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Conference on Iterative Methods for Large Linear Systems

October 19-21, 1988

Compiled & Edited by
David R. Kincaid

December 1988

CNA-229

Final Program

CONFERENCE ON ITERATIVE METHODS FOR LARGE LINEAR SYSTEMS

October 19-21, 1988

Center for Numerical Analysis†
The University of Texas at Austin

Co-sponsored by
Society for Industrial and Applied Mathematics
Special Interest Groups for Linear Algebra and Supercomputing

Celebrating the Sixty-fifth Birthday of
David M. Young, Jr.

Tuesday (October 18, 1988)

5:30p-7:00p Pre-Conference Social (No host) — Calypso Bar / Second Level

5:30p-7:00p Pre-Conference Registration — Ballroom Foyer / Third Level

† All conference events (meetings and social) are to be held at the Austin Marriott at the Capitol, 701 E. 11th St., Austin, Texas 78701. The hotel is located in downtown Austin at the corner of 11th Street and Interstate 35.

Wednesday (October 19, 1988)

8:00a-5:00p	Registration / Information — Marble Desk / Third Level
8:20a-8:30a	Opening Remarks: James W. Vick (University of Texas at Austin) Associate Dean, College of Natural Sciences Salon D / Third Level
	Session WedAM1 — Salon D / Third Level Chair: David R. Kincaid (University of Texas at Austin)
8:30a-9:30a	Garrett Birkhoff* (Harvard University) & Robert E. Lynch (Purdue University) "ELLPACK and ITPACK as Research Tools for Solving Elliptic Problems"
9:30a-9:50a	Robert E. Lynch* (Purdue University) "New Finite Difference Approximations of Boundary Conditions"
9:50a-10:20a	Coffee Break — Ballroom Foyer / Third Level
	Session WedAM2 — Salon D / Third Level Chair: Linda J. Hayes (University of Texas at Austin)
10:20a-11:00a	David M. Young* (University of Texas at Austin) & Tsun-zee Mai (University of Alabama) "The Search for Omega"
11:00a-11:40a	Owe Axelsson* (University of Nijmegen, The Netherlands) "Some Optimal Order Preconditioning Methods for Diffusion Problems Based on Algebraic Decompositions"
11:40a-12:00n	John R. Whiteman* (Brunel University, England) "Finite Element Treatment of Singularities in Elliptic Boundary Value Problems"
12:00n-12:10p	Group Photograph
12:10n-1:30p	Lunch (No host — on-your-own)
	Session WedPM1 — Salon D / Third Level Chair: Graham F. Carey (University of Texas at Austin)
1:30p-2:10p	Mary F. Wheeler* (University of Houston) "Domain Decomposition — Multigrid Algorithms for Mixed Finite Element Methods for Elliptic PDE's"
2:10p-2:50p	Olof B. Widlund* (New York University) "Domain Decomposition Algorithms for Elliptic Problems"
2:50p-3:00p	Stretch Break with Celeste Hamman, fitness consultant
3:00p-3:20p	Coffee Break — Ballroom Foyer / Third Level

* speaker

Thursday, October 20, 1988

8:00a-4:00p	Registration / Information — Marble Desk / Third Level
8:20a-8:30a	Second Day Remarks — Salon D / Third Level
	Session ThuAM1 — Salon D / Third Level Chair: J. Tinsley Oden (University of Texas at Austin)
8:30a-9:10a	David L. Harrar & James M. Ortega* (University of Virginia) "Solution of Three-Dimensional Generalized Poisson Equations on Vector Computers"
9:10a-9:50a	Paul E. Saylor* (University of Illinois) "Iterative Methods for Complex Linear Algebraic Equations"
9:50a-10:20a	Coffee Break — Ballroom Foyer / Third Level
	Session ThuAM2 — Salon D / Third Level Chair: E. Ward Cheney (University of Texas at Austin)
10:20a-11:00a	Richard S. Varga* (Kent State University) "Remarks on k-Step Iterative Methods"
11:00a-11:40a	Louis W. Ehrlich* (John Hopkins University) "A Local Relaxation Scheme (Ad-Hoc SOR) Applied to Nine Point and Block Difference Equations"
11:40a-12:00n	Paul Concus* (Lawrence Berkeley Laboratory) & Paul E. Saylor (University of Illinois) "Preconditioned Iterative Methods for Indefinite Symmetric Toeplitz Matrices"
12:00n-1:30p	Luncheon — Salon E / Third Level
	Session ThuPM1 — Salon D / Third Level Chair: John R. Cannon (Lamar University)
1:30p-2:10p	Howard C. Elman* (University of Maryland) "Uses of Reordering, Partial Elimination and Fourier Methods for Sparse Iterative Solvers"
2:10p-2:50p	Loyce M. Adams* (University of Washington) "Fourier Analysis of Two-Level Hierarchical Basis Preconditioners"
2:50p-3:00p	**Stretch Break with Celeste Hamman, fitness consultant**
3:00p-3:20p	Coffee Break — Ballroom Foyer / Third Level

Session WedPM2a — Salon D / Third Level
Chair: Robert C. Ward (Oak Ridge National Laboratory)

3:20p-3:40p Paul J. Lanzkron, Donald J. Rose* & Daniel B. Szyld (Duke University)
"Convergence of Nested Iterative Methods for Linear Systems"

3:40p-4:00p David J. Evans* & C. Li (Loughborough University of Technology, England)
"$D^{1/2}$-Norms of the SOR and Related Method for a Class of Nonsymmetric Matrices"

4:20p-4:40p Martin Hanke* (Universitat Karlsruhe, W. Germany)
"On Kaczmarz' Method for Inconsistent Linear Systems"

4:40p-5:00p Steven F. Ashby* (Lawrence Livermore National Laboratory)
"Polynomial Preconditioning for Conjugate Gradient Methods"

Session WedPM2b — Salon E / Third Level
Chair: George D. Byrne (Exxon Research)

3:20p-3:40p Robert E. Wyatt* (University of Texas at Austin)
"Iterative Methods in Molecular Collision Theory"

4:00p-4:20p M. Dryja (University of Warsaw, Poland) & Wlodek Proskurowski*
(University of Southern California)
"Composition Method for Solving Elliptic Problems"

4:20p-4:40p Seungsoo Lee, George S. Dulikravich* & Daniel J. Dorney (Pennsylvania State University)
"Distributed Minimal Residual (DMR) Method for Explicit Algorithms Applied to Nonlinear Systems"

4:40p-5:00p M. G. Petkov* (Academy of Sciences, Bulgaria)
"On the Matrix Geometric Progression and the Jordan Canonical Form"

5:00p-7:00p Reception (Light Hors D'oeuvres) — Calypso Terrace / Second Level
Featuring the "Julie Burrell Band"

7:00p Dinner (No host — On-your-own)

8:00p-10:00p Tennis Doubles-Mixer
Penick-Allison Tennis Center — corner of Trinity and Martin Luther King Blvd (alias 19th St.)
[walking distance from hotel (0.6 mile), map available at registration desk,
hotel van available for transportation]

3:00a-5:00p Poster Session — Ballroom Foyer

Session ThuPM2a — Salon D / Third Level
Chair: Kamy Sepehrnoori (University of Texas at Austin)

3:20p-3:40p Kang C. Jea* (Fu Jen University, Taiwan, R.O. China) & David M. Young (University of Texas at Austin)
"On The Effectiveness of Adaptive Chebyshev Acceleration for Solving Systems of Linear Equations"

3:40p-4:00p Anne Greenbaum* (New York University)
"Predicting the Behavior of Finite Precision Lanczos and Conjugate Gradient Computations"

4:00p-4:20p Tsun-zee Mai* (University of Alabama) & David M. Young (University of Texas at Austin)
"On the Adaptive Determination of Iteration Parameters"

4:20p-4:40p David R. Kincaid* (University of Texas at Austin)
"A Status Report on the ITPACK Project"

Session ThuPM2b — Salon FG / Third Level
Chair: Robert van de Geijn (University of Texas at Austin)

3:20p-3:40p C.-C. Jay Kuo* & Tony F. Chan (University of California, Los Angeles)
"Two-Color Fourier Analysis of Iterative Methods for Elliptic Problems with Red-Black Ordering"

3:40p-4:00p Randall B. Bramley* (University of Illinois at Urbana-Champaign)
"A Projection Method for Large Sparse Linear Systems"

4:00-4:20p David V. Anderson* & Alice E. Koniges (Lawrence Livermore National Laboratory)
"The Solution of Large Striped Matrix Systems Derived from Multiple Coupled 3D PDE's"

4:20-4:40p Bernd Fischer*(Stanford University & University of Hamburg, W. Germany) & Lothar Reichel (Bergen Scientific Centre, Bergen, Norway & University of Kentucky)
"A Stable Richardson Iteration Method for Complex Linear Systems"

5:00p-7:00p Conference Social (Cash Bar) — Foyer / Fourth Level

7:00p Banquet — Ballroom (Salon A - D) / Third Level

Friday (October 21, 1988)

