Final Program

Second SIAM Conference on Applied Linear Algebra

April 29–May 2, 1985
Mission Valley Inn
Raleigh, North Carolina

- Core Linear Algebra
- Industrial Applications
- Computer Demonstrations
- Numerical Methods
- Parallelism
- Matrix Methods in Partial Differential Equations
- Perturbation Theory of Operators
- Matrix Polynomials
- Applications of Linear Algebra in Discrete Mathematics, Statistics, Population Biology, Engineering, and Control and Systems Theory
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MEETING HIGHLIGHTS

INVITED PRESENTATIONS

Monday, April 29, 9:30 AM
Invited Presentation 1
PERTURBATION THEORY OF OPERATORS
In numerical analysis and in physics it is often necessary to estimate the difference between corresponding eigenvalues and corresponding eigenvectors of two operators, in terms of the norm of their difference. In recent years our knowledge has grown markedly; the class of operators admitted has been extended, hypotheses have been weakened in other respects, and constants have been improved. In this presentation the focus will be on exact perturbation theory, where explicit inequalities are sought (as a vs asymptotic perturbation theory, which concerns rate of convergence to zero).
Chandler Davis
Department of Mathematics
University of Toronto
Toronto, Ontario, Canada

Monday, April 29, 11:00 AM
Invited Presentation 2
MATRIX POLYNOMIALS
Problems concerning matrix polynomials frequently arise in systems theory and applied mathematics, and many of these problems are clarified by the application of spectral theory. The speaker will focus on basic ideas of spectral theory as they apply to these problems—canonical forms, least common multiples and greatest common divisors, factorization problems, inverse spectral problems, and the special structure and problems associated with hermitian matrix polynomials.
Peter Lancaster
Department of Mathematics and Statistics
University of Calgary
Calgary, Alberta, Canada

Monday, April 29, 3:00 PM
Invited Presentation 3
MATRIX METHODS IN THE NUMERICAL SOLUTION OF PARTIAL DIFFERENTIAL EQUATIONS
The numerical solution of partial differential equations leads to the study of the eigenvalues of families of matrices. These matrices may arise in boundary value problems and in evolution equations. In both cases the “stability” and “rapidity of convergence” of the numerical methods are governed by the asymptotic behavior of their spectra. In some problems it is sufficient to estimate the spectral radius, for others a more detailed knowledge of the distribution of the eigenvalues is required. In this presentation the speaker will describe how these matrix problems arise and how results of matrix theory can be applied.
Seymour V. Parter
Department of Mathematics and Mathematics Research Center
University of Wisconsin—Madison
Madison, WI

Tuesday, April 30, 11:00 AM
Invited Presentation 4
NUMERICAL AND COMPUTATIONAL METHODS IN LINEAR ALGEBRA
One problem of fundamental importance in control theory is to compute a matrix function f(A) in an effective and stable manner. In carrying out the computation, it is necessary to determine invariant subspaces of dimensions as low as possible consistent with their being relatively insensitive to perturbations in A. The grouping of the eigenvalues for this purpose involves very delicate considerations which are closely related to those involved in determining neighboring defective matrices. The speaker will cover both of these numerical problems and highlight their relationships.
James H. Wilkinson
National Physical Laboratory
United Kingdom

Tuesday, April 30, 3:00 PM
Invited Presentation 5
WHY I AM CALLING A TORCH FOR MATRIX THEORY
It is planned to discuss the manner in which matrices as a subject in itself came to the speaker, not only attached to groups, or used in physics or statistics. A few instances are: the Gersgorin theorem that came to her from algebraic number theory, the Stein theorem and hence the Lyapunov theorem that came from topological algebras. Suddenly numerical analysis and hence applied mathematics were swarming with non-trivial applications of matrices. Some strange circumstances brought her to the Hahn theorem concerning commutators of matrices and others to the application of matrices in algebraic number theory. There, she was able to use the eigenvectors of matrices as bases for ideals.
Olga Taussky-Todd
Department of Mathematics
California Institute of Technology
Pasadena, CA

FUNDING SOURCES
SIAM is conducting this meeting with the partial support of the Air Force Office of Scientific Research, the Army Research Office, the Department of Energy and the National Science Foundation.

Cover photograph graciously provided by the Information Services Department of North Carolina State University and the Raleigh Convention and Visitors Bureau.
MINISYMPOSIA

Tuesday, April 30, 4:00 PM
MINISYMPOSIUM 1
EXACT COMPUTATION IN LINEAR ALGEBRA

We will survey the activity that has become known as “Computer Algebra.” The capabilities of existing computer algebra systems for computation with matrices over the integers, rational numbers, polynomials and other domains will be discussed and demonstrated. The role of a computer algebra package as a research tool, as a teaching tool, and as a source of research problems in linear algebra will be shown.

CHAIRMAN AND ORGANIZER
B. David Saunders
Computer Science Department
Rensselaer Polytechnic Institute, Troy NY
Currently visiting:
Computer and Information Sciences Department
University of Delaware, Newark, DE

A Symbolic Computation Package for
*Semirings in REDUCE
S. Kamal Abdali
Computer Research Laboratory
Tektronix, Inc., Beaverton, OR

Exact Linear Algebra with a PC
William Squire
Department of Mechanical and Aerospace Engineering
West Virginia University, Morgantown, WV

MAPLE: A New Computer Algebra System
Bruce W. Char
Computer Science Department
University of Waterloo, Waterloo Ontario, Canada

Fast Computation of Invariant Factors:
Probabilistic and Modular Methods
Erich L. Kaltofen
Mukkai S. Krishnamoorthy
Department of Computer Science
Rensselaer Polytechnic Institute, Troy, NY
and
B. David Saunders
Demonstrations of computer algebra systems such as MuMath, MAPLE and REDUCE.

Wednesday, May 1, 4:00 PM
MINISYMPOSIUM 2
INDUSTRIAL APPLICATIONS OF LINEAR ALGEBRA

Matrix computation is at the heart of many mathematical modeling problems. In this session we will examine some of these matrix problems for modeling in electronics, geology, and structural analysis. The speakers will review the physical motivation, matrix characteristics, and computational approaches to these diverse problems. Though the matrix problems have similar characteristics (generally large and sparse) they are also very different in other ways (e.g., sparsity pattern, numerical properties, symmetry, solution objectives) and these differences give rise to different solution approaches.

CHAIRMAN AND ORGANIZER
Al Erisman
Boeing Computer Services
Tukwila, WA

Matrix Computation in Electronics CAD Software
A. E. Ruehl
Computer Science Department
F. Odeh
Mathematical Science Department
IBM - T. J. Watson Research Center
Yorktown Heights, NY

The Linear Algebra of Seismic Modeling
R. P. Bording
K. R. Kelly
K. -J. Marfurt
Amoco Production Company
Research Center
Tulsa, OK

Symmetric Generalized Eigenproblems in Structural Engineering
Roger G. Grimes
John G. Lewis
Horst D. Simon
Applied Mathematics Department
Boeing Computer Services Co.
Tukwila, WA

Louis Kozlowski
The MacNeal Schwendler Corporation
Los Angeles, CA

David S. Scott
Department of Computer Science
The University of Texas
Austin, TX

Some Sparse Matrix Problems in Structural Analysis
Michael T. Heath
Oak Ridge National Laboratory
Oak Ridge, TN

COMPUTER DEMONSTRATIONS

Garry Helzer of the Mathematics Department of the University of Maryland will demonstrate the computer language APL, and its use in performing matrix calculations. Cleve Moler of The MathWorks will demonstrate PC MATLAB, a new version of the “Matrix Laboratory.” There will be computer demonstrations in connection with the mini-symposium on Exact Computations in Linear Algebra, organized by B. David Saunders of the Computer Science Department of Rensselaer Polytechnic Institute.

SPECIAL FUNCTIONS

Welcoming Reception
Sunday, April 28, 8:00 PM
Location to be announced at Registration Desk
Wine and beer courtesy of North Carolina State University

Cocktails and Hors d’ Oeuvres
Monday, April 29, 6:30 PM
Mission Valley Inn, Poolside
Open Bar: $10.00

Wine and Cheese Party
Tuesday, April 30, 6:30 PM
North Carolina State University
Wine and cheese courtesy of North Carolina State University

Banquet
Wednesday, May 1, 7:00 PM
North Carolina State University
BANQUET SPEAKER:
William M. Kahan, University of California, Berkeley
Dinner and Wine: $10.00
### TIMETABLES

#### INVITED PRESENTATIONS, MINISYMPOSIA AND CONTRIBUTED PAPERS

**MONDAY, APRIL 29**

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**TUESDAY, APRIL 30**

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**Codes:**
- I/S = Invited Speaker
- C/P = Contributed Paper
- * = Indicates the presenter of the paper when more than one author is given.
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<td>P. J. Eberlein</td>
<td>R. Byers</td>
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<td>D. Bini*</td>
<td>G. A. Hewer*</td>
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<td>V. Pan</td>
<td>C. Kenney</td>
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<td>4:00</td>
<td>A. Buehli*</td>
<td>B. W. Peetson</td>
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<td>L. Kaufman</td>
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<td>F. Odeh</td>
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<td>R. P. Bording</td>
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<td>K. R. Kelly</td>
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<td>K. J. Harfurt*</td>
<td>E. D. Saunders*</td>
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<td>R. G. Grimes</td>
<td>M. McAllister</td>
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<td>J. G. Lewis*</td>
<td>D. Summers</td>
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<td>D. S. Scott</td>
<td>P. M. Gibson*</td>
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<td>M. T. Heath</td>
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Codes: I/S = Invited Speaker
M/S = Minisymposium
C/P = Contributed Paper
* = Indicates the presenter of the paper when more than one author is given.
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<tr>
<th>TIME</th>
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<th>C/P 24 (Hinsdale Rm.)</th>
<th>C/P 25 (Haywood Rm.)</th>
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<td>D. W. Robinson</td>
<td>J-S. Fang</td>
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<td>R. Merris</td>
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<td>L. D. Beasley</td>
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<td>D. Carlson*</td>
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<td>J. E. Cohen</td>
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<tr>
<th>TIME</th>
<th>C/P 26 (Cameron Rm.)</th>
<th>C/P 27 (Hinsdale Rm.)</th>
<th>C/P 28 (Haywood Rm.)</th>
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<td>1:00</td>
<td>E. Moore</td>
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<td>D. Pierce*</td>
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<td>K. P. S. Bhaskara Rao</td>
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<td>J. R. Weaver*</td>
<td>W. Squire</td>
<td>J. S. Weber</td>
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<td>E. Zmijewski*</td>
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<td>J. A. Ball</td>
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<td>D. R. Phillips</td>
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<td>V. Pan*</td>
<td>A. Paulraj*</td>
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FINAL PROGRAM

Sunday, April 28 / PM

5:00 PM
Registration Opens
Prefunction Area

8:00 PM
Welcoming Reception

10:00 PM
Registration Closes

Monday, April 29 / AM

8:00 AM
Registration Opens
Prefunction Area

9:00 AM
Cameron-Mordecai Room
Opening Remarks
Richard A. Brualdi, Department of Mathematics, University of Wisconsin-Madison; Garrett Briggs, Dean of the School of Physical and Mathematical Sciences, North Carolina State University; and Gene H. Golub, SIAM President, Department of Computer Science, Stanford University

9:30 AM
Cameron-Mordecai Room
Invited Presentation 1
Richard A. Brualdi, CHAIRMAN
Department of Mathematics
University of Wisconsin-Madison, Madison, WI

Perturbation Theory of Operators
Chandler Davis

Department of Mathematics
University of Toronto, Toronto, Ontario, Canada

10:30 AM
Coffee

11:00 AM
Cameron-Mordecai Room
Invited Presentation 2
Robert J. Plemmons, CHAIRMAN
Department of Mathematics
North Carolina State University, Raleigh, NC

Matrix Polynomials
Peter Lancaster
Department of Mathematics and Statistics
University of Calgary, Calgary, Alberta, Canada

Monday, April 29 / PM

12:00 Noon
Lunch

Monday, April 29/1:00–2:30 PM
Contributed Papers 1/Cameron Room

Parallel Matrix Computations
CHAIRMAN: Robert C. Ward, Mathematics & Research Section, Engineering Physics and Mathematics Division, Oak Ridge National Laboratory, Oak Ridge, TN

1:00
Parallel Cholesky Factorization on a Multiprocessor
Michael T. Heath, Oak Ridge National Laboratory, Oak Ridge, TN; Alan George, Associate Professor of Mathematics, University of Waterloo, Waterloo, Ontario, Canada; Joseph Liu, Department of Computer Science, York University, Downsview, Ontario, Canada

1:15
Vectorizing the Computation of Cholesky Factors, Reflection Coefficients, and Kalman Gains in Toptlz Systems
Louis L. Scharf, Electrical and Computer Engineering, University of Colorado, Boulder, CO; Cedric Demazure, Electrical Engineering, University of Rhode Island, Kingston, RI

1:30
Tors Data-Flow for Parallel Computation of Missed Matrix Problems
George A. Geist, R. E. Vanderploeg, Oak Ridge National Laboratory, Oak Ridge, TN

1:45
A Linear Time Method for Computing the Se- Decomposition
Franklin T. Luk, School of Electrical Engineering, Cornell University, Ithaca, NY; Sanghong Qiao, Center for Applied Mathematics, Cornell University, Ithaca, NY

2:00
Fast Matrix Multiplication on Square and Cubic Grids of Processors
David C. Fisher, Applied Mathematics Program, University of Maryland, College Park, MD

2:15
Efficient Parallel Algorithms for Inertia, Stability, Relativc Primeness and Lyapunov Equation
R. N. Datta and Karabi Datta, Department of Mathematical Sciences, Northern Illinois University, DeKalb, IL

Monday, April 29/1:00–2:30 PM
Contributed Papers 2/Haywood Room

M-Matrices
CHAIRMAN: Hans Schneider, Department of Mathematics, University of Wisconsin-Madison, Madison, WI

1:00
Stability of M-matrix Products
Charles R. Johnson, Department of Mathematical Sciences, Clemson University, Clemson, SC; D. D. Olesky, Department of Computer Science, University of Victoria, Victoria, B.C., Canada; P. van den Driessche, Department of Mathematics, University of Victoria, Victoria, B.C., Canada

1:15
Solving Ax = b when A is a Nonsingular M-matrix
Alan A. Adan, D. D. Olesky, Department of Computer Science, University of Victoria, Victoria, B.C., Canada

1:30
Products of Commuting M M-matrices
Hans Schneider and Jeffrey L. Stuart, Department of Mathematics, University of Wisconsin-Madison, Madison, WI

1:45
Second Order Derivatives of the Perron Vector
Emeric Deutsch, Department of Mathematics, Polytechnic Institute of New York, Brooklyn, NY; Michael Neumann, Department of Mathematics and Statistics, University of South Carolina, Columbia, SC

2:00
Incomplete Factorization of Singular M-matrices
John J. Buoni, Department of Mathematical and Computer Sciences, Youngstown State University, Youngstown, OH

2:15
Singular M-matrices
Ralph DeMarr, Department of Mathematics, University of New Mexico, Albuquerque, NM

Monday, April 29/4:00–5:00 PM
Contributed Papers 4/Cameron Room

Matrix Methods in Differential Equations I
CHAIRMAN: Richard S. Varga, Department of Mathematics, Kent State University, Kent, OH

4:00
A Parallelizable Preconditioning Algorithm for the Fast Solution of Elliptic Problems
J. H. Bramble and A. H. Schatz, Cornell University, Ithaca, NY; J. E. Pasciak, Applied Mathematics Department, Brookhaven National Laboratory, Upton, NY

4:15
Matrix Splittings for the Solution of Higher Order Boundary Value Problems
Suthirth Gupta and Jesse L. Barlow, Department of Computer Science, The Pennsylvania State University, University Park, PA

4:30
Incorporating Time-Dependent Forcing in Locally One-Dimensional Methods
Alan Genz and D. A. Swayne, Computer Science Department, Washington State University, Pullman, WA and Department of Computing and Information Science, University of Guelph, Guelph, Ontario, Canada
FINAL PROGRAM

4:45 A Spectrum Enveloping Algorithm for Solving Central Difference Approximations of Convection Diffusion Equations
Murali M. Gupta, Department of Mathematics, The George Washington University, Washington, DC

Monday, April 29 4:00–5:00 PM Contributed Papers 5/Hindsdale Room

CORE LINEAR ALGEBRA 1
CHAIRMAN: R. C. Thompson, Department of Mathematics, University of California, Santa Barbara, CA

4:00 Consistency: A Survey of Results
Roger A. Horn and Yoopyo Hong, Department of Mathematical Sciences, The Johns Hopkins University, Baltimore, MD and Department of Mathematics and Computer Science, University of Maryland, Baltimore, MD

4:15 Applications of a Canonical Form under Consistency
Yoopyo Hong and Roger A. Horn, Department of Mathematical Sciences, The Johns Hopkins University, Baltimore, MD and Department of Mathematics and Computer Science, University of Maryland, Baltimore, MD

4:30 An Analog of the Singular Value Decomposition for Orthogonal Equivalences
Dipa Choudhury and Roger A. Horn, Department of Mathematical Sciences, The Johns Hopkins University, Baltimore, MD and Department of Mathematical Sciences, Loyola College, Baltimore, MD

4:45 Spectral Factorization of Matrices
A. S. Sourour, Department of Mathematics, University of Victoria, Victoria, B.C., Canada

Monday, April 29 4:00–5:00 PM Contributed Papers 6/Hindsdale Room

MATRIX ANALYSIS 1
CHAIRMAN: B. N. Datta, Department of Mathematical Sciences, Northern Illinois University, DeKalb, IL

4:00 Least Squares Approximation with Smoothed Spline Functions
Daniel D. Warner and Kevin L. Fox, Department of Mathematical Sciences, Clemson University, Clemson, SC

4:15 Stabilizing Certain Iterative Processes
Bryan E. Cain and Elgin H. Johnston, Department of Mathematics, Iowa State University, Ames, IA

Tuesday, April 30 / AM

4:30 Stability Analysis of Interval Matrices—Another Sufficient Condition
Rama K. Yedavalli, Department of Mechanical Engineering, Stevens Institute of Technology, Hoboken, NJ

4:45 On Cubic Spine Interpolants and Postprocessing for Monotonicity Preservation
Rick Beattie, Department of Mathematics, University of Connecticut, Storrs, CT

5:00 PM Cameran Room MEETING OF THE SIAM ACTIVITY GROUP ON LINEAR ALGEBRA
Robert J. Plemmons, CHAIRMAN, Department of Mathematics, North Carolina State University, Raleigh, NC

6:30 PM Poolside Cocktails and Hors d'oeuvres

Tuesday, April 30 8:30–10:30 AM Contributed Papers 7/Cameran Room

CORE LINEAR ALGEBRA 2
CHAIRMAN: David Carlson, Department of Mathematics, San Diego State University, San Diego, CA

