Final Program

SIAM 1983 Fall Meeting
November 7-9, 1983

The symposia for the Fall Meeting are being supported by a grant from the Air Force Office of Scientific Research.

SIAM Conference on Parallel Processing for Scientific Computing
November 10-11, 1983

The symposia for the Conference are being supported by grants from NASA Langley Research Center and the Office of Naval Research.

OMNI International Hotel
Norfolk, Virginia

PROGRAM COMMITTEE

SIAM 1983 FALL MEETING

H. Thomas Banks, Brown University, and Southern Methodist University
Chester Grosch (Co-chairman, Contributed Papers), Old Dominion University
Jules J. Lambiotte (Co-chairman, Contributed Papers), NASA Langley Research Center
James M. Ortega, University of Virginia
Robert G. Voigt (Meeting Chairman), ICASE

SIAM CONFERENCE ON PARALLEL PROCESSING

William Buzbee, Los Alamos National Laboratory
Jack J. Dongarra, Argonne National Laboratory
Albert M. Erisman, Boeing Computer Services Company
David Kuck, University of Illinois
Garry Rodrigue, Lawrence Livermore National Laboratory
Robert G. Voigt (Conference Chairman), ICASE

VICE PRESIDENT, PROGRAMS

James McKenna, Bell Laboratories

VICE PRESIDENT, PUBLICATIONS

H. Thomas Banks, Brown University, and Southern Methodist University

OPERATIONS

Hugh B. Hair, SIAM

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SIAM 1983 Fall Meeting

SIAM Conference on Parallel Processing for Scientific Computing

The symposia for the Fall Meeting are being supported by a grant from the Air Force Office of Scientific Research.

The symposia for the Conference are being supported by grants from NASA Langley Research Center and the Office of Naval Research.

The registration times for the meeting and conference are as follows:

	FROM	TO
SUNDAY, NOVEMBER 6	5:00 PM	9:00 PM
MONDAY, NOVEMBER 7	7:00 AM	5:00 PM
TUESDAY, NOVEMBER 8	8:00 AM	5:00 PM
WEDNESDAY, NOVEMBER 9	8:00 AM	5:00 PM
THURSDAY, NOVEMBER 10	7:30 AM	5:00 PM
FRIDAY, NOVEMBER 11	8:00 AM	2:00 PM

Registration Area: International Promenade

SPECIAL NOTICE TO: Contributed Paper Authors and
Chairmen, Contributed Paper Sessions

Fifteen minutes are allowed for each contributed paper. Authors are requested to allow a maximum of twelve (12) minutes for presentation of their paper and to allow three (3) minutes for questions and answers.

Chairmen of contributed paper sessions are requested to adhere as closely as possible to the scheduled times to facilitate meeting and conference participants moving from one session to another.

ATTENTION ATTENDEES:

THE SIAM COUNCIL PASSED A MOTION IN JUNE 1976 REQUESTING THAT PARTICIPANTS REFRAIN FROM SMOKING IN THE LECTURE ROOMS DURING LECTURES.

SIAM 1983 Fall Meeting
November 7–9, 1983

SYMPOSIA SESSIONS AND SPECIAL LECTURES

MONDAY, NOVEMBER 7

SYMPOSIUM ON CONTROL, STABILIZATION AND OPTIMIZATION IN DISTRIBUTED SYSTEMS

8:30-9:15 AM	M.C. Delfour
9:15-10:00 AM	J.S. Gibson

RETIRING PRESIDENT'S ADDRESS

1:30-2:30 PM	S.V. Parter

TUESDAY, NOVEMBER 8

SYMPOSIUM ON COMPUTATIONAL AERODYNAMICS I

8:30-9:15 AM	W.F. Ballhaus, Jr.
9:15-10:00 AM	J.C. South, Jr.

THE GEORGE POLYA PRIZE IN APPLIED COMBINATORICS

10:30-11:00 AM	A. Björner
11:00-11:30 AM	P. Seymour

SYMPOSIUM ON COMPUTATIONAL AERODYNAMICS II

1:00-1:45 PM	R.W. MacCormack
1:45-2:30 PM	J.L. Lumley

WEDNESDAY, NOVEMBER 9

SYMPOSIUM ON PARALLEL PROCESSING I

8:30-9:15 AM	R.W. Hockney
9:15-10:00 AM	G. Rodrigue

SYMPOSIUM ON PARALLEL PROCESSING II

1:00-1:45 PM	D.J. Kuck
1:45-2:30 PM	J. Schwartz

ALL SESSIONS ARE HELD IN THE POPLAR AND PROVIDENCE ROOMS.

TIMETABLE

MONDAY, NOVEMBER 7

M/S 1
(Stratford Room)

10:30 AM - 12:15 PM

I. Babuska

M. D. Smooke

A. Weiser

M/S 2
(Poplar and Providence Rooms)

10:30 AM - 12:15 PM

R.K. Powers

G. Ammar

J. M. Crowley

W. H. Bennett

TIME (MORNING)	C/P 1A (York Room)	C/P 1B (Claremont Room)	C/P 1C (Brandon Room)
10:30	S-H. Chang* G.M. Johnson	J. Cullum R. Willoughby*	S.M. Watt* K.O. Geddes
10:45	S.F. Davis	J. Cullum* R. Willoughby	B. Lubachevsky* D. Mitra
11:00	B. Grossman	D.S. Watkins	A. Deb
11:15	M.Y. Ishikawa* J.L. Steger	S.G. Nash	C.P. Kruskal A. Weiss*
11:30	S.I. Hariharan* H.C. Lester	J.L. Barlow	K. Culik* R.G. Trenary
11:45	F.T. Johnson* A.C. Woo K.D. Lee D.P. Young J.E. Bussoletti K.W. Sidwell	J.H. Bolstad* H.B. Keller	M. Bertocchi* A. Gnudi
12:00	M.O. Bristeau R. Glowinski* J. Periaux	A.S. Shieh	

M/S 3
(Poplar and Providence Rooms)

3:00-5:00 PM

G. Rodriguez*
R.E. Scheid

D.R. Audley

E.S. Armstrong

R.C. Allen

M/S 4
(Stratford Room)

3:00-5:00 PM

S.A. Orszag

R.W. Metcalfe*
J.J. Riley

J.H. Ferziger

D.A. Kopriva*
T.A. Zang

M/S 5
(York Room)

3:00-5:00 PM

J.F. Thompson*
Z.U.A. Warsi

R.E. Smith*
R. Kudlinski

P.R. Eiseman

C.W. Mastin

TIME (AFTERNOON)	C/P 1D (Claremont Room)	C/P 1E (Brandon Room)
3:00	R.I. Shrager	M.B. Dadfar* J.F. Geer
3:15	T-H.C. Chen	E.C. Gartland
3:30	L.F. Shampine	P. Mbaeyi
3:45	W.F. Moss	J.F. McGrath
4:00	M.A. Hussain* J.F. Schenck	M. Matthews
4:15	B.H. Edwards	J.A. Morrison* D. Mitra
4:30	J. Abruzzo	P. Ramirez-Garcia* M.E. Cortes-Islas
4:45	H.A. Watts* L.F. Shampine	
5:00	M.E. Borasky	

POSTER 1
(International Promenade)

3:00-5:15 PM

C. Sheng-jiang

G.D. Catalano*
C. Shih

J.J. Kelly
A.H. Nayfeh
L.T. Watson*

F. R. Payne

H.E. Brandmaier

D. Deutsch
M.I. Freedman
L. Morino*
K. Tseng

J.C. Strikwerda

*Speaker, when there are two or more authors.

C/P = Contributed Papers
M/S = Minisymposium

TIMETABLE

TUESDAY, NOVEMBER 8

M/S 6 (York Room)

3:00-5:00 PM

R. Hermann

T. Duncan

S. K. Mitter

J. S. Baras

M/S 7 (Poplar and Providence Rooms)

3:00-5:00 PM

W. C. Rheinboldt

J. Oliger*
C. K. Lombard

G. H. Guirguis

J. Boland

Z. Cendes

M/S 8 (Stratford Room)

3:00-5:00 PM

J. D. Cole

N. D. Malmuth

H. K. Cheng

L. W. Schwartz

TIME (AFTERNOON)	C/P 2A (Claremont Room)	C/P 2B (Brandon Room)	POSTER 2 (International Promenade) 3:00-5:00 PM
3:00	T. Lenahan	J.J. Du Croz	D. Salamon
3:15	M. Gupta	J. Lambiotte	L. Korbly
3:30	H. Miller	K. Weilmuenster	A. Giorgini
3:45	J. Brown	O. Johnson	J. Pennline
4:00	A. Cheer	L. Birta O. Abou-Rabia*	J. McDonough* R. Sharman
4:15	A. Giorgini* A. Rinaldo	K. Datta	J. Buhite* E. Conjura N. Greenbaun R. Wharton Y. Lee
4:30	S. Lamkin* J. Hardin	R. White	J. Geer* J. Keller
4:45	J.S. Abolhassani* S. Tiwari R. Smith	I.N. Katz* M. Franklin	J.J. Dongarra

*Speaker, when there are two or more authors.

C/P = Contributed Papers
M/S = Minisymposium

TIMETABLE

WEDNESDAY, NOVEMBER 9

TIME (MORNING)	C/P 3A (York Room)	C/P 3B (Brandon Room)	C/P 3C (Claremont Room)	C/P 3D (Poplar and Providence Rooms)	C/P 3E (Stratford Room)
10:30	D.S. Bernstein* D.C. Hyland	J. Buckmaster A. Nachman* S. Taliaferro	L.P. Cook F. Zeigler*	M. G. Greenberg M.S. Johnson K.G. Stevens* D.S. Eberhardt	M. Clint C. Holt R. Perrott* A. Stewart
10:45	M.T. Tran	R.C. DiPrima* P. Hall	G. Dulikravich* P. Niederdrenk	D.S. Eberhardt* D. Baganoff K.G. Stevens M.S. Johnson	R. Reynolds* G. Cichanowski
11:00	K.E. Brenan	C.E. Grosch* H. Salwen	E. von Lavante* V.S.V. Iyer	D.S. Eberhardt* F.C. Dougherty	T.A. Marsland* F.P. Popowich
11:15	I.H. Khlifa O.H. Abdalla*	J. Dorrepaal	R. Boudreault	D.A. Swayne	C.N. Arnold* C.L. Berkey
11:30	T.S. Angell* R.E. Kleinman	S. Childress M.J. Miksis*	A.A. Hassan	A. Genz* D.A. Swayne	

M/S 9 (Stratford Room)	TIME (AFTERNOON)	C/P 3F (Claremont Room)	C/P 3G (Brandon Room)	C/P 3H (Poplar and Providence Rms.)
3:00-5:00 PM	3:00	D. Salamon	O.A. Kandil* V. Kalburgy	M.H. Kalos
A. H. Sameh D.P. O'Leary	3:15	I.G. Rosen	L. Ting* C-H. Liu	D. Agrawal* G.C. Pathak
B.N. Datta* K. Datta	3:30	T.I. Seidman	B.V. Saunders* P. Smith R.E. Smith, Jr.	M.M. Matthews
D.M. Young* D.R. Kincaid	3:45	P.L. Daniel	A.H. Treadway	A.B. Kovaleski* S. Ratheal F. Lombardi
M/S 10 (York Room)	4:00	K. Ito* R. Teglas	L. Korbly	G.G.L. Meyer* H.L. Weinert
3:00-5:00 PM M. Ginsberg	4:15	W. Desch* W. Schappacher	R.F. Warming* R.M. Beam H.C. Yee	W. Liu
J.F. Gloudeman	4:30	M.W. Spong	J.T. Barton* T.H. Pulliam	R.P. Brent F.T. Luk*
W.J. Cody, Jr. J. Levesque	4:45	D.J. Inman	W.D. Gropp	R. Jones
	5:00	N.U. Ahmed* S.K. Biswas		R.J. Zaccone* J.L. Barlow

*Speaker, when there two or more authors.

C/P = Contributed Papers
M/S = Minisymposium

SIAM 1983 Fall Meeting
November 7–9, 1983
Final Program

SUNDAY, NOVEMBER 6

5:00 - 9:00 PM
REGISTRATION (**International Promenade**)

MONDAY, NOVEMBER 7

7:30 AM - 5:00 PM
REGISTRATION (**International Promenade**)

9:00 AM - 5:00 PM
BOOK EXHIBITS (**International Promenade**)

8:15 - 8:30 AM
OPENING SESSION (**Poplar and Providence Rooms**)
Welcome Remarks: Hirsh Cohen (President, SIAM), IBM - T.J. Watson Research Center
Robert G. Voigt (Meeting Chairman), ICASE

8:30 - 10:00 AM
Invited Speakers. Control, Stabilization and Optimization in Distributed Systems. (Poplar and Providence Rooms)
Chairman: H. T. Banks, Brown University, and Southern Methodist University

8:30 - 9:15 AM
Optimal Design Involving Distributed Systems, Michel C. Delfour, Université de Montreal

9:15 - 10:00 AM
Stabilization and Feedback Control Methods for Partial and Delay Differential Equations, J. S. Gibson, University of California, Los Angeles

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10:00 - 10:30 AM

INTERMISSION

10:30 AM - 12:15 PM
Minisymposium 1. Computable Error Estimates for Partial Differential Equations and Applications. (Stratford Room)
Chairman and Organizer: Randolph E. Bank, University of California, San Diego

10:30-11:05
Some Results Concerning the Principles for the Adaptive Construction of the Optimal Meshes for the Finite Element Method, Ivo Babuska, University of Maryland

11:05-11:40
Numerical Solution of Unstable Problems in Combustion, Mitchell D. Smooke, Sandia National Laboratories

11:40-12:15
Some Computable Error Estimators for Elliptic Problems, Alan Weiser, Exxon Production Research Company

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10:30 AM - 12:15 PM
Minisymposium 2. Control and Estimation. (Poplar and Providence Rooms)
Chairman and Organizer: Patricia Daniel, Southern Methodist University

10:30-10:55
An Application of Chandrasekhar-Type Algorithms for Optimal Control of Delay-Differential Systems, Robert K. Powers, Virginia Polytechnic Institute and State University

10:55-11:20
The Power Method, QR Algorithm, and Riccati Equations, Gregory Ammar, University of Kentucky, Lexington

11:20-11:45
Numerical Methods for Estimation of Coefficients in Elastic and Viscoelastic Structures, James M. Crowley, U.S. Air Force Academy

11:45-12:15
Estimates of Weak Coupling and Stability of Decentralized Control in Large Multi-variate Systems, William H. Bennett, Naval Research Laboratory

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10:30 AM - 12:15 PM
Contributed Papers 1A. Computational Fluid Dynamics I. (York Room)
Chairman: D. L. Dwoyer, NASA Langley Research Center

10:30-10:42
Embedding Methods for the Steady Euler Equations, Shih-Hung Chang,* Cleveland State University, and Gary M. Johnson, NASA Lewis Research Center

10:45-10:57
A Rotationally Biased Upwind Difference Scheme for the Euler Equations, Stephen F. Davis, ICASE

11:00-11:12
Rotational Supersonic Flow Using A Clebsch Velocity Decomposition, Bernard Grossman, Virginia Polytechnic Institute and State University

11:15-11:27
A Fast Accurate Algorithm for Three-Dimensional Inviscid Rotational Flow, Muriel Y. Ishikawa,* NASA-Ames Research Center, and Joseph L. Steger, Stanford University

*Indicates the presenter of the paper when more than one author is given.