8:00a-4:00p	Registration/Information — Ballroom Foyer / Third Level
8:20a-8:30a	Final Day Remarks — Salon D / Third Level
	Session FriAM1 — Salon D / Third Level Chair: Charles H. Warlick (University of Texas at Austin)
8:30a-9:10a	Gene H. Golub* (Stanford University) & John de Pillis (University of California, Riverside) "Toward an Effective Two-Parameter SOR Method"
9:10a-9:50a	Eugene L. Wachspress* (University of Tennessee) "The ADI Minimax Problem for Complex Spectra"
9:50a-10:20a	Coffee Break — Ballroom Foyer / Third Level
	Session FriAM2 — Salon D / Third Level Chair: Olin G. Johnson (University of Houston)
10:20a-11:00a	Thomas A. Manteuffel* (University of Colorado at Denver & Los Alamos National Laboratories) & Wayne D. Joubert (University of Texas at Austin) "Iterative Methods for Nonsymmetric Linear Systems"
11:00a-11:40a	Louis A. Hageman* (Westinghouse — Bettis Laboratory) "Relaxation Parameters for the IQE Iterative Procedure for Solving Semi-Implicit Navier-Stokes Difference Equations"
11:40a-12:00n	Craig Douglas, J. Mandel & Willard L. Miranker* (IBM Watson Research Center, Yorktown Heights) "Fast Hybrid Solution of Algebraic Systems"
12:00n-1:10p	Luncheon — Salon E / Third Level
	Session FriPM1 — Salon D / Third Level Chair: Esmond G. Ng (Oak Ridge National Laboratory)
1:10p-1:50p	Dan C. Marinescu & John R. Rice* (Purdue University) "Multilevel Asynchronous Iterations for PDE's"
1:50p-2:00p	Stretch Break with Celeste Harnman, fitness consultant
2:00p-2:20p	Coffee Break — Ballroom Foyer / Third Level

Session FriPM2a — Salon D / Third Level
Chair: Esmond G. Ng (Oak Ridge National Laboratory)

2:20p-2:40p Avi Lin* (Temple University) # Substitution (see below)
"Asynchronous Parallel Iterative Methods"

2:40p-3:00p Thomas C. Oppe* (University of Texas at Austin)
"Experiments with a Parallel Iterative Package"

3:00p-3:20 Michael I. Navon* & H.-I. Lu (Florida State University)
"A Benchmark Comparison of the ITPACK Package on ETA-10 and Cyber-205 Supercomputers"

3:20p-3:40p Anne C. Elster* (Cornell University),
Hungwen Li (IBM Almaden Research Center, San Jose) &
Michael M.C Sheng (National Chiao-Tung University, Taiwan, R.O. China)
"Parallel Operations for Iterative Methods: A Polymorphic View"

3:40p-4:00p Graham F. Carey*, David R. Kincaid, Kamy Sepehrnoori, & David M. Young
"Vector and Parallel Iterative Solution Experiments"

Session FriPM2b — Salon FG / Third Level
Chair: L. Duane Pyle (University of Houston)

2:20p-2:40p S. Galanis, Apostolos Hadjidimos* & Dimitrois Noutsos
(University of Ioannina, Greece, & Purdue University)
"On an SSOR Matrix Relationship and Its Consequences"

2:40p-3:00p A. Haegemans & J. Verbeke* (Katholieke Universiteit Leuven, Belgium)
"The Symmetric Generalized Accelerated Overrelaxation (GSAOR) Method"

3:00p-3:20p Apostolos Hadjidimos (Purdue University & University of Ioannina, Greece) &
Michael Neumann* (University of Connecticut)
"Convergence Domains and Inequalities for the Symmetric SOR Method"

3:20p-4:00p Jerome Dancis* (University of Maryland)
"Diagonalizing the Adaptive SOR Iteration Method"

3:40p-4:00p Kaibing Hwang* & Jinru Chen (Nanjing Normal University, P.R. China)
"A New Class of Methods for Solving Nonsymmetric Systems of Linear Equations — Constructing and Realizing Symmetrizable Iterative Methods"

Conference Adjourns

Robert van de Geijn (University of Texas at Austin)
"Machine Independent Parallel Numerical Algorithm"

Speaker	Session	
Adams	ThuPM1	
Anderson	ThuPM2b	
Ashby	WedPM2a	
Axelsson	WedAM2	
Birkhoff	WedAM1	
Bramley	ThuPM2b	
Carey	FriPM2a	
Concus	ThuAM2	
Dancis	FriPM2b	
Dulikravich	WedPM2b	
Ehrlich	ThuAM2	
Elman	ThuPM1	
Elster	FriPM2a	
Evans	WedPM2a	
Fischer	ThuPM2b	
Golub	FriAM1	
Greenbaum	ThuPM2a	
Hadjidimos	FriPM2b	
Hageman	FriAM2	
Hanke	WedPM2a	
Hwang	FriPM2b	
Jea	ThuPM2a	
Kincaid	ThuPM2a	
Kuo	ThuPM2b	
Lin	FriPM2a	# Substitution (see below)
Lynch	WedAM1	
Mai	ThuPM2a	
Manteuffel	FriAM2	
Miranker	FriAM2	
Navon	FriPM2a	
Neumann	FriPM2b	
Oppe	FriPM2a	
Ortega	ThuAM1	
Petkov	WedPM2b	
Proskurowski	WedPM2b	
Rice	FriPM1	
Rose	WedPM2a	
Saylor	ThuAM1	
Varga	ThuAM2	
Verbeke	FriPM2b	
Wachspress	FriAM1	
Wheeler	WedPM1	
Whiteman	WedAM2	
Widlund	WedPM1	
Wyatt	WedPM2b	
Young	WedAM2	

van de Geijn   FriPM2a

OBJECTIVE: This conference is dedicated to providing an overview of the state of the art in the use of iterative methods for solving sparse linear systems with an eye to contributions of the past, present, and future. The emphasis is on identifying current and future research directions in the mainstream of modern scientific computing. Currently, the use of iterative methods for solving linear systems is experiencing a resurgence of activity as scientists attack extremely complicated three dimensional problems using vector and parallel supercomputers. Many research advances in the development of iterative methods for high-speed computers over the past forty years are to be reviewed as well as focusing on current research.

ORGANIZATIONS: The conference is organized by D. Kincaid, L. Hayes, G. Carey and W. Cheney, who are members of the host organization — the Center for Numerical Analysis (CNA) of The University of Texas at Austin. This meeting is being co-sponsored by the Special Interest Groups for Linear Algebra and Supercomputing of the Society for Industrial and Applied Mathematics. Support for this conference is provided, in part, by the Office of Naval Research, the Department of Energy, the National Science Foundation, the Air Force Office of Scientific Research, and The University of Texas at Austin.

POSTER SESSION: A poster session will be held where anyone who wants to post recent research results may do so. A limited number of easels (6) will be available in the Ballroom Foyer for posting on Thursday afternoon (3:00p-5:00p). If interested, please sign-up at the registration desk.

MESSAGE BOARD: A message board will be located in the Ballroom Foyer area during the conference.

ACCOMMODATIONS: To make reservations call the Austin Marriott at the Capitol, 701 E. 11th St. [(512) 478-1111 or (800) 228-9290] for rooms at the special conference rate of $55 for single or double rooms. All reservations are handled on a first-come-first-served basis.

TRAVEL: Many major airlines fly into Austin via Dallas or Houston with some direct flights from other locations. The primary air-carriers serving Austin are American, American-West, Continental, Delta, Northwest, Pan Am, Southwest, TWA, United, and USAir. Since airlines give discount rates for those staying over a Saturday night, plan to stay and enjoy the weekend in Austin! An information desk operated by the City of Austin is located in the airport and is a good source for free material on events and sights of interest in and around Austin. (Just ask for a packet of information.)

TRANSPORTATION: A hotel courtesy-van is available for transportation between the airport and the hotel (a short 15 minute trip). [Regular hours of operation are on the hour and half-hour from 6:00a-12:00n and by request 12:00n-12:00m with frequent trips Tuesday evening before the conference and Friday evening after the conference.] The hotel also operates a free shuttle bus to The University of Texas at Austin which is approximately ten blocks north. [See the posted schedule in the hotel.] Please contact the Bell Station to confirm transportation. The City operates the "catch a'dillo bus" (short for armadillo) for transportation around the downtown area.

TENNIS DOUBLES-MIXER: On Wednesday evening, a tennis doubles-mixer has been arranged at Penick-Allison Tennis Center — corner of Trinity and Martin Luther King Blvd. (alias 19th St.).

EXERCISE: Celeste Hamman, fitness consultant, leads the stretch breaks each day during the conference to energize us for the late afternoon sessions. For those interested, Celeste supervises a jog around the Capitol/University area during the Wednesday lunch break (leaving at 12:15pm from the front of the Marriott and finishing at 1:00pm). Also, she is available during the conference for individual instruction on subjects such as conditioning, race-walking, etc.

POINTS OF INTEREST: Austin is the capital of Texas with several points of interest including the State Capitol Building, Governor's Mansion, Lyndon B. Johnson Presidential Library and Museum, Zilker Park and Barton Springs (spring-fed natural swimming pool always 68°), and many more. Near to Austin are several scenic lakes, such as Lake Travis, and the "Texas hill country." Austin is in the center of Texas with historic San Antonio and the Alamo only 70 miles south, Dallas/Ft. Worth 200 miles north, and Houston 200 miles Southeast. The weather is usually quite pleasant in Austin in October but is known to change rapidly (October averages: 80° high, 55° low). Many restaurants and night-spots are located on "6th Street" five blocks south of the hotel. South of 1st Street is "Town Lake" with the popular "hike-'n-bike" trail for jogging, speed-walking, or an enjoyable stroll. Austin also offers a host of other activities that participants can individually arrange. Some information is available at the conference registration desk.

CONFERENCE PROCEEDINGS: The long papers from the conference will be published by Academic Press in book form and will appear in 1989. Pre-publication orders can be placed during the conference.

REGISTRATION: Conference registration fee is $125. This fee includes morning and afternoon coffee breaks, two luncheons, a reception, and a banquet honoring Professor Young. The student registration fee is $18, which allows admission to the technical sessions and coffee breaks only. The evening social activities of the conference are available to companions of conference participants at the following rates: $10.75 reception (Wednesday night), $15 each luncheon (Thursday or Friday), $27.50 banquet (Thursday night), no charge for conference socials (cash bar). To register, detach and mail the registration form below. For additional information, contact the CNA at the address below or at Tel: (512) 471-1242 ; Arpanet: kincaid@cs.utexas.edu; Bitnet: kincaid@uta3081.