8:30 Quasi-Positive Definite Maps
Stephen Pierce, Department of Mathematics, University of Toronto, Toronto, Canada and Department of Mathematics, San Diego State University, San Diego, CA

8:45 More on Cone Reachability
Avi Berman, Department of Mathematics, Technion, Haifa, Israel and Michael Neumann, Department of Mathematics, University of South Carolina, Columbia, SC and Ron Stern, Department of Mathematics, Concordia University, Montreal, Canada

9:00 Inverse Problems For Means of Matrices
William N. Anderson, Jr., Department of Mathematics and Computer Science, Fairleigh Dickinson University, Teaneck, NJ; George E. Trapp, Department of Statistics and Computer Science, West Virginia University, Morgantown, WV

9:15 The Cascade Sum and Difference of Matrices
William N. Anderson, Jr., Department of Mathematics and Computer Science, Fairleigh Dickinson University, Teaneck, NJ; George E. Trapp, Department of Statistics and Computer Science, West Virginia University, Morgantown, WV

Tuesday, April 30 8:30–10:15 AM Contributed Papers 8/Hindsdale Room

PARALLEL MATRIX COMPUTATIONS 2
CHAIRMAN: B. N. Datta, Department of Mathematical Sciences, Northern Illinois University, DeKalb, IL

8:30 Parallel Nonlinear Algorithms
R. E. White, Mathematics Department, North Carolina State University, Raleigh, NC

8:45 A Vector Approach to Large Scale Configuration Interaction Calculations
Christopher Beattie, Mathematics Department, John Schug and Jimmy Vries, Chemistry Department, and Layne Watson, Computer Science Department, Virginia Polytechnic Institute and State University, Blacksburg, VA

9:00 Communication Complexity of Gaussian Elimination on Multicomputers
Yves Saad, Computer Science Department, Yale University, New Haven, CT

9:15 Parallel Matrix Algorithms for Structural Analysis
Michael W. Berry, Department of Mathematics, North Carolina State University, Raleigh, NC

Tuesday, April 30 8:30–10:30 AM Contributed Papers 9/Hindsdale Room

DISCRETE METHODS IN LINEAR ALGEBRA
CHAIRMAN: C. T. Kelly, Department of Mathematics, North Carolina State University, Raleigh, NC

8:30 Sign Nonsingularity and the Odd Cycle Property
Rick Martin, Department of Computer Sciences, University of Wisconsin, Madison, WI; Jai-yu Shao, Tongji University, Shanghai, China

8:45 L-functions and Their Inverses
John C. Maybee, Department of Mathematics, University of Colorado, Boulder, CO; Gerry M. Wiener, Department of Mathematics, University of Colorado at Denver, Denver, CO

9:00 Formulae for det A Corresponding to Zero Patterns of A
Wayne W. Barrett, Department of Mathematics, Brigham Young University, Provo, UT; Chares R. Johnson, Department of Mathematical Sciences, Clemson University, Clemson, SC

9:15 Linear Characterizations for NP-complete and Number Complete Problems
S. Uralc, Madison, WI

9:30 The Cyclic Coloring Problems and Estimation of Sparse Graphical Matrices
Tom F. Coleman and Jin-yi Cai, Computer Science Department, Cornell University, Ithaca, NY

9:45 The Sparse Null Space Basis Problem
Thomas F. Coleman, Computer Science, Cornell University, Ithaca, NY; Alex Pothen, The Pennsylvania State University, Computer Science Department, Whitmore Laboratory, University Park, PA
Tuesday, April 30 / PM

12:00 Noon/Lunch
Tuesday, April 30/1:00-2:30 PM
Contributed Papers 10/Cameron Room

SYSTEMS THEORY 1
Chairman: Nicholas J. Rose, Department of Mathematics, North Carolina State University, Raleigh, NC

1:00
Controllability of Positive Systems
Pamela G. Coxon, Laboratory for Information and Decision Systems, Massachusetts Institute of Technology, Cambridge, MA

1:15
Linear Quadratic Regulator Problem under Equivalence Transformation
S. J. Py and M. E. Sawan, Electrical Engineering Department, Wichita State University, Wichita, KS

1:30
New Numerical Methods of Optimal Control Problems
John Gregory and Rohan Dalpatadu, Department of Mathematics, Southern Illinois University, Carbondale, IL

1:45
Numerical Solution of General Linear Quadratic Gaussian Control Problems
Volker Mehrmann, Department of Mathematics, University of Wisconsin, Madison, WI; Angelika Bunse-Gerstner, Fakultat fur Mathematik, Universitat Bielefeld, Bielefeld I, Federal Republic of Germany

2:00
Control Coordination for Large Scale Linear Systems
Robert E. Fennell and James A. Reneke, Department of Mathematical Sciences, Clemson University, Clemson, SC; S. B. Black, Government Information Systems Division, Harris Corporation, Melbourne, FL

2:15
Numerical Examples of State Feedback Design Algorithms
Chia-Chi Bui, Department of Electrical & Computer Engineering, Northeastern University, Boston, MA

Tuesday, April 30/1:00-2:30 PM
Contributed Papers 11/Hindsdale Room

MATRICES EQUATIONS AND ALGEBRAS
Chairman: Charles R. Johnson, Department of Mathematics, Clemson University, Clemson, SC

1:00
The Matrix Equation AX - BX = C and its Applications
Karabi Dutta
Department of Mathematical Sciences, Northern Illinois University, DeKalb, IL

1:15
Roth's Theorem on the Matrix Equation AX + BY = C
Larry J. Gerstein, Department of Mathematics, University of California, Santa Barbara, CA

1:30
Matrix Equations Over Rings
John Jones, Jr., Mathematics Department, School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, OH

1:45
Similarity over $F[x]$ - Jacob T. B. Beard, Jr., Department of Mathematics and Computer Science, Tennessee Technological University, Cookeville, TN

2:00
Realization of Rational Matrices
Harald K. Wimmer, Mathemat. Institut d Universitat, Wurzburg, W. Germany

2:15
On Homogeneous Algebras
Lowell G. Sweet and James A. MacDougall, Department of Mathematics and Computer Science, University of Prince Edward Island, Charlottetown, P.E.I., Canada

Tuesday, April 30/1:00-2:30 PM
Contributed Papers 12/Haywood Room

COMPUTER SCIENCE
Chairman: Roger Horn, Department of Mathematical Sciences, Johns Hopkins University, Baltimore, MD

1:00
Sparse Projections in Karmarkar's Linear Programming Algorithm
David M. Gay, AT&T Bell Laboratories, Murray Hill, NJ

1:15
A Fast but Unstable Orthogonal Triangularization Technique for Toeplitz Matrices
Franklin T. Luk, School of Electrical Engineering, Cornell University, Ithaca, NY; Sanzheng Qiao, Center for Applied Mathematics, Cornell University, Ithaca, NY

1:30
The Solution of Banded Systems in Block Triangular Form Using Odd-Even Reduction
Cleve Ashcraft, Computer Science Department, General Motors Research Laboratory, Warren, MI

1:45
Storage Versus Runtime Step Preserving Programs
Frank J. Servidio, Department of Mathematics and Computer Science, Montclair State College, Upper Montclair, NJ

2:00
Max and the Singular Value Decomposition
Edward M. Borasky, Sr. Applications/Systems Analyst, Floating Point Systems Inc., Rockville, MD

2:15
Basic Linear Algebra Models for a Concurrent Computing Environment with IEEE Floating Point Arithmetic
Elizabeth R. Ducot and Virginia C. Kiem, Massachusetts Institute of Technology Statistics Center, Cambridge, MA

2:30 PM Coffee

Tuesday, April 30/2:30-4:00 PM
Contributed Papers 13/Hindsdale Room

NUMERICAL ANALYSIS 2
Chairman: Jack Dongarra, Applied Mathematics Division, Argonne National Laboratory, Argonne, IL

4:00
The QR and Inverse QR Algorithms for Unitary Hessenberg Matrices
William B. Gragg and William J. Harrod, Department of Mathematics, University of Kentucky, Lexington, KY

4:15
On Symplectic QR like Methods
Angelika Bunse-Gerstner, Faculty for Mathematics, University Bielefeld, Federal Republic of Germany

4:30
Analogues of Givens and Lanzcos Methods for Pseudosymmetric Matrices
Michael A. Brebner, Department of Computer Science, University of Calgary, Calgary, Alberta, Canada

4:45
Optimal Choice of Truncation Level for Truncated SVD for Linear Ill-posed Problems
C. R. Vogel, Department of Mathematics and Computer Science, University of Kentucky, Lexington, KY

5:00
Resolvent Bounds and Eigenvalue Estimates' Error Bounds
Dennis R. Philips, Middlebury, VT

5:15
Estimating the SOR Extrapolation Parameter
Eugene L. Wachspress, Department of Mathematics, University of Tennessee, Knoxville, TN

5:30
Singularities in Isospectral Flows
David S. Watkins, Department of Pure and Applied Mathematics, Washington State University, Pullman, WA

5:45
Transforming Residual Bounds into Error Bounds for Eigenvalue Estimates

Tuesday, April 30/4:00-5:30 PM
Contributed Papers 14/Haywood Room

LINEAR ALGEBRA IN STATISTICS
Chairman: Peter Gibson, Department of Mathematics, University of Alabama, Huntsville, AL

4:00
Identifying Rank-Influential Groups of Observations in Generalized Linear Regression Models
Peter J. Kumphor, Department of Statistics, Harvard University, Cambridge, MA
FINAL PROGRAM

4:15 Multivariate and Other Forms of the Pitman-Welch Permutation Test for Randomized Blocks
Clayton L. Stuckard, Department of Measurement, Statistics, and Evaluation, University of Maryland, College Park, MD

4:30 The Algebra of Hyperboloids of Revolution
Javier Cabrera, Department of Statistics, Rutgers University, New Brunswick, NJ; Geoffrey S. Watson, Department of Electrical Engineering Systems, Princeton University, Princeton, NJ

4:45 An SVD-Based Algorithm for Stochastic System Identification
K. S. Arun, Coordinated Science Laboratory, University of Illinois at Urbana-Champaign, Urbana, IL; Sun-Yuan Kung, Department of Electrical Engineering Systems, University of Southern California, Los Angeles, CA

5:00 The Early Use of Matric-Diagonal Increments in Statistical Problems
Walter W. Piegl, Biometry and Risk Assessment Program, National Institute of Environmental Health Science, Research Triangle Park, NC; George Casella, Biometrics Unit, Cornell University, Ithaca, NY

5:15 Estimating the Parameters of a Positive Semidefinite Quadratic Form Using a Cholesky Decomposition
Eric Stiatt, Max A. Woodbury and Kenneth G. Manton, Center for Demographic Studies, Duke University, Durham, NC

5:30 A Probabilistic Approach in Approximating the Stationary Distribution of a Nearly Completely Decomposable Markov Chain
Moshe Haviv, Department of Statistics, The Hebrew University, Jerusalem, Israel

6:30 PM Wine and Cheese Party
Sponsored by North Carolina State University

Wednesday, May 1 / AM

Wednesday, May 1/8:30–9:30 AM
Contributed Papers 15/Hinckle Room

APPLICATIONS OF LINEAR ALGEBRA

8:45 A Stability Analysis of Incomplete LU Factorizations
Howard C. Elman, Department of Computer Science, Yale University, New Haven, CT

9:00 The Linear Algebra Challenge of Global Convergent Homotopy Methods
Layne T. Watson, Department of Computer Science and Spatial Data Analysis Laboratory, Virginia Polytechnic Institute and State University, Blacksburg, VA

9:15 An Efficient Method for Determining Symbolically the Characteristic Polynomial of a Matrix
Robert E. Parkin, Electrical Engineering Department, University of Lowell, Lowell, MA

Wednesday, May 1/8:30–9:30 AM
Contributed Papers 15/Hinckle Room

APPLICATIONS OF LINEAR ALGEBRA

8:45 A Stability Analysis of Incomplete LU Factorizations
Howard C. Elman, Department of Computer Science, Yale University, New Haven, CT

9:00 The Linear Algebra Challenge of Global Convergent Homotopy Methods
Layne T. Watson, Department of Computer Science and Spatial Data Analysis Laboratory, Virginia Polytechnic Institute and State University, Blacksburg, VA

9:15 An Efficient Method for Determining Symbolically the Characteristic Polynomial of a Matrix
Robert E. Parkin, Electrical Engineering Department, University of Lowell, Lowell, MA

9:30 Some Special Function Matrices and Identities Derived From Them
Rethinammy Kittappa, Department of Mathematics and Computer Science, Millersville University, Millersville, PA

9:45 A Characterization of Inertia-preserving Secant Updates
Christopher Beattie, Monte Boisen and Lee Johnson, Mathematics Department, Virginia Polytechnic Institute and State University, Blacksburg, VA

9:00 On Certain Strictly Dissipative Matrices
Natalia Bebiano, Departamento de Matematica, Faculdade de Ciencias e Tecnologia Universidad de Coimbra, Coimbra, Portugal

9:15 On Nonnegative Matrices
J. P. MIlaszewicz and L. Moledo, Buenos Aires University, and National Research Council, Argentina

9:30 Cameron-Mordecai Room
Invited Presentation 6
Stephen Campbell, CHAIRMAN
Department of Mathematics
North Carolina State University, Raleigh, NC

PARALLEL ALGORITHMS IN LINEAR ALGEBRA

Robert G. Voigt
ICASE, NASA Langley Research Center Hampton, VA

10:30 AM/ Coffee

11:30 AM Cameron-Mordecai Room
Invited Presentation 7
Richard A. Brualdi, CHAIRMAN
Department of Mathematics
University of Wisconsin—Madison, Madison, WI

LINEAR ALGEBRA IN DISCRETE

8:45 An Application of the Singular Value Decomposition to Manipulability and Sensitivity of Industrial Robots
Masaki Togai, ATR Bell Laboratories, Holmdel, NJ

9:00 Statistical Analysis of the Effects of Matrix Perturbations in Some Least Squares Problems
Donald W. Tufts and S. Parthasarathy, Department of Electrical Engineering, University of Rhode Island, Kingston, RI

9:15 Linear Algebra in Modern Signal Processing
Jeffrey M. Speiser, Naval Ocean Systems Center, San Diego, CA

Wednesday, May 1 / AM

Wednesday, May 1/8:30–9:30 AM
Contributed Papers 15/Hinckle Room

NUMERICAL ANALYSIS 3
CHAIRMAN: Michael Neumann, Department of Mathematics and Statistics, University of South Carolina, Columbia, SC

8:30 Newton-Hankel and Newton-Toeplitz Matrices: Theory and Applications
Daniel W. Sharp, Department of Mathematical Sciences, Clemson University, Clemson, SC

8:45 Some New Efficient Algorithms Related to Cayley–Hamilton Theorem
Victor Pan, Computer Science Department, State University of New York at Albany, Albany, NY

Wednesday, May 1 / PM

Wednesday, May 1/12:00 Noon/Lunch
Contributed Papers 18/Cameron Room

PARALLEL MATRIX COMPUTATIONS 3
CHAIRMAN: Roger Horn, Department of Mathematical Sciences, Johns Hopkins University, Baltimore, MD

1:00 Some New Efficient Algorithms Related to Cayley–Hamilton Theorem
Victor Pan, Computer Science Department, State University of New York at Albany, Albany, NY

1:15 A Parallel Method for the Generalized Eigenvalue Problem
Daniel Boley, Computer Science Department, University of Minnesota, Minneapolis, MN

1:30 Design of and Experience with Frontal and Skyline Solvers for Vector and Parallel Processing of Finite Element Codes
R. E. Benner, D. K. Gartling, and G. G. Weigand, Fluid and Thermal Sciences Department, Sandia National Laboratories, Albuquerque, NM

1:45 Direct Parallel Algorithms for Exact Solution of Sparse Symmetric Linear Systems
Victor Pan, Computer Science Department, University of New York at Albany, Albany, NY; John Reif, Laboratory of Computer Science, Massachusetts Institute of Technology, Cambridge, MA and Aiken Computation Laboratory, Division of Applied Sciences, Harvard University, Cambridge, MA

2:00 A Program for the Parallel Computation of the Schur Decomposition of an Arbitrary Matrix
Patricia J. Eberlein, Department of Computer Science, Cornell University, Ithaca, NY

2:15 Fast Division of Polynomials via Triangular Toeplitz Matrix Inversion
Dario Bini, Department of Informatica, University of Pisa, Pisa, Italy; and Victor Pan, Computer Science Department, State University of New York at Albany, Albany, NY

Wednesday, May 1/12:00 Noon/Lunch
Contributed Papers 19/Hinckle Room

SYSTEMS THEORY 3
CHAIRMAN: Richard Painter, Department of Mathematics, Colorado State University, Fort Collins, CO

1:00 Prolegomena to Numerical Homological Algebra
Bostwick F. Wyman, Mathematics Department, The Ohio State University, Columbus, OH

1:15 Algorithms for Polynomial Matrix Operations
Shou-Yuan Zhang, Department of Electrical Engineering, State University of New York at Stony Brook, Stony Brook, NY

1:30 On the Computation of State Transition Matrices
S. J. Fu and M. E. Sawan, Electrical Engineering Department, Wichita State University, Wichita, KS

1:45 Approximate Linear Realization from Finite Time-Series Data
Stefan Mittnik, Department of Systems Science and Mathematics, and Department of Economics, Washington University, St. Louis, MO
FINAL PROGRAM

2:00
Using Symplectic Structure in Algorithms for Solving the Discrete Riccati Equation
Ralph Byers, Department of Mathematical Sciences, Northern Illinois University, DeKalb, IL

2:15
The Sensitivity of the Stable, Non-negative
Definite Lyapunov Equation
Gary A. Hews, RF Missile Systems Branch, Weapons Synthesis Division, Naval Weapons Center, China Lake, CA; Charles Kenney, Numerical Software for Scientific Engineering, Naval Weapons Center, China Lake, CA

Wednesday, May 1/4:00–5:30 PM
Contributed Papers 21/Hindsdale Room

GRAPH THEORY
CHAIRMAN: G. Kolb, Department of Mathematics, North Carolina State University, Raleigh, NC

4:00
Maximum Chordal Subgraphs of Grid Graphs
Barry W. Peyton, Department of Mathematical Sciences, Clemson University, Clemson, SC

4:15
On the Use of Electrical Network Equations to Draw Graphs in the Plane
Seth Caika, Department of Computer Science, State University of New York at Albany, Albany, NY

4:30
Spectra of the Extended de Bruijn–Good Graphs
Xiao-ling Lin, Department of Mathematics, North Carolina State University, Raleigh, NC

5:00
Hypergraphs of k-Dimensional Matrices
Stephen J. Dow and Peter M. Gibson, Department of Mathematics, University of Alabama, Huntsville, AL

5:15
A Probabilistic Algorithm for Graph Isomorphism
Shainuel Friedland, Department of Mathematics, Cornell University, Ithaca, NY

Wednesday, May 1/4:00–5:45 PM
Contributed Papers 22/Haywood Room

COMPUTER SCIENCE AND SYSTEMS THEORY
CHAIRMAN: John Ted, Department of Mathematics, California Institute of Technology, Pasadena, CA

4:00
Squeezing the Most Out of Eigenvalue Solvers on High-Performance Computers
Linda Kaufman, Computing Mathematics Research, AT&T Bell Laboratories, Murray Hill, NJ

4:15
Cholesky Factorization of Structured Matrices
Hanoch Lev-Ari, Information Systems Laboratory, Stanford University, Stanford, CA

4:30
Transitive Closure and Related Semiring Properties Via Eliminants
S. Kannan, University, Davis, CA; B. David Saunders, Department of Computer Science, University of Wisconsin–Madison, Madison, WI

4:45
Lyapunov Approximation of Reachable Sets for Controlled Linear Systems
Danny J. Dwyer, Department of Mathematics and Statistics, Memorial University of Newfoundland, St. John's, Newfoundland, Canada

5:00
Linear Algebra in Robust Multivariable Control Theory
John Doyle, Department of Electrical Engineering, California Institute of Technology, Pasadena, CA

5:15
On the Generators of a Controllability Matrix
Frank Uhlig, Department of Mathematics, Auburn University, Auburn, AL

5:30
Projectionally Exposed Cones in Convex Programming
George P. Barker, Department of Mathematics, University of Missouri, Kansas City, MO; Michael Laidacker and George D. Poole, Department of Mathematics, Lamar University, Beaumont, TX

7:00 PM
Banquet
North Carolina State University
William M. Kauan, BANQUET SPEAKER
Department of Electrical Engineering and Computer Science
University of California—Berkeley, Berkeley, CA

"If At First You Don't Succeed, Try and Try and Try Again."
How Hard?
The Perron-Frobenius theory of non-negative matrices and their dominant eigenvalues illuminates this question.

