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 Though lately the Lanzocs method has been rapidly developed the subspace iteration method is not superseded.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 $A = A^T > 0$ 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

$$U^{n+1} = AU^n, \quad \dim U^n = p, \quad n = 0, 1, \ldots \quad (1.1)$$

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

$$U^n \to U = \operatorname{span}\{u_1, \ldots, u_p\}, \quad n \to \infty \quad (1.2)$$

Numerical Analysis Of Eigenvalue Algorithms Based On Subspace Iterations

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

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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 **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   **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

   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   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

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 *The Princeton Companion to Mathematics* Timothy Gowers,June Barrow-Green,Imre Leader,2008-09-28 A comprehensive guide to mathematics with over 200 entries divided thematically **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 The Shock and Vibration Digest ,1991 *Energy Research Abstracts* ,1993 *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 **Domain Decomposition Methods in Science and Engineering XVI** Olof Widlund,David E. Keyes,2007-07-30 Domain decomposition is an active interdisciplinary research area concerned with the development analysis and implementation of coupling and decoupling strategies in mathematical and computational models of natural and engineered systems Since the advent of hierarchical distributed memory computers it has been motivated by considerations of concurrency and locality in a wide variety of large scale problems continuous and discrete Historically it emerged from the analysis of partial differential equations beginning with the work of Schwarz in 1870 The present volume sets forth new contributions in areas of numerical analysis computer science scientific and industrial applications and software development 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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