MONDAY (Continued)

11:30-11:42
Acoustic Shocks in a Variable Area Duct Containing Near Sonic Flows, S. I. Hariharan,* ICASE, and Harold C. Lester, NASA Langley Research Center

11:45-11:57
Solution of Steady-State Euler Equations in the Presence of Arbitrary Boundary Surfaces: An Extension of the PAN AIR System of Progress, Forrester T. Johnson,* Alex C. Woo, Ki D. Lee, David P. Young, John E. Bussoletti, and Ken W. Sidwell, Boeing Military Airplane Company

12:00-12:12
Finite Element Solution of the Navier-Stokes Equations for Compressible Viscous Fluids, M. O. Bristeau, Roland Glowinski,* INRIA-Cedex, France; and J. Periaux, AMD/BA 78 quai Carnot

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10:30 AM - 12:15 PM
Contributed Papers 1B. Numerical Algorithms. (Claremont Room)

Chairman: Charlie H. Cooke, Old Dominion University

10:30-10:42
Calculation of Eigenvalues for Nondefective, Complex Symmetric Tridiagonal Matrices, Jane Cullum, and Ralph Willoughby,* IBM - T. J. Watson Research Center

10:45-10:57
A Lanczos Algorithm for Nondefective Complex Symmetric Matrices, Jane Cullum,* and Ralph Willoughby, IBM - T. J. Watson Research Center

11:00-11:12
Isospectral Flows and the Power Method, David S. Watkins, Washington State University

11:15-11:27
Linearly-Constrained Optimization Using a Truncated-Newton Algorithm, Stephen G. Nash, The Johns Hopkins University

11:30-11:42
Error Analysis of the G-Algorithm for the Weighted Linear Least Squares Problem, Jesse L. Barlow, The Pennsylvania State University

11:45-11:57
A Multi-Grid Continuation Method for Elliptic Problems with Turning Points, John H. Bolstad,* and Herbert B. Keller, California Institute of Technology

12:00-12:12
A Highly Compact High Order Multi-Grid Method for Nonlinear Elliptic Problems, Arthur S. Shieh, EG&G Idaho, Inc.

10:30 AM - 12:00 PM
Contributed Papers 1C. Parallel Processing and Computer Science. (Brandon Room)
Chairman: J. Shoosmith, NASA Langley Research Center

10:30-10:42
Exploiting Parallelism in Symbolic Mathematical Computation, Stephen M. Watt,* and Keith O. Geddes, University of Waterloo

10:45-10:57
An Asynchronous Chaotic Algorithm for Computing Equilibrium Distributions of Markov Chains, Boris D. Lubachevsky,* New York University, and Bell Laboratories; and D. Mitra, Bell Laboratories

11:00-11:12
Optimal Parallel Accessing of Nonlinear Structures Using Linear Skewing Schemes, Ashoke Deb, Memorial University of Newfoundland

11:15-11:27
Allocating Independent Subtasks on Parallel Processors, Clyde P. Kruskal, University of Illinois, Urbana-Champaign; and Alan Weiss,* Bell Laboratories

11:30-11:42
Parallelizability Degree of Synchronous and Asynchronous Parallel Programs, Karel Culik,* and Robert G. Trenary, Wayne State University

11:45-11:57
The Kernel of the Operating System of a Multi-Microprocessor Prototype, Maria Bertocchi,* and Adriana Gnudi, Istituto Universitario di Bergamo, Italy

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12:15 - 1:30 PM
Lunch

1:30 - 2:30 PM
Retiring President's Address. (Poplar and Providence Rooms)
Chairman: Hirsh Cohen, IBM - T. J. Watson Research Center

The Analysis of Iterative Methods for Elliptic Boundary Value Problems and the Discovery of "q", Seymour V. Parter, University of Wisconsin, Madison

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2:30 - 3:00 PM
INTERMISSION

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*Indicates the presenter of the paper when more than one author is given.

MONDAY (Continued)

3:00 - 5:00 PM
Minisymposium 3. Distributed Systems in Large Space Structures. (Poplar and Providence Rooms)
Chairman and Organizer: H. T. Banks, Brown University, and Southern Methodist University

3:00-3:30
Estimation and Identification Methodology for Elliptic Systems, Guillermo Rodriguez,* and R. E. Scheid, Jr., Jet Propulsion Laboratory

3:30-4:00
Space Shuttle Reentry Aerothermodynamic Flight Test: An Identification Problem for a Parabolic Evolution Equation, David R. Audley, Air Force Institute of Technology

4:00-4:30
Parameter and State Estimation for Distributed Models of the Maypole (Hoop/Column) Antenna Surface, E. S. Armstrong, NASA Langley Research Center

4:30-5:00
A Distributed Model for Thermoelastic Distortion in High Power Lasers, Richard C. Allen, Jr., The University of New Mexico

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3:00 - 5:00 PM
Minisymposium 4. Application of Spectral Methods to Hydrodynamic and Aerodynamic Problems. (Stratford Room)
Chairman and Organizer: M. Y. Hussaini, ICASE

3:00-3:30
Solution of Problems in Complicated Geometries Using Spectral Methods, Steven A. Orszag, Massachusetts Institute of Technology

3:30-4:00
The Application of Spectral Methods to Reacting Flow Problems, Ralph W. Metcalfe,* and James J. Riley, Flow Research Company

4:00-4:30
Spectral Methods for Flow Computation, Joel H. Ferziger, Stanford University

4:30-5:00
Application of Spectral Collocation Methods to Inviscid Compressible Flows, David A. Kopriva,* ICASE; and Thomas A. Zang, NASA Langley Research Center

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3:00 - 5:00 PM
Minisymposium 5. Grid Generation. (York Room)
Chairman and Organizer: C. Wayne Mastin, Mississippi State University

3:00-3:30
Three-Dimensional Grid Generation from Elliptic Systems, Joe F. Thompson,* and Z.U.A. Warsi, Mississippi State University

3:30-4:00
Surface Grid Spacing Control for Aerodynamic Configurations, R. E. Smith, Jr.,* and Robert Kudlinski, NASA Langley Research Center

4:00-4:30
Locally-Controlled Algebraic Coordinate Generation, Peter R. Eiseman, Columbia University

4:30-5:00
Composite Grid Systems, C. Wayne Mastin, Mississippi State University

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3:00 - 5:15 PM
Contributed Papers 1D. Numerical Analysis. (Claremont Room)
Chairman: S. Hariharan, University of Tennessee Space Institute

3:00-3:12
An Algorithm for Finding A Zero of A Function, Richard I. Shrager, National Institutes of Health

3:15-3:27
Error Estimates for the Weighted Least Squares Approximation, Tsann-Hoa Charles Chen, The University of Alabama, Huntsville

3:30-3:42
Measuring Stiffness, Lawrence F. Shampine, Sandia National Laboratories

3:45-3:57
Spid Mode Acoustic Radiation From A Thick Wall Duct, William F. Moss, Clemson University

4:00-4:12
An Approximate Solution of an Integral Equation That Arises in the Design of Magnetic Field Coils, M. A. Hussain,* and J. F. Schenck, General Electric Company

4:15-4:27
Some Applications of the Method of Lines to Elliptic Partial Differential Equations, Bruce H. Edwards, University of Florida

4:30-4:42
FFT Noise Analysis with Recommendations for Scaling Procedures, Joseph Abruzzo, Westinghouse Electric Corporation

4:45-4:57
A Smoother Interpolant for DE/STEP, INTRP, H. A. Watts,* and L. F. Shampine, Sandia National Laboratories

5:00-5:12
Numerical Differentiators for Pseudo-Spectral Methods, M. Edward Borasky, Floating Point Systems, Inc.

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*Indicates the presenter of the paper when more than one author is given.

MONDAY (Continued)

3:00 -4:45 PM
Contributed Papers 1E. Analysis I.
(Brandon Room)
Chairman: J. J. Swetits, Old Dominion University

3:00-3:12
Perturbation Analysis of Forced Nonlinear Motion of a Simple Pendulum with Oscillating Support, Mohammad B. Dadfar,* Bowling Green State University, and James F. Geer, SUNY-Binghamton

3:15-3:27
Uniform Finite-Difference Schemes for Singularly Perturbed Ordinary Differential Equations, Eugene C. Gartland, Jr., Southern Methodist University

3:30-3:42
Bricklayering Approximation, Peter Mbaeyi, University of Tuebingen

3:45-3:57
Numerical Inversion of Interference Patterns, Joseph F. McGrath, KMS Fusion, Inc.

4:00-4:12
An Algorithm for Hamiltonian Cycles in the Square of K1,3-free Graphs, Manton Matthews, University of South Carolina

4:15-4:27
Heavy-Traffic Asymptotic Expansions for the Waiting Time in Closed Processor-Sharing Systems with Multiple Job-Classes, John A. Morrison,* and Debasis Mitra, Bell Labs.

4:30-4:42
Age Distribution Function for a Catalyst in Fluidized Systems Under a Discrete Addition, Pablo Ramirez-Garcia,*and M. Eugenia Cortes-Islas, Instituto Mexicano del Petroleo

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3:00 - 5:15 PM
Poster Session 1. (International Promenade)

The Boundary Value Problem of Non-Newton Flow, Cheng Sheng-jiang, Xian Jiaotong University

An Analytical Model for the Turbulent Flow Over a Shallow Cavity, G. D. Catalano,* and C. Shih, Louisiana State University

Acoustic Propagation in Partially Choked Converging-Diverging Ducts, J. J. Kelly A. H. Nayfeh, and Layne T. Watson,* Virginia Polytechnic Institute and State University

Formal Integration of ODE/PDE and Subsequent Numerics, Fred R. Payne, The University of Texas, Arlington

On the Flow of Real Compressible Fluids, Harold E. Brandmaier, Burns and Roe, Inc.

Integral Equation Formulation for Computational Transonic Flows About Aircraft in Arbitrary Motion, David Deutsch, Baltimore, Maryland; Marvin I. Freedman, Luigi Morino,* Boston University; and Kadin Tseng, ICARUS

A Numerical Study of Taylor Vortex Flows, John C. Strikwerda, University of Wisconsin, Madison

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5:30 - 7:30 PM
Cash Bar Cocktail Reception
(International Promenade)

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*Indicates the presenter of the paper when more than one author is given.

TUESDAY, NOVEMBER 8

8:00 AM - 5:00 PM
REGISTRATION (**International Promenade**)

9:00 AM - 5:00 PM
BOOK EXHIBITS (**International Promenade**)

8:30 - 10:00 AM
Invited Speakers. Computational Aerodynamics I. (Poplar and Providence Rooms)
Chairman: Randolph A. Graves, NASA Langley Research Center

8:30-9:15 AM
The Status of Computational Aerodynamics, William F. Ballhaus, Jr., NASA-Ames Research Center

9:15-10:00 AM
Numerical Simulation of Transonic Flow, Jerry C. South, Jr., NASA Langley Research Center

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10:00 - 10:30 AM
INTERMISSION

10:30 - 11:30 AM
The George Polya Prize in Applied Combinatorics. Prize Presentations and Lectures. (Poplar and Providence Rooms)
Citation: Ronald L. Graham, Bell Laboratories
Prize Presentation: Hirsh Cohen, IBM - T.J. Watson Research Center

10:30-11:00
Which Complexes are Shellable? A Short Survey of Shellability and its Applications, Anders Björner, University of Stockholm

11:00-11:30
The Structure of Totally Unimodular Matrices, Paul Seymour, Ohio State University

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11:30 AM - 1:00 PM
Lunch

1:00 - 2:30 PM
Invited Speakers. Computational Aerodynamics II. (Poplar and Providence Rooms)
Chairman: M. E. Rose, ICASE

1:00 - 1:45 PM
Numerical Solution of the Navier-Stokes Equations, Robert W. MacCormack, University of Washington

1:45 - 2:30 PM
Mathematical Aspects of Turbulence Modeling, John L. Lumley, Cornell University

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2:30 - 3:00 PM
INTERMISSION

3:00 - 5:00 PM
Minisymposium 6. Approximation to Distributed Parameter Systems. (York Room)
Chairman and Organizer: Clyde F. Martin, Texas Tech University

3:00-3:30
Linear System Approximation and Grassmann Geometry, Robert Hermann, Massachusetts Institute of Technology

3:30-4:00
Stochastic System Theory and Affine Lie Algebras, Tyrone Duncan, University of Kansas

4:00-4:30
The Approximation Problem for Nonlinear Filtering, Sanjoy K. Mitter, Massachusetts Institute of Technology

4:30-5:00
Transfer Function Classes Appearing in Linear Distributed Systems: Applications to Feedback Compensation, John S. Baras, University of Maryland

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3:00 - 5:00 PM
Minisymposium 7. Novel Techniques and Algorithms for the Numerical Solution of Partial Differential Equations. (Poplar and Providence Rooms)
Chairman and Organizer: Max Gunzburger, Carnegie-Mellon University

3:00-3:24
On the Numerical Solution of Differential Equations on Manifolds, Werner C. Rheinboldt, University of Pittsburgh

3:24-3:48
Boundary Approximations for Alternating Sweep Implicit Upwind Methods for Hyperbolic Systems, Joseph Oliger,* Stanford University, and C. K. Lombard, PEDA Corp.

3:48-4:12
On the Exterior Stokes Problem in Three Dimensions, Georges H. Guirguis, North Carolina State University

4:12-4:36
Low Order Finite Elements and the Divergence Constraint for Viscous Flows, James Boland, University of Pittsburgh

4:36-5:00
Vector Basis Functions for High-Order Triangular Finite Elements, Zoltan Cendes, Carnegie-Mellon University

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3:00 - 5:00 PM
Minisymposium 8. Theoretical Aerodynamics. (Stratford Room)
Chairman and Organizer: L. Pamela Cook, University of California-Los Angeles, and University of Delaware

3:00-3:30
Pseudo-Transonic Flow, Julian D. Cole, Rensselaer Polytechnic Institute

*Indicates the presenter of the paper when more than one author is given.

TUESDAY (Continued)

3:30-4:00
Combined Computational and Asymptotic Methods in Transonic Flows, Norman D. Malmuth, Rockwell International Science Center

4:00-4:30
Asymptotic and Computational Studies of an Unsteady Transonic Flow About a Thin Airfoil, H. K. Cheng, University of Southern California

4:30-5:00
An Approximate Method in Viscous Free-Boundary Problems, Leonard W. Schwartz, Exxon Research and Engineering Co.