Thursday, May 2 / AM

Thursday, May 2/8:30–9:30 AM
Contributed Papers 23/Cameron Room

CORE LINEAR ALGEBRA 3
CHAIRMAN: Daniel Hershkowitz, Department of Mathematics, University of Wisconsin–Madison, Madison, WI

8:30
Nullities of Submatrices of Generalized Inverses
Donald W. Robinson, Department of Mathematics, Brigham Young University, Provo, UT

8:45
The Second Immanent and the Moment Sum of a Graph
Russell Merris, Department of Mathematics and Computer Science, California State University, Hayward, CA

9:00
On the Null Space of a Subspace of Singular Matrices
LeRoy D. Case, Department of Mathematics, Utah State University, Logan, UT

9:15
Null Vectors and Singularity of Acyclic Matrices
David Carlson, Mathematical Sciences Department, San Diego State University, San Diego, CA;
Danny Hershkowitz, Mathematics Department, University of Wisconsin-Madison, Madison, WI

Thursday, May 2/8:30–9:30 AM
Contributed Papers 24/Hindsdale Room

APPLICATIONS TO ECONOMICS AND DECISION SCIENCE
CHAIRMAN: Charles R. Johnson, Department of Mathematics, Clemson University, Clemson, SC

8:30
A Polynomially Bounded Pivoting Algorithm for a Linear Complementarity Problem
with a Quasi-Diagonally Dominant Matrix
Jong-Shi Pang, School of Management, University of Texas at Dallas, Richardson, TX

8:45
Existence of Nonnegative Solutions for Leon
tief's Closed Dynamic Input-Output Model
Daniel B. Szyld, Institute for Economic Analysis, New York University, New York, NY

9:00
Path Addition and Marginal Cost on User
Optimized Transportation Networks
Marguerite Frank, Department of Decision Science and Computers, Rider College, Lawrenceville, NJ

9:15
Sensitivity of the Stationary Distribution Vector for an Ergodic Markov Chain
R. E. Funderlic, Oak Ridge National Laboratory, Oak Ridge, TN; C. D. Meyer, Jr., Department of Mathematics, North Carolina State University, Raleigh, NC

Thursday, May 2/8:30–9:30 AM
Contributed Papers 25/Haywood Room

ITERATIVE METHODS
CHAIRMAN: Volker Mehrmann, Department of Mathematics, University of Wisconsin, Madison, WI

8:30
K-Part Iterative Solutions to Linear Systems
Bradley N. Parsons, Systems Engineering and Analysis, Hughes Aircraft Company, Fullerton, CA

9:00
K-Part Iterative Solutions to Linear Systems
Bradley N. Parsons, Systems Engineering and Analysis, Hughes Aircraft Company, Fullerton, CA
FINAL PROGRAM

1:15 Conditions for Asymptotically Exponential Solutions of Linear Difference Equations with Variable Coefficients
Marc Arizmendi, Department of Bioestatistics, School of Public Health, University of North Carolina, Chapel Hill, NC

1:30 Centrosymmetric Generalized Wright Model
James R. Weaver and David L. Sherry, Department of Mathematics/Statistics, The University of West Florida, Pensacola, FL

1:45 An Assessment of the Customary Linear Model for Tracer Kinetics in a Nonlinear Environment
H. Robert van der Vaart, Department of Statistics, Biostatistics Division, North Carolina State University, Raleigh, NC

Thursday, May 2/1:00–2:00 PM
Contributed Papers 27/Iliffsdale Room

NUMERICAL ANALYSIS 4
CHAIRMAN: Robert J. Plemmons, Department of Mathematics, North Carolina State University, Raleigh, NC

1:00 Generalized Deflated Block Elimination
Tony F. Chan and Diana C. Benson, Department of Computer Science, Yale University, New Haven, CT

1:15 Curves on $S^1$ That Lead to Eigenvalues or
Their Means of a Matrix
Moody T. Chu, Department of Mathematics, North Carolina State University, Raleigh, NC

1:30 Some Applications of Vandermonde Systems
William Squire, Department of Mechanical and Aerospace Engineering, West Virginia University, Morgantown, WV

1:45 The Conjugate Gradient Method with Element by Element Preconditioners:
Preliminary Report
Steven J. Leon, Department of Mathematics, Northeastern Massachusetts University, North Dartmouth, MA

2:00 Parallel Block Jacobi Algorithms
David St. Clair Scott, Computer Sciences Department, University of Texas at Austin, Austin, TX

2:15 Wide Quotient Trees for Finite Element Problems
Karl Zemel and John R. Gilbert, Computer Science Department, Cornell University, Ithaca, NY

2:30 Numerical Algorithms for Determining an Invariant Subspace of a Matrix
Dennis S. Philipps, Scientific Programming and Applied Mathematics, Inc. Middleton, WI

2:45 Efficient Parallel Matrix Inversion
Victor Pan, Computer Science Department, State University of New York at Albany, Albany, NY; John Reif, Laboratory of Computer Science, Massachusetts Institute of Technology, Cambridge, MA

Thursday, May 2/1:00–3:00 PM
Contributed Papers 28/Haywood Room

MATRIX ANALYSIS 3
CHAIRMAN: Nicholas J. Rose, Department of Mathematics, North Carolina State University, Raleigh, NC

1:00 Analysis of Convergence of Nonlinear Nonstationary Functional Iterations
Srikant K. Dey, Department of Mathematics, Eastern Illinois University, Charleston, IL

1:15 Functions of Perturbed Matrices
Lester J. Senechal, Department of Mathematics, Mount Holyoke College, South Hadley, MA

1:30 Derivatives of Di,Ad Matrices
James S. Weber, Department of Management, Roosevelt University, Chicago, IL

1:45 Rationalization of Fractions
Dietrich W. Wendt, Phoenixville, PA

2:00 Nonlinear Eigenvalue Approximation
William F. Moss, Department of Mathematical Sciences, Clemson University, Clemson, SC; Philip W. Smith, Department of Mathematical Sciences, Old Dominion University; and Joseph D. Ward, Department of Mathematics, Texas A&M University, College Station, TX

2:15 Unitary Completions and Noncanonical LU Factorization
Joseph A. Ball, Department of Mathematics, Virginia Polytechnic Institute and State University, Blacksburg, VA

2:20 Inexact One-Step Method
Elizabeth L. Yip, Boeing Computer Services Company, Tukwila, WA

2:45 The Role of the Schur Product in the Eigenstructure Approach to Parameter Estimation
A. Paulraj and T. Kailath, Information Systems Laboratory, Stanford University, Stanford, CA

Thursday, May 2/1:00–3:00 PM
Contributed Papers 29/Mordecai Room

CORE LINEAR ALGEBRA 3
CHAIRMAN: Joe Marlin, Department of Mathematics, North Carolina State University, Raleigh, NC

1:00 A Numerical Comparison of Methods for Computing the Inertia of a General Matrix
R. N. Datta Department of Mathematics, Northern Illinois University, DeKalb, IL; and Daniel Pierce, Department of Mathematics, North Carolina State University, Raleigh, NC

1:15 Generalized Inverses of Matrices Over Rings
K. P. S. Bhaskara Rao, Department of Mathematical and Computer Sciences, Michigan Technological University, Houghton, MI

1:30 Monotonicity of Permanents in 0,
John L. Goldwasser, Department of Mathematics, Iowa State University, Ames, IA

1:45 An Inequality for the Second Immanant
Bob Grone, Department of Mathematics, Auburn University, Auburn, AL

2:00 Some Generalizations of the Singular Value Concept
J. F. Queiro, Departamento de Matemática, Universidade de Coimbra, Coimbra, Portugal

2:15 Platzer's Problem Revisited
John G. Lewis and Horst D. Simon, Boeing Computer Services Company, Applied Mathematics Division, Tukwila, WA

2:30 Some Comments About Seminonotone and
Coxpositive Matrices
Melvyn W. Jeter and Wallace C. Pye, Department of Mathematics, University of Southern Mississippi, Hattiesburg, MS

2:45 Some Comments on Substochastic Matrices
Cecil Eugene Robinson, Jr., Department of Mathematics, University of Southern Mississippi, Hattiesburg, MS
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I/S = Invited Speaker    C/P = Contributed Paper    M/S = Minisymposium
A Symbolic Computation Package for *-Semirings in REDUCE

*-Semirings are algebraic structures that provide a unified approach to several problems of computer science and operations research. The theory of matrices over *-semirings has a number of similarities to the theory of matrices over fields. For example, eliminants and asterates behave analogously to determinants and matrix inverses. Since *-semirings lack additive and multiplicative inverses, the expressions resulting from various computations are often quite complex and thus provide an opportunity for symbolic manipulation by computers. We describe a set of REDUCE procedures for symbolic eliminant computation, asteration, and solution of systems of linear equations over *-semirings.

S. Kamal Abdali
Computer Research Laboratory
Tektronix, Inc.
Beaverton, OR 97077

Maple: A New Computer Algebra System

Maple is a system for symbolic computation in development at the University of Waterloo since 1980, distributed to a variety of systems and sites since 1982. A brief overview of the system's features and design philosophy will be given, illustrated by discussion of library software such as Maple's equation solver, Taylor series computations, and its package for matrices and vectors. The accomplishments and future plans of the Maple project will be placed in perspective with other symbolic computation systems. The Waterloo experience with Maple's usage by introductory calculus classes will be detailed.

Bruce W. Char
Computer Science Department
University of Waterloo
Waterloo, ON, N2L 3G1
Ontario, Canada

Exact Linear Algebra With A PC

The m4MATH/muSIMP computer algebra system for microcomputers provides an exact rational arithmetic and the capability of evaluating determinants, solving systems of numerical or symbolic elements. We will review these capabilities and explore the application of the extended arithmetic capabilities to such procedures as the method of conjugate gradients (which is exact in the absence of round-off) and the Bareiss division free procedure which normally requires rescaling to eliminate large or small numbers.

William Squire
Dept. of Mechanical and Aerospace Engineering
West Virginia University
Morgantown, WV 26506

Matrix Computation in Electronics CAD Software

The modeling and analysis of electronic system is accomplished via lumped as well as distributed models. The solution techniques which give the designer the quantities of interest involve matrix computations.

A variety of important problems need to be solved like circuit analysis, capacitance and resistance computations and semiconductor device analysis.

In this talk we plan to outline the mathematical formulation of such problems, the solution technique involved and what some of the results are. All these problems involve matrix computation. We plan to give examples of matrices, what their properties are and what the conventional solution techniques in common use are.

A. E. Ruehli
Computer Science Dept.
F. Odeh
Mathematical Science Dept.
T. J. Watson Research Ctr.
P. O. Box 218
Yorktown Hts., NY 10598

Fast Computation of Invariant Factors: Probabilistic and Modular Methods

Algorithms for the exact computation of the Hermite normal form and Smith normal form - and hence the invariant factors - of a matrix over \( \mathbb{F}[[x]] \) are discussed. While seeking limits to the speedup possible through parallel computation, we have found new algorithms which perform well in practice on current non-parallel computers. Some of the algorithms achieve speed at the cost of introducing a minute probability of incorrect results. Theoretical complexity results and experimental findings are reported.

Erich L. Kaltofen
Mukkai S. Krishnamoorthy
B. David Saunders*

Department of Computer Science
Rensselaer Polytechnic Institute
Troy, NY 12181

*on leave at
Department of Computer and Information Sciences
University of Delaware
Newark, DE 19716
Some Sparse Matrix Problems in Structural Analysis

Michael T. Heath
Oak Ridge National Laboratory
P. O. Box Y, Bldg. 9207A
Oak Ridge, Tennessee 37831

The Linear Algebra of Seismic Modeling

Seismic modeling codes can be used both to simulate seismic exploration and to process seismic data. Numerical approximation of the viscoelastic Helmholtz equations using a finite element method are characterized by large \((10^6 \times 10^6)\), sparse (block tri-diagonal) non-positive definite complex symmetric systems of linear equations for 2-dimensional geologies. One wishes to obtain the solution at a restricted \((10^3)\) number of nodes due to multiple \((10^2)\) source locations (right hand sides). Unlike reservoir simulation, conventional iterative equation solvers perform poorly for models many wavelengths in size. Multifrontal direct methods perform well.

Totally direct methods that we know of will not be able to solve the 3-dimensional problem \((10^9 \times 10^9)\) matrices) on machines of the next five years.

We solicit from the linear algebra community the proper mix of direct/iterative solution techniques and machine architectures that will allow us to solve the 3-dimensional seismic modeling problem.

R. P. Borden, Amoco Production Company Research Center, Tulsa, Oklahoma 74102 (Geophysics)

K. R. Kelly, Amoco Production Company Research Center, Tulsa, Oklahoma 74102 (Geophysics)

K. J. Marfurt, Amoco Production Company Research Center, Tulsa, Oklahoma 74102 (Geophysics)

David S. Scott
Computer Science Department
The University of Texas
Austin, TX 78712

SYMmetric GENERALIZED EIGENPROBLEMS
IN STRUCTURAL ENGINEERING

Vibration and buckling analyses of structures give rise to symmetric generalized eigenproblems of large order. Standard sparse algorithms, such as the shifted Lanczos algorithms by Ericsson and Ruhe, and Nour-Omid and Parlett, provide a sound basis for solving such problems in isolation. Incorporating such an algorithm into an existing structural engineering package, as a "user-friendly" black box eigen solver, adds substantially to the complexity of the algebraic problem. We shall discuss the implementation of a shifted block Lanczos algorithm into MSC NASTRAN to illustrate the practical problems that must be faced.

Structural engineering eigenproblems have numerical characteristics that pose further difficulties. Typical sparse algorithms require, as a key subproblem, solution of linear equations with one or more matrices. The matrices in the eigenproblem may be very poorly conditioned. The eigenvalue problems may, in fact, be ill-posed. We shall discuss some of the effects of ill-conditioning and ill-posedness on the numerical solution of these problems.

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John G. Lewis
Horst D. Simon
Boeing Computer Services Company
Applied Mathematics Staff
Mail Stop 9C-01
565 Andover Park West
Tukwila, WA 98188

Louis Komzsik
The MacNeal Schwendler Corporation
815 Colorado Blvd.
Los Angeles, CA 90041
Parallel Cholesky Factorization on a Multiprocessor

A parallel algorithm is developed for Cholesky factorization on a multiprocessor. The algorithm is based on self-scheduling of a pool of tasks. The subtasks in several variants of the basic elimination algorithm are analyzed for potential concurrency in terms of precedence relations, work profiles, and processor utilization. This analysis is supported by simulation results. The most promising variant, which we call column-Cholesky, is identified and implemented for the Denelcor REP multiprocessor. Experimental results are given for this machine.

Michael T. Heath
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Alan George
Faculty of Mathematics
University of Waterloo
Waterloo, Ontario
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Joseph Liu
Department of Computer Science
York University
Downsview, Ontario
Canada

Torus Data-Flow for Parallel Computation of Missized Matrix Problems

A data-flow approach can be used to solve large dense systems of equations on a processor array with only nearest-neighbor communication. Although this approach requires no global synchronization, the development of our simulator provided additional understanding of the necessity of local synchronization of data movement when there are more computational nodes than processors (missized). New definitions for missized problems and parallel algorithms are given. For the Cholesky decomposition the lower triangle was mapped onto a torus configuration of processors. Various data movement, efficiency, and processor utilization plots are given.

George A. Geist, R. E. Funderlic
Oak Ridge National Laboratory
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Oak Ridge, Tennessee 37831

Vectorizing the Computation of Cholesky Factors, Reflection Coeficients, and Kalman Gains in Toeplitz Systems

Let R= \(r_{n-1} \ldots r_0 \ldots r_{-l} \ldots \) denote a Toeplitz correlation matrix and \(r=(r_0 \ldots r_{-l})\) the corresponding correlation sequence. This sequence is used to initialize a fixed point vector recursion for computing reflection coefficients, Kalman gains, and triangular Cholesky factors of \(R\). The recursion is presented in a form that makes it suitable for implementation on a vector processing machine. This provides an alternative to the nested scalar recursions and to the lattice algorithms usually advocated for these computations. The results are applicable to the analysis and synthesis of stationary time series.

Louis L. Scharf
Electrical and Computer Engineering
University of Colorado
Boulder, CO 80309

Cedric Demeure
Electrical Engineering
University of Rhode Island
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A Linear Time Method for Computing the CS-Decomposition

We describe a new parallel algorithm for computing the CS-decomposition, and compare it against a recently published procedure due to Kaplan and Van Loan. For a \(2nxn\) orthonormal matrix that is partitioned into two square blocks, their procedure needs \(O(n^2)\) time and \(O(n^2)\) processors (probably in the form of two distinct arrays), whereas our new procedure requires only \(O(n)\) time and one triangular array of \(O(n^2)\) processors.

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Fast Matrix Multiplication on Square and Cubic Grids of Processors

Parallel processing algorithms are given for these three problems:
(a) Multiply an \(nnx\) matrix by an \(n\) vector on a square grid in time \(= O(n^{2/3})\).
(b) Multiply an \(nnx\) matrix by an \(n\) vector on a cubic grid in time \(= O(n^{1/2})\).
(c) Multiply two \(nnx\) matrices on a cubic grid in time \(= O(n^{3/4})\).