Dr. David R. Kincaid
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CONFERENCE ON ITERATIVE METHODS FOR LARGE LINEAR SYSTEMS

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The University of Texas at Austin
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ABSTRACTS

OBJECTIVE: This conference is dedicated to providing an overview of the state of the art in the use of iterative methods for solving sparse linear systems with an eye to contributions of the past, present and future. The emphasis is on identifying current and future research directions in the mainstream of modern scientific computing. Recently, the use of iterative methods for solving linear systems has experienced a resurgence of activity as scientists attack extremely complicated three-dimensional problems using vector and parallel supercomputers. Many research advances in the development of iterative methods for high-speed computers over the past forty years are reviewed, as well as focusing on current research.

ORGANIZATIONS: The conference is organized by David R. Kincaid, Linda J. Hayes, Graham F. Carey and E. Ward Cheney, who are members of the host organization—the Center for Numerical Analysis (CNA) of The University of Texas at Austin. Support for this conference is provided, in part, by the Office of Naval Research, the Department of Energy, the National Science Foundation, the Air Force Office of Scientific Research, and The University of Texas at Austin.

Fourier Analysis of Two-Level Hierarchical Basis Preconditioners

Loyce M. Adams*
Applied Mathematics
University of Washington
Seattle, WA 98195

Abstract

The use of hierarchical basis functions to precondition the conjugate gradient method has been proposed by Yserentant. It has shown the condition number of the resulting $N \times N$ system in two dimensions to be $O(log_2^2 N)$, independent of the number of refinement levels. In three dimensions, an upper bound using tetrahedral elements, has been shown by Ong to be $O(N^{\frac{1}{3}})$, independent of the number of refinement levels. The analysis that leads to these results gives an order bound and hence fails to produce the exact condition number.

We present an analysis of a two-level hierarchical basis preconditioner in one, two, and three dimensions using Fourier analysis. This technique has been used recently by Chan and Elman, Kuo and Levy, Adams, LeVeque, and Young, and Kuo and Chan to analyze iterative methods, preconditioners, and a two-level multigrid procedure. The crucial observation is the identification of different node types that make up the two levels. For example, in two dimensions, four types of nodes are identified (as opposed to two for Kuo and Chan's two-level multigrid analysis). The Fourier results show the two-level preconditioner has the condition number behavior described above as the number of dimensions increases. (This research was supported by AFOSR Grant No. AFOSR-86-0154.)

The Solution of Large Striped Matrix Systems Derived from Multiple Coupled 3D PDE's

David V. Anderson* and Alice E. Koniges
National Magnetic Fusion Energy Computer Center
Lawrence Livermore National Laboratory
Livermore, CA 94550

Abstract

In the context of physics applications it is often desired to solve coupled PDE's because uncoupled approximations require additional iterations to represent the coupling that is physically present. For time evolutionary problems, the coupled approximation is not only more accurate but has good numerical stability properties for the temporal discretization. For generally asymmetric systems we have applied point incomplete factorization to precondition the problem which is then subsequently solved either by conjugate gradient (on the normal form) or biconjugate gradient techniques. Assuming that any discretizations in time are treated explicitly one is left with coupled PDE's over a 3D spatial domain. We allow each spatial operator up to a 27 point stencil which is adequate for most finite difference or finite element methods constructed on topologically rectangular domains. These ideas have been embodied in the code CPDES3 which generates a compact striped matrix representation and solves it. When several coupled systems are to be solved hundreds of stripes may appear in the matrix. Periodic boundary conditions, allowed as an option, lead to further stripes in the corners of the various matrix blocks. Two portions of the code that were formerly recursive have been indirectly vectorized across the stripes thus yielding a code that is fully vectorized. One version of the code employs the biconjugate gradient algorithms which we have multitasked on two processors. We regard this code as capable but test of it on the Cray-2 show

modest performance which we believe is the result of poor indirect vector speed. We attribute this partly to our use of insufficiently long vectors and partly to the poor object code coming from the compiler. To make this code faster we have considered writing the indirect vector loops in assembler. We do not see any way to exploit higher levels of multitasking or to avoid the use of indirect vectorization unless we abandon the point preconditioner. We are currently investigating the use of block preconditioning which has enjoyed some success in simpler 2D applications where the convergence properties, multitasking efficiency, and vector performance were superior to that obtainable from pointwise preconditioning.

Polynomial Preconditioning for Conjugate Gradient Methods

Steven F. Ashby*
Computing and Mathematics Research Division
Lawrence Livermore National Laboratory
Livermore, CA 94550

Abstract

In this talk we examine the use of polynomial preconditioning in conjugate gradient methods for both Hermitian positive definite and indefinite matrices. Such preconditioners are easy to employ and well-suited to vector and/or parallel architectures. We first exploit the versatility of polynomial preconditioners to design several new CG methods. To obtain an optimum preconditioner, we solve a constrained minimax approximation problem. The preconditioning polynomial is optimum in that it minimizes a bound on the condition number of the preconditioned matrix. An adaptive procedure for dynamically determining the optimum preconditioner form the CG iteration parameters is also discussed. Finally, in a variety of numerical experiments on a Cray X-MP/48, we demonstrate the effectiveness of polynomial preconditioning.

Some Optimal Order Preconditioning Methods for Diffusion Problems Based on Algebraic Decompositions

Owe Axelsson*
Department of Mathematics
University of Nijmegen
Toernooiveld 6525 ED Nijmegen
The Netherlands

Abstract

Recently many new interesting results for the construction of preconditioning methods of optimal order ($O(1)$) or nearly optimal order ($O(\log h)$) condition numbers for the solution of diffusion problems, which depend only on some algebraic properties, have appeared. The theory for optimal order of classical multigrid methods (W. Hackbusch and others) on the other hand depends on the regularity of the solution and the mesh used for the discretization. The theory of the hierarchical basis function method (H. Yserentant and others) is based on an interpolation estimate which is closely associated with the behaviour of discrete Greens functions and the condition number is $O(\log h)^2$ in 2D but $O(h^{-1})$ in 3D (two and three space dimensional problems, respectively).

For domain decomposition methods similar results have been derived by Bramble, Pasciak and Schatz and by Widlund among others.

In the talk we report on two new methods of algebraic decomposition

(i) by use of domain decomposition and

(ii) by recursive reordering of the mesh points to form a nested sequence of meshes.

In (i) a decomposition of the domain into thin strips is used to get a block-tridiagonal matrix for which an approximate factorization method is used to

compute a preconditioner. In this the Schur complements are approximated using an indirect method which requires only the computation of the action of the exact Schur complements.

Using an odd-even reordering of the subdomains the method parallelizes very well. It is most efficient to use the method as a corrector on the coarse mesh in a two-level V-cycle method, where some smoother, such as an incomplete factorization, is used on the fine mesh. In (ii) one utilizes the two by two block structure of the nodal basis stiffness matrices for a sequence of nested meshes. Using a polynomial approximation of the Schur complements in the recursive block matrix factorization, we construct optimal order preconditioners, where only the constant γ, i.e. the cosine of the "angle" between the corresponding finite element basis function subspaces, in the strengthened C-B-S inequality is used. γ can be determined locally on individual elements, and depends on the angles of the triangulation but is independent on the diffusion coefficients, if these are piecewise constant, and is also independent of the regularity of the solution.

The condition number is of optimal order and if γ is sufficiently small (a condition met by practical F.E. meshes) the work estimate is also of optimal order.

The new methods which are easy to implement in a computer code, are presented with their basic properties. Some numerical comparisons are also presented. The methods perform about as well as classical multigrid methods when these latter perform at their best (for model type problems) but are in addition very robust.

ELLPACK and ITPACK as Research Tools for Solving Elliptic Problems

Garrett Birkhoff*
Department of Mathematics
Harvard University
Cambridge, MA 02138

Robert E. Lynch
Computer Sciences Department
Purdue University
West Lafayette, IN 47907

Abstract

While writing our recent book [BL], we became aware of many basic research questions that we did not have time to investigate. These include:

A. When are direct methods more efficient than iterative methods?

B. In general, *self-adjoint* linear elliptic problems are associated with *symmetric* operators, and so one would like their discretized form, $Au = b$, to involve a symmetric matrix A. How practical is this?

C. When does it pay to use "HODIE" or other methods having more than $O(h^2)$ accuracy?

D. How adequate is the ELLPACK two-dimensional *domain processor*? In using it, how should one choose the mesh lines?

E. When are *finite element* methods (F.E.M.) preferable to *difference* methods (Δ ES)?

F. How feasible is it to construct a useful analog of ELLPACK for solving three-dimensional (3D) problems?

G. How hard is it to treat *quasilinear* elliptic problems numerically?

H. Same question for *eigenproblems*?

I. How efficiently could *Frankel's method* be adapted to *parallel* machines?

For the past six months, we have been trying to utilize ELLPACK and ITPACK as research tools to help us answer these questions and also the following new question:

J. How much more efficient and accurate is the new HODIE-G ELLPACK module than previous discretization modules?

Our talk will be a progress report on the conclusions we have been able to make by the time of the Austin meeting.

Reference: [BL] "The Numerical Solution of Elliptic Problems," SIAM Publications, 1984.