3:00 - 5:00 PM
Contributed Papers 2A. Computational Fluid Dynamics II. (Claremont Room)
Chairman: W. D. Lakin, Old Dominion University

3:00-3:12
Computing Stokes Flow by Longitudinal Partitioning, Terrence A. Lenahan, Bell Laboratories,

3:15-3:27
On the Integral Formulation of the Vorticity Boundary Condition, Murli M. Gupta, The George Washington University

3:30-3:42
A Comparison of Explicit Finite Difference Schemes For Incompressible Convection Dominated Flow, Harvey P. Miller, Drexel University

3:45-3:57
Parabolized Navier-Stokes Solutions of Subsonic Separation and Trailing-Edge Flows, James L. Brown, NASA-Ames Research Center

4:00-4:12
Unsteady Flow Development of the Wake Behind an an Impulsively Started Circular Cylinder at Reynolds Number 9500, Angela Cheer, University of California, Berkeley

4:15-4:27
High Order Vortex Formations in the Wake of an Impulsively Started Circular Cylinder, Aldo Giorgini,* and Andrea Rinaldo, Purdue University

4:30-4:42
Aeroacoustic Computation From Vortex-Pair Merging, Stanley L. Lamkin,* Kentron International, Inc., and Jay C. Hardin, NASA Langley Research Center

4:45-4:57
Stiffness Characteristic and the Application of the Method of Lines on Nonuniform Grids, J. S. Abolhassani,* S. N. Tiwari, Old Dominion University; and R. E. Smith, Jr., NASA Langley Research Center

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3:00 - 5:00 PM
Contributed Papers 2B. Vector Processing. (Brandon Room)
Chairman: Robert C. Ward, Union Carbide Corp.

3:00-3:12
Adapting the NAG Library to Vector-Processing Architectures, J. J. Du Croz, N.A.G. Ltd.

3:15-3:27
Sparse Matrix-Vector Multiplication Software for a Vector Computer, Jules J. Lambiotte, Jr., NASA Langley Research Center

3:30-3:42
Vectorized, Three-Dimensional Flow Field Computations with Applications to the Space Shuttle Orbiter, K. James Weilmuenster, NASA Langley Research Center

3:45-3:57
Three-Dimensional Wave Equation Computations on Vector Computers, Olin G. Johnson, University of Houston

4:00-4:12
A Multi-microprocessor System for Parallel Solution of ODE's, Louis G. Birta, and Osman Abou-Rabia,* University of Ottawa

4:15-4:27
A Fast QR Algorithm for Any Arbitrary Matrix in Parallel, Karabi Datta, Northern Illinois University

4:30-4:42
Parallel Splitting of a Matrix, Robert E. White, North Carolina State University

4:45-4:57
Two Strategies for Root Finding on Multiprocessor Systems, I. Norman Katz,* and Mark A. Franklin, Washington University

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3:00 - 5:00 PM
Poster Session 2. (International Promenade)

Two Algebraic Riccati Equations for Retarded Systems with General Delays in State, Control, and Observation, Dietmar Salamon, University of Wisconsin, Madison

Displaying Results of 3-D Numerical Calculations, Letitia Korbly, University of Alabama, Birmingham

Computer Imaging in the Visualization of Computed Flow Fields, Aldo Giorgini, Purdue University

Conversion of Two-Point Boundary Value Problems to Parametrized Integral Equations, James A. Pennline, NASA Lewis Research Center

Solution of Two-Dimensional Elliptic Equations Via a Strongly Implicit Procedure with Optimal Iteration Parameter, James M. McDonough,* The Aerospace Corporation; and Robert Sharman, University of California, Los Angeles

*Indicates the presenter of the paper when more than one author is given.

TUESDAY (Continued)

Aerodynamic Coefficients from Free Flight Test Data - Improvements to Chapman and Kirk, Jack L. Buhite,* Edward J. Conjura, Nicholas Greenbaun, Yong M. Lee, and Robert M. Wharton, Trenton State College

Acoustical Wave Propagation in Slender Wave-Guides and Resonant Cavities, James Geer,* SUNY-Binghamton; and Joseph B. Keller, Stanford University

Performance of Various Computers Using Standard Linear Equations Software in a Fortran Environment, Jack J. Dongarra, Argonne National Laboratory

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WEDNESDAY, NOVEMBER 9

8:00 AM - 5:00 PM
REGISTRATION (**International Promenade**)

9:00 AM - 5:00 PM
BOOK EXHIBITS (**International Promenade**)

8:30 - 10:00 AM
Invited Speakers. Parallel Processing I. (Poplar and Providence Rooms)
Chairman: James M. Ortega, University of Virginia

8:30 - 9:15 AM
The Influence of Computer Architecture on the Choice of Numerical Algorithms, Roger W. Hockney, Reading University, U.K.

9:15 - 10:00 AM
Large Scale Numerical Simulations and Parallel Computers, Garry Rodrigue, Lawrence Livermore National Laboratory

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10:00 - 10:30 AM
INTERMISSION

10:30 - 11:45 AM
Contributed Papers 3A. Applications of Control Theory I. (York Room)
Chairman: J. Broussard, Information and Control Systems, Inc.

10:30-10:42
Explicit Optimality Conditions for Finite-Dimensional Fixed-Order Dynamic Compensation of Infinite-Dimensional Systems, Dennis S. Bernstein,* and David C. Hyland, MIT - Lincoln Laboratory

10:45-10:57
Optimal Quadratic Stability of Discrete-Time Distributed Parameter Systems, Minh T. Tran, Boeing Military Airplane Company

11:00-11:12
Numerical Solution of Trajectory Path Control Problems by the Backward Difference Method, Kathryn E. Brenan, The Aerospace Corporation

11:15-11:27
Hybrid Adaptive Excitation Control of Turbo-Generator System, Iraky H. Khlifa, and O.H. Abdalla,* University of Helwan, Egypt

11:30-11:42
A Constructive Method for Optimal Control of Radiating Structures, T. S. Angell,* and R. E. Kleinman, University of Delaware

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10:30 - 11:45 AM
Contributed Papers 3B. Fluid Dynamics Theory. (Brandon Room)
Chairman: S. F. Davis, ICASE

10:30-10:42
The Fast-Time Instability of Diffusion Flames, J. Buckmaster, University of Illinois; A. Nachman,* Southwest Research Institute; and S. Taliaferro, Texas A&M University

*Indicates the presenter of the paper when more than one author is given.

WEDNESDAY (Continued)

10:45-10:57
Complex Eigenvalues for the Stability of Couette Flow, Richard C. DiPrima,* Rensselaer Polytechnic Institute; and P. Hall, Imperial College, England

11:00-11:12
Spatial Eigenfunction Expansions of Disturbances Originating in the Free Stream, Chester E. Grosch,* Old Dominion University; and Harold Salwen, Stevens Institute of Technology

11:15-11:27
The Resistance Tensors for a Spherical Cap in Stokes Flow, J. Mark Dorrepaal, Old Dominion University

11:30-11:42
Efficient Feeding of Small Organisms: The Generation of Scanning Currents in Stokes Flow, Stephen Childress, New York University; and Michael J. Miksis,* Duke University

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10:30 - 11:45 AM
Contributed Papers 3C. Transonic Flow. (Claremont Room)
Chairman: M. D. Salas, NASA Langley Research Center

10:30-10:42
The Stabilization Law, L. Pamela Cook, University of California, Los Angeles, and University of Delaware; and F. Zeigler,* General Dynamics

10:45-10:57
Switching Function for the Numerical Solution of Transonic Full Potential Equation, George S. Dulikravich,* University of Texas-Austin; and Peter Niederdrenk, Institute fur Theoretische, F.R. Germany

11:00-11:12
Composite Form of the Implicit Block-Bidiagonal Finite Difference Method for Solving the Navier Stokes Equations, Ernst von Lavante,* and Venkitachalam S.V. Iyer, Texas A&M University

11:15-11:27
Optimization of the Shape of an Axisymmetric Body for Minimum Wave Drag of Transonic Speeds, Richard Boudreault, Universite de Sherbrooke

11:30-11:42
A Semi-Inverse Method for the Design of Sub-critical and Shock Free Supercritical Slender Bodies of Revolution, Ahmed A. Hassan, Arizona State University

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10:30 - 11:45 AM
Contributed Papers 3D. Parallelism in Scientific Applications. (Poplar and Providence Rooms)
Chairman: R. A. Nicolaides, Carnegie-Mellon University

10:30-10:42
A Study of the Relationship Between MIMD Architectures and Computational Fluid Dynamics, M. G. Greenberg, M. S. Johnson, K. G. Stevens,* NASA Ames Research Center; and D. S. Eberhardt, Stanford University

10:45-10:57
Mapping Approximate Factored Algorithms Onto Concurrent Processing Computers, D. Scott Eberhardt,* Donald Baganoff, Stanford University; K. G. Stevens, and M.S. Johnson, NASA Ames Research Center

11:00-11:12
An Application of Concurrent Processing to Flows About Multiple Bodies, D. Scott Eberhardt,* Stanford University; and F. Carroll Dougherty, NASA Ames Research Center

11:15-11:27
Parallel Locally One-Dimensional Schemes, D. A. Swayne, University of Guelph

11:30-11:42
Parallel Implementation of LOD Methods for Partial Differential Equations, Alan Genz,* University of Kent; and D. A. Swayne, University of Guelph

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10:30 - 11:30 AM
Contributed Papers 3E. Software for Parallel Systems. (Stratford Room)
Chairman: J. Van Rosendale, ICASE

10:30-10:42
Classifying Parallel Sorting Algorithms, M. Clint, C. Holt, R. Perrott,* and A. Stewart, Queens University

10:45-10:57
A Parallel Algorithm for On-Line Bin Packing, Robert G. Reynolds,* and G. Cichanowski, Michigan State University

11:00-11:12
Parallel Game-Tree Search, Thomas Anthony Marsland,* and Frederick Paul Popowich, University of Alberta

11:15-11:27
Multiprocessing Applied to FORTRAN Applications, Clifford N. Arnold,* and Chester L. Berkey, Control Data Corporation

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11:45 AM - 1:00 PM
Lunch

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*Indicates the presenter of the paper when more than one author is given.

WEDNESDAY (Continued)

1:00 - 2:30 PM
Invited Speakers. Parallel Processing II. (Poplar and Providence Rooms)
Chairman: Bill Buzbee, Los Alamos National Laboratory

1:00 - 1:45 PM
Performance Potentials of Various Parallel Architectures, David J. Kuck, University of Illinois at Urbana

1:45 - 2:30 PM
Present Status and Future Direction of Parallel Computers, Jack Schwartz, Courant Institute of Mathematical Sciences, New York University

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2:30 - 3:00 PM
INTERMISSION

3:00 - 5:00 PM
Minisymposium 9. Parallel and Vector Algorithms for Matrix Computations.* (Stratford Room)
Chairman and Organizer: Robert J. Plemmons, North Carolina State University

3:00-3:30
Parallel Algorithms in Numerical Linear Algebra, Ahmed H. Sameh, University of Illinois at Urbana-Champaign

3:30-4:00
Parallel Computations for Sparse Linear Systems, Dianne P. O'Leary, University of Maryland

4:00-4:30
Parallel Computations for Some Linear Algebra Problems in Control Theory, Biswa N. Datta,* and Karabi Datta, Northern Illinois University

4:30-5:00
Vector Computations for Sparse Linear Systems, David M. Young,* and David R. Kincaid, The University of Texas, Austin

*Arranged by SIAM Activity Group on Linear Algebra.

3:00 - 5:00 PM
Minisymposium 10. (Panel Discussion). Number Crunching on Small, Medium, and Large-Scale Computers. (York Room)
Chairman and Organizer: Myron Ginsberg, General Motors Research Laboratories

3:00-3:25
An Overview of the Computational Environments Offered by Micros, Minis, Mainframes, and Supercomputers, Myron Ginsberg, General Motors Research Lalboratories

3:25-3:50
Performance Improvement in Structural Analysis on Supercomputers, Joseph F. Gloudeman, The MacNeal-Schwendler Corporation

3:50-4:15
Floating-Point Issues, William J. Cody, Jr., Argonne National Laboratory

4:15-4:40
Tradeoffs Between Using Supercomputers and Array Processors for Scientific Computations, John Levesque, Pacific-Sierra Research Corp.

4:40-5:00
Panel Discussion

3:00 - 5:15 PM
Contributed Papers 3F. Applications of Control Theory II. (Claremont Room)
Chairman: E. Armstrong, NASA Langley Research Center

3:00-3:12
Spline Approximation for Retarded Systems and the Riccati Equation, Dietmar Salamon, University of Wisconsin, Madison

3:15-3:27
Cubic Spline Based Approximation Schemes for the Identification of Parabolic Systems, I. Gary Rosen, Charles Stark Draper Laboratory

3:30-3:42
Boundary Feedback Stabilization of Parabolic PDE's Using Finite Memory, Thomas I. Seidman, University of Maryland, Baltimore County

3:45-3:57
Estimation of Discontinuous Coefficients in Parabolic Distributed Systems, Patricia L. Daniel, Southern Methodist University

4:00-4:12
Legendre-Tau Approximations for Functional Differential Equations, Part II: The Linear Quadratic Optimal Control Problem, Kazufumi Ito,* and Russell Teglas, ICASE

4:15-4:27
Finite Dimensional Feedback Control for Partial Differential Equations, Wolfgang Desch,* Universitat Graz, and Southern Illinois University; and Wilhelm Schappacher, Universitat Graz

4:30-4:42
Feedback Stabilization of Retarded and Neutral Delay-Differential Systems with Non-Commensurable Delays, Mark W. Spong, Cornell University

4:45-4:57
Modal Control of a Class of Non Self-Adjoint Systems, Daniel J. Inman, SUNY-Buffalo

5:00-5:12
Mathemtical Modelling and Stabilization of Flexible Spacecrafts, N. U. Ahmed,* and S. K. Biswas, University of Ottawa

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3:00 - 5:00 PM
Contributed Papers 3G. Analysis II. (Brandon Room)
Chairman: J. E. Kroll, Old Dominion University

3:00-3:12
Higher-Order Vortex Panel Method for Wings Having Leading and Side-Edge Separations, Osama A. Kandil,* and Vijay Kalburgy, Old Dominion University

*Indicates the presenter of the paper when more than one author is given.

