

# A New Subspace Iteration Algorithm for Solving Generalized Eigenvalue Problems

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## Abstract

It is needed to solve generalized eigenvalue problems (GEP) in many applications, such as the numerical simulation of vibration analysis, quantum mechanics, electronic structure, etc. The subspace iteration is a kind of widely used algorithm to solve eigenvalue problems. To solve the generalized eigenvalue problem, one kind of subspace iteration method, Chebyshev-Davidson algorithm, is proposed recently. In Chebyshev-Davidson algorithm, the Chebyshev polynomial filter technique is incorporated in the subspace iteration [15]. In this paper, based on Chebyshev-Davidson algorithm, a new subspace iteration algorithm is constructed. In the new algorithm, the Chebyshev filter and inexact Rayleigh quotient iteration techniques are combined together to enlarge the subspace in the iteration. Numerical results of a vibration analysis problem show that the number of iteration and computing time of the proposed algorithm is much less than that of the Chebyshev-Davidson algorithm and some typical GEP solution algorithms. Furthermore, the new algorithm is more stable and reliable than the Chebyshev-Davidson algorithm in the numerical results.

**Keywords:** Generalized eigenvalue problem, Davidson algorithm, Chebyshev filter, Rayleigh quotient iteration, Acceleration

**Mathematics Subject Classification (2010):** 65F15, 65N25, 65H17

## 1 Introduction

Consider the following symmetric generalized eigenvalue problem (GEP)

$$\mathbf{A}\mathbf{x} = \lambda\mathbf{B}\mathbf{x}, \quad \text{with} \quad \|\mathbf{x}\|_{\mathbf{B}} = 1, \quad (1)$$

where  $\mathbf{A} \in \mathbb{R}^{N \times N}$  and  $\mathbf{B} \in \mathbb{R}^{N \times N}$  are large, sparse and symmetric matrices with  $\mathbf{B}$  being positive definite,  $\|\mathbf{x}\|_{\mathbf{B}}$  is the  $\mathbf{B}$ -norm of the vector  $\mathbf{x}$  which will be defined later. In many applications, it is needed to solve GEP (1), such as the vibration analysis, quantum mechanics, electronic structure calculations, etc. In (1), the matrix  $\mathbf{A}$  is the stiffness matrix, and  $\mathbf{B}$  represents the mass matrix.  $\lambda$  is an eigenvalue of the matrix pencil  $(\mathbf{A}, \mathbf{B})$ , and the nonzero vector  $\mathbf{x}$  is the corresponding eigenvector.  $(\lambda, \mathbf{x})$  is called an eigenpair of GEP. If  $\mathbf{B}$  is a diagonal matrix, then the generalized eigenvalue problem reduces to the standard eigenvalue problem (SEP). Usually, the smallest eigenvalues and the corresponding eigenvectors play more important role in real applications than the largest ones. We are interested in the computation for the smallest eigenvalues and corresponding eigenvectors of a large sparse eigenvalue problem in this paper.

By now, many algorithms have been developed for solving eigenvalue problems [6, 25, 29]. These algorithms can be divided roughly into two classes: the direct methods and iterative methods. For large

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# Numerical Analysis Of Eigenvalue Algorithms Based On Subspace Iterations

**Yousef Saad**



## **Numerical Analysis Of Eigenvalue Algorithms Based On Subspace Iterations:**

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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**

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**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 Proceedings of the 16th International Modal Analysis Conference Society for Experimental Mechanics (U.S.), 1998 **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

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Sameh, 2015-07-25 This book is primarily intended as a research monograph that could also be used in graduate courses for the design of parallel algorithms in matrix computations It assumes general but not extensive knowledge of numerical linear algebra parallel architectures and parallel programming paradigms The book consists of four parts I Basics II Dense and Special Matrix Computations III Sparse Matrix Computations and IV Matrix functions and characteristics Part I deals with parallel programming paradigms and fundamental kernels including reordering schemes for sparse matrices Part II is devoted to dense matrix computations such as parallel algorithms for solving linear systems linear least squares the symmetric algebraic eigenvalue problem and the singular value decomposition It also deals with the development of parallel algorithms for special linear systems such as banded Vandermonde Toeplitz and block Toeplitz systems Part III addresses sparse matrix computations a the development of parallel iterative linear system solvers with emphasis on scalable preconditioners b parallel schemes for obtaining a few of the extreme eigenpairs or those contained in a given interval in the spectrum of a standard or generalized symmetric eigenvalue problem and c parallel methods for computing a few of the extreme singular triplets Part IV focuses on the development of parallel algorithms for matrix functions and special characteristics such as the matrix pseudospectrum and the determinant The book also reviews the theoretical and practical background necessary when designing these algorithms and includes an extensive bibliography that will be useful to researchers and students alike The book brings together many existing algorithms for the fundamental matrix computations that have a proven track record of efficient implementation in terms of data locality and data transfer on state of the art systems as well as several algorithms that are presented for the first time focusing on the opportunities for parallelism and algorithm robustness      *The Shock and Vibration Digest* , 1991      Energy Research Abstracts , 1993      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 significant progress in the past decades Among the major techniques available for numerically analyzing continuum mechanics problems finite difference method is most early developed It is difficult to deal

with continuum 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 finite element method In addition boundary element method is also a useful numerical method In the past decade the differential quadrature and generic differential quadrature based discrete element analysis methods have been developed and used to solve various continuum mechanics problems These methods have the same advantage as finite element method of consistently discretizing continuum 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 differential quadrature based spatial and temporal elements It is attempted to introduce the developed numerical techniques as applied to the solution of various continuum mechanics problems systematically **NASA Tech Briefs** ,1992 **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 **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 **Applied Mechanics Reviews** ,1975

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