These algorithms use only communications between adjacent processors. At the start of computation, only one copy of each input is needed.

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The design and analysis of time-invariant linear control systems give rise to a variety of interesting linear algebra problems. In an invited talk at the last Gaitlinburg meeting in Waterloo, one of the authors, B. Datta, presented efficient parallel algorithms for some of these problems. The present talk is a sequel to the Gaitlinburg talk. In this talk, after reviewing briefly the state of art in parallel matrix algorithms relevant to the talk, efficient parallel algorithms will be presented for three important problems, namely, the problem of determining the inertia and stability of matrix, finding the relative primeness of two matrices, and solving lyapunov equation. These algorithms have parallel efficiency of \( O\left(\frac{1}{\log n}\right) \) and can be implemented in \( O(n \log n) \) steps using almost \( O(n^2) \) processors. A desirable feature of these algorithms is that they are composed of basic linear algebraic operations such as vector matrix multiplication, matrix multiplications and QR factorizations, for which efficient parallel algorithms already do exist. Thus, these algorithms have potential for implementations on the existing and future parallel machines.

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Stability of M-matrix Products

Various types of stability for powers and products of nonsingular M-matrices are discussed. Stability of the matrix powers is categorized according to the length of the longest simple circuit in the digraph of the matrix, while stability of the general products is categorized by the order of the matrices. Additional results are given regarding stability of the Hadamard product of M-matrices.

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Solving \( Ax = b \) when \( A \) is a Nonsingular M-matrix

Various types of pivoting and diagonal scaling strategies are considered for solving a system of linear equations \( Ax = b \) using Gaussian elimination, where \( A \) is a nonsingular M-matrix. The numerical stability of such algorithms is analyzed, and bounds are given for the growth factor which occurs in a backward error analysis of the LU decomposition.

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SECOND ORDER DERIVATIVES OF THE PERRON VECTOR

In a previous work the authors developed formulas for the second partial derivatives of the Perron root as a function of the matrix entries at an essentially nonnegative and irreducible matrix. These formulas, which involve the group generalized inverse of an associated M-matrix, were used to investigate the concavity and convexity of the Perron root as a function of the entries.

The authors now combine the above results together with an approach taken in an earlier joint paper of the second author with L. Elsner and C. Johnson and they develop formulas for the second order derivative of an appropriately normalized Perron vector, which again are given in terms the group gener-

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Products of Commuting MMA-matrices

An irreducible M-matrix (possibly singular) is called MMA if all of its positive integral powers are irreducible M-matrices. It is known that if \( A \) is MMA, then \( A = \sum_{i=1}^{k} \lambda_i E_i \) where \( \lambda_i \) are the distinct nonnegative eigenvalues and the \( E_i \) are certain projectors. We show there is a combinatorially-generated partial order \( \leq \) on the set \( \{ E_i : 1 \leq i \leq k \} \).

**THEOREM 1:** If the \( E_i \) are as above, and if \( \beta_1, \ldots, \beta_k \) are distinct nonnegative reals, then the following are equivalent:

1. \( B = \sum_{i=1}^{k} \beta_i E_i \) is MMA,
2. \( E_i < E_j \Rightarrow \beta_i < \beta_j \).

**THEOREM 2:** Let \( A \) and \( B \) be MMA with \( B \) nonderogatory. If \( AB = BA \), then \( AB \) is MMA.

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Incomplete Factorization of Singular M-matrices

In 1981, Varga and Cai characterized those M-matrices A (perhaps singular) which admit a factorization into M-matrices L and U (A = LU) where L is required to be non-singular, lower triangular M-matrix and U is required to be upper triangular M-matrix A result that was first proved by Fiedler and Ptak (1962) in the non-singular case. Because this factorization may produce a lower triangular matrix which is considerably less sparse than A, one attempts to control the fill-in of the factorization of A by means of a graph. This method leads to the concept of Incomplete Factorizations of A. Mejierink and van der Vorst (1977) have shown that Incomplete Factorizations of non-singular M-matrices are possible. The purpose of this paper is to give a condition on a singular M-matrix which guarantee the Incomplete Factorization of a singular M-matrix.

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Singular M-matrices

We discuss various inequalities involving a singular M-matrix A and its generalized inverse B. We show how these inequalities determine the structure of both A and B. We also give a simpler and more general proof of a theorem of I. Iwo (Linear Algebra and its Applications, 1977).

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Condition Numbers of Rectangular Systems and Bounds for Generalized Inverses

A natural extension of the notion of condition number of a matrix to the class of all finite matrices is shown to enjoy properties similar to the classical condition number. For example, the relative distance to the set of all matrices of smaller rank is just the reciprocal of this generalized condition number. The question of whether a matrix with a small generalized condition number must also have a generalized inverse of small norm is then studied. The answer turns out to be norm dependent. In particular, only if p is 1 or 2, must an intrinsically well conditioned full rank matrix in the ∇p sense have a nicely bounded generalized inverse; in particular in the ∇1 norm this need not be true. These facts are consequences of recent results in Banach space theory.

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Purcell’s Method and Projective n-Space

A new look at Purcell’s method via real projective n-space leads to a new encoding technique and a reasonable error analysis. The results show promise for some sparse systems and a new approach to estimating condition numbers.

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Linear Algebra Problems in the Use of the Repeated Integration Parameter Estimation Basis

Attempts to apply the Repeated Integration Parameter Estimation Basis (RIPEB) successfully have been thwarted by failure to account for certain fundamental profound effects, by difficulties in executing certain operations of linear algebra, and by integration algorithm inaccuracy. The source and nature of the two former difficulties are described, as are strategies to overcome them. Also described is an apparently previously unreported property of a certain determinant which is crucial to the successful use of the RIPEB.

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Some NewIll-Conditioning Numbers via Differential Geometry

A simple method is posed that permits an answer to the question, “when can linear algebraic equations be solved accurately/not be solved accurately.” Appealing to differential geometry one reasons that when any two (or more) hyperplanes have nearly identical unit hypernormals then “sensitivity of solution” occurs just as in the special case of 2-space when two lines have nearly equal slopes (i.e. nearly equal unit normals). Thus if all the inner products of the unit hypernormals associated with the hypersurfaces are sufficiently less than unity then the associated linear equations are well-conditioned. These ideas and corollary results are presented and illustrated with diverse examples.

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A Parallelizable Preconditioning Algorithm for the Fast Solution of Elliptic Problems

A "good" preconditioner for elliptic problems is defined which can be efficiently solved by using substructuring and/or block Gaussian elimination techniques. The mesh domain is decomposed into a union of subdomains on which "good" preconditioners are available. These subdomains need not be rectangles and can be joined in a rather general way. The proposed preconditioner is such that when substructuring techniques are applied to obtain its solution, the resulting boundary system decouples into many independent systems which can be solved in parallel. Theoretical estimates for the condition number of the preconditioned system will be given. Implementation of the algorithm in serial and parallel architectures will be discussed. Numerical results for the model problem will also be presented.

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Matrix Splittings for the Solution of Higher Order Boundary Value Problems

Butcher, Hairer, and Wanner have developed a calculus which can be used for solving Runge-Kutta processes. Hairer has also developed a calculus for higher order differential equations. We use a variation of this calculus to develop a class of processes for the second order boundary value problems of the form $y''=f(x,y)$, $y(a)=A$, $y(b)=B$. These processes do not require derivatives of $f$ and lead to systems of nonlinear equations with block tridiagonal Jacobians.

However, these Jacobians are expensive to form and factor. Hence, the use of quasi-Newton methods based upon a matrix splitting or approximate LU factorization technique is used. We give bounds for the rate of convergence of these iterations. Computational experiments showing that the rate of convergence is fast. One important special case of this class of matrix splitting is the method of deferred correction.

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Incorporating Time-Dependent Forcing in Locally One-Dimensional Methods

When a partial differential equation of parabolic type is discretized in space, a system of ordinary differential equations is defined. It is frequently possible to split the resulting matrix operator into two or more components and to proceed in a locally one-dimensional fashion. That is, the solution of $\frac{d}{dt}u = (L_1+L_2)u$ is replaced by an appropriate linear combination of $\frac{d}{dt}u_1 = 2L_1u_1$ and $\frac{d}{dt}u_2 = 2L_2u_2$.

One such locally one-dimensional scheme utilizes $\frac{1}{2}\exp(\tau L_1)\exp(\tau L_2)\exp(\tau L_2\exp(\tau L_1)) = \exp(\tau (L_1+L_2) + O(\tau^3))$. The methods based on this splitting are well-suited to parallel computation.

One drawback to LOD schemes has been the inability to incorporate, to full accuracy, time-dependent boundary conditions. This paper describes the way this problem has been solved for a number of LOD schemes. A by-product of the research has been a method to incorporate interior source terms at main (unsplit) time-points, either in predictor-corrector fashion or and with variable stepsize. Nonlinearities may be locally linearized, as with unsplit methods. Various numerical experiments are also reported.

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A Spectrum Enveloping Algorithm for Solving Central Difference Approximations of Convection Diffusion Equations

When a convection-diffusion equation is discretized using central difference scheme, the resulting coefficient matrix loses diagonal dominance whenever the convection terms are large and the conventional iterative procedures often fail to converge. The eigenvalue spectrum of some iteration matrices can be approximated by an ellipse with major axis on the imaginary axis and minor axis in the real interval $(-1,1)$.

This ellipse is used to define a convergent iteration scheme. A computational algorithm is described. Numerical examples show that the spectrum enveloping technique works well when the original iterations diverge. When the original iterations converge, the spectrum enveloping technique converges even faster.

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Consimilarity: A Survey of Results

Two square complex matrices $A$ and $B$ are consimilar if $A = SBS^{-1}$ for some nonsingular square complex matrix $S$ of the same size. This concept arises naturally from a classical problem in the theory of univalent analytic functions, in which one wants to diagonalize simultaneously two quadratic forms, one symmetric and one Hermitian. We survey the consimilarity analog of basic matrix theoretic notions such as invariant subspaces, $*$-complementation, diagonalization, normality, simultaneous reduction, and canonical forms. Complex symmetric matrices play a role in the theory of consimilarity that is analogous to the role played by normal matrices in the theory of ordinary similarity. Consimilarity is a natural extension to matrices of the notion of rotation in the complex plane.

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Applying a Canonical Form under Consimilarity

Complex square matrices $A$ and $B$ are consimilar if there exists a nonsingular complex square matrix $S$ such that $A = SBS^{-1}$, where $S$ denotes the componentwise complex conjugate of $S$. We establish a canonical form under consimilarity that is analogous to the Jordan canonical form for ordinary similarity. $A$ and $B$ are consimilar if and only if $A$ is similar to $B$ and a rank condition is satisfied. Every complex square matrix $A$ is consimilar to its conjugate, transpose, and adjoint, as well as to a real matrix and a Hermitian matrix. The Witt cancellation property extends to consimilarity.
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Spectral Factorization of Matrices

We prove that a nonscalar invertible square matrix can be written as a product of two matrices with preassigned eigenvalues subject only to the obvious determinant condition. As corollaries, we give short proofs of some known results such as Ballantine's characterization of products of four or five positive definite matrices.

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Least Squares Approximation with Smoothed Spline Functions

In 1967 Christian Reinsch developed an algorithm for finding the smoothest Natural Cubic Spline function whose weighted square error was less than a prescribed bound. The authors present an algorithm which generalizes Reinsch's algorithm to B-spline functions of arbitrary order. In addition the knot sequence is independent of the data points and the inner product used in the constraint is generalized. The complexity of each Newton iteration is only O(n), where n is the dimension of the space of B-splines. In those cases where the number of data points is significantly larger than n the use of B-splines is significantly more efficient than Natural splines.

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Stability Analysis of Interval Matrices - Another Sufficient Condition

A sufficient condition for the stability of interval matrices is presented based on Liapunov approach. The condition, while requiring the solution of a Liapunov matrix equation, removes the restrictions imposed in a previous paper by Benner. Examples given illustrate the improvement of the proposed condition over the previously published results.

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An Analog of the Singular Value Decomposition for Orthogonal Equivalence

Let A be a given m-by-n complex matrix. We give necessary and sufficient conditions for the existence of square complex orthogonal matrices P and Q such that $A = P A Q^*$, where $A = (\lambda_{ij})$ is an m-by-n complex matrix such that $\lambda_{ij} = 0$ for $i \neq j$. We also give necessary and sufficient conditions for the simultaneous reduction of a family of matrices to the above form, which may be thought of as an analog of the ordinary (unitary) singular value decomposition. As an application of these results we show that, subject to certain restrictions, a complex square matrix $A$ such that $AA^* = A^*A$ can be reduced to an analog of the real normal form by complex orthogonal similarity.

Stabilizing certain iterative processes

Let $A$ be an $n \times n$ matrix and $x_0$ an $n \times 1$ column vector. We try to stabilize (i.e. cause to be bounded) the sequence $x_0, Ax_0, A^2x_0, \ldots$ by subtracting a fixed vector $y$ at times $t_1 < t_2 < \ldots$ during its evolution. Thus a typical term of the new sequence is

$A_n^{t_{m+1}}(A_n^{t_{m+1}}A_n^{t_{m+1}}(A_n^{t_{m+1}}A_n^{t_{m+1}}(A_n^{t_{m+1}}y))\ldots)\ldots - y$,

where $0 < n < t_{m+1} - t_m$. We modify and extend results of V. Abe1 which characterized those real diagonalizable $A$ such that $x_0, Ax_0, A^2x_0, \ldots$ can be stabilized whatever the choice of $x_0$ and $t_1 < t_2 < \ldots$. For example our results include all compact operators on a complex Banach space.

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On cubic spline interpolants and postprocessing for monotonicity preservation

The main purpose of this talk is to discuss algorithms for postprocessing spline interpolants in order to impose monotonicity constraints while retaining optimal order approximation. One such algorithm will be presented. A secondary purpose is to obtain error estimates for some "practical" unconstrained spline interpolation schemes. Here "practical" means that derivative values are not needed in order to fit the interpolant. One result of the latter type is a different proof of de Boor's recent error estimate for the not-a-knot cubic spline. The proofs of these results are essentially estimates for the inverses of certain band matrices.
Quasi-Positive Definite Maps

Let $V$ be an $n$-dimensional unitary space. Let $W$ be the $m \times m$ tensor product of $V$. Suppose $T$ is a hermitian transformation on $W$ satisfying $(Tw,w) \geq 0$ for every rank one (decomposable) tensor $w$ in $W$. Then $T$ is called quasi-positive semi-definite (qpsd). Such a map need not be positive semi-definite and in fact we show that its negative signature can be quite large. If the largest eigenvalue of $T$ is 1, we discuss lower bounds for the smallest eigenvalue and compute the lower bound explicitly if $m = 2$.

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Inverse Problems For Means of Matrices

Given two hermitian positive semidefinite (HSD) matrices $A$ and $B$, there are natural definitions for their arithmetic and harmonic means. This work considers and answers the following question: Given HSD $C$ and $D$, when do there exist HSD $A$ and $B$ so that $C$ is the arithmetic mean of $A$ and $B$ and $D$ is the harmonic mean of $A$ and $B$? The question of the uniqueness of $A$ and $B$ is also answered. A similar representation results are presented for the arithmetic and geometric means. All of the results presented are generalizations of results obtained by Gauss in the Scalar Case.

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More on Cone Reachability

In recent years, there has been a good deal of research on positively invariant cones; e.g., Elsner (Arch. Rat. Mech. Anal. 1970) and Schneider and Vidyasagar (STIN Num. Anal. 1970). The present work continues this study.

Given the linear system of o.d.e.'s $\dot{x} = Ax$ ($A \in \mathbb{R}^{n \times n}$), a problem of interest in economics and engineering is to determine those initial states $x(0)$ whose trajectories become and remain non-negative with respect to a positively invariant simplicial cone $K$. That is, we want to characterize the set $X_A(K) := \{e^{-\lambda t}K; \lambda \geq 0\}$. We do this in case $A$ has a real spectra, generalizing results of the second and third author (Appl. Anal., to appear), in which diagonability was assumed.

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2) Michael Neumann, Dept. of Mathematics, University of South Carolina.
3) Ron Stern, Dept. of Mathematics, Concordia University, Montreal.

The Cascade Sum and Difference of Matrices

Whenever a physical system can be described as a function from inputs to outputs it is natural to consider the cascade connection of two or more systems. That is, the outputs of one system furnish the inputs for the next. In the linear case the systems are described by matrices, and the connection gives rise to the cascade sum of matrices. We develop various properties of the cascade sum, and also give conditions for the existence of a cascade difference. This latter problem is closely related to classical problems of electrical network synthesis.

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Mathe matical Aspects of the Relative Gain Array $(A \otimes A^{-1})$
CONTRIBUTED PAPERS

The relative gain array (RGA) associated with a non-singular matrix $A$ is the Hadamard product $A \circ A^{-1}$, where $A^{-1}$ abbreviates $(A^{-1})^T$. Bristol (IEEE Trans. Autom. Control AC-11, 1961) introduced the RGA in connection with control theory in chemical engineering design problems. The matrix $A \circ A^{-1}$ also appears in a matrix theoretic problem and perhaps has other uses.

We study the map $A \mapsto \phi(A) = A \circ A^{-1}$. We show the sequence of iterates $\phi^k(A)$ converges to $I$ when $A$ is a positive definite symmetric matrix, and also when $A$ is an $H$-matrix. We also investigate some intriguing questions about the range of $\phi$ and the fixed points of $\phi$.

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Semistability Factors and Semifactors

A (semistability) factor [semifactor] of a matrix $A \in \mathbb{C}^{n \times n}$ is a positive definite (positive semi-definite) matrix $H$ such that $AH + HA^*$ is positive semidefinite. We give three proofs to show that if $A$ has a semistability factor then it cannot be unique. We give necessary and sufficient conditions for a matrix $H$ to be a (semi)factor of a given matrix and we determine the dimension of the cone of semistability factors. We also discuss the relation of rank $H$ to the rank of $AH + HA^*$, when $H$ is a semifactor of $A$.

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Upper Bounds on the Maximum Modulus of Subdominant Eigenvalues of Nonnegative Matrices

Upper bounds for the maximum modulus of the subdominant roots of square nonnegative, matrices are obtained. We provide a unified approach that yields or improves upon most of the bounds that have been obtained so far.

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Parallel Nonlinear Algorithms

This talk will describe some iterative linear and nonlinear algorithms whose parts may be executed simultaneously. Parallel versions of the nonlinear Gauss-Seidel method, and the Newton-GQR method will be presented. The convergence of these algorithms will be discussed, and applications to some elliptic and parabolic partial differential equations will be given.

