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

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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 Though lately the Lanzocs method has been rapidly developed the subspace iteration method is not superseded.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

Eugene G. D'yakonov

Numerical Analysis Of Eigenvalue Algorithms Based On Subspace Iterations:

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 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 *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 **Multigrid Finite Element Methods for Electromagnetic Field Modeling** Yu Zhu,Andreas C. Cangellaris,2006-02-03 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 *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 **Matrix Computations and Semiseparable Matrices** Raf Vandebril,Marc Van Barel,Nicola Mastronardi,2008-12-15 The general properties and mathematical structures of semiseparable matrices were presented in volume 1 of Matrix Computations and Semiseparable Matrices In volume 2 Raf Vandebril Marc Van Barel and Nicola Mastronardi discuss the theory of structured eigenvalue and singular value computations for semiseparable matrices These matrices have hidden properties that allow the development of efficient methods and algorithms to accurately compute the matrix eigenvalues This thorough analysis of semiseparable matrices explains their theoretical underpinnings and contains a wealth of information on implementing them in practice Many of the routines featured are coded in Matlab and can be downloaded from the Web for further exploration Proceedings of the 16th International Modal Analysis Conference Society for Experimental Mechanics (U.S.),1998 **Numerical Analysis and**

Its Applications Svetozar D. Margenov,Lubin Georgiev Vulkov,Jerzy Wasniewski,2009-02-07 This book constitutes the thoroughly refereed post conference proceedings of the 4th International Conference on Numerical Analysis and Its Applications NAA 2008 held in Lozenetz Bulgaria in June 2008 The 61 revised full papers presented together with 13 invited papers were carefully selected during two rounds of reviewing and improvement The papers address all current aspects of numerical analysis and discuss a wide range of problems concerning recent achievements in physics chemistry engineering and economics A special focus is given to numerical approximation and computational geometry numerical linear algebra and numerical solution of transcendental equations numerical methods for differential equations numerical modeling and high performance scientific computing Engineering Geology and the Environment G.C. Koukis,P.G. Marinos,G.C. Stourna,G.C. Tsiambaos,1997-01-01 Composed of the proceedings of a symposium on engineering geology and the environment held in Athens in June 1997 this work provides a survey of trends in engineering geology and an interdisciplinary collaboration with hydrogeology geochemistry geomorphology and soil and rock mechanics *Discrete Element Analysis Methods of Generic Differential Quadratures* Chang-New Chen,2008-09-12 Following the advance in computer technology the numerical technique has made signi cant progress in the past decades Among the major techniques available for numerically analyzing continuum mechanics problems nite d ference method is most early developed It is di cult to deal with cont uum mechanics problems showing complex curvilinear geometries by using this method The other method that can consistently discretize continuum mechanics problems showing arbitrarily complex geometries is nite element method In addition boundary element method is also a useful numerical method In the past decade the di erential quadrature and generic di erential quadraturesbaseddiscreteelementanalysismethodshavebeendevelopedand usedto solve various continuum mechanics problems These methods have the same advantage as nite element method of consistently discretizing cont uum mechanics problems having arbitrarily complex geometries This book includes my research results obtained in developing the related novel discrete element analysis methods using both of the extended di erential quadrature based spacial and temporal elements It is attempted to introduce the dev oped numerical techniques as applied to the solution of various continuum mechanics problems systematically **Energy Research Abstracts** ,1993 The Shock and Vibration Digest ,1991 *NASA Tech Briefs* ,1992 **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 Pole-Swapping Algorithms for the Eigenvalue Problem Daan Camps,Thomas Mach,Raf Vandebril,David S. Watkins,2025-05-01 Matrix eigenvalue problems arise in a wide variety of fields in science and engineering so it is important to have reliable and efficient methods for solving them Of the methods devised bulge chasing algorithms such as the famous QR and QZ algorithms are the most important This book focuses on pole swapping algorithms a new class of methods that are generalizations of bulge chasing algorithms and a bit faster and more accurate owing to their inherent flexibility The pole swapping theory developed by the authors sheds light on the functioning of the whole class of algorithms including QR and QZ Pole Swapping Algorithms for the Eigenvalue Problem is the only book on the topic It describes the state of the art on eigenvalue methods and provides an improved understanding and explanation of why these important algorithms work This book is for researchers and students in the field of matrix computations software developers and anyone in academia or industry who needs to understand how to solve eigenvalue problems which are ubiquitous in science and engineering **Applied Mechanics Reviews** ,1975 **A Journey through the History of Numerical Linear Algebra** Claude Brezinski,Gérard Meurant,Michela Redivo-Zaglia,2022-12-06 This expansive volume describes the history of numerical methods proposed for solving linear algebra problems from antiquity to the present day The authors focus on methods for linear systems of equations and eigenvalue problems and describe the interplay between numerical methods and the computing tools available at the time The second part of the book consists of 78 biographies of important contributors to the field A Journey through the History of Numerical Linear Algebra will be of special interest to applied mathematicians especially researchers in numerical linear algebra people involved in scientific computing and historians of mathematics

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