3:15-3:27
Boundary Conditions for Navier Stokes Solutions Merging with Boundary Layer and Potential Solutions, Lu Ting,* Courant Institute of Mathematical Sciences; and Chen-Huei Liu, NASA Langley Research Center

3:30-3:42
Smooth External Patched Grid Generation, Bonita V. Saunders,* Philip Smith, Old Dominion University; and Robert E. Smith, Jr., NASA Langley Research Center

3:45-3:57
Some Effects of Three Dimensional Non-Orthogonal, Curvilinear Coordinate Systems on the Calculation of the Bow Shock, A. H. Treadway, Sandia National Laboratories

4:00-4:12
An Automatic Mesh Generator Which Changes Density in Two Directions Simultaneously, Letitia Korbly, University of Alabama, Birmingham

4:15-4:27
Stability of Difference Approximations for Hyperbolic Initial-Boundary-Vvalue Problems, R. F. Warming,* R. M. Beam, and H. C. Yee, NASA Ames Research Center

4:30-4:42
The Effect of Smoothing Filters on Solutions to the Euler Equations, John T. Barton,* and Thomas H. Pulliam, NASA Ames Research Center

4:45-4:57
Local Uniform Mesh Refinement with Moving Grids for Time Dependent Problems, William D. Gropp, Yale University

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3:00 - 5:15 PM
Contributed Papers 3H. Parallel Computer Architectures. (Poplar and Providence Rooms)
Chairman: K. G. Stevens, NASA Anes Research Center

3:00-3:12
The NYU Ultracomputer, M. H. Kalos, Courant Institute of Mathematical Sciences - New York University

3:15-3:27
Performance of Multicomputer Architectures, Dharma P. Agrawal,* and Girish C. Pathak, North Carolina State University

3:30-3:42
Communication Times for Grid Computations on the Mago Tree Machine, Manton M. Matthews, University of South Carolina

3:45-3:57
Evaluation of a Bus Network Parallel Processing Architecture, A. B. Kovaleski,* S. Ratheal, and F. Lombardi, Texas Tech University

4:00-4:12
Strict and Stochastic Redundancy for Fault Tolerant Computational Networks, Gerard G. L. Meyer,* and Howard L. Weinert, The Johns Hopkins University

4:15-4:27
Two-Dimensional Fast Fourier Transform: New Algorithm and Architecture, Wentai Liu, North Carolina State University

4:30-4:42
Linear Systolic Arrays for Toeplitz and Singular Value Problems, Richard P. Brent, Australian National University; and Franklin T. Luk,* Cornell University

4:45-4:57
A Mathematical Computer Architecture to Vectorize Recursive Algebra, Ralph Jones, Analogic Corporation and Mathematical Architectural Ltd.

5:00-5:12
Digit On-Line Arithmetic for Solving Ordinary Differential Equations, Richard J. Zaccone,* and Jesse L. Barlow, The Pennsylvania State University

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6:00 - 7:30 PM
Cash Bar Cocktail Reception (International Promenade)

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*Indicates the presenter of the paper when more than one author is given.

SIAM 1983 Fall Meeting
Author Index

SYMBOLS: C/P = Contributed Paper
M/S = Minisymposium
I/S = Invited Speaker
S/L = Special Lecture
P/S = Poster Session

SIAM 1983 Fall Meeting
Abstracts: Invited Speakers and Special Lecturers

The Status of Computational Aerodynamics

Remarkable progress has been made in using advanced computers to solve fluid flow equations for aerodynamic applications. The paper highlights current capability with illustrative examples. Promising research areas are considered that offer promise for continued progress. A discussion of the changing user environment resulting from advances in computational systems is also provided.

Dr. William F. Ballhaus, Jr.
Director of Astronautics
National Aeronautics and Space Administration
Ames Research Center
Moffett Field, California 94035

Optimal Design Involving Distributed Systems

Current trends indicate that future communications satellites and spacecrafts will grow ever larger, consume ever more electrical power and dissipate larger amounts of thermal energy. Various techniques and devices can be employed to condition the thermal environment for payload boxes within a spacecraft, but it is desirable to employ those which offer good performance for low cost, low weight and high reliability.

Thermal diffusers and radiators are examples of such devices. The diffuser is a protection device. The radiator (or radiating fin) dissipates the thermal power to space at moderately low temperature over large areas. However, without careful design, they can be unnecessarily bulky and heavy. It is the mass-optimized design which is the problem at hand. Shape optimal design techniques will be used.

Michel C. DELFOUR
CRMA,(Centre de recherche de mathématiques appliquées)
Université de Montréal
C.P. 6128 - succ. "A"
Montréal, Québec
H3C 3J7
Canada

Stabilization and Feedback Control Methods for Partial and Delay Differential Equations

In linear-quadratic-Gaussian control of systems represented by partial and functional differential equations, the optimal compensator is infinite dimensional; i.e., it has an irrational transfer function. In applications, this ideal compensator can only be approximated by finite dimensional compensators. The subject of the presentation is the approximation theory for computing the control and estimator gains for the ideal compensator and how this theory can be used to guide the design of finite dimensional compensators for infinite dimensional systems. Both continuous-time and discrete-item control will be discussed. For approximation of the ideal infinite dimensional compensator, both direct and indirect approaches will be considered. The ways in which open-loop system parameters such as damping affect convergence will be discussed, as well as closed-loop characteristics like stability and robustness. Applications in hyperbolic and delay systems will be discussed.

J. S. Gibson
University of California, Los Angeles
4731 Boelter Hall
Los Angeles, CA 90024

The Influence of Computer Architecture on the Choice of Numerical Algorithms

The great variety of different computer architectures that are becoming available under the general term "Parallel Computers", present the numerical analyst with a major problem. On the one hand, it is known that the performance of algorithms on such computers may vary by an order of magnitude depending on the suitability of the algorithm to the architecture of the computer. On the other hand, there seems to be no generally accepted method for judging the suitability of an algorithm. The traditional scalar operations' count is clearly inadequate as it ignores all parallel features in a machine; and the number of parallel timesteps used in the complexity analysis of parallel algorithms only applies, in general, to theoretical computers which are assumed to be infinitely parallel. A two-parameter characterization of computer architecture will be presented that partially solves this problem, and can be applied to a wide range of architectures. In particular it applies to real computers with a finite amount of parallelism, and forms a bridge between the two extreme cases of zero and infinite parallelism. This characterization will then be used as the basis for choosing algorithms for some common problems on several parallel computers.

Roger W. Hockney, Computer Science Dept.,
Reading University, Reading, RG6 2AX, Berks, U.K.

Performance Potentials of Various Parallel Architectures

The Parafrase system is being used to restructure many Fortran packages to expose high degrees of parallelism for various kinds of architectures.

Architectures that can execute single-array instructions will be compared with those than can simultaneously execute many scalar instructions.

Speedup and other performance characteristics will be presented for limited and unlimited processor cases. Implications will be discussed for the design of algorithms, compilers, and computer systems.

D. J. Kuck
University of Illinois
Department of Computer Science
Urbana, IL 61801

Mathematical aspects of turbulence modeling*

Second-order modeling of turbulent flows involves the simultaneous solution of several dozen approximate non-linear PDE's, usually of first order in time and second in space, most commonly by time-stepping, using an implicit code. The dependent variables are various second moments of the fields involved. The exact equation system for these variables is not determinate, since it contains both higher order moments and second moments of other quantities. The approximate system of determinate equations is constructed by relating these extraneous quantities to the dependent variables, called modeling. Every effort is made, of course, to model the terms in a physically realistic manner. However, a number of mathematical questions arise: a large number of bounding inequalities relate all these quantities, and it is necessary to construct the models in such a way as to guarantee automatically that the inequalities will be satisfied during the course of a computation. We discuss ways of doing this.

*Supported in part by the U.S. Office of Naval,the U.S. National Science Foundation and the U. S. Air Force Office of Scientific Research.

Dr. John L. Lumley
Mechanical & Aerospace Engineering
238 Upson Hall
Cornell University
Ithaca, New York 14853

Numerical Solution of the Navier-Stokes Equations

Within the next three years the required computer resources will become available for solving the complete Navier-Stokes equations with turbulence modeling for flows about complete aircraft (fuselage, wing, pylons, nacelles, and tail assembly) at cruise conditions. This paper discusses the numerical problems to be solved and indicates approaches to be taken so that the coming computer power can be used effectively. Calculations of engineering accuracy for complete aircraft configurations near design flight conditions can be made for studying incipient flow separation, shock and vortex boundary layer interactions, buffet, reduced lift, and component interference phenomena. The calculations will cost less than $1000 per run. Improvements in numerical methods and computer hardware will reduce costs further. Improvements in turbulence modeling will extend the range of application, perhaps, to aircraft in maneuver with moderate flow separation.

Prof. Robert W. MacCormack
Department of Aeronautics & Astronautics, FS-10
University of Washington
Seattle, WA 98195

THE ANALYSIS OF ITERATIVE METHODS FOR ELLIPTIC BOUNDARY VALUE PROBLEMS AND THE DISCOVERY OF "q"

We review a basic theory for the determination of the precise asymptotic rate of convergence of certain iterative methods for the solution of the system of linear algebraic equations which arise in the discritization of linear elliptic partial differential equations. The major difficulty in applying this theory is connected with determining the operator "q". The operator q is a lower order operator $(< 2m)$ which is weakly approximated by certain terms in the iterative scheme. In many cases of interest q is a simple multiplication operation, i.e. q is a function. In the application of SOR to 2nd order elliptic problems q is a first order operator.

Seymour V. Parter
Department of Mathematics
University of Wisconsin-Madison
Madison, WI 53706

Large Scale Numerical Simulations and Parallel Computers

The study of a scientific phenomena by a computer is an arduous and, often, an expensive task. Large scale numerical simulations of these phenomena are constructed from years of analysis and experiments. Choices of the appropriate mathematical models, numerical approximations, and numerical algorithms are made on the basis of known physical evidence, the desired accuracy of the solution, and the constraints of the computer hardware at hand. The introduction of the parallel computer into this process has significantly altered the picture. These issues and others will be discussed.

Garry Rodrigue
Computing Research Group, L-306
University of California
Lawrence Livermore National Laboratory
Livermore, California 94550

Present Status and Future Direction of Parallel Computers

Many universities are now studying large-scale parallel computer architectures; between 25 and 50 such machine designs have been proposed. This talk will attempt a taxonomy of these designs, will attempt to relate machines to the problem areas which they attempt to satisfy, and will describe their software requirements and implications, together with the manner in which they are likely to be programmed.

Jack Schwartz
Courant Institute of Mathematical Sciences
New York University
251 Mercer Street
New York, NY 10012

The Structure of Totally Unimodular Matrices

A matrix is "totally unimodular" if every square submatrix has determinant ± 1 or 0. One way to construct such matrices is as follows. Let G be a connected graph, let T be one of its spanning trees, and let the edges of G be directed, arbitrarily. Let X be the edge-set of T, and let Y be $E(G)-X$. For each $y \in Y$, let P_y be the path of T from the head of y to its tail. For each $x \in X$, define

$$
\begin{aligned}
a_{xy} &= 0 \text{ if } x \text{ is not in } P_y \\
&= 1 \text{ if } P_y \text{ uses } x \text{ in its positive sense} \\
&= -1 \text{ if } P_y \text{ uses } x \text{ in its negative sense}
\end{aligned}
$$

Then the $X \times Y$ matrix (a_{xy}) is totally unimodular.

The main result described here is that every totally unimodular matrix can be constructed from matrices of this special kind and their transposes, and two 5×5 "sporadic" exceptions.

Paul Seymour
Dept. of Mathematics
The Ohio State University
231 West 18th Avenue
Columbus, Ohio 43210

NUMERICAL SIMULATION OF TRANSONIC FLOW

Most of the numerical simulations of complex transonic flow fields are carried out today via the inviscid velocity-potential equation coupled interactively with the viscous boundary-layer equations. This paper will discuss recent developments in algorithms for solution of the mixed-type, nonlinear potential equation, including Multigrid methods, approximate-factorization methods, and artificial compressibility. Also to be described is a simple, yet reasonably accurate, Cartesian-coordinate finite-volume scheme which may be a promising approach to analysis of truly general aircraft configurations. Research interest is now focusing on numerical solutions to the Euler equations, where some of the best current methods are explicit, and hence efficiently solved on any large vector processor. Reasonable three-dimensional transonic wing solutions can be obtained in 3 to 10 minutes on current supercomputers. Some comparisons between potential and Euler solutions will be shown, highlighting the "nonuniqueness" problem for the potential solutions which has been recently explored.

Mr. Jerry C. South, Jr., Head
Theoretical Aerodynamics Branch, TAD
Mail Stop 360
NASA Langley Research Center
Hampton, VA 23665

Which complexes are shellable?
A short survey of shellability and its applications

In its general form shellability is a combinatorial notion for piecing together a topological space out of equidimensional cells in a favorable way. When the cells are simplices, shellability reduces to a purely set-theoretic property.

The notion of shellability was first used mainly in connection with geometric objects such as convex polytopes. Recent work has shown that shellability in fact applies to a multitude of abstractly defined set systems arising in several parts of discrete mathematics. The theoretical aspects make shellability a useful combinatorial tool for dealing with certain questions in related fields.

This talk will survey some of the important examples of shellable set systems and exemplify some notable applications of shellability in algebra, combinatorics and topology.

Anders Björner
Department of Mathematics
University of Stockholm
Box 6701
11385 Stockholm
Sweden

SIAM 1983 Fall Meeting
Mini-Symposia: Invited and Contributed Summaries and Abstracts

Invited Summary and Abstracts

SUMMARY ON

CONTROL, STABILIZATION AND OPTIMIZATION IN DISTRIBUTED SYSTEMS

In addition to the two invited lectures by Professors Delfour and Gibson, three invited minisymposia on related topics in distributed system theory and applications have been organized. Symposium I, in which each of the speakers will lecture on research projects at various U.S. government labs, has as its focus distributed systems in space structures. Specific topics include state and parameter estimation techniques for large flexible space structures such as deployable communications antennas, estimation of parameters in models for heat diffusion during atmospheric reentry of the Space Shuttle Orbiter, and distributed models for thermoelastic distortion in laser beams. The focus of lectures in Symposium II is approximation techniques and topics include analysis of transfer function techniques, geometric aspects of approximation of linear systems, and approximation schemes for nonlinear filtering problems. Symposium III deals with topics in estimation and control and includes lectures on techniques for analysis and computation of Riccati feedback gains for distributed control systems, computational schemes for estimation of spatially varying parameters in models of elastic systems, and techniques for estimation of stability margins in feedback controls for distributed systems.

Invited Minisymposia and Speakers:

I. Distributed Systems in Large Space Structures

Chairman and Organizer: H. T. Banks
Brown University

Speakers: G. Rodriguez
Jet Propulsion Laboratory

D. Audley
Air Force Institute of Technology

E. Armstrong
NASA Langley Research Center

R. Allen
University of New Mexico
and
Air Force Weapons Laboratory

II. Approximation to Distributed Parameter Systems

Chairman and Organizer: C. Martin
Case Western Reserve University

Speakers: R. Hermann
Massachusetts Institute of Technology

T. Duncan *
University of Kansas

S. Mitter
Massachusetts Institute of Technology

J. Baras
University of Maryland, College Park

III. Control and Estimation

Chairman and Organizer: P. Daniel
Southern Methodist University

Speakers: R. Powers
Virginia Polytechnic Institute and State University

G. Ammar
Case Western Reserve University

J. Crowley
USAF Academy

W. Bennett
Naval Research Laboratories

Estimation and Identification Methodology for Elliptic Systems

A theory is developed for state estimation and parameter identification for elliptic systems. The theory is applicable to the problem of shape determination of complex elastic mechanical systems which can be modeled by interconnected elliptic partial differential equations. The estimation methods are obtained by means of a function-space approach that seeks to minimize a quadratic functional of the model errors. The identification techniques are based on the method of maximum likelihood that finds

*See page 6 for abstract.

parameter values such that the likelihood functional associated with the system model is maximized. Both the estimation and identification methods lead to an interesting class of boundary-value problems whose solutions are obtained by the finite-element method. To illustrate the foregoing approaches, a piecewise-continuum distributed-parameter model of a large antenna is analyzed.

