realistic and large electrical power systems includes detailed and in depth analysis including non linear and other advanced aspects provides theoretical understanding and advanced numerical techniques essential for secure operation of power systems provides a comprehensive set of illustrative examples that support theoretical discussions **Finite Element Methods for Eigenvalue Problems** Jiguang Sun,Aihui Zhou,2016-08-19 This book covers finite element methods for several typical eigenvalues that arise from science and engineering Both theory and implementation are covered in depth at the graduate level The background for typical eigenvalue problems is included along with functional analysis tools finite element discretization methods convergence analysis techniques for matrix evaluation problems and computer implementation The book also presents new methods such as the discontinuous Galerkin method and new problems such as the transmission eigenvalue problem *Applied Linear Algebra* Mr. Rohit Manglik,2024-07-15 EduGorilla Publication is a trusted name in the education sector committed to empowering learners with high quality study materials and resources Specializing in competitive exams and academic support EduGorilla provides comprehensive and well structured content tailored to meet

the needs of students across various streams and levels *Spectra and Pseudospectra* Lloyd N. Trefethen,Mark Embree,2020-05-05 Pure and applied mathematicians physicists scientists and engineers use matrices and operators and their eigenvalues in quantum mechanics fluid mechanics structural analysis acoustics ecology numerical analysis and many other areas However in some applications the usual analysis based on eigenvalues fails For example eigenvalues are often ineffective for analyzing dynamical systems such as fluid flow Markov chains ecological models and matrix iterations That s where this book comes in This is the authoritative work on nonnormal matrices and operators written by the authorities who made them famous Each of the sixty sections is written as a self contained essay Each document is a lavishly illustrated introductory survey of its topic complete with beautiful numerical experiments and all the right references The breadth of included topics and the numerous applications that provide links between fields will make this an essential reference in mathematics and related sciences **Nuclear Science Abstracts** ,1974 *Optimization in Solving Elliptic Problems* Eugene G. D'yakonov,2018-05-04 Optimization in Solving Elliptic Problems focuses on one of the most interesting and challenging problems of computational mathematics the optimization of numerical algorithms for solving elliptic problems It presents detailed discussions of how asymptotically optimal algorithms may be applied to elliptic problems to obtain numerical solutions meeting certain specified requirements Beginning with an outline of the fundamental principles of numerical methods this book describes how to construct special modifications of classical finite element methods such that for the arising grid systems asymptotically optimal iterative methods can be applied Optimization in Solving Elliptic Problems describes the construction of computational algorithms resulting in the required accuracy of a solution and having a pre determined computational complexity Construction of asymptotically optimal algorithms is demonstrated for multi dimensional elliptic boundary value problems under general conditions In addition algorithms are developed for eigenvalue problems and Navier Stokes problems The development of these algorithms is based on detailed discussions of topics that include accuracy estimates of projective and difference methods topologically equivalent grids and triangulations general theorems on convergence of iterative methods mixed finite element methods for Stokes type problems methods of solving fourth order problems and methods for solving classical elasticity problems Furthermore the text provides methods for managing basic iterative methods such as domain decomposition and multigrid methods These methods clearly developed and explained in the text may be used to develop algorithms for solving applied elliptic problems The mathematics necessary to understand the development of such algorithms is provided in the introductory material within the text and common specifications of algorithms that have been developed for typical problems in mathema **Matrix Computations** Gene H. Golub,Charles F. Van Loan,1996-10-15 Revised and updated the third edition of Golub and Van Loan s classic text in computer science provides essential information about the mathematical background and algorithmic skills required for the production of numerical software This new edition includes thoroughly revised chapters on matrix multiplication problems

and parallel matrix computations expanded treatment of CS decomposition an updated overview of floating point arithmetic a more accurate rendition of the modified Gram Schmidt process and new material devoted to GMRES QMR and other methods designed to handle the sparse unsymmetric linear system problem **Multigrid Finite Element Methods for Electromagnetic Field Modeling** Yu Zhu,Andreas C. Cangellaris,2006-02-17 This is the first comprehensive monograph that features state of the art multigrid methods for enhancing the modeling versatility numerical robustness and computational efficiency of one of the most popular classes of numerical electromagnetic field modeling methods the method of finite elements The focus of the publication is the development of robust preconditioners for the iterative solution of electromagnetic field boundary value problems BVPs discretized by means of finite methods Specifically the authors set forth their own successful attempts to utilize concepts from multigrid and multilevel methods for the effective preconditioning of matrices resulting from the approximation of electromagnetic BVPs using finite methods Following the authors careful explanations and step by step instruction readers can duplicate the authors results and take advantage of today s state of the art multigrid multilevel preconditioners for finite element based iterative electromagnetic field solvers Among the highlights of coverage are Application of multigrid multilevel and hybrid multigrid multilevel preconditioners to electromagnetic scattering and radiation problems Broadband robust numerical modeling of passive microwave components and circuits Robust finite element based modal analysis of electromagnetic waveguides and cavities Application of Krylov subspace based methodologies for reduced order macromodeling of electromagnetic devices and systems Finite element modeling of electromagnetic waves in periodic structures The authors provide more than thirty detailed algorithms alongside pseudo codes to assist readers with practical computer implementation In addition each chapter includes an applications section with helpful numerical examples that validate the authors methodologies and demonstrate their computational efficiency and robustness This groundbreaking book with its coverage of an exciting new enabling computer aided design technology is an essential reference for computer programmers designers and engineers as well as graduate students in engineering and applied physics **Modern Algorithms for Large Sparse Eigenvalue Problems** Arnd Meyer,1987-12-31 No detailed description available for Modern Algorithms for Large Sparse Eigenvalue Problems **Scientific and Technical Aerospace Reports** ,1995-05 *Solution of Superlarge Problems in Computational Mechanics* James H. Kane,2012-12-06 There is a need to solve problems in solid and fluid mechanics that currently exceed the resources of current and foreseeable supercomputers The issue revolves around the number of degrees of freedom of simultaneous equations that one needs to accurately describe the problem and the computer storage and speed limitations which prohibit such solutions The goals of tHis symposium were to explore some of the latest work being done in both industry and academia to solve such extremely large problems and to provide a forum for the discussion and prognostication of necessary future direc tions of both man and machine As evidenced in this proceedings we believe these goals were met Contained in this volume are discussions of