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A Vector Approach to Large Scale Configuration Interaction Calculations

A computational scheme is offered for resolving the extremely large matrix eigenvalue problems arising frequently in quantum chemistry. The primary feature of our approach is the use of the nearly separating character of the molecular Hamiltonian to form a Rayleigh-Ritz matrix expressible as a sum of Kronecker products of relatively small matrices. This special structure provides an analog to sparsity in formulating a vector algorithm involving an inexpensive matrix-vector multiply which drives both a Lanczos-based procedure for eigenvalue extraction and a conjugate-gradient procedure for simultaneous eigenvector extraction.

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Communication complexity of Gaussian Elimination on multiprocessors

We propose a few lower bounds for communication complexity of the Gaussian Elimination algorithm implemented on three types of multiprocessor architectures: a bus architecture, a nearest neighbor ring network and a nearest neighbor grid network. It is shown that for the bus and the ring architectures, the minimum communication time is lower bounded by $O(N^2)$, independent of the number of processors, while for the grid this bound is reduced to $O(k^2/N^2) + O(k^{1/2}N)$, where $k$ is the total number of processors. These bounds take into account both the total bandwidth of the system and latency times. An important consequence of these results is that the minimum time required to solve a linear system by a parallel Gaussian elimination algorithm using an arbitrary number of processors is of the order $O(N^2)$ for the broadcast bus architecture and the ring, and of the order $O(N^{3/2})$ for the grid array. We will discuss the practical implications of these results.

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A9
Parallel Matrix Algorithms for Structural Analysis

A fundamental problem in linear elastic analysis is that of finding the vector of stresses and strains, given a finite element model of a structure and a set of external loads. To obtain the solution to this linear constrained minimization problem, a variety of methods such as the displacement method, the force method, the natural factor method, and the weighted least squares method may be used. While the advantages of implementing one of these methods over another depend on the digital computer or computer system with which each of these methods have not. In this talk, a comparative study of the use of serial and parallel versions of popular matrix methods in solving the fundamental problem of linear elastic analysis on SIMD multiprocessors such as the Denelcor HEP will be presented.

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Parallelism of Block-Preconditioned-Conjugate-Gradient Method on HEP-like MIMD Machines

Block-preconditioned-conjugate-gradient-like iterative schemes have found applications in large scale computations in areas such as oil reservoir simulation, numerical grid generation, and others. We discuss an efficient scheduling of these schemes for HEP-like MIMD machines. In particular, we consider matrices generated by 9-point operators with a natural order. We study parallel schedules for the block-diagonal-scaling and the block-incomplete-ILU-decomposition preconditionings. With a processor utilization rate of 66%, we derive a speed up linear in the number of processors and proportional to the square root of the number of grid points.

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Efficient Parallel Solution of Linear Systems with Hyperbolic Rotations

An algorithm based on hyperbolic rotations is presented for the solution of linear systems of equations,

$$Ax = b,$$

with symmetric positive definite coefficient matrix $A$. Forward elimination and backsubstitution are replaced by matrix vector multiplications, rendering the method most amenable to implementation on a variety of parallel and vector machines. The stability behaviour compares favourably with that of the best, known methods.

The method can be simplified and formulated without square roots if $A$ is also Toeplitz; a corresponding systolic architecture (in VLSI) for the resulting recurrence equations is more efficient than previously proposed pipelined Toeplitz system solvers. The hardware count becomes independent of the matrix size if its inverse is banded.

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Sign Nonsingularity and the Odd Cycle Property

A nonsingular real matrix $A$ is sign nonsingular if every matrix with the same sign-pattern as $A$ is nonsingular. We give necessary and sufficient condition for the existence of sign nonsingular matrices with a given zero pattern. Our method and condition are graph-theoretic. In particular we study when does a given digraph $D = (V, E)$ contain a subset $S$ of the edge set $E$ such that every cycle in $D$ has an odd number of edges from $S$. We also consider the analogous question for undirected graphs.

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L-functions and Their Inverses

In 1969 Ortega introduced a class of $M$-functions, a generalization of the linear mappings induced by $M$-matrices. The convergence of Gauss-Seidel and Jacobi iteration for $M$-matrices naturally extends to $M$-functions

Similarly, we introduce a class of $L$-functions which generalize the linear mapping induced by $L$-matrices. A real non matrix is an $L$-matrix if it is the matrix of at least one sign solvable system. This implies that the diagonal of $A$ is negative and all cycles in the signed digraph associated with $A$ are negative. Since $L$-matrices are invertible, we examine the invertibility of $L$-functions and present an implicit function theorem for $L$-functions.

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CONTRIBUTED PAPERS

Formulae for $\det A$ Corresponding to Zero Patterns of $A^{-1}$

We address the problem of expressing the determinant of a matrix $A$ as a quotient $p/q$ where $p$ and $q$ are products of principal minors of $A$. A broad class of such formulae is demonstrated in Barrett and Johnson, Determinant Formulae for Matrices with Sparse Inverses, Linear Algebra and its Applications 36: 73-88 (1984), for various symmetric zero patterns in $A^{-1}$. Given any of these formulae, we consider the problem of finding all (asymmetric) zero patterns of $A^{-1}$ for which the formula holds. The solution of this problem involves the notion of a directed spanning tree of the intersection graph of a collection of node sets each of which is an index set of one of the principal minors appearing in $p$.

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Linear Characterizations for NP-complete and Number Complete Problems

The problem of computing the number of solutions to many combinatorial problems is reduced to a linear program in a polynomial number of variables. The construction shows that a complete linear characterization would lead to both $\text{NP = CoNP}$ and $\text{NP = P}$. The construction uses techniques from: S. Ursic, A Linear Characterization of NP-complete Problems, Springer-Verlag Lecture Notes in Computer Science; 7th International Conference on Automated Deduction, ed.: R. E. Shostak, 170 (1984) 80-100. It shows that incomplete linear characterizations lead to imprecise counting. It gives a meaning to the fractional solutions we sometimes obtain when incomplete descriptions of the polytopes are used in linear programs. Known facets of the counting polytopes are boolean symmetric and partially symmetric functions.

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The Cyclic Coloring Problem and Estimation of Sparse Hessian Matrices

Numerical optimization algorithms often require the (symmetric) matrix of second derivatives of some smooth problem function. If this Hessian matrix is large and sparse then estimation by finite differences can be quite attractive since several schemes allow for estimation in relatively few gradient evaluations.

The purpose of this paper is to analyze, from a combinatorial point of view, a class of methods known as substitution methods. We present a concise characterization of such methods in graph-theoretic terms. Using this characterization, we develop a complexity analysis of the general problem and derive a roundoff error bound on the Hessian approximation. Moreover, the graph model immediately reveals procedures to effect the substitution process optimally (i.e., using fewest possible substitutions given the differing directions) in space proportional to the number of nonzeroes in the Hessian matrix.

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A New Public-key Cipher Which Allows Signatures

A block substitution cipher is described which appears to be adequate for computer-implemented signed public-key encryption of messages given in the form of a sequence of binary digits. In this cipher, for a suitably large value of $n$, $n$-blocks of binary digits are identified with elements of the finite field $GF(2^n)$ and plaintext $n$-blocks are replaced by corresponding ciphertext $n$-blocks by using an encoding permutation which is a sparse permutation polynomial of high degree defined on the field $GF(2^n)$.

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Unit-Memory Convolutional Codes as a Mean in Cryptographic Systems

In this paper we show that finding good unit-memory convolutional codes with rates $r/b/n$, $b$ and $n$, integers, is equivalent to solve a Knapsack Problem. For small values of $b$, this knapsack problem is easily solved whereas for large values it is a very difficult one. Since knapsack problems are known to be NP, unit-memory convolutional codes can be considered as good candidates for use in cryptosystems. We show by a simple example how these codes are employed in such cryptographic systems.

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Controllability of Positive Systems

Positive systems are used to represent a wide range of applications for which the state vector is constrained to lie in the nonnegative orthant. We will discuss some implications of the positivity constraint for the purpose of control. The results will be illustrated by examples from pharmacokinetics and chemical process systems.

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Linear Quadratic Regulator Problem under Equivalence Transformation

The control input to minimize the cost functional of an infinite-time linear quadratic regulator (LQR) problem is given by

$$ u = -R^{-1}B^TPx $$

where $x$ is the state vector, $A$ is the system matrix, $B$ is the control matrix, $Q$ and $R$ are the weighting matrices for the state and input respectively, and $P$ is the solution of the algebraic matrix Riccati equation

$$ A^TP + PA - PBR^{-1}B^TP + Q = 0 $$

When the original system is transformed into an equivalent system, i.e., let $x = Tz$, and the weighting matrices for the state $z$ and the input $u$ are defined as $T^TQ$ and $T^TR$, the LQR problem for the equivalent system will be solved as

$$ u = -R^{-1}B^T(Tz) $$

where $k = T^TP$, and $P$ satisfies equation (1). This result provides a convenient means to solve LQR problem for equivalent systems.

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New Numerical Methods for Optimal Control Problems

We present new numerical methods to solve optimal control problems. The basic idea is that the first variation and not a Hamiltonian type method is used. Examples are given which include the non-linear quadratic case.

For problems with "full-rank" our methods which include initial value problems are easy to apply and lead to convergence of order $O(h^2)$. For problems with less than full-rank an augmentation theory is used.

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Numerical Solution of General Linear Quadratic Gaussian Control Problems

A new method is prescribed for the numerical solution of the linear quadratic Gaussian control problem: Minimize

$$ J(x(t), u(t)) = \frac{1}{2} \int_{0}^{\infty} (x(t)^T Q x(t) + u(t)^T R u(t) + x(t)^T S x(t)) + x(t)^T S u(t) dt $$

subject to the constraint $x(t) = A x(t) + B u(t)$, $x(0) = x_0$, where $A, Q \in \mathbb{R}^{n \times n}$, $B, S \in \mathbb{R}^{n \times m}$, $R \in \mathbb{R}^{m \times m}$, $Q$ is hermitian positive semidefinite and $R$ is hermitian positive definite. The method is based on the computation of an invariant subspace of the hermitian pencil:

$$ \begin{bmatrix} A & B \\ B^T & S^T \end{bmatrix} - \lambda \begin{bmatrix} 0 & I \\ -I & 0 \end{bmatrix} $$

Full use of the symmetry is made and the method is also applicable if $R$ is almost singular. The connection to other algorithms for the solution of this problem is discussed.

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There are three eigenvalue assignment state feedback design algorithms ([1] Miminis & Paige, 1982; Int. J. Contr., [2] Tzou, 1983, A.C.C.; [3] Petkov et al., 1984, IEEE Trans. AC), all using Hessenberg form system matrices and orthogonal operations, and all claimed to have good numerical property. However, only algorithm 3 is claimed to be numerically stable using Wilkinson's analysis about deflation techniques. This note is to compare the algorithms 2 and 3 using a numerical example since the algorithm 2, which uses Kyman's method, is also very stable according to Wilkinson's analysis. The example used is an ill-conditioned 20x20 matrix of eigenvalues 1 to 20.

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Roth's Theorem on the Matrix Equation AX + BY = C

Let R be a principal ideal domain, and let A, B, C be M(R). Using determinantal divisors, W.E. Roth (Proc. Amer. Math. Soc. 3 (1952), 392-396) showed that the matrix equation \( AX + BY = C \) is solvable in \( M(R) \) if and only if the matrices \( \begin{pmatrix} A & C \\ B & 0 \end{pmatrix} \) and \( \begin{pmatrix} A & 0 \\ 0 & B \end{pmatrix} \) are equivalent over \( R \). A new proof is now given that avoids determinantal divisors, using the local approach to matrix equivalence given in Lin. Alg. Appl. 16 (1977), 221-232.

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Numerical Example of State Feedback Design Algorithms

The main purpose of this work is to establish necessary and sufficient conditions for the existence of solutions of matrix equations such as the Lyapunov and Riccati and higher order Riccati type matrix equations. The elements of the coefficient matrices belong to the polynomial domain \( \mathbb{F}[\theta_1, \theta_2, \ldots, \theta_n] \) of polynomials in \( \theta_1, \theta_2, \ldots, \theta_n \) with coefficients belonging to the field \( \mathbb{F} \). Use is made of various generalized inverses of matrices over \( \mathbb{F}[\theta_1, \theta_2, \ldots, \theta_n] \) to establish algorithms for obtaining solutions to such matrix equations which have applications in systems theory, control theory and elsewhere. Results obtained extend earlier results of W. E. Roth and others.

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Similarity Over \( F[x] \)

Let \( F \) be an arbitrary field having prime subfield \( F_p \), \( p \) either zero or a prime, and let A be an \( n \times n \) matrix of arbitrary rank over the polynomial domain \( F[x] \). Whenever \( A \) lies in a subfield \( M \) of the complete matrix ring \( (F[x])_n \) and \( M \) is a finite simple extension of its scalar interior, then the similarity invariants of \( A \) over the field \( F(x) \) of rational functions lie over \( F \), i.e., the rational canonical form \( C \) of \( A \) over \( F(x) \) satisfies \( C \in (F) \). Moreover, unless the field \( M \) is intrinsically irregular, it is shown that \( A \) is similar to \( C \) over \( F(x) \) whenever \( [F:F] < \). In particular, if \( F = \mathbb{Q} \) or \( F = GF(p) \), then \( A \) is similar over \( F(x) \) to its rational canonical form over \( F(x) \). The conditions on \( M \) are equivalent to conditions on the canonical factorization of the minimal polynomial of \( A \) over \( F \). Matrices \( A \) satisfying these conditions have been constructively characterized.

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Realizations of Rational Matrices

A matrix W of rational numbers can be expressed in the form \( W = C(P-N)^{-1}B + D \) such that all matrices involved are integer matrices, the elementary divisors of P are primes and N is nilpotent. An analogon to the state space isomorphism theorem in linear system theory is proved. Duality of finite abelian groups and the concept of straight bases lead to a Jordan factorization of integer matrices.

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Sparse Projections in Karmarkar's Linear Programming Algorithm

The computationally expensive part of Karmarkar's linear programming algorithm is the projection of the cost vector onto null space of the constraint matrix. This projection must be (approximately) orthogonal with respect to the inner product determined by a diagonal matrix that is updated each iteration. Although the projection operator itself may change substantially during the course of the algorithm, the sparsity pattern behind it remains the same, and it may be worthwhile to spend some time on symbolic analysis at the beginning of the algorithm. For example, it may be worthwhile to choose a subset of the constraint matrix columns to be included in a sparse Cholesky or QR factorization (in the George-Reid style) that then serves as a preconditioner for conjugate gradient iterations. This talk discusses some of the heuristics we are trying and presents some preliminary computational experience.

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A Fast but Unstable Orthogonal Triangularization Technique for Toeplitz Matrices

D. Sweet's clever QR-decomposition algorithm for Toeplitz matrices is considered. It requires only \( O(n^2) \) flos to factor an \( n \times n \) matrix. We show why this novel algorithm is numerically unsound, and suggest techniques for its stabilization.

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The Solution of Banded Systems in Block Tridiagonal Form Using Odd-Even Reduction

The odd-even reduction algorithm is well known for the solution of block tridiagonal systems arising from finite difference problems. An important property is that by performing operations in parallel, the size of the system is reduced to half the previous. In previous work, the algorithm had been extended to give a greater reduction factor for special cases, and had been extended to banded systems in general.

We show that both these extensions are applications of odd-even reduction on block tridiagonal systems with suitably defined blocks. Proceeding in this direction, we define two block parameters which determine the reduction factor and the resulting degree of parallelism in the calculations. Through a suitable definition of these parameters, a solution algorithm for banded systems may be mapped onto a range of architectures which have little to massive parallelism. Accurate operation counts are given and computational results given for tridiagonal and pentadiagonal systems on the Cray 1-S.

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Storage Versus RUN-TIME Step Preserving Programs

Upper triangular unipotent matrices over a ring preserve the composition series \(<Ci>\) and induce the identity on \(<Ci/Ci+1>\). Two types of programs computing in stages \(M=1\) to \(n\) which preserve the quotient homomorphisms on \(<Ci/Ci+M>\) are given. One type requires duplicate storage but has RUN-TIME \(O(n^3)\) whereas the other type works in place but has RUN-TIME \(O(2^n)\). It is proved that the storage versus RUN-TIME relationship must hold for programs doing matrix inversion. The corresponding property is conjectured for programs which multiply matrices.

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MAX and the Singular Value Decomposition

The Floating Point Systems FPS-164/MAX is a scientific computer capable of a peak throughput of 341 megaflops. Up to 124 vector operations can be performed concurrently, obtaining high performance on large problems of numerical linear algebra. This paper describes the computational structure of the FPS-164/MAX, and documents work in progress towards highly efficient singular value decomposition routines in the FPS-164/MAX environment.

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A14
The QR and Inverse QR Algorithms for Unitary Hessenberg Matrices.

Let H be a unitary right Hessenberg matrix with positive subdiagonal elements. Using the "Schrödinger parameterization" of H, and the shift strategy of Euler and Huang, the QR algorithm can be implemented to find the spectrum of H, and the weights of the associated Gauss-Szegő quadrature formula, to machine precision, in \(O(n^3)\) operations. The spectrum of \(H^1\), strictly interlaces, on the unit circle, that of \(H\), obtained from \(H\) by negating the first row. The corresponding inverse problems will be treated by the "inverse QR algorithm".

More generally, the forward algorithm can be used to find zeros of Szegő polynomials.

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On Symplectic QR Like Methods

In several applications one has to solve the matrix eigenvalue problem \(Mx = \lambda x\), where \(M\) is a \(2n \times 2n\) matrix with one of the following properties: for \(J = [J, J^T]\), \(J\) the \(n \times n\) identity, \(JM\) is Hermitian, symmetric, skew-Hermitian or skew-symmetric. Similarity transformations with symplectic matrices \(S\), i.e. with matrices \(S\) for which \(S^*JS = J\) or \(SJS = J\), respectively, would preserve this special structure of \(M\). Conditions are given under which a QR like method using symplectic transformations can be derived. It is shown why it is in general not possible to work with symplectic matrices which in addition are unitary or orthogonal. Connections with some known symplectic methods are pointed out.

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Basic Linear Algebra Modules for a Concurrent Computing Environment with IEEE Floating Point Arithmetic

IEEE Floating Point Arithmetic relaxes many of the programming constraints previously required to avoid the side-effects of arithmetic exceptions, particularly underflow, for matrix computations. However, the requirement for a minimal operating system on each node of a concurrent computing system reveals the need for floating point arithmetic exception handlers and associated communication primitives to access them.

The exception handlers and communication primitives designed and used on an Intel 8086/87 or 80286/287 microprocessor based concurrent computing system will be described.

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Analogue of Givens and Lanczos methods for Pseudosymmetric Matrices

A pseudosymmetric matrix \(A\) is defined as \(A = B^TJ\), where \(J = \text{diag}(1,1)\) and \(B = B^T\).