A Projection Method for Large Sparse Linear Systems

Randall B. Bramley*
Center for Supercomputing Research and Development
University of Illinois at Urbana-Champaign
Urbana, IL 61820

Abstract

A block-Kaczmarz row projection method, RP, is described and tested. The method is extremely robust and has convergence properties completely independent of the eigenvalue distribution of the linear system to be solved. For structured systems and many sparse unstructured systems RP allows parallelism in the computations, and when combined with conjugate gradient (CG) acceleration it is competitive with unpreconditioned generalized CG methods as well as CG applied to the normal equations of the system.

Vector and Parallel Iterative Solution Experiments

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Abstract

The solution of partial differential equations such as the Navier-Stokes equations and transport equations for reservoir simulation lead to large sparse linear algebraic systems. Here we consider some issues related to vector and vector-parallel solutions of these systems using iterative algorithms. In particular, we show performance results for accelerated conjugate gradient type methods applied to viscous flow and reservoir applications, using finite element and finite difference discretization methods. Additional results are included for full systems of equations such as those encountered in boundary element computations, and comparison studies of iterative and elimination solver performance are described.

Preconditioned Iterative Methods for Indefinite Symmetric Toeplitz Matrices

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Abstract

Stable fast-direct methods for solving symmetric, positive-definite, Toeplitz-matrix systems of linear equations have been known for a number of years. Recently, a conjugate-gradient method has been proposed with circulant preconditioner as an effective means for solving these equations. For the (non-singular) indefinite case, the only stable algorithms that appear to be known are the general $O(Nsup3)$ direct methods, such as LU decomposition, which do not exploit the Toeplitz structure. In this talk we report on our initial results for developing iterative methods for the indefinite symmetric case.

Diagonalizing the Adaptive SOR Iteration Method

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Abstract

The SOR iteration method is a popular method for solving the large sparse systems of linear algebraic equations which approximate many partial differential equations that arise in engineering. Often the associated SOR matrix $M^{-1}N$ is diagonalizable except at the eigenvalue $\lambda = \omega - 1$, and the non-eigenvector p_* associated with the $\lambda = \omega - 1$ (i) slows down the convergence and (ii) in the adaptive SOR method, reduces the accuracy of the calculation of the next relaxation factor ω_i. Of course, $M^{-1}N$ cannot be diagonalized, but the error vector can be pushed into the span of the eigenvectors of $M^{-1}N$, thereby eliminating the p_*-coordinate of the error vector, together with its undesirable effects. We do this with the simple polynomial acceleration associated with the polynomial $P_1(x) = [x - (\omega - 1)]/[1 - (\omega - 1)]$, and $P_n(x) = x^{n-1}P_1(x)$, $n = 2, 3, \ldots$.

In the adaptive SOR method, this acceleration reduces the size of the error (i) by enabling the program to update the value of ω_i sooner, and (ii) by eliminating the contribution of p_* to the error vector.

In our computer run, using this polynomial acceleration resulted in an extra digit of accuracy over the results using the standard adaptive SOR method.

Distributed Minimal Residual (DMR) Method for Explicit Algorithms Applied to Nonlinear Systems

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Abstract

A new algorithm for the acceleration of explicit iterative schemes for the numerical solution of nonlinear systems of partial differential equations has been developed. The method is based on the idea of allowing each partial differential equation in the system to approach the converged solution at its own optimal speed. The DMR (Distributed Minimal Residual) method introduces a separate sequence of optimal weighting factors to be used for each component of the general solution vector. The acceleration scheme was applied to a highly nonlinear coupled system of four time-dependent partial differential equations of inviscid gas dynamics in conjunction with the finite volume Runge-Kutta explicit time-stepping algorithm. Using DMR without multigridding, between 30% and 70% of the total computational efforts were saved in the subsonic compressible flow calculations. DMR method offers most time savings when applied to stiff systems of equations. Several attempts have been made to accelerate the iterative convergence of this method. They include local time stepping, implicit residual smoothing, enthalpy damping and multigrid techniques. Also, an extrapolation procedure based on the power method and the Minimal Residual Method (MRM) were applied to the finite volume Runge-Kutta method. In the MRM, a weighted combination of the corrections at consecutive iteration levels is extrapolated and the weights are chosen to minimize the L_2 norm of the future residual. The extrapolation was performed without considering the

properties of the governing equations. The GNLMR (Generalized Nonlinear Minimal Residual) method utilizes the information about the governing equations. It has been applied successfully to a number of scalar nonlinear partial differential equations.

Both MRM and GNLMR methods are based on using the same values of optimal weighting factors for the corrections to every equation in a system. Since each component of the solution vector in a system of equations has its own convergence speed, the sequence of optimal weights could be allowed to be different for each component. This concept is the essence of the DMR method. Thus, for example, we combined corrections from four consecutive time steps by introducing four weighting factors to each of the four equations. Hence, a set of sixteen algebraic equations needs to be solved to determine the four sequences of four weighting factors in each of them. The DMR method requires about 200% more storage than the original non-accelerated algorithm.

A Local Relaxation Scheme (Ad-Hoc SOR) Applied to Nine Point and Block Difference Equations

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Abstract

The ad-hoc SOR method was originally devised for five point difference equations. Interest developed on how it might be applied to nine point schemes and block schemes. In this talk we will give a brief history and description of the method. Then we will discuss its application to nine point schemes, with justification as to its expected behavior. Several examples will be presented. Finally, we note its application to block methods and indicate why this may not be a wise move.

Uses of Reordering, Partial Elimination and Fourier Methods for Sparse Iterative Solvers

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Abstract

Three tools for the development and analysis of iterative methods for solving discretized partial differential equations are reordering, partial elimination, and Fourier methods. These techniques have their origins in Young's original work on iterative solvers, and they are in common use today. We discuss some recent results concerning these methodologies, and show how each of them relates to Young's work. In particular, we show how reordering and partial elimination is used to develop iterative methods for parallel and vector computers, and the effects and advantages of such strategies for solving nonsymmetric linear systems. In addition, we discuss the use of Fourier methods for analyzing convergence rates of preconditioned conjugate gradient methods.

Parallel Operations for Iterative Methods: A Polymorphic View

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Abstract

Matrix and vector operations such as *matrix-vector multiplication*, *FTTs*, and *cyclic reduction* are used in a wide class of scientific problems, quite often in the context of iterative methods. As these problems become larger and more computationally intensive, it becomes desirable to consider highly parallel computer systems. However, sparse structured matrix problems as well as the distant data transfers needed during the computations of techniques such as the FFT and cyclic reduction, usually result in a high percentage of idle processors and thus a low system performance — especially on SIMD machines.

In this paper, issues concerning how to efficiently map such problems onto the Polymorphic Torus architecture, a *reconfigurable* massively parallel fine-grained system, are presented. In particular, how the reconfigurability minimizes communication costs by letting the architecture match the problem structures is discussed.

$D^{\frac{1}{2}}$-Norms of the SOR and Related Method for a Class on Nonsymmetric Matrices

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Abstract

In this lecture, $D^{\frac{1}{2}}$-norms of SOR with optimal and non-optimal parameters are considered. The related methods such as modified SOR, Sheldon, modified Sheldon, and cyclic Chebyshev semi-iterative methods are also included.

Our basic difference with the already existing literature, concerning the norms of SOR and related methods will be the assumption that the coefficient matrix of the concerned linear has the form,

$$A = \begin{bmatrix} D_1 & -H \\ H^T & D_2 \end{bmatrix}$$

with D_1 and D_2 symmetric and positive definite. Such algebraic systems arise in the computation of cubic splines and the numerical solution of large linear least square problems.

A Stable Richardson Iteration Method for Complex Linear Systems

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Abstract

The Richardson iteration method is conceptually simple, as well as easy to program and parallelize. This makes the method attractive for the solution of large linear systems of algebraic equations containing matrices with complex eigenvalues. We choose the relaxation parameters to be subsets of sets of reciprocal of Fejer points. An ordering of the relaxation parameters is described which ensures that the obtained iterative method is stable and converges asymptotically optimally.

Toward an Effective Two-Parameter SOR Method

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Abstract

Given Jacobi matrix

$$B = \begin{bmatrix} 0 & M_{p\times q} \\ N_{q\times p} & 0 \end{bmatrix}$$

where

$$\text{rank }(M) = \text{ rank }(N) = \text{ rank }(MN) = \text{ rank }(NM)$$

Then matrices M and N are decomposed in a quasi-diagonal form which gives us insight into the structure of the general two-parameter SOR iteration matrix $B(w_0, w_1)$. A new proof of the eigenvalue equation results for $B(w_0, w_1)$. If the eigenvalues of B fall between -1 and $+1$, then it is known that $B(w_0, w_1)$ is optimal (has minimal spectral radius) only when both scalars, w_0 and w_1 equal w_{opt}, the "standard" optimizing relaxation parameter, in which case, $B(w_0, w_1) = B(w_{opt})$. But this isn't so if gaps in the spectrum of B are taken into account. We show when the spectral radius $B(w_0, w_1)$ is less that of any single-parameter $B(w)$ further structural results relating to the singular values and the norm equation are obtained.

Predicting the Behavior of Finite Precision Lanczos and Conjugate Gradient Computations

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Abstract

A recently-proved backward error analysis for the Lanczos and conjugate gradient algorithms explains the behavior of the finite precision algorithms applied to a matrix A in terms of the behavior of the exact algorithms applied to a larger matrix B. The matrix B can be considered to have infinitely many distinct eigenvalues, but all of its eigenvalues must lie in tiny intervals about the eigenvalues of A.

This analogy is used to estimate the convergence rate of finite precision computations, given some information about the eigenvalues of A. For solving symmetric positive definite linear systems, it is shown that convergence estimates based on the condition number of A hold to a close approximation in finite precision arithmetic, since the condition number of B is approximately the same as that of A. Estimates based on the number of distinct eigenvalues of A may fail in finite precision arithmetic but can be replaced by slightly weaker bounds based on the number of distinct eigenvalue "clusters" of B.