iterative solvers and their application to a variety of problems e g structures fluid dynamics and structural acoustics iterative dynamic substructuring and its use in structural acoustics the use of the boundary element method both alone and in conjunction with the finite element method the application of finite difference methods to problems of incompressible turbulent flow and algorithms amenable to concurrent computations and their applications Furthermore discussions of existing computational shortcomings from the big picture point of view are presented that include recommendations for future work *Krylov Methods for Nonsymmetric Linear Systems* Gérard Meurant,Jurjen Duintjer Tebbens,2020-10-02 This book aims to give an encyclopedic overview of the state of the art of Krylov subspace iterative methods for solving nonsymmetric systems of algebraic linear equations and to study their mathematical properties Solving systems of algebraic linear equations is among the most frequent problems in scientific computing it is used in many disciplines such as physics engineering chemistry biology and several others Krylov methods have progressively emerged as the iterative methods with the highest efficiency while being very robust for solving large linear systems they may be expected to remain so independent of progress in modern computer related fields such as parallel and high performance computing The mathematical properties of the methods are described and analyzed along with their behavior in finite precision arithmetic A number of numerical examples demonstrate the properties and the behavior of the described methods Also considered are the methods implementations and coding as Matlab like functions Methods which became popular recently are considered in the general framework of Q OR quasi orthogonal Q MR quasi minimum residual methods This book can be useful for both practitioners and for readers who are more interested in theory Together with a review of the state of the art it presents a number of recent theoretical results of the authors some of them unpublished as well as a few original algorithms Some of the derived formulas might be useful for the design of possible new methods or for future analysis For the more applied user the book gives an up to date overview of the majority of the available Krylov methods for nonsymmetric linear systems including well known convergence properties and as we said above template codes that can serve as the base for more individualized and elaborate implementations **Lanczos Algorithms for Large Symmetric Eigenvalue Computations** Jane K. Cullum,Ralph A. Willoughby,2002-09-01 First published in 1985 this book presents background material descriptions and supporting theory relating to practical numerical algorithms for the solution of huge eigenvalue problems This book deals with symmetric problems However in this book symmetric also encompasses numerical procedures for computing singular values and vectors of real rectangular matrices and numerical procedures for computing eigenelements of nondefective complex symmetric matrices Although preserving orthogonality has been the golden rule in linear algebra most of the algorithms in this book conform to that rule only locally resulting in markedly reduced memory requirements Additionally most of the algorithms discussed separate the eigenvalue singular value computations from the corresponding eigenvector singular vector computations This separation prevents losses in accuracy that can occur in methods which in

order to be able to compute further into the spectrum use successive implicit deflation by computed eigenvector or singular vector approximations **Stochastic Analysis of Offshore Steel Structures** Halil Karadeniz,2012-08-01 Stochastic Analysis of Offshore Steel Structures provides a clear and detailed guide to advanced analysis methods of fixed offshore steel structures using 3D beam finite elements under random wave and earthquake loadings Advanced and up to date research results are coupled with modern analysis methods and essential theoretical information to consider optimal solutions to structural issues As these methods require and use knowledge of different subject matters a general introduction to the key areas is provided This is followed by in depth explanations supported by design examples relevant calculations and supplementary material containing related computer programmers By combining this theoretical and practical approach Stochastic Analysis of Offshore Steel Structures cover a range of key concepts in detail including The basic principles of standard 3D beam finite elements and special connections Wave loading from hydrodynamics to the calculation of wave loading on structural members Stochastic response calculations with corresponding solution algorithms including earthquakes and Fatigue damage reliability calculation and reliability based design optimization The broad and detailed coverage makes this a solid reference for research oriented studies and practical sophisticated design methods Students researchers insuring bodies and practical designer offices can turn to Stochastic Analysis of Offshore Steel Structures to broaden their theoretical understanding and develop their practical designs and applications of 3D finite analysis in fixed offshore steel structures **Parallel Processing and Applied Mathematics** Roman Wyrzykowski,Jack Dongarra,Konrad Karczewski,Jerzy Waśniewski,2014-05-05 This two volume set LNCS 8384 and 8385 constitutes the refereed proceedings of the 10th International Conference of Parallel Processing and Applied Mathematics PPAM 2013 held in Warsaw Poland in September 2013 The 143 revised full papers presented in both volumes were carefully reviewed and selected from numerous submissions The papers cover important fields of parallel distributed cloud computing and applied mathematics such as numerical algorithms and parallel scientific computing parallel non numerical algorithms tools and environments for parallel distributed cloud computing applications of parallel computing applied mathematics evolutionary computing and metaheuristics

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