Guillermo Rodriguez

R. E. Scheid, Jr.

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109

Space Shuttle Reentry Aerothermodynamic Flight Test: An Identification Problem for a Parabolic Evolution Equation

We consider the system identification problem associated with determining the aerothermodynamic heating environment of the Space Shuttle Orbiter Columbia during reentry. A mathematical characterization of this environment is required for mission capability assessment as well as operational flight planning. The identification problem is one of estimating certain parameters in a fairly complete nonlinear, nonstationary partial differential equation (diffusion) model of the heat transfer characteristics of the orbiter thermal protection system (tiles) interacting with the surface boundary phenomena of aerodynamic forced convection and radiation. Our solution uses a maximum likelihood technique that incorporates discrete, depthwise (thermocouple) temperature measurements and reentry trajectory data. Results of analyzing flight test data collected during the first flight of the Columbia are included for illustrative purposes.

David R. Audley
Department of the Air Force
Air Force Institute of Technology (ATC)
Wright-Patterson Air Force Base, OH 45433

Parameter and State Estimation for Distributed Models of the Maypole (Hoop/Column) Antenna Surface

Results are presented from a research program directed towards developing systems identification techniques for flexible systems modeled by partial differential equations with an emphasis on large space structures. Parameter and state estimation techniques are discussed for an elliptic system arising from a developmental model of the surface of the Maypole (Hoop/Column) antenna. A computational algorithm based on spline approximations for the state and elastic parameters is given and numerical results are summarized.

E. S. Armstrong
NASA Langley Research Center
Hampton, VA 23665

A Distributed Model for Thermoelastic Distortion in High Power Lasers

Beam control systems for high power lasers are typically one of a kind and relatively expensive. It is widely recognized that a cost effective first step in the design of a new system is the development of a mathematical model and its subsequent use in a computer based simulation. The simulation is used in the initial feasibility and design phases and, hopefully, will grow and mature with the refinement of hardware specifications, developing into an accurate diagnostic tool.

One of the major modeling efforts in such a simulation centers on the quantification of the thermoelastic distortion of beam train optical components. These optical components are not perfect reflectors or transmitters of radiation. Even small deviations from ideality, because of the enormous power levels flowing through the system, impose significant heat loads on critical optical components that render the optical performance unacceptable.

This talk will outline the historical/chronological development of such a model, its formulation as a partial differential equation of thermoelasticity, and its solution in the context of high power mirror application.

Richard C. Allen, Jr.
Department of Mathematics and Statistics
The University of New Mexico
Albuquerque, NM 87131

Linear System Approximation and Grassmann Geometry

Clyde Martin and the speaker introduced a new geometric gadget in linear system theory: A holomorphic curve in a Grassmann manifold instead of what is traditionally called the "transfer function." This assignment is really a variant and extension of what is called the "symbol" in the theory of pseudodifferential operators. It is then natural to ask for relations between approximations of one system by another (or by a sequence of systems) and approximation of its symbol-curve. To do this in terms of Grassmann geometry involves discussing various modes of convergence and approximation of one Grassman submanifold by another. The talk will deal with this from a geometric point of view, involving integration of differential forms defined on the enveloping Grassmann manifold over the symbol-submanifolds.

Robert Hermann
Massachusetts Institute of Technology
Cambridge, MA 02139

The Approximation Problem for Nonlinear Filtering

In this lecture we discuss the pathwise approach to nonlinear filtering which leads to the study of a parabolic partial differential equation, parametrized by the observation paths. By exploiting the relationship between parabolic partial differential equations and Bellman-Hamilton-Jacobi equations, approximation schemes for nonlinear filtering problems are proposed. A justification of the Extended Kalman Filter is presented.

Sanjoy K. Mitter
Massachusetts Institute of Technology
Room 35-233
Cambridge, MA 02139

Transfer Function Classes Appearing in Linear Distributed Systems: Applications to Feedback Compensation

An anlysis of time constant linear distributed parameter systems from typical classes, such as delay, parabolic, hyperbolic, is performed in order to precisely identify the analytic class of their transfer functions. Based on these results, a classification of transfer functions is produced which is of fundamental importance for frequency domain design. For two classes, we demonstrate the significance of the detailed information obtained for feedback compensation.

John S. Baras
Electrical Engineering Department
University of Maryland
College Park, MD 20742

An Application of Chandrasekhar-Type Algorithms for Optimal Control of Delay-Differential Systems

We discuss an application of Chandrasekhar-type algorithms to optimal control problems governed by delay-differential equations. We approximate an infinite-dimensional system with a finite-dimensional system and use a Chandrasekhar-type algorithm to compute the gain operator. Computational advantages are discussed and numerical examples presented.

Robert K. Powers
Department of Mathematics
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

The Power Method, QR Algorithm, and Riccati Equations

The power method and the QR algorithm, two of the classical methods for finding the invariant subspaces of a matrix, are shown to be directly related to the matrix Riccati equations. We consider the power method as an iteration on the Grassmann manifold, and observe that in local coordinates, this iteration is given by a discrete Riccati equation. The QR algorithm is interpreted in an analogous way as an action on the flag manifold. We then use ideas from Lie theory and differential geometry to study these algorithms as actions on compact homogeneous spaces of the general linear group. This approach provides a natural geometric setting for studying the existing matrix eigenvalue algorithms and for developing new algorithms for special classes of matrices. In particular, we consider a restricted QR algorithm for the Hamiltonian and symplectic matrices.

Gregory Ammar
Department of Mathematics
University of Kentucky
Lexington, KY 40506

Numerical Methods for Estimation of Coefficients in Elastic and Viscoelastic Structures

We discuss a class of numerical methods for estimating both constant and variable parameters in Euler-Bernoulli and Timoshenko beam models, based upon a Galerkin semi-discretization of the partial differential equations using splines. Computational results will be included.

James M. Crowley
U.S. Air Force Academy
USAF Academy, CO 80840

Estimates of Weak Coupling and Stability of Decentralized Control in Large Multivariate Systems

In classical feedback control certain distributed parameter effects are considered by examining the system frequency response and determining closed loop stability margins. In this talk we consider the problem of obtaining estimates for stability margins for multiloop feedback with decentralization in a frequency dependent setting. A frequency dependent notion of weak coupling between subsystems is developed based on an abstract geometric multiloop Nyquist criterion. The essential topological features of this generalized Nyquist criterion involve intersections between certain subspaces of the inputs and outputs. The measures employed here are derived from the idea of principal angles between a pair of subspaces.

William H. Bennett
Aerospace Systems Division
Naval Research Laboratory
Washington, DC 20375

Stochastic System Theory and Affine Lie Algebras

All Lie algebras are useful in the study of some infinite dimensional phenomena. Theta functions are described in terms of affine Lie algebras and some well-known theta function identities are established using stochastic system theory.

Tyrone Duncan
Department of Mathematics
University of Kansas
Lawrence, KS 66045

Contributed Summaries and Abstracts

SUMMARY ON
PARALLEL AND VECTOR
ALGORITHMS FOR MATRIX COMPUTATIONS

Many large-scale problems in linear algebra and its applications are ideally suited for solution techniques using parallel arrays of processing equipment or using pipelined or vector arithmetic units. Accordingly the SIAM Activity Group on Linear Algebra has arranged a minisymposium on the timely topic of parallel and vector algorithms for matrix computations. The invited speakers for this minisymposium will discuss recent trends in solving large sparse systems of linear equations, along with least-squares and eigenvalue computations, by parallel and vector algorithms.

The speakers and the titles of their presentations are: Ahmed Sameh, "Parallel algorithms in numerical linear algebra"; B. N. Datta, "Parallel computations for some linear algebra problems in control theory"; Dianne O'Leary, "Parallel computations for sparse linear systems"; and David Young, "Vector computations for sparse linear systems".

Organizer:

Robert J. Plemmons
Departments of Computer Science
and Mathematics
North Carolina State University
Raleigh, North Carolina 27650

Parallel Algorithms in Numerical Linear Algebra

A brief survey of parallel algorithms for solving linear systems of equations and the algebraic eigenvalue problem will be presented. Specifically, we describe parallel algorithms for: (i) direct solvers for dense and banded linear systems of equations, (ii) iterative schemes for solving elliptic difference equations, and (iii) solving dense and sparse algebraic eigenvalue problems. Throughout the presentation we point out the interplay between the computer architecture and algorithm organization.

Ahmed H. Sameh
Department of Computer Science
University of Illinois at Urbana-Champaign
Urbana, IL 61801

Parallel Computations for Sparse Linear Systems

In this talk, some issues and open problems in the solution of sparse linear systems on parallel computers will be surveyed. The issues will be illustrated on one class of problems, the solution of linear systems involving sparse positive definite M-matrices. A solution technique will be presented and illustrated for machines of fixed and dynamically reconfigurable connectivities.

Dr. Dianne P. O'Leary
University of Maryland
Department of Computer Science
College Park, Maryland 20742

Parallel Computations for Some Linear Algebra Problems in Control Theory

Linear algebraic problems such as determining eigenvalue distribution of a matrix in regions of complex plane (the so-called Root-separation problems for polynomials are special cases), solving matrix equations (Lyapunov, Sylvester, Riccatti, etc.), determining if two matrices have common eigenvalues, testing controllability and observability of a pair of matrices, calculating a matrix F so that for a given controllable pair (A,B), the matrix $A + BF$ has a desired spectrum (pole assignment problem) etc., arise in Linear Control Theory.

In this talk, we will briefly survey existing sequential algorithms for these problems, that have potentials for parallel implementations. Our attention will be directed mainly on designing $O(\log^2 n)$ steps algorithms using unlimited processors.

Biswa Nath Datta and Karabi Datta
Department of Mathematical Sciences
Northern Illinois University
DeKalb, IL 60115-2854

Vector Computations for Sparse Linear Systems

The advent of high-performance vector computers such as the Cyber 205 and the Cray I is having a profound effect on the areas of numerical analysis and mathematical software. This is true, in particular, in the area of iterative algorithms and software for solving large sparse systems of linear algebraic equations. Some iterative algorithms which are effective when used with conventional, or scalar, machines may not be effective when used with vector machines. In such cases modifications can sometimes be made in order to make the methods more amenable to vectorization. This may result in more iterations for convergence, but this is more than offset by the substantial decrease in computer time. Also, it may be necessary to modify the sparse storage format in order to achieve efficient vectorization. These questions are discussed and illustrated by a description of the recent conversion to the Cyber 205 of the routines of ITPACK, which are designed to solve linear systems by a variety of iterative algorithms. Timing comparisons are given for a sample problem.

David M. Young and David R. Kincaid
Center for Numerical Analysis
RLM 13.150
The University of Texas
Austin, Texas 78712

SUMMARY ON GRID GENERATION

The construction of a grid is an integral part of any problem in computational aerodynamics. The accuracy and efficiency of the numerical algorithm depend on the grid properties. This minisymposium will review the state-of-the-art and introduce new ideas on topics including grid construction for three-dimensional regions and control of the grid point distribution. It is proposed that this minisymposium consist of four thirty-minute presentations.

Organizer:

C. Wayne Mastin
Department of Mathematics and Statistics
Mississippi State University
Mississippi State, MS 39762

Three-Dimensional Grid Generation From Elliptic Systems

The various types of elliptic partial differential systems of equations which have been used for three-dimensional grid generation are surveyed, and correlations among these systems are made. The determination of control functions used in these equations to control the coordinate line spacing and orientation is discussed. It is noted that general three-dimensional configurations are best treated by segmentation into sub-regions.

Dr. Joe F. Thompson
Dr. Z. U. A. Warsi
Department of Aerospace Engineering
P. O. Drawer A
Mississippi State, MS 39762

Surface Grid Spacing Control for Aerodynamic Configurations

Three-dimensional boundary-fitted grids about aircraft configurations are partially controlled by fixed-boundary surface grids. Configuration-boundary surfaces are intially defined with the Harris geometry and classical interpolation techniques. A method of determining a computationally suitable grid superimposed on the initial surface definition with controls for concentration and dispersion is presented. Coons' patch-surface representation, plane-patch intersections, and three-dimensional spline representations with embedded-control functions are the ingredients of the process. Several examples are presented.

R. E. Smith, Jr.
Computer Science and Applications Branch
NASA Langley Research Center
Hampton, VA 23665

Robert A. Kudlinski
Computer Science and Applications Branch
NASA Langley Research Center
Hampton, VA 23665

LOCALLY CONTROLLED ALGEBRAIC COORDINATE GENERATION

Algebraic coordinate generation techniques with precise controls over mesh properties are examined. The controls are precise because mesh properties can be explicitly specified within a local region independent of the mesh elsewhere. The local regions can adjoin boundaries where a particular mesh form can greatly simplify a problem or can be used for a smooth juncture between distinct coordinate systems where, in effect, a branch cut with a prescribed geometry and mesh distribution can be obtained. Away from boundaries, a local region can be given a particular mesh form to model internal objects or to simplify a problem. The coordinate generation techniques are established to obtain a maximal amount of control subject to the desired number of continuous derivatives. The pattern is established with the developments for continuity up to first and second derivatives and is further extended afterwards. The results for the first derivative case are applicable only to two dimensional meshes. The second and higher derivative cases are applicable in higher dimensions.

Research supported by AFOSR Grant AFOSR-82-0176 and NASA Grant NCCI-59

Peter R. Eiseman
Department of Applied Physics
and Nuclear Engineering
S.W. Mudd Building
Columbia University
New York, N.Y. 10027

Composite Grid Systems

The computational grids for many complex regions encountered in aerodynamics are constructed by joining several curvilinear coordinate systems on simpler subregions. A survey of techniques used for deriving difference equations on this type of composite grid will be presented. The form of the difference equations at the subregion boundaries may effect the order and the stability of the numerical algorithm.

C. Wayne Mastin
Department of Mathematics and Statistics
Mississippi State University
Mississippi State, MS 39762

SUMMARY ON THEORETICAL AERODYNAMICS

This minisymposium is intended to complement the symposium on computational aerodynamics. The four lectures will center on perturbation methods for aerodynamic flows. Special emphasis will be placed on transonic flows, and on viscous flows.

Organizer:

L. Pamela Cook
Department of Mathematics
University of California
Los Angeles, CA 90024

and

Department of Mathematical Sciences
University of Delaware
Newark, DE 19711

PSEUDO-TRANSONIC FLOW

Pseudo-transonic flow was identified by W. Hayes (1954) for slightly non-linear waves close to Mach waves. A related flow appears near the leading edge of thin supersonic wing swept at the Mach angle. Linearized theory has a singularity at such an edge. A local non-linear expansion is constructed which matches to linear theory away from the edge. The local equation is the two-dimensional T.S.D. unsteady equation, with distance along the edge analogous to time. It is thus also related to an equation derived by H.K. Cheng for sweptback wings. It is shown that the drag with the non-linear theory is reduced, compared to linearized theory. Some similarity solutions are discussed.

Professor Julian D. Cole
Department of Mathematical Sciences
Rensselaer Polytechnic Institute
Troy, N.Y. 12181

Combined Computational and Asymptotic Methods in Transonic Flows*

A number of examples will be discussed in which perturbation methods used in conjunction with numerical procedures can provide insights into the structure of transonic flows. This combination often allows the roles of the important parameters and the analytical dependence of the solution on them to become more apparent. In addition, it can reduce the amount of computation required to understand the features of the flow. One illustration to be described exemplifying these concepts is the singular perturbation problem of transonic wind tunnel interference. Other problems to receive attention are applications of slender body theory and the treatment of tangentially blown wings in transonic flows.