The frequency of occurrence of multiple "copies" of eigenvalues in finite precision Lanczos computations is equal to the frequency at which the exact Lanczos algorithm, applied to the matrix B, finds different eigenvalues within the same cluster. This can be estimated by considering the number of roots of the minimizing polynomial which must be present in each interval containing eigenvalues of B in order to insure that the polynomial is small throughout these

intervals. Finally, the number of steps required to generate at least one good approximation to every eigenvalue is estimated, knowing the components of the initial vector in the direction of each eigenvector. This information is used to evaluate the usefulness of various reorthogonalization strategies.

On an SSOR Matrix Relationship and Its Consequences

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Abstract

A matrix relationship connecting the Jacobi and the SSOR matrices associated with a k-cyclic consistently ordered matrix A is presented. For the solution of the linear algebraic system $Ax = b$, the k-step one is established. The aforementioned equivalence can be exploited to derive regions of convergence, optimum parameters involved, etc., of the two iterative methods above. This is done by studying the simplest one of the two methods that is the monoparametric k-step one. To show how the idea works, the trivial case $k = 2$ is very briefly discussed.

Relaxation Parameters for the IQE Iterative Procedure for Solving Semi-Implicit Navier-Stokes Difference Equations

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Abstract

Numerical solutions of the time-dependent Navier-Stokes equations for an incompressible fluid require advancing the unknown flow variables in time by either an implicit, a semi-implicit, or an explicit procedure. Explicit methods require a modest amount of computational effort per time step but require excessively small time-step lengths to ensure numerical stability. On the other hand, implicit and semi-implicit schemes allow the use of large time step lengths but suffer from increased computational complexities. Fully-implicit methods generate coupled systems of nonlinear equations that must be solved at each point in time, whereas semi-implicit procedures generate coupled systems of linear equations.

The focus of this paper is on the use of a recently formulated iterative procedure called the IQE method for solving the linear systems produced by a semi-implicit method. The IQE method requires the use of a relaxation parameter ω which must be properly chosen to obtain the greatest rate of convergence. Using heuristic arguments, we develop a numerical procedure for estimating near-optimal values for ω. Numerical test results are included.

On Kaczmarz' Method For Inconsistent Linear Systems

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Abstract

Let the linear system $Ax = b$ be rectangular but solvable. If A is a large, sparse matrix then one possibility to solve the system is to use the iterative method of Kaczmarz. If the system is unsolvable and the relaxation parameters are kept fixed in a certain interval, this method converges, too. To get a meaningful result, however, one has to apply strong underrelaxation. We give an interpretation of the limit in terms of a generalized inverse of A and derive bounds with respect to the least squares solution. Using a result of Buoni and Varga we estimate the speed of convergence. It is further shown that the eigenvalues of the iteration matrix are nearly real and we propose to use Chebyshev acceleration. This results in a significant speedup.

A New Class of Methods for Solving Nonsymmetric System of Linear Equations — Constructing and Realizing Symmetrizable Iterative Methods

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Abstract

We present a new class of methods for solving the non-singular, nonsymmetric linear system

$$Ax = b$$

by constructing symmetrizable iterative methods. The idea is to choose a splitting matrix Q such that $Q^{-1}A$ is symmetrizable and that the spectral condition number of $Q^{-1}A$ is small. Once Q is chosen, we can set up the symmetrizable iterative method

$$x = (I - Q^{-1}A)x + Q^{-1}b$$

(I is the identity matrix), and apply either the Chebyshev or the CG acceleration to solve for x.

Both theoretical investigations and applications to numerical examples show that such a scheme is plausible for non-singular, nonsymmetric linear systems. The key to the scheme is how to choose the splitting matrix Q. We suggest several alternatives of Q and compare them in numerical experiments. Results show that the best choice is to have

$$Q^{-1} = A^H[U\ diag\ (\sigma_1^{-2}, \sigma_2^{-2}, \sigma_N^{-2})U^H]\ ,$$

and then apply the CG acceleration in the iterative procedure. In the above expression, the columns of matrix U represent N (the dimension of A) orthonormal eigenvectors of $A^H A$; and $\sigma_i (i = 1, 2, \ldots, N)$ are the singular values of A arranged in decreasing order. We prove that in this case, the spectral condition number of $Q^{-1}A$ is 1.

One advantage of our methods is that they could successfully solve nonsingular, nonsymmetric linear systems where the basic iterative methods such as the Jacobi, the Gauss-Siedel, or the CG method would fail. (This work was supported in part by the National Science Foundation of P.R. China through grant 860451.)

On the Effectiveness of Adaptive Chebyshev Acceleration for Solving Systems of Linear Equations

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Abstract

A symmetrizable basic iterative method $u^{(n+1)} = Gu^{(n)} + k$ can be greatly accelerated by Chebyshev acceleration. This method requires estimates of the extreme eigenvalues $m(G)$ and $M(G)$ of the iteration matrix G. An adaptive procedure for finding the eigenvalues was introduced by Hageman and Young [1981]. We describe a scheme of using contours to test the effectiveness of this adaptive Chebyshev acceleration procedure. We conclude that the adaptive process is not sensitive to the starting estimate unless it is very close to $M(G)$. Moreover, the adaptive procedure takes at most 35% more work than the optimal nonadaptive procedure.

The idea of this research was given by D. M. Young in 1977 when he was writing his book with L. A. Hageman. At the time, the Cyber computer at The University of Texas at Austin could not provide enough memory storage for us to carry out the numerical experiments. Moreover, the computation time was unexpectedly long if we did not save some previous information.

A Status Report on the ITPACK Project

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Abstract

Over the past several years a number of research-oriented software packages for solving large sparse systems of linear algebraic equations have been developed within the Center for Numerical Analysis as part of the ITPACK Project. This report includes a brief discussion of each of the packages. References are given to other reports and papers which describe the individual packages in more detail.

Two-Color Fourier Analysis of Iterative Methods for Elliptic Problems with Red/Black Ordering

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Abstract

One common approach to obtain parallel numerical algorithms for solving partial differential equations (PEDs) is *reordering*. By reordering, we rearrange the computational sequences to increase the percentage of computations which can be done independently. For example, the multicolor ordering scheme for grid points provides more parallelism than the natural row-wise or column-wise ordering scheme. It is well known that by using red and black two colors to order the grid points in a checkered-board fashion for the five-point Laplacian, we are able to separate the coupling between any two red (or black) points so that the values at all red (or black) points can be updated simultaneously. One important problem with the multicolor ordering scheme is how the convergence rate of an iterative algorithm is affected by such a reordering. The objective of this paper is to provide a unified approach called the *two-color Fourier analysis* to study the convergence rates of different types of algorithms with the red/black ordering, including the successive overrelaxation (SOR), symmetric successive overrelaxation (SSOR), SSOR, ILU and MILU preconditioned iterative methods and multigrid (MG) methods.

Due to the multicolor ordering scheme, the resulting system of iteration equations is not spatially homogeneous but is periodic with respect to grid points. Consequently, the Fourier modes are not eigenfunctions for the periodic system, and therefore, a straight forward Fourier analysis does not apply. When these

components are operated by periodic operators, there exists a coupling between high and low frequency components. By exploiting the periodic property, we reformulate the conventional Fourier analysis as a two-color Fourier analysis. ¿From this new viewpoint, components in the high frequency region are folded into the low frequency region so that there exist two, i.e., red and black, computational waves in the low frequency region. The coupling between the low and high conventional Fourier components is therefore transformed into a coupling between red and black computational waves with the same frequency in the low frequency region. With this new Fourier tool, the spectral representation of red/black periodic operators can be easily derived and interpreted.

We compare the convergence rates of algorithms with natural and red/black orderings for the model Poisson problem on a square with Dirichlet boundary conditions, and show analytically that although the red/black ordering does not effect the rate of convergence in the context of SOR and MG methods, it slows down the convergence significantly in the context of SSOR and preconditioned iterative methods.

Asynchronous Parallel Iterative Methods

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Abstract

When asynchronized computation is executed, by definition, the processors never wait for each other and the processors are fully utilized by the distributed algorithm. The main goal of this paper is to show theoretical results and to discuss the nature of distributed iterative algorithms with applications to computing two and three dimensional elliptic fields. We will present a classification of an explicit iterative computational scheme with respect to the amount of synchronization needed by the algorithm. Based on that, several theorems on the existence of distributed iterative computing algorithms in linear algebra that do not make any use of synchronization, yet produce correct subsets to the solution will be proven and discussed. These theorems lead to appropriate conditions that guarantee convergence of the iterative distributed algorithm. Since the proof for the existence theorem is constructive, it suggests also a class of iterative numerical algorithms that can be asynchronizedly distributed. We will discuss other important features of this class of algorithms, for example, changing dynamically by the appropriate processor as a function of the availability of the needed data which resides or is being produced by another resource in the distributed system. Finally we compare theoretically and technically the suggested distributed algorithms to other known numerical distributed algorithms (like the Chaotic Relaxation algorithm, the AJ algorithm, the AGS algorithm and the PA algorithm). It will be shown that in a certain sense they are special cases of the present approach. Given this view of the present approach, the following questions will be studied:

1. Uniqueness of the solution. It will be shown that in the general case the above distributed algorithms may have more than one fixed point. Conversely, it is conjectured (and hopefully will be proven) that for a given distributed algorithm $(x^{(0)}, F)$ there exist a finite class of problems that this distributed iterative method solves.

2. Understanding the reason for the above fact, some algorithms may be suggested so as to narrow this class of admissible problems. By using this procedure iteratively (yet in a sequential manner), the unique solution for the problem $Z(P)$ may be obtained.