An analogue of Givens method for pseudosymmetric matrices is discussed as described in (1). The paper then shows how Lanczos method (2, p.388-391) for reducing a general matrix to a tridiagonal matrix has a relatively simple form for pseudosymmetric matrices. A comparison of the special cases where these two methods break down is discussed.

REFERENCE


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Optimal choice of truncation level for truncated SVD for linear ill-posed problems

We apply the truncated singular value decomposition to solve linear ill-posed problems when the data are noisy. We define an optimal truncation level and apply a generalization of cross validation to choose an estimate for this optimal truncation level which depends on the data. Convergence rates and an example will be discussed.

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Resolvent bounds and eigenvalue estimates' error bounds

Majorants and accompanying norm bounds are found for the resolvent of a matrix on a closed curve consisting of segments of circles. These bounds are employed to transform residual norms into error bounds for an eigenvalue estimate close to a simple isolated eigenvalue and to count the number of eigenvalues contained in the curve.

A natural bound is found for the \(L_\infty\) norm for the resolvent on a curve around a component of the Gershgorin Disk set. This norm bound is calculated in \(n^2\) squared operations. Majorants are also found for the resolvent of a matrix close to a cluster of eigenvalue approximations that have been exposed through an application of the QR algorithm.

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Estimating the SOR Extrapolation Parameter

Effective use of any of a family of Successive OverRelaxation (SOR) methods requires estimation of an overrelaxation parameter. Several procedures have been used for adaptive refinement of an initial estimate. These often involve preliminary computation with parameters that are less than optimum. When insufficient iterations are performed between updates, a disastrous "creep" toward an erroneous value of two has been observed. In some cases, iteration for accurate update of the overrelaxation parameter consumes significant computation time. Some popular modern iteration programs use SOR as a component of a two-level procedure in which the SOR iteration is interrupted cyclically with a coarse-grid computation or a conjugate-gradient iteration. One variant involves periodic correction of the SOR iterate with a low-order polynomial correction. This reduces sensitivity to the overrelaxation parameter and in some cases reduces computation time by an order of magnitude. A procedure has been devised for using the polynomial correction equations to refine the extrapolation parameter for the next SOR cycle. Nearly-optimum parameters may be computed along with reasonable estimates of their accuracy. Theory and numerical results will be described for this new procedure.

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Singularity in Isospectral Flows

The Toda flow and its generalizations are related to the QR matrix decomposition and the QR algorithm. An analogous class of flows, the class of LU flows, is based on the LU matrix decomposition. These flows, unlike the QR flows, can have singularities in their solutions. We will examine these singularities and relate them to various subspace conditions, the existence of LU decompositions, and the LR eigenvalue algorithm.

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Transforming residual bounds into error bounds for eigenvalue estimates

Often researchers associate a pessimistic n-th root bound limitation with the use of residual norms for determining error bounds for eigenvalue estimates. For nonzero eigenvalues, we demonstrate that this pessimistic n can be replaced with the smallest integer greater than M/n where M is the Frobenius norm of the matrix. Applications are made to matrices generated by the QR algorithm to count the number of actual eigenvalues near a cluster of eigenvalue estimates and to create a function, locally valid, which maps residual norms onto error bounds for eigenvalue estimates.

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Group-invariant Covariance Models

A group-invariant covariance model may be described as a family of covariance matrices that remain invariant under the action of a finite group of orthogonal transformations. S. Andersson, H. Bruns and S.T. Jensen have noted that all classical statistical hypothesis-testing problems for the covariance structure of a multivariate normal population reduce to that of testing one group-invariant model against another. We review the theory of such models and present several examples to illustrate their main features: maximum likelihood and least squares estimators coincide, and hypothesis-testing problems admit ANOVA-like decompositions.

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Identifying Rank-Influential Groups of Observations in Generalized Linear Regression Models

When fitting a generalized linear regression model, deleting a small group of observations from the data may decrease the precision of parameter estimates substantially or worse, render certain parameters inestimable. These effects occur when the deletion of the group reduces the rank of the design matrix for the model. We present theory and methods for identifying such rank-influential groups of observations.

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The Algebra of Hyperboloids of Revolution

If we change the sign of p \leq m columns (or rows) of a m \times m positive definite symmetric matrix A, the resultant matrix B has p negative eigenvalues. We will give systems of inequalities for the eigenvalues of B and of the matrix obtained from B by deleting one row and column. To obtain these, we first develop characterizations of the eigenvalues of B which are analogous to the minimum-maximum properties of the eigenvalues of a symmetric A, i.e. the Courant-Fischer theorem. These results arose from studying probability distributions on the hyperboloid of revolution

\[ x_1^2 + \ldots + x_{m-p+1}^2 - \ldots - x_m^2 = 1. \]

By contrast, the familiar results are associated with the sphere

\[ x_1^2 + \ldots + x_m^2 = 1. \]

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CONTRIBUTED PAPERS

Multivariate and Other Forms of the Pitman-Welch Permutation Test for Randomized Blocks

The objective of this paper is three-fold. First, the Pitman-Welch permutation test for the randomized blocks design is extended for analysis of multiple dependent variables. Next, this extension is shown to subsume the analysis of a design with a single dichotomous dependent variable. Cochran's test for homogeneity of proportions for multiple dichotomous variables, and McNemar's test for two correlated proportions are shown to be special cases. Last, the univariate design is also shown to subsume special cases, including Friedman's ranked data test and Fisher's randomization test for paired observations.

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The Early Use of Matrix Diagonal Increments in Statistical Problems

The early motivation for and development of diagonal increments to ease matrix inversion in least squares problems is discussed. It is noted that this diagonal incrementation evolved from three major directions: modification of methodology in non-linear least squares, additional information in linear regression, and improvement of the numerical condition of a matrix. The interplay among these factors, and the advent of ridge regression, are considered in an historical framework.

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Estimating the Parameters of a Positive Semidefinite Quadratic Form Using a Cholesky Decomposition

Maximum likelihood estimates of the parameters of a p.s.d. matrix B are obtained by reparameterization to the form B=C^2, where C is an upper triangular matrix. The parameter matrix C is estimated using a Newton-Raphson search routine with variable step size. This procedure is a substantial improvement over the algorithm previously reported at the 1st SIAM Conference. The new algorithm is presented along with procedures for generating start values, imposing constraints, determining the rank of B, and developing standard errors of the estimates in B. We also deal with the problem that the empirical information (Hessian) matrix may not be p.d. and show that negative pivots should be treated separately from zero-valued pivots. Examples will be provided.

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Newton-Hankel and Newton-Toeplitz Matrices: Theory and Applications

Certain generalizations of Toeplitz and Hankel matrices, arising from the Hermite rational interpolation problem, are shown to be of interest in other contexts. As in the classical case, they provide an important connection between orthogonal polynomials, interpolation problems, control theory, and other topics. Some computational aspects of working with these matrices are also discussed.

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A Stability Analysis of Incomplete LU Factorizations

The combination of iterative methods with preconditionings based on incomplete LU factorizations constitutes an effective class of methods for solving the sparse linear systems arising from the discretization of elliptic partial differential equations. We show that there are some settings in which the incomplete LU preconditioners are not effective, and we demonstrate that their poor performance is due to numerical instability. Our analysis consists of an analytic and numerical study of a sample two-dimensional elliptic problem discretized by several finite difference schemes.
The Linear Algebra Challenge of Globally Convergent Homotopy Methods

Traditionally nonlinear systems of equations have been solved by locally convergent iterative techniques, with global algorithms considered the realm of topologists or impractical. Recent theoretical work has developed some powerful global theory, and some of the ensuing algorithms have been shown to be indeed practical. This talk will survey the unique numerical linear algebra problems of probability one globally convergent homotopy algorithms—the theory, algorithms and their implementation, and applications ranging from image processing to fluid mechanics. The software package HOMPACK will also be discussed.

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An Efficient Method for Determining Symbolically the Characteristic Polynomial of a Matrix.

A method is presented that determines the characteristic polynomial of a real matrix $A$ of order $n$. The result is presented as the product of powers of $\lambda$ multiplied by real number coefficients. The computation time involved is approximately $5n^2t_1 + 6n^3t_2/6$ seconds, where $t_1$ is the arithmetic time to multiply or divide two numbers, and $t_2$ is the arithmetic time to add or subtract two numbers. This compares favorably to other methods. The method is well behaved since most degenerate cases simplify and speed the solution. If the characteristic polynomial is ill-conditioned whilst $A$ is well behaved, however, the method should be avoided.

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Design of Extended Model Following Servo Controller

A servo controller is designed so that the response of the plant is as close as possible to that of a reference model system, which has an arbitrary input from a trajectory generating model. The controller is named "the extended model following servo" and its control law is determined by discrete optimization.

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An Application of the Singular Value Decomposition to Manuipulability and Sensitivity of Industrial Robots

In designing and evaluating industrial robots, it is important to find optimal postures and locate optimum points in the workspace for the anticipated tasks. In the talk the singular value decomposition and the perturbation analysis are applied to the Jacobian of robot kinematics; the condition number of the Jacobian is proposed to be a measure of the "weaves" to degeneracy. Then qualitative measures called "manipulability" and "sensitivity" are proposed. Some properties of proposed measures are investigated and the relation between these measures are investigated. Optimal postures of various types of industrial robots are obtained.

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Statistical Analysis of the Effects of Matrix Perturbations in Some Least Squares Problems

A central problem in many signal processing techniques is the solution of a system of linear equations. The coefficients are functions of observed data. We examine two such problems: (1) frequency estimation by linear prediction, and (2) adaptive detection of a signal in Gaussian noise. Low-rank approximation of the coefficient matrix in solving systems of linear equations has been shown to be useful in both problems. We present a statistical analysis that relates the accuracy of the frequency estimate in problem 1 and the detector performance in problem 2, to the perturbations in the observed data and a suitably defined coefficient matrix.

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Linear Algebra in Modern Signal Processing

This tutorial presentation surveys the role of linear algebra in modern signal processing. The discussion begins with the conceptual role of linear algebra ideas and methods in the formulation of signal processing methods for such representative tasks as spectrum analysis, beamforming, and data compression. Next, the numerical stability of matrix algorithms needed for several types of signal processing computations is discussed. Finally, parallel algorithms and architectures for matrix computations are surveyed, with emphasis on systolic and related cellular architectures.

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ON CERTAIN STRICTLY DISSIPATIVE MATRICES

Let \( A = H + iK \) be a strictly dissipative matrix such that \( H \) is semi-definite positive. Let \( \alpha_1 \geq \ldots \geq \alpha_n \) and \( \gamma_1 \geq \ldots \geq \gamma_n \) be the eigenvalues of \( H \) and \( K \), respectively. We show that

\[
\min_{j=1}^{n} \left( |\alpha_j + \gamma_{(j)}| \right) \leq \det(A) \leq \max_{j=1}^{n} \left( |\alpha_j + \gamma_{(j)}| \right),
\]

where \( \alpha \in S_n \), \( S_n \) the symmetric group of degree \( n \).

If \( \alpha_1 \geq \ldots \geq \alpha_n \) and \( \gamma_1 \geq \ldots \geq \gamma_n \), then

\[
\min_{j=1}^{n} \left( \arg(\alpha_j + \gamma_{(j)}) \right) \leq \arg(\det(A)) \leq \max_{j=1}^{n} \left( \arg(\alpha_j + \gamma_{(j)}) \right).
\]

We present an example showing that the set of values attained by the determinant of a strictly dissipative matrix, whose real and imaginary parts have fixed eigenvalues, may not be simply connected.

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A Characterization of Inertia-preserving Secant Updates

A characterization is given for scale-invariant inertia-preserving secant updates expressible in real product form \((A_k = FA_k F^T + F^T a_k r_k r_k F^T)\). This not only includes the BFGS and DFP updates but also provides distinct updates that may be of utility in resolving saddle point problems. The constructive nature of proof provides a new parameterized family of updates.

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Some New Efficient Algorithms Related to Cayley-Hamilton Theorem

The evaluation of the roots of a polynomial \( p(x) \) of degree \( n \) is performed by the power and shifted inverse power methods applied to the companion matrix. This is reduced to the evaluation of \( x^m \mod p(x) \) for large \( K \) so that all roots of \( p(x) \) are computed to \( K \) correct digits very fast, involving \( O(n \log n \log K) \) sequential arithmetic operations or \( O(\log(Kn)) \) parallel steps, \( n^{\frac{K}{2}} \) processors, or \( O(\log n \log K) \) steps, \( n \) processors, provided that the roots are not clustered. If they are clustered, running time increases \( n/\log n \) times (in real case) and \( n^2/\log n \) times (in general case). Some other similar algorithms evaluate a matrix polynomial \( q(X) \) of degree \( K \), \( X \) is an \( n \times n \) matrix, in \( O(K \log K n^{2.5}) \) sequential arithmetic operations or \( O(\log^2 Kn) \) parallel steps with \( K n^{2.5} \) processors. The number of processors can be reduced to \( K n^3 \) if \( q(X) \) is to be computed with arbitrary precision rather than exactly or if \( O(\log n \log (Kn)) \) steps are allowed to be involved.

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A Parallel Method for the Generalized Eigenvalue Problem

We present a parallel method to solve the generalized eigenvalue problem on a linear array of processors, each connected to their nearest neighbors and operating synchronously. We also include a wraparound connection from end to end. Our method is based on the well-known QZ algorithm of Maier and Stewart, which simulta-
neously reduces two nxm matrices to upper triangular form by orthogonal or unitary transformations. We show how this algorithm may be partitioned and distributed over n! processors, achieving a speed-up over the serial algorithm of O(n). We use the concept of windows to describe the action of each processor at each step. We show how to incorporate single shifts, and how to apply orthogonal plane rotations on either side of a matrix without the need to transpose the matrix itself.

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Design of and Experience with Frontal and Skyline Solvers for Vector and Parallel Processing of Finite Element Codes

Frontal and skyline methods are efficient means for Gauss elimination of large systems of finite element equations. We discuss modifications to Hogg's (1976) frontal algorithm for nonsymmetric systems which: (1) enhance vectorization on a Cray 1; (2) achieve high-level parallelism on an EXLSI 6400 via nested dissection of a computational domain (e.g., a 2-D test code runs on a four processor EXLSI with 55-95% utilization of each processor, even though frontwidth is at most 18). The parallel algorithm is readily extended to out-of-core solution and to as many processors as there are elements in the mesh. We also discuss vectorization of Hasbani & Engleman's (1979) nonsymmetric skyline solver. We compare performance of the two solvers on the Cray.

On Homogeneous Algebras

A homogeneous algebra is a finite-dimensional algebra whose automorphism group acts transitively on the one-dimensional subspaces. R^3 with the usual vector cross product is the best known example. The talk will survey known results about homogeneous algebras, including the authors' classification of all such algebras of dimension less than or equal to 4. The existence of a homogeneous algebra of dimension n can be studied by considering subspaces of n \times n matrices all of whose members are projectively similar.

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Direct Parallel Algorithms for Exact Solution of Sparse Symmetric Linear Systems

A direct parallel algorithm for exact solution of a sparse n \times n real symmetric (or Hermitian) linear system A\textbf{x} = \textbf{b} is presented. If the graph \textbf{G}(A) = (\textbf{V}, \textbf{E}) (which has n vertices and an edge for each nonzero entry) is \textbf{s}(n)-separable, then the algorithm requires \textbf{O}(\log n \log \textbf{s}(\textbf{n}))^2 \textbf{time} and | \textbf{E} | + \textbf{M}(\textbf{s}(\textbf{n}))\textbf{Vs}(\textbf{n}) \text{ processors. The algorithm computes a special factorization of A so that solving another linear system A\textbf{x} = \textbf{b}' with the same A requires only } \textbf{O}(\log n \log \textbf{s}(\textbf{n})) \text{ time and } | \textbf{E} | + \textbf{s}(\textbf{n}))^2 \text{ processors.}

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A Program for the Parallel Computation of the Schur Decomposition of an Arbitrary Matrix

We present a working program, which, given a square matrix A of order n, finds a unitary matrix U, such that UAU is upper triangular to working accuracy. U is formed as a product of plane rotations. The choice of pivot planes for these rotations is an extension of the Brent-Luk schemata. Hence, the program will run on an (n/2)-square array of processors in \textbf{O}(\textbf{n}) \textbf{time}. We present motivation for the algorithm, as well as experimental results. However, no convergence proof is given.

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Prolegomena to Numerical Homological Algebra

Recent work by M. L. J. Hautus shows that the solvability of a regulator problem depends on the splitting of an exact sequence

\[ 0 \rightarrow \mathbf{Z} \rightarrow \mathbf{H} \rightarrow \mathbf{X} \rightarrow 0, \]

where \( \mathbf{Z} \) is the multivariable zero module of the system to be regulated, \( \mathbf{X} \) is the pole module of an external disturbance generator, and \( \mathbf{H} \) is defined by various connection matrices. This result is equivalent to some detailed results on matrix equations of the form \( \mathbf{A} \mathbf{T} - \mathbf{T} \mathbf{B} = \mathbf{C} \).

Standard homological algebra dictates that Ext(\( (x, \mathbf{Z}) \) is "generically" zero for the modules considered here. That is, classical results give no insight into sequences which are split in a "badly conditioned" or "non-robust" way. This preliminary report introduces numerical considerations into the study of module deformations and groups of module extensions.

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Algorithms For Polynomial Matrix Operations

Among the polynomial matrix operations, the inverse and division are probably the most difficult ones. In this paper, we present some algorithms for finding the inverses of unimodular matrices and other invertible polynomial matrices as well as the division of polynomial matrices. The polynomial matrices are expanded by s-powers, and the algorithms are based on equating the coefficient matrices of same s-powers. The algorithms are easy to program and simpler than the previous ones. There is no substantial obstacle to extend the algorithms into the case where more than one variables are involved.

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On the Computation of State Transition Matrices

The infinite series is often used to compute the state transition matrix of a linear system

\[ X = AX + BU \]

The advantages are that it is not necessary to compute the eigenvalues of A, and is easy for programming. However, when the eigenvalues of A have large negative real parts, numerical errors caused by smearing occur for large t. Smearing is the loss of significant digits due to large intermediate sums in the computation of the sum of a series when computed in floating-point arithmetic. To avoid this situation, an alternate algorithm is proposed:

1. Compute \( e^{-A}t \) using the infinite series.
2. Evaluate \( e^{At} = (e^{-A})^{-1} \).

The existence of \( e^{-At} \) is guaranteed since \( e^{At} \) is nonsingular for all t.

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Approximate Linear Realization from Finite Time-Series Data

A scheme for modeling finite sequences of multivariate time-series data in the form of linear, discrete-time systems is presented. The resulting state space model can, for example, be used for analyzing dynamic behavior or forecasting purposes. The approach combines the ideas of approximate balanced realization and a recently suggested realization algorithm for finite sequences of impulse responses, both developed in system theory. Special attention will be given to the problem of initial state determination. The presentation will conclude with an illustrative application of the scheme suggested.