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*A portion of the work to be discussed was supported under ONR Contract N00014-81-C-0104 and AFOSR Contract F49620-80-C-0081.

Norman D. Malmuth
Rockwell International Science Center
P.O. Box 1085
Thousand Oaks, California 91360

ASYMPTOTIC AND COMPUTATIONAL STUDIES OF AN UNSTEADY TRANSONIC FLOW ABOUT A THIN AIRFOIL

Asymptotic theories and computational methods of unsteady transonic flow are reviewed; questions and issues arising from recent developments on the influence of entropy and vorticity corrections, perturbations of supercritical flows involving shocks, the far-field condition as well as the merits of certain monotone shock-capturing schemes are discussed in the context of an unsteady thin airfoil problem.

The theoretical development on which the discussions are based corresponds to the familiar unsteady version of the (nonlinear) transonic small-disturbance equation but carried out to a higher order. Entropy increase across the shock is shown to give a significant second-order correction to the velocity field, confirming the results of Hafez (1983) for steady flows. However, unlike in the steady case, the time-dependent contribution in this regime leads to a vorticity correction behind the shock comparable to that of the entropy. The second-order contributions from the trailing vortex sheet and to the radiation condition in the far field are also examined.

H.K. Cheng
Department Aerospace Engineering
University of Southern California
Los Angeles, CA

AN APPROXIMATE METHOD IN VISCOUS FREE-BOUNDARY PROBLEMS

The detailed prediction of multi-phase viscous fluid behavior is quite difficult because the location of fluid interfaces is a priori unknown. For certain simple geometries a quasi-unidirectional flow assumption, often called "lubrication theory", may be justified. For plane or axisymmetric geometries, the interface shape is given by the solution of a nonlinear ordinary differential equation which may be found either by perturbation methods or numerically. Examples include two-dimensional unstably-stratified Couette flow and concentric two-phase flow in a tube. In the latter case, the existence of travelling interfacial waves of permanent form is demonstrated.

LEONARD W. SCHWARTZ
EXXON RESEARCH AND ENGINEERING CO.
CORPORATE RESEARCH SCIENCE LABORATORIES
P. O. Box 45
LINDEN, NEW JERSEY 07036

SUMMARY ON NUMBER CRUNCHING ON SMALL, MEDIUM AND LARGE-SCALE COMPUTERS

During the past several years there has been a significant increase in the speed, sophistication, and versatility of small, medium, and large-scale computing devices which are appropriate for scientific and engineering calculations. It is now possible to perform very complex computations on micros, numeric coprocessors, array processors, minis, mainframes, and supercomputers or on any combination thereof. This situation creates several potential dilemmas for the user who is anxious to reap the benefits of a multi-machine facility: Which computer should be selected for each computational task? How effective is it to sub-divide a large application into several parts and ship each to specialized machines via a local area network? What are the hardware and software limitations for each type of processor?

This panel sessions will focus attention on the variety of computational capabilities provided by this milieu of machines as well as on the strengths and weaknesses inherent in each environment. Topics to be discussed include the following: existing computer arithmetic versus the IEEE Floating-Point Standard, reliability and transportability of numerical software from one type of machine to another, mapping and partitioning user problems onto different classes of computers (e.g. array processor and supercomputer), compatibility of computational devices, influences of computational environment on the selection of a programming language and on algorithm design, the user interface and commumications amongst several different machines. Panelists will present examples on several different types of processors. The advantanges and disadvantages of current machines will be discussed along with future needsfor scientific and engineering computations.

Organizer and Chairman:

Myron Ginsberg
General Motors Research Laboratories
Computer Science Department
Warren, MI 48090

An Overview of the Computational Environments Offered by Micros, Minis, Mainframes, and Supercomputers

This presentation provides background information for the panel session theme. Some illustrative computational results will be given to indicate approximate comparative speeds for floating-point operations and a few engineering kernels executed on representative micros, minis, mainframes, and supercomputers. Some emphasis will be placed on the microprocessor environment with an indication of the hardware and software available to support scientific and engineering computations. Additional issues which will be discussed include: similarities and differences of computational environments with particular emphasis on scalar versus vector capabilities, problems of interfacing amongst different computers with respect to math software transportability, communications from one machine to another, problem partitioning amongst several different types of processors (e.g.supercomputer and array processor). A brief summary will be given of the areas covered by each panelist presentation. Also issues will be listed to stimulate audience discussion.

Myron Ginsberg
Computer Science Department
General Motors Research Laboratories
Warren, MI 48090

PERFORMANCE IMPROVEMENT IN STRUCTURAL ANALYSIS ON SUPERCOMPUTERS

The primary purpose of this paper is to present the expected and actual development efforts and resulting performance of MSC/NASTRAN on a CRAY-1 supercomputer. Additionally, current work to adapt MSC/NASTRAN to the FPS-164 attached processor is discussed and anticipated performance is presented. First, the primary types of matrix equations typically solved in the analysis of large, complex structures are briefly described. Then the size and general architecture of MSC/NASTRAN are discussed, followed by a brief overview of typical computational sequences.

The architecture and performance of both the CRAY-1 computer and the FPS-164 attached processor are then discussed from the viewpoint of MSC/NASTRAN's particular requirements. The efforts to adapt MSC/NASTRAN to both the standard CRAY operating system (COS) and Lawrence Livermore National Laboratory's CTSS operating system are presented along with some observations on their respective performance. Problems encountered in the FPS-164 adaptation effort are also discussed.

Based on experiences to date, the challenges and opportunities offered by vector processing are addressed. Included is the rationale for deactivating the vector processor depending on the nature of particular matrix operations. Actual performance figures for the CRAY versions are given for both typical element generation and matrix operations. The performance for these operations is also estimated for the future FPS-164 version.

Finally, some observations are made about the strengths and weaknesses of these two versions of MSC/NASTRAN. Additional areas in need of attention are identified.

Joseph F. Gloudeman
The MacNeal-Schwendler Corporation
815 Colorado Boulevard
Los Angeles, California 90041

Floating-Point Issues

Arithmetic engines implementing the new IEEE Floating-Point arithmetic will alter the way we view computation. We compare these new engines with traditional engines, using simple examples to illustrate the fundamental numerical differences. We also discuss issues of proper language support and implications for development of numerical software.

William J. Cody, Jr.
Mathematics and Computer Science Division
Argonne National Laboratory
Argonne, Illinois 60439

Tradeoffs between Using Supercomputers and Array Processors for Scientific Computations

This presentation focuses attention on the advantages and disadvantages of using an array processor or supercomputer for various types of scientific and engineering computations. Topics to be discussed include: comparison of computational environments, guidelines on how to partition a problem into segments which effectively utilize both types of machines, differences in preparing and fine-tuning programs for array processors and supercomputers, selecting appropriate numerical algorithms for each machine, systems and applications software support, communications and data transfer problems, transportability considerations, other compatibility concerns, performance examples, cost effectiveness issues.

John Levesque
Pacific-Sierra Research Corporation
12340 Santa Monica Blvd.
Los Angeles, California 90025

SUMMARY ON
NOVEL TECHNIQUES AND ALGORITHMS
FOR THE NUMERICAL SOLUTION OF
PARTIAL DIFFERENTIAL EQUATIONS

Every year, important and interesting advances take place in the development and analysis of algorithms for the approximate solution of partial differential equations. We gather here speakers who have participated in such developments. Their work is especially featured by the novelty of their analytic techniques and their algorithms.

Organizer:

Professor Max Gunzburger
Department of Mathematics
Carnegie-Mellon University
Pittsburgh, PA 15213

On the Numerical Solution of Differential Equations on Manifolds

Various applications involve mixed systems of differential and algebraic systems. These systems are considered as differential equations on manifolds which in turn allows for the formulation of existence and uniqueness results for them. A class of algebraically incomplete systems is introduced for which such results only hold on certain lower dimensional manifolds. This class includes systems for which the application of ODE solvers is known to lead to difficulties. A new solution approach based on continuation techniques is outlined and several numerical examples are given.

Werner C. Rheinboldt
University of Pittsburgh
Pittsburgh, PA 15260

Boundary Approximations for Alternating Sweep Implicit Upwind Methods for Hyperbolic Systems

We will introduce boundary approximations of predictor-corrector type with an alternating sweep solution process for use with upwind implicit methods for initial-boundary value problem for hyperbolic systems of partial differential equations. These methods have beeter stability properties than those which result from known explicit boundary approximations but still allow the solutions to be obtained effectively explicitly even though the boundary conditions link the incoming and outgoing charateristics at the boundaries. The use of usual implicit boundary approximations prohibits such a solution process. We will present a stability analysis for these methods for linear problems and present computations for gas dynamics which show that these methods can often be at least a factor of ten more efficient for such computations.

Joseph Oliger
Department of Computer Science
Building 460
Stanford University
Stanford, CA 94305

C. K. Lombard
PEDA Corporation
Palo Alto, CA 94306

Low Order Finite Elements and the Divergence Constraint for Viscous Flows

A description of recent work with R.A. Nicolaides on numerical stability of low order finite element discretizations of divergence constraints in connection with viscous flow problems is given. Included are results concerning the effects of the "spurious modes" in bilinear/constant and linear/constant "box" elements on square grids and extenstions to more general quadrilateral grids.

James Boland
University of Pittsburgh
Pittsburgh, PA 15260

On the Exterior Stokes Problem in Three Dimensions

We discuss the exterior Stokes problem in R^3. The natural spaces in which we pose the problem are weighted function spaces. We show the existence, uniqueness and the regularity of the solution in those weighted spaces. Some aspects of the numerical approximation methods are discussed. In particular, we mention approximation by a problem on a bounded subdomain with an artificial boundary condition imposed at the artificial boundary. The error in the solution of the truncated problem is discussed as are finite element approximations.

Georges H. Guirguis
North Carolina State University
Raleigh, NC 27650

Vector Basis Functions for High-Order Triangular Finite Elements

The purpose of this paper is to provide simple algebraic expressions that represent the divergence, the curl, and the gradient of a vector field in triangular finite element spaces. These expressions are given in terms of elementary matrices universally valid for a triangular finite element of any shape. We show that by writing the divergence, the curl, and the gradient operators in terms of homogeneous coordinates, these expressions may be inverted explicitely. The resulting inverse expressions, again universally valid, provide basis functions for approximating vector field problems using triangular finite elements. These vector basis functions may then be used to solve field problems having any specified divergence or curl.

Zoltan Cendes
Department of Electrical Engineering
Carnegie-Mellon University
Pittsburgh, PA 15313

SUMMARY ON SPECTRAL METHODS

The theme of this minisymposium is the recent applications of spectral methods to hydrodynamic and aerodynamic problems. The topics will include, but not limited to, stability, transition to turbulence, large eddy simulation, shock wave turbulence interactions, and flows past aerdynamic configurations.

Organizer:

M. Y. Hussaini
Senior Scientist
ICASE
Mail Stop 132C
NASA Langley Research Center
Hampton, VA 23665

Solution of Problems in Complicated Geometries Using Spectral Methods

A survey will be given of techniques to apply spectral methods in complicated geometries. The basis for the spectral iteration method, spectral element method, and spectral embedding method will be discussed. Applications will be given to fluid flows in complicated geometries.

Professor Steven A. Orszag
Massachusetts Institute of Technology
Department of Mathematics
2-347
Cambridge, MA 02139

THE APPLICATION OF SPECTRAL METHODS TO REACTING FLOW PROBLEMS

We have performed simulations of reacting flows by solving the non-linear Navier-Stokes equations in two and three spatial dimensions plus time using spectral numerical methods. The reaction-diffusion equations are also computed to simulate the effects of a binary reaction with negligible heat release and no reaction effects on the flow field. The dependent variables are expanded in Fourier series and the equations advanced with second order time differencing. The solutions of these equations can be difficult to simulate for several reasons. First, the concentration fields must be strictly non-negative at all times. Second, steep gradients can develop in the concentration fields if the reaction rate significantly exceeds the diffusion rate. We have experimented successfully with several methods for preventing the development of negative concentration fields while retaining high accuracy. Our results also indicate that with moderate spectral resolution, it is possible to approach the infinite reaction rate limit. Spectral methods appear to have significant potential in the simulation of reacting flows.

Ralph W. Metcalfe and James J. Riley
Flow Research Company
21414 68th Ave. S.
Kent, WA 98031

Spectral Methods For Flow Computation

This talk will cover three topics. The first two are new applications of spectral methods made by the author's colleagues; the last is an assessment of the future of spectral methods in computational fluid dynamics.

Cain has developed a spectral method for the computation of derivatives in infinite domains. The concept is to map the infinite domain into a finite one in a way which minimized the bandwidth of the derivative operator in spectral space. This reduces the truncation error and permits the solution of differential equations via the inversion of matrices of small bandwidth.

Leonard and Moser have developed an approach which is specifically applicable for the computation of incompressible flows. They choose basis vector-valued functions which are devergence-free, satisfy the boundary conditions, and produce matrices of the smallest possible bandwidth. The functions are related to the Chebychev polynomials but specific to the geometry and boundary conditions.

Spectral methods have proven to be extremely powerful and their properties recommend their use whenever possible. Their principal disadvantage is the need for a new formulation for each geometry and/or boundary condition. Since many important problems involve complex geometrices, it is the author's opinion that the range of applicability of spectral methods will remain restricted in the future; however, the boundary can be expected to broaden with time.

Joel H. Ferziger
Department of Mechanical Engineering
Stanford University
Stanford, CA 94305

APPLICATION OF SPECTRAL COLLOCATION METHODS TO INVISCID COMPRESSIBLE FLOWS

Spectral collocation methods for the Euler gas-dynamics equations are characterized by the fact that the solutions are approximated by global interpolants such as Fourier or Chebyshev series. Derivatives are computed at the collocation points in real space as the analytic derivatives of the interpolant. The goal has been to obtain accuracy comparable to that which can be reached for incompressible flows. For smooth flows, accuracy superior to that of second order finite differences can be obtained. The presence of shocks in the computational region, however, degrades the accuracy of spectral methods. We present one-dimensional examples of this degradation. If shocks are placed at boundaries as in shock-fitting methods, the superior accuracy is retained. Examples of shock-fitting spectral methods will be given for some two-dimensional aerodynamic applications.

Dr. David A. Kopriva
ICASE
M/S 132C
NASA Langley Research Center
Hampton, VA 23665

Dr. Thomas A. Zang
NASA Langley Research Center
M/S 409
Hampton, VA 23665

SUMMARY ON COMPUTABLE ERROR ESTIMATES FOR PARTIAL DIFFERENTIAL EQUATIONS AND APPLICATIONS

Much attention has been focused in recent years on the use of adaptive methods for solving partial differential equations. Adaptivity in this context can refer to the construction of the mesh or sequence of meshes on which the problem is to be solved, or to the local order of approximation to be used. Such automated discretization procedures require the availability of information about the solution and the error in order to be effective. This mini-symposium will focus on procedures for computing the relevant data, and how it is then incorporated in adaptive procedures.