New Finite Difference Approximations of Boundary Conditions

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Abstract

A new method for incorporating boundary conditions in finite difference approximations of linear second-order elliptic differential equations is described. The method, which is based on the "HODIE" approximation, is designed to achieve $O(h^4)$ accuracy for problems with smooth solutions on general domains for general boundary conditions. A new Ellpack module, HODIE-G, uses the method to discretize problems on 2-dimensional domains.

On the Adaptive Determination of Iteration Parameters

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Abstract

For many iterative algorithms for solving large sparse linear systems, the rate of convergence is very sensitive to the choice of iteration parameters. Examples of such parameters include the relaxation factor ω for the SSOR method, the shift parameter α for the shifted incomplete Cholesky method (SIC method), as well as the smallest and largest eigenvalues, $m(G)$ and $M(G)$, respectively, of the matrix of a basic iterative method when accelerated by Chebyshev acceleration. The parameters ω and α are referred to as "splitting parameters" since they relate to the basic iterative method which is defined by a matrix splitting. The parameters $m(G)$ and $M(G)$ are referred to as "acceleration parameters" since they relate to the Chebyshev acceleration procedure.

We consider here two procedures for the automatic, or adaptive, determination of iteration parameters. The first procedure is a so-called "dual adaptive procedure" for the determination of the parameters $m(G)$ and $M(G)$ for use with Chebyshev acceleration of a basic iterative method. The procedure is based on the use of generalized Rayleigh quotients. With this procedure improved values of $m(G)$ and $M(G)$ are obtained simultaneously.

The second procedure is a "composite adaptive procedure." This procedure is used to find the splitting parameter for an iterative algorithm consisting of a basic iterative method involving a single splitting parameter, such as the SSOR method or the shifted incomplete Cholesky method, accelerated by conjugate gradient acceleration. A variational principle is used along with a search algorithm to determine the splitting parameter. The variational principle is the

same as that used for conjugate gradient acceleration of a basic iterative method with a fixed splitting parameter.

Numerical experiments were carried out for both the dual adaptive procedure and for the composite adaptive procedure. In many cases these procedures were found to perform better than previously developed procedures.

Iterative Methods for Nonsymmetric Linear Systems

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Abstract

This talk will present a survey of polynomial methods for solving nonsymmetric linear systems. Starting with a general definition of polynomial methods, several classes of methods will be presented. First, stationary and semi-iterative methods will be described. Then, conjugate gradient and orthogonal error methods as well as truncated forms of these methods will be presented. Finally, methods based on the Lanczos algorithm will be reviewed. An attempt will be made to expose open questions.

Fast Hybrid Solution of Algebraic Systems

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Abstract

We explore the possibility of a fast equation solver consisting of both analog and digital circuitry. We expect this hybrid combination to give better results than digital techniques alone. The basic idea is to use an analog solver as a preconditioner for a digital iterative process. Thus, we can obtain both high speed from a fast exchange of information in analog circuitry and high precision from digital circuitry. Eventually, both types of circuits should be integrated onto a single chip. Related approaches occur in optical computing where the term bimodal is used.

We define an analog defect correction algorithm and discuss the sources of error. We also provide an error analysis and characterize the speedup of this approach. Then we define a basic model for a simple analog solver. We analyze its response speed and its precision. A general example is examined in detail. Next we define and motivate a two-stage analog solver. We analyze it and examine an example. Finally, we define and analyze a multilevel solver. We use the term multilevel in the abstract multigrid solution of partial differential equation sense.

The applicability of the method is essentially limited by the condition $\epsilon\kappa \ll 1$, where ϵ is the relative precision of the analog circuitry and κ is the condition number of the linear system. For the multilevel solver, the condition number involved is the one for the linear system on the coarsest level. The time for the analog part of the method also depends on the condition number. We conclude

that this time is negligible in comparison to that for the digital part of the method when $\epsilon\kappa \gg 1$.

We expect the principal benefits of the proposed method to manifest themselves with advances in technology: analog circuitry has the potential to avoid the information exchange bottleneck of massively parallel digital computation. Essentially, we are trading (recoverable) precision for fast dissemination of information between the processors.

We expect that these techniques will be advantageous for large but moderately conditioned positive definite problems with well defined sparsity structures. Systems arising by either finite element or finite difference discretizations of partial differential equation problems are one possible application. for a general, non-sparse system, the number of connections required is prohibitive.

The technique used in the analysis is classical and can be found in any electrical engineering textbook. We believe the defect correction approach to the hybrid method is new and offers, as yet, unexplored possibilities in massive parallel computation.

The precision of contemporary analog circuitry is up to 10 bits using capacitors as basic circuit components. Optical processors have the same or lower precision.

A Benchmark Comparison of the ITPACK Package on ETA-10 and Cyber-205 Supercomputers

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Abstract

The ITPACKV 2C adaption for vector supercomputers has been run on ETA-10 and Cyber-205 vector supercomputers using the ELLPACK code data structure which stores efficiently matrices resulting from the discretization of elliptic partial differential equations.

A number of sample problems derived from the elliptic PDE population (Dyksen, Houstis and Rice, 1985) have been benchmarked on the ETA-10 and Cyber-205 using various grid resolutions — resulting in variable vector lengths for vectorization.

Results of the benchmark comparison for each of the seven ITPACKV solution modules in terms of execution times on the ETA-10 and Cyber-205 will be presented.

Since ITPACK codes in ELLPACK are modified subset of the entire ITPACK package we also tested ITPACK as a stand-alone package on the two supercomputers.

The impact of differences in the vector start-up time for the ETA-10 and Cyber-205 for short, medium and long vectors resulting from various grid resolutions on the execution time performance will be discussed.

Convergence Domains and Inequalities for the Symmetric SOR Method

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Abstract

In the last twenty five years many papers have appeared in which the spectral radius of the symmetric successive overrelaxation (SSOR) iteration matrix is given as a function of the relaxation parameter and some or all of the eigenvalues of the Jacobi iteration matrix. For certain classes of matrices it has been possible to determine the optimal relaxation parameter, for others it has only been possible to determine regions of convergence for the method or even less, just bounds on these regions. We review some of the results in this area as they were developed chronologically and discuss how they inter-relate to each other and also to some known convergence bounds for the (usual) SOR method.

Experiments with a Parallel Iterative Package

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Abstract

One design for a computer package for solving large sparse systems of linear equations by iterative methods on parallel computers is presented. The package contains acceleration routines from the NSPCG package rewritten to employ Level 1 BLAS (SAXPY, SCOPY, SDOT, SNRM2, and SSCAL) and Level 2 BLAS (SMXPY). These operations, in addition to the matrix-vector product, do most of the work in an acceleration algorithm and are all easily parallelizable on shared memory machines. By localizing most of the work in this relatively small number of subroutines, the package can be easily ported to several shared memory parallel computers by replacing these subroutines with versions which are tailored to a specific parallel computer. Experiments using the package on several different shared memory parallel computers, such as the Sequent Balance, Alliant FX/8, and Cray X-MP, are described.

Solution of Three-Dimensional Generalized Poisson Equations on Vector Computers

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Abstract

We consider generalized Poisson equations of the form $\nabla(K\nabla u) = f$ on a parallelpiped in three dimensions. The equation is discretized by finite differences with variable spacing and the resulting linear system is solved by the SSOR polynomial preconditioned conjugate gradient method. An example problem is treated and results reported for a Cyber 205 and a single processor Cray-2 for problems varying in size up to 250,000 grid points.

On the Matrix Geometric Progression and the Jordan Canonical Form

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Abstract

Very short proofs of the following well known theorems are given:

Theorem I. If A is a given $n \times n$ matrix with eigenvalues $\lambda_1, \lambda_2, \ldots, \lambda_n$, then a necessary and sufficient condition for

$$\lim_{k \to \infty} A^k = 0$$

is

$$|\lambda_s| < 1 \qquad (s = 1, 2, \ldots, n)$$

Theorem II. Matrix A has Jordan canonical form.

The proof of the Theorem I is inductive and it is based only on the following.

Lemma. If $\alpha \in [0, 1]$ and the decreasing sequence $a_0 \leq a_1 \leq a_2 \leq \ldots$, tends to 0, then

$$\lim_{k \to \infty} (a_0 \alpha^k + a_1 \alpha^{k-1} + \cdots + a_k) = 0$$

The proof of Theorem II is inductive also.

Remark. Theorem II was proved jointly with my colleague I.G. Ivanov.

Composition Method for Solving Elliptic Problems

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Abstract

A finite element piecewise linear approximation to a self-adjoint second-order elliptic equation in a non-rectangular bounded two-dimensional region with Dirichlet boundary condition is considered. A composition method for the arising linear systems of algebraic equations is presented. It consists of inner-outer iterations. Preconditioned Richardson iterations are chosen as the outer iterations, in which the discrete Laplacian is employed as a preconditioner. In each outer iteration systems with the Laplacian in an irregular region are solved by the imbedding capacitance matrix method that uses conjugate gradients — inner iterations in our composition method.

We prove that with an optimal control of inner iterations the rate of convergence of this inner-outer iterative process depends only logarithmically on h, the parameter of triangulation:

Theorem: Let the inner iterative process be carried out so that $||r_k|| \leq q^k/k^2$, $k = 1, 2, \ldots$ is satisfied (here, q is a constant depending on the operator and the region). Then the total number of iterations of the composite process is proportional to $\ln^2 h^{-1}$.

We also present results of extensive numerical experiments that confirm the theoretical estimates.