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Using Symplectic Structure in Algorithms for Solving the Discrete Riccati Equation

Solutions of the discrete Riccati equation are associated with invariant subspaces of symplectic matrices and deflating subspaces of symplectic matrix pencils. Symplectic matrices have a rich variety of elementary symplectic factors. We describe some of these factors and suggest ways in which numerical algorithms can preserve and exploit them.

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The Sensitivity of the Stable, Non-negative Definite Lyapunov Equation

A priori and posteriori error bounds for the stable matrix Lyapunov equation

\[ A^* + HA = -W \]

are derived, where A is an N x N stable matrix (i.e., the real part of all the eigenvalues of A are less than zero) and the pair (A, W) is controllable. These bounds are counterparts of the usual error bounds for the solutions of linear systems. As a consequence of these bounds, condition number values are proposed and three distinct qualitative estimates are identified that predict large condition numbers. Large condition numbers will occur when the ratio of a selected eigenvalue of A and A plus a perturbation is large or when W is positive definite and ill conditioned with respect to inversion or when the maximum eigenvalue of the Hermitian part of A is a large positive number. These bounds are less conservative than those currently available.

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Matrix-Free Methods for Stiff Systems of ODE's

When integrating stiff systems of ODE's by BDF methods, the resulting nonlinear algebraic system is usually solved by a modified-Newton method and a suitable linear system algorithm. Instead, Newton's method (unmodified) coupled with an iterative linear system method is substituted. The latter is a projection method called the Incomplete Orthogonalization Method (IOM). A form of IOM, which requires no matrix storage whatever and with scaling included to enhance robustness, will be discussed in the
setting of Inexact Newton Methods. Tests on several stiff problems, with up to 16000 unknowns, show the method to be quite effective, and much more economical in both computational cost and storage than standard solution techniques.

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**Linear Algebra in Phase Space Analysis of Ordinary Differential Equations**

Phase space topology of a system of ordinary differential equations depends upon location and classification by local behavior of critical points, by solving the algebraic eigenproblem for the Jacobian of the system, evaluated at each critical point. A basis for the plane of real oscillation associated with a pair of complex conjugate eigenvalues, i.e., the real and imaginary parts of the associated complex conjugate eigenvectors, taken as two real vectors. Two illustrative applications are from system dynamics (a business example from Forrester) and from sociodynamics (system analysis of human relations), wherein classification depends upon higher order terms, analyzed by linear algebra, including a linear transformation to the above basis.

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**Solution Of Linear Systems Of Equations Of Saddle Point Type By Domain Decomposition Techniques.**

Systems of linear equations of saddle point type arise in different applications such as mixed formulation of self-adjoint partial differential equations, Stokes equations, and structural analysis. An iterative method of SOR type, that needs only a local calculation of the null space of the constraints is presented.

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**Infinite Matrices and Some Applications**

In this survey, we discuss applications of infinite matrix techniques to linear systems. In mathematical formulation of physical problems and their solutions, infinite matrices arise more naturally than finite matrices. For an infinite matrix A, the following cases are considered. Existence, uniqueness and boundedness of solutions are established for A\(x = b\) and \((dx/dt) = Ax\). Approximation by finite truncation is also obtained, complete with error bounds. Furthermore, we give intervals for eigenvalues of \(A\) \& \(\lambda\) and of the differential system \(-y'' + f(x)y = \lambda y\), \(y(0) = y(\omega) = 0\). In the latter case and in \(-y'' + f(x)y = g(x)\), \(y(0) = y(\omega) = 0\), finite difference techniques are used. We illustrate our results by considering the Mathieu equation and the Schrödinger wave equation.

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**MAXIMUM CHORDAL SUBGRAPHS OF GRID GRAPHS**

Recently, Dearing, Shier, and Warner developed a polynomial-time algorithm for finding a maximal chordal subgraph of an arbitrary undirected graph. The complexity of finding a maximum chordal subgraph is an open problem in general. However, this paper will present bounds and algorithms for determining maximum chordal subgraphs of grid graphs associated with the discretization of PDE's on quadrangular domains. The bounds and algorithms generalize to the graphs associated with higher order methods, e.g., the Rayleigh-Ritz-Galerkin method with tensor product B-splines.

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**On the Use of Electrical Network Equations to Draw Graphs in the Plane**

W.T. Tutte, "How to draw a graph", Proc. London Math. Soc. 13 (1963) implies that a convex, straight line embedding of a sufficiently connected planar graph is obtained by solving node voltage electrical network equations in 2 dimensions. Imagine a "spider web" whose threads are linear springs with zero unstressed length. Different embeddings result from different relative values of the positive spring constants. We find for all graphs and for n dimensions that when any one spring constant is changed, each vertex can only move parallel to that spring. A matrix tree theorem is then applied to give combinatorial conditions for the determination of the sign of each vertex's motion. We investigate the magnitudes of the changes and consider possible applications to heuristics for planar or non-planar graph layout problems.

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Spectra of the Extended de Bruijn-Goods Graphs

The de Bruijn-Goods graphs are extended. It is shown that the spectra of the extended de Bruijn-Goods graphs are all zeros except one which is index.

The above results are applied to the calculation of the numbers of the maximal circuits for the extended de Bruijn-Goods of order n.

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Nullities of Submatrices of Generalized Inverses

Let \( (a, a^c) \) and \( (b, b^c) \) be partitions of the lists \( (1, \ldots, m) \) and \( (1, \ldots, n) \), respectively. If \( m \geq n \) and \( A \in \mathbb{R}^{m \times n} \) is invertible with inverse \( A^{-1} \in \mathbb{R}^{n \times m} \), then it is known that the submatrices \( A(a, b) \) and \( A^{-1}(b^c, a^c) \) have equal row nullities and equal column nullities. [W. H. Gustafson, A note on matrix inversion, Linear Algebra Appl. 57: 71-73 (1984).] In this paper we consider \( A \in \mathbb{C}^{m \times n} \) with Moore-Penrose inverse \( A^+ \in \mathbb{C}^{n \times m} \) and provide relationships between the nullities of \( A(a, b) \) and \( A^+(b^c, a^c) \).

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The Second Immanant and the Moment Sum of a Graph

Let \( G \) be a graph on \( n \) vertices affording a Laplacian matrix \( L(G) \). If \( d \) is the immanant corresponding to the partition \( n = 2 + 1 \ldots + 1 \), then the coefficient of \( x \) in \( d^2(xL + L(G)) \) is the 'moment sum' of \( G \).

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On the Null Space of a Subspace of Singular Matrices

A classical result of Dieudonné is generalized. We prove: If \( W \) is a subspace of \( \mathbb{R}^{m \times n} \) matrices of dimension \( m \times n \times k \), and \( W \) contains no matrix of rank \( m \), and if \( 0 \leq k \leq n - 3 \) or \( m = n \) then there exists a nonzero \( m \)-vector \( x \) such that \( x^T A x = 0 \) for all \( A \in W \).

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Null Vectors and Singularity of Acyclic Matrices

Let \( A \) be an \( n \times n \) complex matrix which is combinatorially symmetric. Let \( G \) be the undirected graph with vertex set \( V(G) = \{v\} \) and edge set \( E(G) = \{e_{ij} : a_{ij} \neq 0 \} \). We define the class of A-closed subsets of \( V(G) \), and a special A-closed set \( Q(A) \) (determined inductively using certain low-order principal minors of \( A \)).

Theorem 1. For every null-vector \( x \) of \( A \), \( Q(A) \subseteq \omega(x) \), where \( \omega(x) \) is the set of indices of zero entries of \( x \). Also, \( A \) is nonsingular iff \( Q(A) = \{v\} \).

Theorem 2. Let \( A \) be irreducible and acyclic, with all \( a_{ii} = 0 \). Then, for every A-closed set \( \omega \), there is a null-vector \( x \) of \( A \) with \( \omega(x) = \omega \). Thus \( A \) is nonsingular iff \( \omega(x) = \omega \) is the only A-closed set.

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The Second Immanant and the Moment Sum of a Graph

A classical result of Dieudonné is generalized. We prove: If \( W \) is a subspace of \( \mathbb{R}^{m \times n} \) matrices of dimension \( m \times n \times k \), and \( W \) contains no matrix of rank \( m \), and if \( 0 \leq k \leq n - 3 \) or \( m = n \) then there exists a nonzero \( m \)-vector \( x \) such that \( x^T A x = 0 \) for all \( A \in W \).

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A Polynomially Bounded Pivoting Algorithm for a Linear Complementarity Problem With a Quasi-Diagonally Dominant Matrix

In this talk, we describe a parametric principal pivoting algorithm for "solving" a linear complementarity problem defined by an \( n \times n \) quasi-diagonally dominant matrix. The algorithm will in \( O(n) \) time, either (i) conclude that the problem has no complementary solution, or (ii) computes a solution if it exists.
Sensitivity of the Stationary Distribution Vector for an Ergodic Markov Chain

Stationary distribution vectors \( p^o \) for Markov chains with associated transition matrices \( T \) are important in the analysis of many models in the mathematical sciences, such as queuing networks, input-output economic models and compartmental tracer analysis models. The purpose of this talk is to provide insight into the sensitivity of \( p^o \) to perturbations in the transition probabilities of \( T \) and to understand some of the difficulties in computing an accurate \( p^o \). The group inverse of \( I-T \) is shown to be of fundamental importance in understanding sensitivity or conditioning of \( p^o \). Ecological examples are given. A new stable algorithm for calculating the group inverse is described.

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K-part iterative solutions to Linear Systems

The solution of the linear system \((I-B)x=b\) is sought by considering iterative schemes of the form

\[
y_m = B^{-1}(C \cdot p_i \cdot y_{m-1}) + \sum_{i=1}^{k} q_i \cdot y_{m-1} \cdot a_i + w_b.
\]

The convergence of \( y_m \) to \( x \) is shown to depend on \( \sigma(B) \in C-n(S_i) \) where

\[
\sigma(a) = (1 - \sum_{i=1}^{k} q_i \cdot a_i) / (\sum_{i=1}^{k} p_i \cdot a_i).
\]

The asymptotic rate of convergence is shown to be the log of the radius of the largest Disc, centered at the origin, which has no preimage points of \( \sigma(a) \).

The material in this talk is contained in a paper which has been tentatively accepted by the SIAM Journal of Numerical Analysis.
CONTRIBUTED PAPERS

has been generated to test the new option. Results show that not only is it fast for most PDE applications, but it performs well on highly nonsymmetric and/or indefinite problems. An implementation scheme appropriate for vector computers will also be presented.

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A Matrix Model of the Population Dynamics of the Pacific Salmon

This deterministic model describes the population's growth rate and age distribution in terms of a general transition matrix and its associated eigenvalues and eigenvectors. The main result is that matrices with this specific form always have exactly four distinct eigenvalues (one positive, one negative, and two complex) with the positive eigenvalue dominant. (Its value determines the maximum sustainable level of harvesting.) Following this general discussion, approximate values of the parameters are supplied for each of several species of salmon. The eigenvalues and eigenvectors of the resulting matrices are then computed numerically.

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Conditions for Asymptotically Exponential Solutions of Linear Difference Equations with Variable Coefficients

In the positive domain, conditions for asymptotically exponential growth (AEG) of the solutions B(i) of a linear difference equation with variable coefficients are explored. If x(i) is the positive solution of the i-th characteristic equation, then rapid convergence of x(i) to x ensures AEG with growth rate x-1 (rapid convergence is the absolute convergence of the series of remainders \( \sum x(i)-x \)). Convergence of x(i) to x is necessary. These conditions are close and are based on a recent result by the author on infinite products of matrices (forthcoming in LAA). These results have applications in population dynamics as they yield weak conditions on time dependent vital rates for AEG of the sequence of births B(i) at period i.

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Centrosymmetric Generalized Wright Model

The eigenvalues of the transition matrix P of the generalized Wright model which allows for mutation, migration and selection are given when P is a centrosymmetric matrix. The speaker will give an example and discuss the proofs.

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Generalized Deflated Block-Elimination

A stable algorithm is presented to solve a nonsingular system of the form

\[
\begin{bmatrix}
A & B \\
C^T & D
\end{bmatrix}
\begin{bmatrix}
x \\
y
\end{bmatrix}
=
\begin{bmatrix}
f \\
g
\end{bmatrix}
\]

where B and C are n by m matrices and the n by n matrix A could be singular with at most s small singular values. The algorithm needs only a solver for A and the solution to an m by m dense linear system. It is, thus, well suited for problems for which A has easily exploitable structures and m is small with respect to n, such as continuation methods, bifurcation problems and constrained optimization.

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Curves on \( S^{n-1} \) That Lead to Eigenvectors or Their Means of a Matrix

This paper discusses a couple of dynamical system on \( S^{n-1} \), each defined in terms of a real square matrix M. The solutions of the system are found to always converge to point which provide essential information about eigenvalues of that matrix M. We show, in particular, how the dynamics of a special flow is analogous to that of the Rayleigh quotient iteration.

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An Assessment of the Customary Linear Model for Tracer Kinetics in a Nonlinear Environment

In a simple nonlinear chemical kinetics model an exact tracer kinetics model is set up in accordance with the standard assumptions and then compared with the customary linear approximation. Certain qualitative differences are shown to exist between the exact and the approximate model. There will also be a report on ongoing work concerning the question whether or not these qualitative differences have practical quantitative consequences.

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Some Applications of Vandermonde Systems

Bjork and Pereya in 1970 developed an efficient algorithm for solving Vandermonde systems. Gustafson utilized this procedure to compute weights for quadrature and interpolation. This presentation will show the application of
Efficient Parallel Matrix Inversion

We present parallel algorithms for \( n \times n \) matrix inversion that are numerically stable and asymptotically efficient (unlike the previously known algorithms). In particular, a quadratically convergent iterative method gives the inverse (within the accuracy \( 2^{-n} \epsilon > 0 \)) of a rational matrix with condition \( < O(n^4) \) in \( O(n \log n) \) time using \( M(n) \) processors, \( M(n) = n^2 \), \( b = n^2 \), the exponent of matrix multiplication, \( n < 25 \). This is the optimum processor bound and a \( \sqrt{n} \) improvement of known processor bounds for polynomial time matrix inversion. It is the first known polynomial time algorithm for matrix inversion that is numerically stable.

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Wide Quotient Trees for Finite Element Problems

SPARSPAK contains an algorithm due to George and Liu that solves sparse symmetric positive definite systems by using a quotient tree partitioning of the matrix. It uses breadth-first search to find quotient trees that tend to be tall and narrow. We suggest a method based on nested dissection that finds short, wide quotient trees. On large two-dimensional finite element grids, these trees induce a finer partition than breadth-first quotient trees. In theory this is more efficient for sufficiently large problems; we present experiments to estimate what "sufficiently large" means.

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Numerical Algorithms for Determining an Invariant Subspace of a Matrix

Numerical algorithms are developed for finding an invariant subspace of a matrix corresponding to an eigenvalue or cluster of eigenvalues. This approach requires that one already has available several eigenvectors and generalized eigenvectors whose span lies close to the desired subspace.

These vectors are used to select a subset of coordinate vectors thereby establishing a partition of the matrix. This partition is used to generate a geometrically convergent sum of matrices whose range coincides with the invariant subspace. Error bounds establishing the accuracy of the approximation of the subspace are also found. Examples are given.

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Parallel Block Jacobi Algorithms

Recently F. T. Luk and R. P. Brent have introduced algorithms for solving symmetric eigenvalue problems with systolic arrays (Cornell CS reports TR83-562 and TR84-629). In this paper we derive and analyze a few block Jacobi algorithms which use systolic arrays to solve diagonal subproblems. This allows the solution of problems which are too large for the systolic array. Parallelism is obtained by solving several subproblems simultaneously. With a mild constraint on the termination criteria of the systolic arrays, it is shown that cyclic algorithms always converge. Without the constraint some pivoting is needed to guarantee convergence. A kind of partial pivoting is shown to be sufficient.

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The Conjugate Gradient Method with Element by Element Preconditioners: Preliminary Report

This study deals with techniques for solving large symmetric positive definite linear systems which arise in the finite element analysis of problems in structural and solid mechanics. The conjugate gradient method is used with preconditioners constructed element-wise. Specifically the preconditioner is constructed from factors of the individual scaled element arrays. The factors are either of the form LDL' or QR. They can be combined to form an approximation to a factorization of the global array. The whole process can be carried out without ever actually constructing the global array. An important feature of these methods is that much of the array processing can be done in parallel.

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Analysis of Convergence of Nonlinear, Nonstationary Functional Iterations

Here convergence properties of a nonlinear, nonstationary Gauss-Seidel type functional given by \( k+1 = C_k(x_{k+1}, x_k), (x_k = \text{ the kth iteration is considered, where } C_k = D_k + x_k^2 D_k^{-1} \)

Local linearization principle has been used together with some properties of a sequence of square matrices \( (A_k) k = 1, 2, \ldots \) which satisfy \( \lim_{k \to \infty} A_k = A \). These matrices called D-matrices, showed the mode of convergence.

Suhrat K. Day
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Functions of Perturbed Matrices

The perturbation series

\[ f(A + tB) = f(A) + t f_1 + t^2 f_2 + \ldots \]

is explicitly computed for n x n matrices A, B and functions f which are analytic on \( \sigma(A) \). The H-matrices turn out to be "relative iterates" of the perturbation matrix B, in a natural sense. The results which will be presented are reformulations and extensions of portions of the author's paper Chain algebras. Discrete Mathematics 37 (1981), 229-244. Various applications will be indicated.

Lester J. Sehgal
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Derivatives of \( D_1A D_2 \) Matrices

We consider two approaches to derivatives of \( D_1A D_2 \) matrices with respect to entries of A as well as row and column sums. This might be interesting since (1) an implicit function approach requires an inverse of a singular matrix; (2) Differentiating a result due to Sinkhorn (1967) shows that \( D_1A D_2 \) matrices are not differentiable w.r.t. row and column sums unless the definition of \( D_1A D_2 \) matrices is modified slightly. Also (2) motivates computing the derivatives as the limit of the derivatives of the iterative scaling procedure which may be computed to compute \( D_1A D_2 \) matrices. Jacobian matrices of \( D_1A D_2 \) derivatives evaluated at \( A^* = D_1A D_2 \) are idempotent.

While these derivatives have been studied before, apparently the points raised here have been overlooked previously. [eg., Bacharach, 1970.]

James S. Weber
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Chicago, Illinois 60605

Rationalization of Fractions:

I will consider two areas: 1) ordinary fractions over the integers & 2) rational functions of n-th degree polynomials. The basic principle is that when dividing the smaller of the numerator/denominator polynomials of a fraction into the larger, the remainder contains a constant factor; the greatest common factor of the numerator/denominator. Repeated application yields this factor. Applications include matrix calculations using fractions without accumulating large numerators/denominators. Also, multiple factors of polynomials can be removed by considering the quotient p/p'.