Organizer:

Randolph E. Bank
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Numerical Solution of Unstable Problems in Combustion

We consider the solution of one and two-dimensional unstable problems in combustion by adaptive numerical methods. Our work focuses on the selection of grid points by equidistributing positive weight functions on consecutive intervals in each coordinate direction. This enables us to resolve efficiently regions in which the solution exhibits high spatial activity. We apply the method to the solution of an unstable, freely propagating flame and a solid-solid alloying problem.

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Some results concerning the principles for the adaptive construction of the optimal meshes for the Finite Element Method

Although much attention has been focussed on various adaptive procedures for solving PDE's, the content of the notion "adaptive" is used very loosely. The talk will concentrate on the formulation of desired results and some available theorems.

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Some Computable Error Estimators for Elliptic Problems

Several locally-computable error estimators in the energy norm for approximate solutions to elliptic partial differential equations are discussed. The forms of the error estimators depend on the methods used to obtain the approximate solutions. Two of the estimators apply specifically to the approximate solutions obtained from standard finite element methods when direct methods are used to solve the resulting linear systems. Another estimator applies to the approximate solutions obtained from block-centered finite difference methods using direct methods. Several other estimators may be applied to somewhat larger classes of approximate solutions. These estimators are generally less accurate than the special-purpose estimators.

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Optimization of the shape of an axisymmetric body for minimum wave drag of transonic speeds

The historical importance of this problem is demonstrated and its usefulness for today's fighter and transport aircraft is explained. A transonic flow model based on irrotational flow is explicited and the approximations of a slender body and of small perturbations are retained. Close field and far field solutions are derived and the formulation of the transonic wave drag is performed. A projected gradient method combined with a penalty function is used in the optimization. The transonic flow equations are approximated with finite differences. Axisymmetric bodies of minimal wave drag are obtained and an example is shown.

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THREE DIMENSIONAL WAVE EQUATION COMPUTATIONS ON VECTOR COMPUTERS

There are now several laboratories worldwide which routinely perform dimensional physical modeling of interest to seismologists. Corresponding computerized mathematical models have been limited to two dimensions on convential computers due to the immense computational requirements of accurate full size problems.

The introduction of high performance vector processors in the 100+MFLOP range has at last made three dimensional computerized models a practical reality. We now have such models and we have some limited experience in using them, however, much more work is required before these mathematical models can routinely supplant the physical ones.

Here we describe one such model which was developed for the Cyber 205. A 2D model for the VAX-11 with FPS-100 Array Processors wad modified to 3D and vectorized suitably for the larger system.

We state the acoustic wave problem in mathematical form and present the algorithm used for its solution. We then review the theoretical justification for selecting this particular algorithm. We also discuss the most important technical aspects of implementing the algorithm in vector form on the Cyber system.

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Explicit Optimality Conditions for Finite-Dimensional Fixed-Order Dynamic Compensation of Infinite-Dimensional Systems*

Recent efforts in the control of linear infinite-dimensional systems characterize the optimal control by state estimation and linear feedback. Although the optimal control can be approached by a sequence of control designs for finite-dimensional approximate problems of increasing order, an adequate design may exceed real-time processing capability. Our approach accepts an infinite-dimensional model with disturbance and observation noise and seeks to minimize a quadratic performance criterion when the order of the dynamic controller is fixed in advance by implementation constraints. The principal result is a set of necessary conditions which characterize the optimal steady-state dynamic compensator of prescribed order. In contrast to the pair of operator Riccati equations for the LQG case, the optimal fixed-order dynamic compensator is characterized by four operator equations (two modified Riccati equations and two modified Lyapunov equations) coupled by a projection whose rank is precisely the order of the compensator. This projection gives insight into the compensator structure and determines the optimal compensator gains. The results apply to a semigroup formulation in Hilbert space and hence are applicable to a broad range of control problems governed by partial differential equations.

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AN ALGORITHM FOR FINDING A ZERO OF A FUNCTION

A numerical algorithm is presented for solving one non-linear equation in one real variable. Given f(x) with brackets a and b, i.e. sign(f(a)) = -sign(f(b)), the algorithm finds a zero of f(x), a<x<b. Alternately, a crossover pair is found, i.e.(x,y):sign(f(x))=-sign(f(y)), where there is no floating-point number in the system between x and y. This feature allows full use of machine precision. Optionally, a tolerance t>0 may be given, to permit termination when y-x <t. The method, once rapid

convergence sets in, is alternation of one linear interpolation or extrapolation with one inverse quadratic interpolation. The resulting asymptotic convergence rate is 1.732, a rate competitive with other methods that refine both brackets and do not require df/dx. Other merits of the algorithm are : robust calculation, efficient three point interpolation, and superior behaviour in bad cases. The algorithm is tested and compared with others.

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On the Integral Formulation of the Vorticity Boundary Condition

In the numerical solution of the stream function vorticity form of the Navier-Stokes equations, a major consideration is given to correct specification of the vorticity boundary condition. Several authors (1,2) have recently advocated certain integral formulations for the vorticity boundary condition; these formulations have been used in conjunction with finite element methods. One of the itegral formulations reduces the problem of solving the biharmonic equation into that of solving (N+4) Poisson equations, N being the number of boundary mesh points. Another formulation requires solution of (2N+4) Poisson equations.
We apply these integral formulations to finite difference methods on a set of biharmonic boundary value problems. Preliminary results indicate that the behaviour of these integral formulations is problem dependent: On some problems we obtain $O(h^2)$ convergence whereas on other problems the rate of convergence is $O(h)$. This method is also applied to Stokes flow (Re=0) in a driven cavity and the numerical solutions are found to be very accurate.

(1) R. Glowinski & R. Pironneau, SIAM Rev. 21 (1979), 176. (2) L. Quartapelle, J. Comput. Phys 40 (1981), 453.

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Error Estimates for the Weighted Least Squares Approximation

It is known that the error of the weighted least squares approximation can be written as

$$\int_{-1}^{1} w(x)[f(x) - f_N(x)]^2 dx = \int_{-1}^{1} w(x)f^2(x)dx - \sum_{n=0}^{N} a_n^2$$

We denote by $\{p_n(x)\}$ the set of orthonormal polynomials with respect to the weight function $w(x)$ on $[-1,1]$. Then the generalized Fourier coefficients, a_n, are defined as $a_n = \int_{-1}^{1} f(x)p_n(x)dx$. Usually the orthonormal polynomials $p_n(x)$ are difficult to construct. We present asymptotic estimates for a_n without requiring explicit forms of the orthonormal $p_n(x)$. The method holds for a certain class of weight functions.

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The Boundary Value Problem of Non-Newton Flow

In this paper we prove the existence and uniqueness of the solutions of first boundary value problem and mixed boundary value problem for non-newton flow (we only consider stationary incompressible situation). In the two problems we use penalty method to cancel the variable pressure p, in this way to avoid the difficulty to construct the finite element subspace to satisfy approximately the continuous equation. We also prove the existence and uniqueness of the solutions of penalty formulations. In this paper we refer the results which R. Glowinski have got in the problem of so-called elliptic variational inequality of the second kind and use contract imagine principle i.e. we first appropriately define a closed convex set K, then construct a auxiliary problem and so construct an operator which maps the set K into itself and is contractive. Therefore it has a unique fixed point, this fixed point is just solution we want to find. In this paper we study the finite element approximations of the two problems. We give the error estimates.

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An Analytical Model for the Turbulent Flow Over a Shallow Cavity

A two dimensional discrete vortex model is used to represent turbulent flow over a shallow cavity. The free shear layer which originates at the cavity's leading edge is modelled by the periodic insertion of point vortices near the separation point. The Lagrangion evolution of the point vortices is traced, and their initial strengths are determined by the Kutta condition. A vortex decaying function based on the turbulent energy spectrum equation is employed to simulate the effect of viscous dissipation on a point vortex. Experimental data is presented to examine the credibility of the analytical model.

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Acoustic Propagation in Partially Choked Converging-Diverging Ducts

A computer model based on the wave-envelope technique is used to study acoustic propagation in converging-diverging ducts carrying near sonic mean flows. The influences of the liner admittance, boundary layer thickness, spinning mode number, and mean Mach number are considered. The numerical results indicate that the diverging portion of the duct can have a strong reflective effect for partially choked flows.

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Measuring Stiffness*

Many problems have been proposed for the testing and evaluation of mathematical software for the solution of the initial value problem for a system or ordinary differential equations. The stiffness of a given problem is of great significance for testing, but the concept is at best somewhat vague and the few quantitative measures of stiffness being used are of limited value. A relatively precise and quantitative way is proposed to answer the questions: How does the stiffness vary in the course of the integration of a given problem? Is a given problem A stiffer than a given problem B, and if so, by how much?

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Calculation of Eigenvalues for Nondefective, Complex Symmetric Tridiagonal Matrices

The real symmetric tridiagonal subroutine IMTQL1 in the EISPACK library was modified to handle nondefective, complex symmetric tridiagonal matrices. The resulting 'Q'L procedure utilizes similarity transformations which preserve the complex symmetric and the tridiagonal properties. Thus, this procedure can handle large matrices and as such is a key ingredient in the complex symmetric version of our Lanczos procedure for large, sparse complex symmetric matrices.

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A Lanczos Algorithm for Nondefective Complex Symmetric Matrices

We extend our Lanczos algorithms with no reorthogonalization to the computation of distinct eigenvalues and corresponding eigenvectors of nondefective, complex symmetric matrices. A matrix $A \equiv B+iC$ where B and C are real is complex symmetric if and only if B and C are both real symmetric matrices. This class of matrices is considerably more difficult than the real symmetric and Hermitian classes. Complex symmetric matrices have complex-valued eigenvalues and eigenvectors, and the eigenvectors are not unitary.

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Complex Eigenvalues for the Stability of Couette Flow

The linear eigenvalue problem for the stability of Couette flow to axisymmetric disturbances is considered for the case when the outer cylinder is at rest. It is shown through numerical calculations and by formal perturbation methods that there are complex eigenvalues corresponding to damped disturbances. The result does not contradict the conjectured principle of exchange of stabilities: the first eigenvalue giving growth is real.

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Linearly-Constrained Optimization using a Truncated-Newton Algorithm

Truncated-Newton methods are a flexible class of iterative methods that are useful in solving large-scale minimization problems. At each major iteration, the Newton equations are approximately solved by an inner iterative algorithm (such as the linear conjugate-gradient method) in order to compute a search direction. Numerical results have shown that a carefully chosen truncated-Newton method can perform well in comparison with other algorithms for this problem class. Here, a truncated-Newton approach is applied to a general linearly-constrained minimization problem. In particular, techniques for computing a search direction and Lagrange multiplier estimates are discussed, without assuming convexity of the objective function. Numerical results are given.

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SPLINE APPROXIMATION FOR RETARDED SYSTEMS AND THE RICCATI EQUATION

We introduce a finite dimensional approximation scheme for the retarded functional differential equation

(1) $\dot{x}(t) = A_0x(t) + A_1x(t-h) + B_0u(t)$

which is based on a projection of the product space $M^2 = R^n \times L^2$ onto a spline subspace. The scheme approximates both the original semigroup $S(t) \in L(M^2)$ associated with system (1) and the adjoint semigroup $S^*(t)$ in a strong sense. This fact guarantees the strong convergence of the solutions to the differential Riccati equations. Numerical findings also indicate a strong convergence of the solutions to the algebraic Riccati equation.

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TWO ALGEBRAIC RICCATI EQUATIONS FOR RETARDED SYSTEMS WITH GENERAL DELAYS IN STATE, CONTROL, AND OBSERVATION

We consider the linear retarded system

(1) $\dot{x}(t)=Lx_t+Bu_t,\ y(t)=Cx_t,$

with quadratic performance index

(2) $J(u)=\int_0^\infty(|y(t)|^2+u^T(t)Ru(t))dt.$

System (1) is described via two different state concepts in the Hilbert spaces $X = R^n \times L^2(-h,0;R^n)\times L^2(-h,0;R^\ell)$ and $Z = R^n \times L^2(0,h;R^n)\times L^2(0,h;R^m)$ leading to evolution equations with unbounded i/o-operators. These two Cauchy problems are related through a structural operator $F : X \to Z$. The solution to the optimal control problem is derived in feedback form via two algebraic Riccati equations. The Riccati operators $\Pi \in L(X)$ and $P \in L(Z)$ satisfy the relation

(3) $\Pi = F^*PF.$

This paper is based on a common work with Professor A.J. Pritchard, Univ. Warwick, England.

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Optimal parallel accessing of non-linear structures using linear skewing schemes

The real efficiency of parallel algorithms in an Array processor depends on the efficiency of accessing of various substructures of the matrix. Pioneering work in this area has been done originally in connection with Illiac IV and, later, BSP [1,2]. It has been shown by Shapiro [3] that linear skewing schemes, $\phi[i,j]=[ai+bj+k] \bmod N$ mapping NxN, $N=2^p$, matrix on N memory module, although no less powerful than periodic schemes, suffer from several limitations. We define linear shift skewing scheme where b=+1 or -1. The scheme is a right shift or left shift if b=+1 or -1, respectively. In this paper we show that some of the limitations of linear skewing schemes can be overcome by applying much simpler linear shift skewing schemes on sections, MxN submatrices of the matrix. We also study techniques of using such juxtaposed linear shift schemes in order to access various nonlinear substructures, eg. banded, blocked and band-of-blocks submatrices in optimal time. [1] Budnick et al., "The organization and use of parallel memories", IEEETC, V. C-20, #12, Dec. 71. [2] Lawrie et al., "The prime memory system for array access". IEEETC, V. C-31, #5, May '82. [3] Shapiro, "Theor. limitations on the use of parallel memories", Ph.D. thesis, U. of Illinois at Urbana, Dept. of C.S., Rep. No. 75-776, Dec. 75.

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Perturbation Analysis of Forced Nonlinear Motion of a Simple Pendulum with Oscillating Support

A general method is presented which can be used to find a large number of terms (e.g. 50 or 100) in the power series solution of a class of forced nonlinear oscillations involving a small parameter ε. The motion of a simple pendulum with oscillating support (where ε is a measure of the amplitude of the oscillation) is discussed. Three cases corresponding to the driving frequency being either greater than, equal to, or less than the natural frequency are considered and the singularities in the complex ε-plane are estimated. The limit cycles and ratio and root tests indicate that the perturbation series converges only for small values of ε. A new expansion parameter is introduced, which leads to a new expansion which is valid for all values of ε.

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DISPLAYING RESULTS OF 3-D NUMERICAL CALCULATIONS

Comparison of methods of displaying 3-D functions which are the output of numerical solutions of the equations of fluid dynamics. Methods include: particle tracing, smoke particles, raytracing, 3-D contours, density maps. In all of these the viewer can "fly around" the volume of interest. Scaling is important and the effect of scaling on the display is examined. Most of the output is to be on a color raster terminal or a film recorder. Relative cost of using each method is examined. Most of these solutions are time dependent, so movies are considered.