Multilevel Asynchronous Iterations for PDE's

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Abstract

Consider solving a PDE on a domain D using a domain decomposition or Schwarz splitting approach. We decompose D_a several times with each level having a finer (more accurate) decomposition than the preceding one. Iterative methods are initiated on each level and improved results are passed down from level to level so long as the higher level iterations have not converged. This is implemented in a parallel computing environment (such as a hypercube machine). The passing of information between levels is asynchronous. Parameters of such a method are (1) number of levels and number of domains per level, (2) number of processors per level, (3) choice of method on the subdomains of each level (and their convergence rates), and (4) the tolerances used to terminate higher level iterations. We report on both analytic and experimental studies of the effectiveness of such methods and of good values for the parameters.

Convergence of Nested Iterative Methods for Linear Systems

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Abstract

Suppose that we are trying to solve the linear system, $Ax = b$, by an iterative method described by a splitting $A = M - N$. This involves solving linear systems of the form $My = k$, and we could image solving these linear systems also by iteration described by splitting $MF - G$. And so on with further nested splitting, perhaps. Our results analyze the convergence of such methods. In addition we examine the behaviour of the rate of convergence as more inner iterations are performed or better inner iterative methods are used. In order to apply our results to block Gauss-Seidel-like iterative methods where the diagonal blocks are solved also by iteration, we need to introduce the notions of a backward splitting as well as the more natural forward splitting. The theory of non-negative matrices plays an important role in our analysis, and a new comparison theorem for weak regular splitting is established

Iterative Methods for Complex Linear Algebraic Equations

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Abstract

Complex linear algebraic equations arise in many scientific and engineering studies. Many well-known algorithms are applicable to complex matrices, such as SOR, the bi-conjugate gradient method, and Manteuffel's adaptive Chebyshev algorithm. For large problems, Richardson's method is attractive but requires a set of parameters. An early paper of David Young's presents optimum parameters as transformed roots of the Chebyshev polynomial in the symmetric positive definite case. An adaptive algorithm for optimum parameters will be described in the nonsymmetric case. The parameters are optimum in a least squares sense that includes Chebyshev parameters.

Remarks on k-Step Iterative Methods

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Abstract

In this paper, we review the theory of k-step stationary iterative methods, and we investigate the practical problem of estimating optimal parameters.

The Symmetric Generalized Accelerated Overrelaxation (GSAOR) Method

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Abstract

We introduce the symmetric generalized accelerated overrelaxation method (GSAOR). The derivation of this method from the GAOR method is analogous to the way the SSOR method was obtained from the SOR and the SAOR method from the AOR. We prove the following theorems:
Theorem 1: If A is a real symmetric positive definite matrix,

$$\begin{array}{lll} D > 0 & & A = D - L - U \\ D_1 = k\,D & (k > 0) & D = D_1 - D_2 - D_3 \\ D_2 = 0 & & \end{array}$$

then the SGAOR method converges, that is,

$$S(J_{rw}(D_1, D_2)) < 1$$

iff

$$0 < w < 2k \text{ and } w + \frac{(2k - w)}{u_{min}} < r < w + \frac{(2k - w)}{u_{max}}$$

where u_{min} and u_{max} are the minimum and maximum eigenvalues of the iteration matrix B of the Jacobi method and $J_{rw}(D_1, D_2)$ is the iteration matrix of the SGAOR method.

Theorem 2: If A is a real symmetric matrix, w and r satisfy the conditions from the previous theorem,

$$A = D - L - U \qquad D_1 = k\,D \quad (k > 0)$$
$$D = D_1 - D_2 - D_3 \qquad D_2 = 0$$

Then the matrix $J_{rw}(D_1, D_2)$ has real eigenvalues and $\mathcal{S}(J_{rw}(D_1, D_2)) < 1$ implies that A is positive definite.

We also give some examples which illustrate that the method gives better results than the SAOR one.

The ADI Minimax Problem for Complex Spectra

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Abstract

ADI minimax problem has been solved for a range of complex spectral domains. This analysis was motivated by new application to solution of Sylvester's equation. The commutation property required for application to the Dirichlet problem is not restrictive in this new application. However, complex spectra to which conventional ADI theory does not apply are often encountered. Theory of elliptic functions plays a prominent role in the analysis. Optimum parameters are derived only for a class of "elliptic-function domains" which are not apt to occur in practice. However, this theory is then applied to obtain nearly-optimum parameters for realistic spectral regions. nonsymmetric systems create other problems. Convergence of ADI iteration is retarded by deficient eigenvector spaces. A Lanczos-type generation of a basis for deficient spaces is described. This basis is used to develop a low-order system which may be solved by a direct method to correct the result of the ADI iteration.

Domain Decomposition — Multigrid Algorithms for Mixed Finite Element Methods for Elliptic PDE's

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Abstract

A numerical algorithm combining multigrid and domain decomposition is developed for mixed finite element methods. Numerical results will be discussed from addressing anisotropic elliptic problems and point source singularities as well as parallelization efficiencies involved in the implementation.

Finite Element Treatment of Singularities in Elliptic Boundary Value Problems

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Abstract

Techniques for post processing piecewise linear finite element approximation to the solution of elliptic boundary value problems to produce superconvergence gradient approximation have consistently demanded high regularity of the analytic solution. The manner in which this superconvergence may be obtained for problems involving singularities is discussed.

Domain Decomposition Algorithms for Elliptic Problems

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Abstract

We will discuss domain decomposition in which the often very large linear systems of algebraic equations, arising when elliptic problems are discretized by finite differences or finite elements, are solved with the aid of exact or approximate solvers for the same equations on subregions. The interaction between the subregions, to enforce appropriate continuity requirements, is handled by an iterative method. One of these methods, the Schwarz alternating algorithms, was discovered already in 1870. In that algorithm the subregions overlap. As has been pointed out by P.L. Lions and others, Schwarz' algorithm can conveniently be expressed in terms of certain projections. We will discuss recent work carried out jointly with Maksymilian Dryja inside this framework. An interesting additive version of the classical Schwarz algorithm will be presented. The study of Schwarz' algorithm has led to the development of a general framework for the study of a variety of domain decomposition methods. Among them are the so called iterative substructuring methods, where the subregions do not overlap.

Iterative Methods in Molecular Collision Theory

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Abstract

The use of iterative methods for solving large linear algebraic systems is essential for the successful implementation of several recent approaches to molecular collision dynamics. Two approaches which lead to linear systems will be described. In the first, discretization of the Fredholm integral equation describing the collision leads to a large system of algebraic equations. In the second approach, a basis set expansion in the variational formulation for transition amplitudes again leads to a large algebraic system. Computational results obtained with both the GMRES and Lanczos algorithms for both of the above approaches will be described. These iterative methods are significant because they scale as $O(N^2)$, where N is the matrix dimension, thus permitting calculations on complex systems of chemical interest. (Supported in part by the National Science Foundation and the Robert A. Welch Foundation.)

The Search for Omega

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Abstract

For the effective use of iterative algorithms for solving large sparse linear systems it is often necessary to select certain iteration parameters. Examples of iteration parameters are the relaxation factor, omega, for the SOR and SSOR methods and the largest and smallest eigenvalues of the matrix for a basic iterative method when Chebyshev acceleration is used to speed up the convergence. For many iterative algorithms the performance is extremely sensitive to the choice of iteration parameters. Moreover, uncertainty as to how to choose iteration parameters has often, in the past, discouraged the use of iterative methods, as opposed to direct methods, for certain classes of problems.

The purpose of this paper is to review the development of procedures for choosing iteration parameters, with special emphasis on methods applicable to linear systems arising from the numerical solution of partial differential equations. The discussion will include *a priori* procedures including analytic techniques, spectral methods, and methods based on related differential equations. Automatic, or "adaptive," procedures will also be discussed. Some of these procedures have been incorporated into the ITPACK software packages for solving large sparse linear systems. Numerical experiments indicate that the amount of overhead needed to determine satisfactory parameters is not excessive. Methods for choosing iteration parameters for nonsymmetric systems will also be discussed.

Professor David M. Young, Jr.

Professor David M. Young received his PhD in Mathematics from Harvard University. Following a year of post-doctoral research at Harvard he went to the Computing Laboratory of the Aberdeen Proving Ground. A year later he went to the University of Maryland where he held the rank of Associate Professor of Mathematics. Three years later he joined the staff of the Ramo-Wooldridge Computation in Los Angeles where he was Head of the Mathematics and Computation Department.

In 1958, Professor Young joined the faculty of The University of Texas as Professor of Mathematics and Director of the Computation Center. While Director of the Computation Center he was involved in the acquisition of two large computer systems — the Control Data 1604 computer in 1961 and the Control Data 6600 computer in 1966. In 1970, Professor Young left the Computation Center to become Director of the Center for Numerical Analysis. He currently holds the title of Ashbel Smith Professor of Mathematics and Computer Sciences at The University of Texas at Austin. He is also a member of the Texas Institute for Computational Mechanics.

Professor Young has worked extensively on the numerical solution of partial differential equations with emphasis on the use of iterative methods for solving large sparse systems of linear algebraic equations. His early work on iterative methods involved the analysis of the successive overrelaxation (SOR) method for consistently ordered matrices. He was also one of the first to use Chebyshev polynomials for the solution of linear systems. He has written over 90 technical papers and is the author of three books. The first of these books, which appeared in 1971, is devoted to the basic theory of iterative methods. The second book, with Robert Todd Gregory, is a two volume survey of numerical mathematics that first appeared in 1972 and was reprinted in 1988. The third book, with Louis A. Hageman, appeared in 1981 and is devoted to iterative algorithms, including automatic procedures, for choosing iteration parameters, as well as accurate procedures for deciding when to stop the iterative process.

Since the mid 1970s, Professor Young has collaborated with Dr. David R. Kincaid and others on the ITPACK project. This project is concerned with research on iterative algorithms and on the development of research-oriented mathematical software. Several software packages have been developed with the capability of handling nonsymmetric, as well as symmetric, systems. The emphasis of the work has been increasingly on the use of advanced computer architectures.