Dieter W. F. Wendt, 681 St. John's Circle, Phoenixville, Penna. 19460, (215) 933-5128

Fast Division of Polynomials via Triangular Toeplitz Matrix Inversion

How many arithmetic operations (ops), (parallel) steps and processors (prs) are needed for division with remainder of 2 complex polynomials? The known Sieveking-Kung algorithm relies on computing the power series reciprocal and uses \( n \log n \) ops, \( \log^2 n \) steps, \( n^2 \) prs (all estimates within constant factors); \( n \log \log n \) steps suffice for the solution over arbitrary field of constants. We attain all the above estimates via the inversion of triangular Toeplitz matrices. Furthermore the problem can be solved with arbitrary precision in \( n \log n \) steps, n prs in this way.

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Victor Pan
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State University of New York at Albany
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Perturbation theory for a group of eigenvalues

We present a generalization of Kato's perturbation theory, which treats simultaneously a group of several eigenvalues. Numerical applications are given.

Professor Françoise Chatelin
IBM Développement Scientifique
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NONLINEAR EIGENVALUE APPROXIMATION

Let $F(x)$ denote a $n \times n$ matrix valued, holomorphic function of $x$ in some open subset $U$ of the complex plane. It is well-known that $1-F(x)$ is nonsingular in $U$ except possibly for a countable set of points with no limit point in $U$. Let $\xi$ denote such a point. The problem is to approximate $\xi$. We examine the generalized eigenvalue problem (GEVP) $L(\xi) + (2-\xi)L(\xi')$ where $L(x) = I - F(x)$. Now given $x \in U$, define $S(x)$ to be the element of the spectrum of this GEVP which is closest to $x$. If $\xi$ is a nondefective eigenvalue of the GEVP, then fixed point iteration on $S$ will converge quadratically to $\xi = S(\xi)$ if started sufficiently close to $\xi$.

William F. Moss
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Clemson, SC 29631

Philip W. Smith
Department of Mathematical Sciences
Old Dominion University
Norfolk, VA 23508

Joseph D. Ward
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Texas A&M University
College Station, TX 77843

Unitary Completions and Noncanonical LU Factorization

Any matrix $F$ has a noncanonical LU factorization $F = LU$ where $L$ and $U$ are block lower and block upper triangular matrices respectively and $M$ is a unique block subpermutation matrix in canonical form. We also specify when unitary completions of a partially defined matrix with prescribed block lower triangular entries exist. When this is the case we obtain a linear fractional map parameterization of all such completions. Moreover, we can specify exactly which middle factors $M$ arise in the noncanonical LU factorization $F = LMU$ for such completions. The results follow by classifying subspaces of matrices which are modules over the algebra of upper triangular matrices. This is joint work with Israel Gohberg.

Joseph A. Ball, Department of Mathematics
Virginia Polytechnic Institute & State University
Blacksburg, VA 24061

A Numerical Comparison of Methods for Computing the Inertia of a General Matrix

A comparison is given of several numerical methods for computing the inertia of an unreduced Hessenberg matrix. These direct methods are based upon finding a Hermitian solution to a particular Lyapunov matrix equation and then computing the inertia of this solution. The methods have been developed by David Carlson, B. N. Datta, and Karabi Datta. In these direct methods the solution of the Lyapunov matrix equation is not computed explicitly and this is what makes these methods viable alternatives to using the QR methods for solving the inertia problem. The comparison is made on the basis of numerical efficiency, storage requirements and accuracy. The results indicate that the inertia of a matrix can be computed effectively by direct methods for matrices of moderate size.

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Daniel Pierce
Department of Mathematics
North Carolina State University
Raleigh, North Carolina 27695-8205

Lyapunov Approximation of Reachable Sets for Controlled Linear Systems

We calculate an approximation to the reachable set of a class of linear control systems. The method involves the construction of a Lyapunov-like function, and ultimately requires the numerical solution of a simple optimisation problem. Advantages of the method are that it is applicable to $n$ dimensional systems, and does not require calculation of orbits or a choice of boundary conditions. Further, the system need not be completely controllable for the method to be applicable. However, while the method ensures that the reachable set lies within a specified set, a closeness-of-fit criterion is not available.

Dr. Danny Summers
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Memorial University of Newfoundland
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PLATZMAN’S PROBLEM REVISITED

A decade ago George Platzman, an oceanographer, created a global tidal model that required computing the interior eigenvalues of a large sparse symmetric matrix. Platzman’s problem stimulated much interest among numerical linear algebraists, especially among Lanczos aficionados, but the eigensystem proved to be very difficult to compute.

The intervening decade has seen several significant advances in the understanding and application of the Lanczos algorithm. Platzman’s problem has remained a formidable
Inexact One-Step Method

The classical one-step stationary iteration for a nonlinear equation is of the form $x^{k+1} = G x^k$, $k = 0, 1, \ldots$. In the case of $G$ linear, $G$ is usually chosen to be the product of triangular matrices (for example, the SOR method), or a product of tridiagonal matrices (for example, the ADI method). We consider a generalization of these methods: $x^{k+1} = G x^k + r^k$, $k = 0, 1, \ldots$. In the case of $G$ linear, $r^k$ can be computed iteratively, for instance, by a preconditioned conjugate gradient method. We extend some of the classical theories regarding the convergence rate of the one-step methods to this new class of methods; we present upper bounds for the norm of $r^k$ to guarantee convergence.

Elizabeth L. Yip
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status of the SSV including computational issues and applications.

*J. Doyle, Lecture Notes, 1984 ONR/Honeywell Workshop on Advances in Multivariable Control, Oct. 8-10, 1984, Minneapolis, MN.

John Doyle
Electrical Engineering
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(Jan. 1 to June 15)

Honeywell SRC MN 17-2375
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Minneapolis, MN 55413
(June through December)

The Role Of The Schur Product In The Eigenstructure Approach To Parameter Estimation

The Schur or the element to element product of matrices has not been extensively studied and is rarely used in estimation theory. In this paper we describe an application of the Schur product in the modeling of covariance matrices related to parameter estimation via eigenstructure methods. For example, in the direction of arrival (DOA) estimation problem with spatial decorrelation of wavefronts, the resulting array covariance matrix can be shown to be the Schur product of the spatial coherence matrix (a property of the medium) and the array covariance assuming perfect spatial coherence. This observation, in conjunction with some interesting though easily proved properties of the Schur product, has suggested ways to solve the DOA problem via an eigen decomposition of the covariance.

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On the generators of a controllability matrix

A matrix \( C = (b_1, \ldots, b_k) \) in \( R^n \) is called a controllability matrix if rank \( C = k \) whenever for some \( k \) the columns \( b_1, \ldots, b_k \) are linearly independent while \( b_1, \ldots, b_k, b_{k+1} \) are dependent. Given such a \( C \), we determine all \( A \) in \( R^{n \times n} \) such that \( C = (b_1, Ab, \ldots, A^{k-1}b_k) \). Moreover we find all possible ranks for such \( A \) and study the sparsity structure available for all such \( A \) of a given rank.

Frank Uhlig, Department of Mathematics, Auburn University, Auburn, AL 36849

The Generalized Householder Transformation

Many algorithms for solving eigenvalue, least squares and nonlinear programming problems require the determination of an orthogonal matrix \( Q \) such that for a given matrix \( C \), \( Q \) transforms \( C \) into an upper triangular matrix, \( QC \). Usually \( Q \) is a product of Householder transformations. Each transformation is a rank 1 correction of the identity matrix designed to annihilate elements in one vector.

Several years ago, Bronlund and Johnsen proposed a generalization of the Householder transformation that is a rank \( k \) correction of the identity matrix designed to annihilate elements in \( k \) vectors simultaneously. In this talk, their generalized Householder transformation will be discussed from the context of sparse problems.

Linda Kaufman
AT&T Bell Laboratories
Computing Mathematics Research
600 Mountain Avenue
Murray Hill, NJ 07974

Projectionally Exposed Cones in Convex Programming

Relative to the Convex Programming Problem, Jon Borwein and Henry Wolkowicz introduced the concept of projectionally exposed cones. A cone is projectionally exposed if for each face there exists a projection which projects the entire cone onto the given face. When the associated constraint function of a convex programming problem takes values in a projectionally exposed cone, then certain multipliers may be chosen from a smaller set. Under this motivation the authors begin characterizing both polyhedral and nonpolyhedral cones which are projectionally exposed or orthogonally projectionally exposed.

George P. Barker
University of Missouri
Kansas City, MO

Michael Laidacker
Lamar University
Beaumont, TX

George D. Poole
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Beaumont, TX 77710

Squeezing the Most out of Eigenvalue Solvers on High-Performance Computers

This talk describes modifications to many of the standard algorithms used in computing eigenvalues and eigenvectors of matrices. These modifications, which decrease the number of vector memory references, can dramatically increase the performance of the underlying software on high performance computers without resorting to assembler language, without significantly influencing the floating point operation count, and without effecting the roundoff error properties of the algorithms. The techniques are applied to a wide variety of algorithms and are beneficial in various architectural settings.

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Cholesky Factorization of Structured Matrices

Cholesky factorization of Hermitian positive-definite matrices is required in applications involving least-squares criteria, such as inverse scattering, linear estimation (and, in particular, Kalman filtering), and second-order modeling of stochastic processes. The recent derivation of efficient algorithms for Cholesky factorization of Toeplitz and Hankel matrices spurred a growing interest in characterizing classes of matrices whose factorization can be accomplished in less than the $O(N^3)$ operations required to factor nonstructured matrices of size $N \times N$.

We show that the pursuit of "fast-Cholesky" algorithms leads in a natural way to the notion of matrices with a displacement structure, whose factorization requires $O(N^2)$ operations, where $N$ is a structural index independent of $N$ (i.e., 1 for Toeplitz matrices).

Kanoe Lev-Ari
Information Systems Laboratory, Stanford University
Stanford, CA 94305

An Inequality for the Second Immanant

Let $x$ be the degree $n-1$ character of $S_n$, corresponding to the partition $(2,1,\ldots,1)^n$, and let $d_2$ be the corresponding immanant defined on $n\times n$ complex matrices. Then

$$\text{per}(A) \geq (n-1)^{d_2}(A)$$

for all positive semidefinite $A$, where per($A$) is the permanent of $A$.

Bob Grone
Department of Mathematics
Auburn University, Alabama 36849

Some Generalizations of the Singular Value Concept

The singular values of a complex matrix can be characterized in several ways. Each of these characterizations, when suitably generalized, leads to the definition of a new chain of numbers associated with a matrix, containing the singular values as a particular case. This communication surveys some properties of these various types of generalized singular values.

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Hypergraphs of k-Dimensional Matrices

Let $A = (a_{i_1 \ldots i_k})$ be a nonzero $d_1 \times d_2 \times \ldots \times d_k$ matrix. The hypergraph of $A$ is the hypergraph $H(A)$ with vertices the hyperplanes $x_R = \{x_i : i \in R\} = x_1$; $i_1 = 1,2,\ldots,n_1$; $t = 1,2,\ldots,k$ and edges the sets $\{x_{i_1}, x_{i_2}, \ldots, x_{i_k}\}$ for which $a_{i_1 \ldots i_k} \neq 0$. If $A$ is a graph, then $H(A)$ is the bipartite graph usually associated with $A$. In general, if $x_R = \{x_i : 1 \leq i \leq n_{1}\}$, $r = 1,2,\ldots,k$, then $H(A)$ is a simple uniform hypergraph of rank $k$ with $|E \cap x_R| = 1$ for each edge $E$ of $H(A)$. A number of properties of $H(A)$ are presented.

Stephen J. Dow and Peter M. Gibson
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A Probabilistic Algorithm for Graph Isomorphism

In this paper we derive a probabilistic algorithm for checking the graph isomorphism problem which is based only on solutions of linear equations and is extremely easy to apply. Surprisingly, this algorithm shows that for graphs with bounded eigenvalue multiplicity the isomorphism test is of order $O(n^6)$ independently of the multiplicity bound! Compare this with Babai, Grigor'ev and Mount [1982]. In fact this result holds for directed multigraphs with bounded eigenvalue multiplicity. Our algorithm would remain polynomial for graphs of unbounded valency with the logarithm growth.

Shmuel Friedland
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Some Comments about Semimonotone and Copositive Matrices

For a square matrix $M \in \mathbb{R}^{n \times n}$ and column vector $q \in \mathbb{R}^n$, the linear complementarity problem $(q,M)$ is the following: find nonnegative column vectors $w,z$ such that $w - Mz = q$ and $w^T z = 0$. The paper focuses on the relation of $M$ being semimonotone (copositive) and having at least one solution to $(q,M)$ for each column vector $q$ to the property of $(0,M)$ having a unique solution.

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Hattiesburg, MS 39406-5045

Some Comments on Substochastic Matrices

This paper will investigate the problem of solving certain sets of equations within the semigroup of all $n \times n$ substochastic matrices. These results will lead us to certain applications such as describing the maximal subgroups of the semigroup of all $n \times n$ substochastic matrices and finding generalized inverses of a substochastic matrix.

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The book exhibit times are from 9:00 AM to 5:00 PM Monday to Wednesday;
9:00 AM to 12:00 Noon, Thursday

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Contributed Paper Authors and Chairmen,
Contributed Paper Sessions

Fifteen minutes are allowed for each contributed paper. Presenters are
requested to spend a maximum of twelve (12) minutes for presentation of
their paper, and three (3) minutes for questions and answers. Chairmen of
contributed paper sessions are requested to adhere to the scheduled times.

SPECIAL NOTICE TO:
All Conference Participants

SIAM requests participants to refrain from smoking in the session rooms
during lectures. Thank you.

REGISTRATION INFORMATION

The registration desk will be located in the Prefunction Area on the Lobby
Level of the hotel and will be open as listed below:
Sunday April 28: 5:00 PM-10:00 PM
Monday, April 29-Thursday, May 2: 7:30 AM-6:00 PM

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Monday, April 29 Wednesday, May 1
Pool Party $10 Banquet $10
Open Bar, Hors d'oeuvres

Special Note:
There will be no prorated fees. There will be no refunds after the conference
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UPCOMING SIAM CONFERENCES

June 24–26, 1985
SIAM 1985 National Meeting
Pittsburgh Hyatt at Chatham Center
Pittsburgh, Pennsylvania

October 28–30, 1985
SIAM Fall Meeting
Arizona State University
Tempe, Arizona

July 15–19, 1985
SIAM Conference on Geometric
Modeling and Robotics
Hilton Hotel
Albany, New York

November 18–21, 1985
SIAM Conference on Parallel
Processing
Omni Hotel
Norfolk, Virginia
SIAM Meetings & Conferences

June 24-26, 1985
SIAM 1985 National Meeting
Pittsburgh Hyatt, Pittsburgh, PA
Modern topics in Applied Mathematics. Included will be robotics, variational problems, nonlinear partial differential equations, and computational fluid dynamics. Program chairman: George Fix, Carnegie-Mellon University, Pittsburgh.

June 24-26, 1985
SIMS 1985 Research Application Conference (RAC-85): Modern Statistical Methods in Chronic Disease Epidemiology
Alta Lodge Conference Center, Alta, Utah
Topics include: relative risk regression methods (the cohort study, the case-control study, and regression diagnostics), carcinogenesis models and methods in low dose extrapolation, and genetic epidemiology. There will be invited papers, applications from observers will be welcome. Co-chairs: Ross L. Prentice and Bruce H. Woolfson, University of Washington, Seattle.

July 15-19, 1985
SIAM Conference on Geometric Modeling and Robotics
Albany, NY
An international conference to bring together those concerned with the implementation of robots and geometric design techniques with theoreticians. Talks and workshops will focus on surface modeling, solid modeling, robotics and database structures for geometric modeling. Organizing committee: Carl de Boor, David Ferguson, John Hopcroft, Harry McLaughlin, Leon Seidelman, and Michael Wozny.

October 28-30, 1985
SIAM 1985 Fall Meeting
Arizona State University, Tempe

November 18-21, 1985
Second SIAM Conference on Parallel Processing for Scientific Computing
Omni Hotel, Norfolk, VA
The first day of the conference will be a full-day tutorial on parallel processing. It will focus on the influence of computer architecture and give a review of parallel numerical algorithms. The main conference program will address experience with operational parallel machines and developments in numerical algorithms. Program chairman: R.G. Voigt, ICASE-NASA Langley Research Center. Abstract deadline: June 7, 1985

May 14-16, 1986
Third SIAM Conference on Discrete Mathematics
Clemson University, Clemson, SC
A conference to encourage interaction between the developers and users of discrete mathematics. Topics include: discrete optimization; graph theory; discrete mathematics in biology, computational engineering, medical, physical, and social sciences; cryptology; operations research; algebraic network reliability; domination numbers; and partially ordered sets. Program co-chairman: Richard D. Ringrose (Clemson University) and Fred S. Roberts (Rutgers University). Abstract deadline: December 9, 1985

July 21-25, 1986
SIAM 1986 National Meeting
Boston Park Plaza Hotel, Boston, MA
Topics include: parallel computation; multi-grid methods; compressible flow calculations; surface approximation and computer-aided design; bubbly fluids or fluidized beds; geophysical modeling; computer tomography; crystal growth in materials; porous media; and iterated mappings and chaos. Program chairman: Robert O'Malley, Rensselaer Polytechnic Institute.

PAPERS AND POSTERS
Contributed papers and poster presentations at the SIAM national and fall meetings may treat any aspect of applied mathematics, although contributions consistent with the themes of the plenary symposia are especially desired. At SIAM conferences, papers and poster presentations must be related to conference topics.

MINISYMPOSIA
Proposals for minisymposia are invited for the national and fall meetings. Minisymposia that focus on a topic consistent with the themes of the plenary symposia are especially desired. Organizers of minisymposia must be SIAM members.

STANDARD FORM
Abstracts of contributed papers and poster presentations, as well as proposals for minisymposia, must be submitted on standard SIAM forms. These may be obtained by contacting SIAM Conference Coordinator, Suite 1400, 17 South 17th Street, Philadelphia, PA 19103, (215) 564-2929.

REPLY FORM

Please send me information on the following SIAM meetings and conferences:

CONFERENCMEETING PLEASE CHECK
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June 24-26, 1985
Pittsburgh Hyatt, Pittsburgh, PA
SAMS 1985 Research Application Conference (RAC-85)
June 24-26, 1985
Alta Lodge Conference Center, Alta, UT
SIAM Conference on Geometric Modeling and Robotics
July 15-19, 1985
Albany, NY
SIAM 1985 Fall Meeting
October 28-30, 1985
Arizona State University, Tempe, AZ
Second SIAM Conference on Parallel Processing for Scientific Computing
November 18-21, 1985
Omni Hotel, Norfolk, VA
Third SIAM Conference on Discrete Mathematics
May 14-16, 1986
Clemson University, Clemson, SC
SIAM 1986 National Meeting
July 21-25, 1986
Boston Park Plaza Hotel, Boston, MA

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