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David M. Young, Jr.

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Tsun-zee Mai	"Adaptive Iterative Algorithms for Large Sparse Linear Systems"	1986
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David M. Young, Jr.

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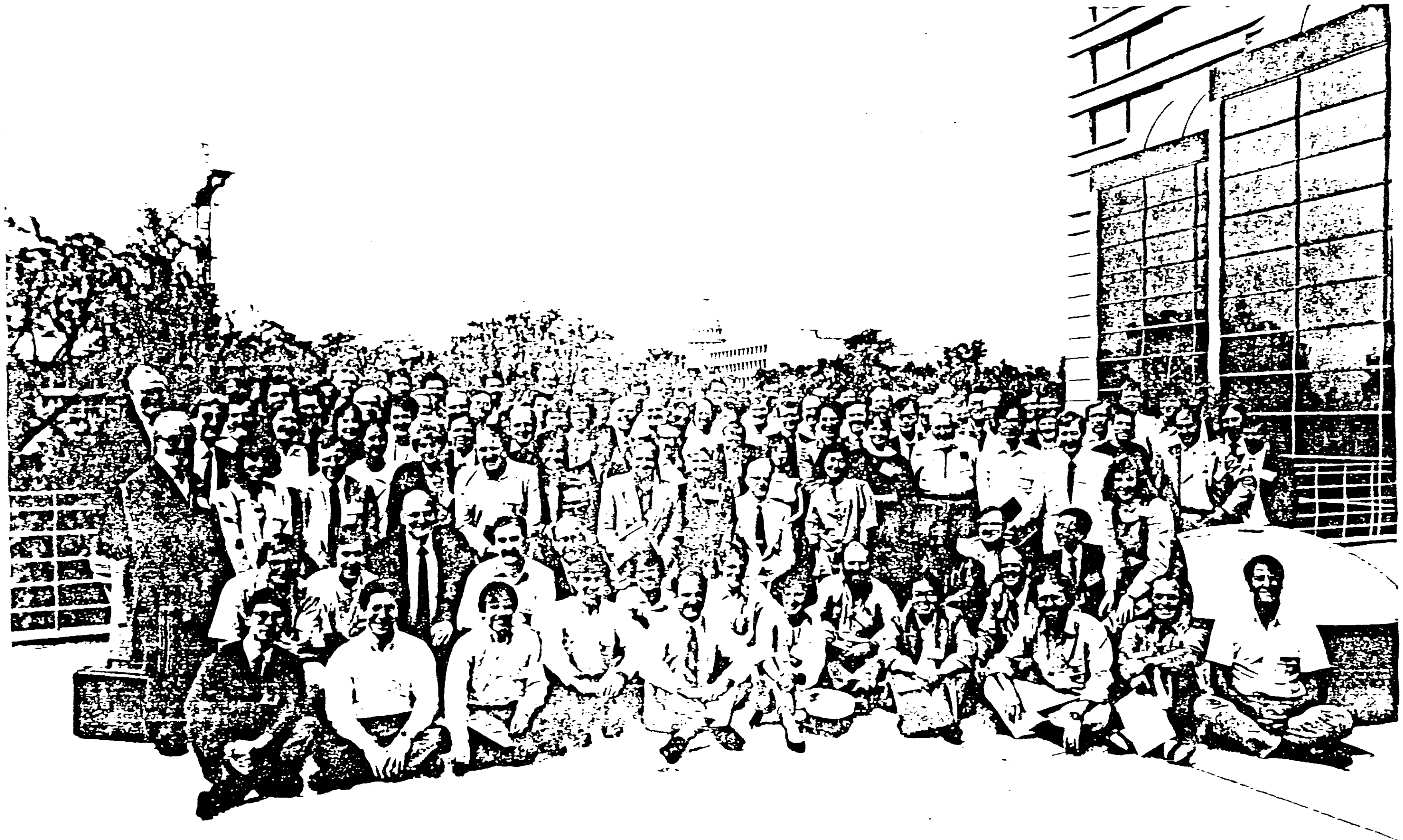

—Honors

Colleagues Honor Young Numerical Linear Algebra Meeting

David M. Young, Jr.

For his many contributions to the field of computational mathematics, **David M. Young, Jr.**, was honored at a banquet held last month on the occasion of his 65th birthday. The banquet was the highlight of the conference Iterative Methods for Large Linear Systems, held October 19-21, 1988, in Austin, Texas.

The conference, which was hosted by the University of Texas at Austin's Center for Numerical Analysis, attracted many of the world's most distinguished mathematicians and computer scientists. Many of Young's friends and colleagues—from academe, industry, and government—attended a reception on the first evening of the conference and then capped off the evening with some social tennis.

David Kincaid and Linda Hayes, together with Gene Golub, hosted the Thursday night banquet. Many of Young's former students were in attendance, and messages from those who could not be there were read. Hayes touched on some of the highlights of Young's career, and the slide show narrated by Kincaid included family pictures as well as scenes from the early days of the Center for Numerical Analysis. Golub and others reminisced about their past associations with Young in the form of anecdotes—some humorous and others serious, all of them heartfelt.

The conference began on Wednesday morning with a lecture by Garrett Birkhoff, followed by a series of invited and contributed talks. In addition to reviewing the many research advances that have been made in the development of iterative methods for high speed computers during Young's career of almost 40 years, the speakers identified current and future research directions.

As a frequent participant in SIAM meetings, Young is well known to SIAM members. He recalls taking a train from Aberdeen, Maryland, to Philadelphia to attend the first SIAM meeting in the spring of 1952.

A member of the UT Austin faculty since 1958, Young is currently Ashbel Smith Professor of mathematics and computer science. Anyone who has worked with him knows that it is hard to keep up with his active schedule, which includes daily tennis matches. He consults regularly with students at conferences and during his travels.

Young's involvement in scientific computing spans the time from his days as a graduate student at Harvard in the late 1940s to the current generation of supercomputers. He is best known for the development of the theoretical analysis associated with the successive overrelaxation (SOR) method. That material is now considered classical analysis and appears in most textbooks on numerical analysis. The conference offered the unique opportunity to hear from many of those who—along with Young—had firsthand involvement in the development of that area of scientific computing.

A former director of the Computation Center, Young was involved in the acquisition of two large computer systems—the Control Data 1604 computer in 1961 and the Control Data 6600 computer in 1966, machines that helped establish UT Austin as a leading university in scientific computing. He left the Computation Center in 1970 to become director of the Center for Numerical Analysis, a title he still holds.

Young has worked extensively on the numerical solution of partial differential equations, with the emphasis on the use of iterative methods for solving large sparse systems of linear algebraic equations. He has written more than 90 technical papers and three books.

Since the mid-1970s, Young has collaborated with David R. Kincaid and others in research on iterative algorithms and on the development of research-oriented mathematical software as part of the ITPACK project. Their work has resulted in the development of several software packages with the capability of handling nonsymmetric as well as symmetric systems. The emphasis of the work has been increasingly on the use of advanced computer architectures.

Banquet honors Young on 65th birthday as part of math conference

A banquet honoring Dr. David M. Young Jr. for his many contributions to the field of computational mathematics and on the occasion of his 65th birthday highlights the "Iterative Methods for Large Linear Systems" conference to be held Oct. 19-21 at Austin's Marriott at the Capitol.

The conference, with UT Austin's Center for Numerical Analysis as host, is expected to attract many of the world's most distinguished mathematicians and computer scientists. They will review the many research advances in the development of iterative methods for high-speed computers during Young's career of almost 40 years as well as identify current and future research directions.

A member of the UT Austin faculty since 1958, Young currently is Ashbel Smith Professor of mathematics and computer sciences. He has been involved in scientific computing from his days as a graduate student at Harvard in the late 1940s until the current generation of supercomputers.

Young is best known for the development of the theoretical analysis associated with the Successive Overrelaxation (SOR) method. That material is now considered classical analysis and appears in most textbooks on numerical analysis. The conference will offer the unique opportunity to hear from many of those who, along with Young, had firsthand involvement in the development of that area of scientific computing.

A former director of the Computation Center, Young was involved in the acquisition of two large computer systems — the Control Data 1604 computer in 1961 and the Control Data 6600 computer in 1966, machines that helped establish UT Austin as a leading university in scientific computing. He left the Computation Center in 1970 to become director of the Center for Numerical Analysis, a title he still holds.

Young has worked extensively on the numerical solution of partial differential equations with emphasis on the use of iterative methods for solving large sparse systems of linear algebraic equations. He has written more than 90 technical papers and three books.

Since the mid-1970s, Young has collaborated with Dr. David R. Kincaid and others on the ITPACK project, a project concerned with research on iterative algorithms and on the development of research-oriented mathematical software. Several software packages have been developed with the capability of handling nonsymmetric, as well as symmetric, systems. The emphasis of the work has been increasingly on the use of advanced computer architectures.

Gregory Lecture slated

A Harvard University educator has been selected to present the second Robert Todd Gregory Memorial Lecture at the University.

Dr. Garrett Birkhoff, the George Putnam Professor of Pure and Applied Mathematics Emeritus at Harvard, will speak on "A Taxonomy of Square Matrices." The lecture begins at 4 p.m. Oct. 18 in R.L. Moore Hall 4.102 with refreshments being served preceding the lecture at 3 p.m. in R.L. Moore Hall 12.104.

Gregory was a faculty member in the departments of mathematics and computer sciences from 1959 until 1974. From 1959 until 1965, he served as associate director of the Computation Center. Gregory died in Knoxville, Tenn., in 1984 while on the faculty at the University of Tennessee.

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