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THE RESISTANCE TENSORS FOR A SPHERICAL CAP IN STOKES FLOW

Under Stokesian assumptions, the resistance experienced by an arbitrary particle undergoing translational and rotational motions in a linear shear flow can be described in terms of six independent tensors whose components depend only on the geometry of the particle and the origin about which the torque is calculated. The exact values of the six tensors are known only for the ellipsoid and its various special cases and for the spherical dumbbell. Knowledge of these tensors for a particular shape enables one to calculate the rheological properties of a dilute suspension of such particles.

The spherical cap is a body of revolution which lacks fore-aft symmetry. Five of the tensors have been calculated for the cap and in this paper a method is presented for determining the sixth analytically for arbitrary cap angle. This lays the groundwork for extending the theory of suspensions to include suspensions of spherical caps and for considering the effect of the cap's asymmetry on the bulk properties of such suspensions.

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HIGH ORDER VORTEX FORMATIONS IN THE WAKE OF AN IMPULSIVELY STARTED CIRCULAR CYLINDER

The polar coordinates form of the Navier-Stokes equations are subjected to logarithmic radial transformation and to a Discrete Fourier transformation in the angular coordinate. The system of equations so obtained is numerically solved by applying fourth order time differencing, third order finite difference schemes for the radial coordinate and Fast Fourier Transform techniques for the angular coordinate. Computational experiments for the case of an impulsively started circular cylinder have been conducted for Re=20, 300, 400, 550, 1000, 1700, 3000, 5000, 6000, 9500. Each experiment has been performed as long as the computations were deemed reliable by comparison with available laboratory visualizations and by the behavior of some diagnostic parameters.

Secondary, tertiary and fourth order vortex formations have been observed and are fully presented by means of sophisticated computer imaging and graphics techniques.

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Computer Imaging in the Visualization of Computed Flow Fields

The result of the numerical solution of the Navier-Stokes equations for the case of the impulsively started circular cylinder have been subjected to sophisticated graphical and imaging techniques by the use of CALCOMP plotter and of the TEKTRONIX 4027 color terminal.

The flow visualizations so obtained have revealed high order vortex formations in the wake of the cylinder that only laboratory visualizations had previously shown. The computer visualizations afford the means for a sytematic description of the mechanics of an impulsively started circular cylinder.

The presentation includes illustrations of the vorticity around the cylinder.

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A Comparison of Explicit Finite Difference Schemes For Incompressible Convection Dominated Flows

A comparison is made between the flux-corrected transport (FCT) method and various other low-dispersive explicit finite difference schemes for the pathological problem of numerical dispersion resulting in the solution of incompressible convection dominated flows. Physical diffusion has been ignored for the sake of isolating the numerical dispersion effects. A method by Fromm and a better known method by Leith are presented, along with a comparison for a one-dimensional, incompressible flow with a slowly varying velocity. Methods by Godunov and a more recent method called the Leapfrog-Trapezoidal are also presented and compared against the FCT method. From this numerical comparison, it is clear that the FCT method is the most accurate for obtaining an explicit finite difference solution of the incompressible forced convection of an initially square wave distribution of the transported fluid property. The FCT method results in being the best choice for eliminating numerical dispersion. These results have also been extended to two-dimensional incompressible flows.

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Heavy-Traffic Asymptotic Expansions For The Waiting Time In Closed Processor-Sharing Systems With Multiple Job-Classes

We consider, for each of p job-classes, the equilibrium waiting time in some closed processor-sharing systems, when the class populations are large and the traffic intensity ρ is close to 1. The service time requirements in the CPU depend on the job-class, and are independent and exponentially distributed, with mean $1/q_j$, $j=1,\ldots,p$. The system includes a band of terminals grouped accouding to job-classes, and the time spent by a user in generating a job is independent and exponentially distributed, with mean $1/p_j$, $j=1,\ldots,p$. The fixed number of jobs in each class, and the ratios q_j/p_j, $j=1,\ldots,p$ are all $O(N)$, where $N>>1$, and $\rho = 1-O(N^{-\frac{1}{2}})$. The leading term in the asymptotic expansion is obtained for the distribution of the equilibrium waiting time, and the first two terms in the asymptotic expansions are derived for the corresponding first and second moments. We have previously presented a procedure for deriving the asymptotic expansions of the first and second mements in the case of a fixed $\rho<1$.

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An Asynchronous Chaotic Algorithm For Computing Equilibrium Distributions Of Markov Chains

We are solving the fixed point problem $x = Px$ on a multiprocessor where x is an unknown vector and P is a given matrix. The classical power method $x(t+1) = Px(t)$, in which the task of updating each coordinate is assigned to a processing element (PE) typically involves large synchronization penalties. These penalties are considerably less severe in chaotic iterative schemes in which it is permissible to update different coordinates at different rates and to use obsolete values of coordinates and which are therefore attractive for parallel processing. We propose an asynchronous chaotic algorithm for the case in which P is nonnegative, irreducible and has spectral radius equal to unity. Markov chain applications are thus allowed. We prove that the algorithm converges exponentially under some weak assumptions. For example, convergence follows if, importantly, P has at least one positive diagonal element, the PE assigned to update the corresponding coordinate always uses the most recently computed value of that coordinate and the rate at which coordinates are updated is bounded from below.

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FORMAL INTEGRATION OF ODE/PDE AND SUBSEQUENT NUMERICS

A simple, formal integration of differential equations leads to either integro-differential or pure integral equations. This approach, termed "FLOSIM" by its inventor (Payne, 1979,1982) whose orientation is continuum fluids, has been quite successful in similarity flows (Falkner-Skan, 1981-82;

mixing layer, 1982), unsteady heat conduction (both linear and quasi-linear, 1982-3), and extended rather easily to non-similar Prandtl flows (Mokkapatti, 1983). Motivations include: 1) flows, especially turbulence, exhibit an essential globality compatable with iteration solution of integral, as opposed to differential equations; 2) almost all the usual stability and convergence difficulties typically associated with differential solutions (numeric) never even arise; 3) computer time and memory requirements are neglible compared with FDM; 4) accuracy is equal or better than, say, fourth-order Runge-Kutta for Falkner-Skan and uses only 40% the computer time. "shooting," i.e. $\geq$ 2-point BVP are treated quite naturally (mixing layer is a 3-point BVP). Author has formally extended to turbulence (1982) and Navier-Stokes (1983). Finally, due to reduced machine requirements, "FLOSIM" appears ideally suited to desk-top micro-CPU which appears to be a "wave of the future."

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THE STABILIZATION LAW

For free stream velocities close to sonic the local Mach number distribution over the surface of an airfoil stabilizes, that is depends weakly on changes in the free stream velocity. Within a two-dimensional transonic small disturbance formulation the stabilization phenomena is described as an $O(K^3)$ perturbation from sonic flow. (Here $K = (1-M_\infty^2)/\delta^{2/3}$ is the transonic similarity parameter, M_∞ is the free stream Mach number, δ is the thickness ratio of the wing.) The order of this perturbation was found by examining the far fields of transonic flow, which are described by similarity solutions of the basic transonic equation. A complete boundary value problem for the correction is formulated in the case $K \to 0^-$. By the application of an analytic technique called the method of conservation laws the (previously unknown) constants needed to formulate this problem are determined.

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Finite Dimensional Feedback Control for Partial Differential Equations

The objective of this paper is devoted to the investigation of the control problem

$$\dot{x}(t) = Ax(t) + Bu(t)$$

in a (real) Banach space X. Here A is the infinitesimal generator of a linear C_0-semigroup on X. Assuming that we are interested in feedback controls we consider the Cauchy problem

$$\dot{x}(t) = (A+F)x(t)$$

and present a general generation result for this problem.

In the sequel this theorem is applied to both, linear and nonlinear finite-dimensional boundary feedback control problems.

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Allocating Independent Subtasks on Parallel Processors

When using MIMD (Multiple Instruction, Multiple Data) parallel computers, one must often solve a task composed of many independent subtasks where it is necessary to synchronize the processors after all the subtasks have been completed. This paper studies how the subtasks should be allocated to the processors in order to minimize the time it takes to finish all the subtasks. We assume that the running times of the subtasks are independent, identically distributed increasing failure rate random variables, and that assigning one or more subtasks to a processor entails some overhead, or communication time, which is independent of the number of subtasks allocated. Out methods of analysis permit the determination of an optimal strategy subject to the constraint that each processor must take a fixed number of jobs at any given time. We show that this strategy can give results remarkably close to an unrestrictedly optimal one. Our analysis is asymptotic as the number of jobs or processors becomes large, and uses a novel extension of the central limit theorem.

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A Fast Accurate Algorithm For Three-Dimensional Inviscid Rotational Flow

An algorithm has been developed for the three-dimensional Euler equations for steady subsonic flow. In calculations it is generally found to be an order of magnitude faster than other Euler schemes and accurate. The numerical algorithm is developed by perturbing the Euler equations in nonconservative form about an arbitrary reference state. The use of the perturbed form allows nonstreamwise velocity components to be solved by the solution of second-order partial differential equations (similar to vector potential equations in form), after which simple integrations suffice to update pressure, density, and the streamwise velocity component. To verify the algorithm, a computer code was developed and extensively tested. Two-dimensional results successfully compared with analytically obtained subcritical solutions. Inviscid three-dimensional flow calculations were carried out in a closed s-shaped duct, and for a nonuniform incoming stream has successfully shown secondary features of flow reversal and swirl.

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Parabolized Navier-Stokes Solutions of Subsonic Separation and Trailing-Edge Flows

Presented is an implicit finite-difference solution method for the Parabolized Navier-Stokes equations with a unique boundary condition treatment. A boundary-layer methodology provides for elliptic upstream influence by inclusion of the y-momentum equation and iterative sweeps in x. Metrics are included and extension to three-dimensional flows is straightforward. The method is second-order accurate, with backward or central differences used for all streamwise derivatives. While the formulation is stable for small marching steps, rapid convergence to accurate solutions occurs on coarse grids. Boundary conditions for external flows are: direct pressure prescribed, edge stream-function prescribed, and psuedo-direct modes. For internal flows, the condition used is global mass conservation. The boundary condition treatment is crucial towards enhancing rapid convergence. The present code is designed for coupling with an inviscid code for solution of flows over external surfaces. As the Euler equations are a subset of the equations solved, internal flows are solved without viscous-inviscid coupling. The method is successfully applied to strong viscous-inviscid interactions including separation.

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OPTIMAL QUADRATIC STABILITY OF DISCRETE-TIME DISTRIBUTED PARAMETER SYSTEMS

The problem of controlling distributed parameter systems has received considerable attention in recent automatic control literature. In this paper the objective is to study the stability property of discrete-time linear shift invariant distributed parameter systems. The uncertain parameters, which appear in the dynamic difference equations, are functions of time and do not have statistical descriptions. Rather, only a priori knowledge of the bounds on the region of allowable variations is assumed. Also, the uncertain parameters might be rapidly varying. These properties make this kind of problems differ from those of stochastic and adaptive control problems. The goal here is to guarantee uniformly asymptotically stable operation for all allowable variations of the uncertain parameters within their bounds. Stabilization can be obtained by appropriately choosing an optimal quadratic Lyapunov function. The choice of this Lyapunov function is dictated in part by the manner in which the uncertain parameters enter the systems. This approach will lead to criteria which are both necessary and sufficient for quadratic stability.

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Numerical inversion of interference patterns

The electron number density of an inertial fusion plasma determines its time and space dependent refractive index. Holographic interferometry generates snapshots of the diffraction pattern of the plasma. Thus, the density profile can be found by solving the first kind integral equations that describe these images. Methods of computer tomography have involved the numerical solution of analytic inversion formulas for the equations. These incorporate certain symmetry assumptions. Recent developments involve the direct solution of the integral equations which permits more general applications. Further work may lead to the reconstruction of strongly refracting object fields. The results apply to other research areas in which holographic interferometry is useful such as aerodynamics and stress analysis.

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Embedding Methods for the Steady Euler Equations

A recent approach to the numerical solution of the steady Euler equations is to embed the first-order Euler system in a second-order system and then to recapture the original solution by imposing additional boundary conditions. The advantage of such an approach is that the difficulties associated with the numerical solution of a direct finite difference version of the steady Euler equations can be bypassed and the resulting second-order embedded system can be solved by a variety of well-proven numerical procedures. Initial development of this approach and computational experimentation with it have been based on heuristic physical reasoning. This has led to the development of a relaxation procedure for the solution of two-dimensional flow problems. In this paper the theoretical justification for the embedding approach is addressed. We prove that, with appropriate choices of embedding systems and additional boundary conditions, the solution to the embedding system is exactly the one to the original Euler equations. Hence, solving the embedding version of the Euler equations will not produce extraneous solutions. Given a theoretically sound embedding procedure for the Euler equations, attention may be focused on the issue of computational efficiency. Progress toward the development of efficient two-dimensional Euler solvers will be discussed.

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COMPOSITE FORM OF THE IMPLICIT BLOCK-BIDIAGONAL FINITE DIFFERENCE METHOD FOR SOLVING THE NAVIER STOKES EQUATIONS

An efficient implicit two step method is developed to solve compressible viscous flows about arbitrary two-dimensional bodies using general body fitted coordinates. In the first step, a spectral normal form of the recently introduced implicit block-bidiagonal predictor-corrector algorithm for solving the Navier Stokes equation is employed. The contribution of the implicit portion of the final operator is reduced by multiplication by factor C_2, where $C_2 = 1 - C_1$ and $C_1 = \min[1.0, 0.9/(2*\text{local 2-D CFL number})]$, as introduced by Kordulla and MacCormack. The resulting scalar bi-diagonal system of equations can be solved very rapidly. This scheme is computationally efficient and displays favourable stability properties. The inviscid part of the flow is correctly modeled; however, the viscous effects are not predicted accurately. Therefore, a second step of the procedure is introduced. In the second step, the full original implicit block-bidiagonal method is applied as a post-processor to achieve accurate steady state solutions.

The resulting procedure gives correct results at significant time savings. It was used to compute flows in supersonic diffusor and about transonic airfoils. Computed results are compared with other existing numerical solutions for the same geometries.

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SWITCHING FUNCTION FOR THE NUMERICAL SOLUTION OF TRANSONIC FULL POTENTIAL EQUATION

A second order quasilinear partial differential equation of mixed elliptic-hyperbolic type governing steady transonic isentropic, irrotational flow of an inviscid fluid is usually integrated using artificial dissipative terms known as artificial viscosity and artificial density that are introduced in the supersonic regions only. In this work it is shown analytically that the conventional form of artificial density (or viscosity) produces previously unknown truly nonlinear terms for all the finite grid sizes. The influence of these nonlinearities does not vanish even on the sonic line. A new concept of artificial mass flux is developed and shown to be suitable for analytically evaluating a new exact form of the switching function that eliminates all the nonlinear terms for any value of the local Mach number. The resulting expanded full potential equation consequently becomes a third order partial differential equation of permanently parabolic type that can be readily formulated in a fully conservative form suitable for shocked flow calculations. The expanded full potential equation does not require the introduction of the customarily used artificial time concept and can be numerically integrated using marching techniques.

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An Approximate Solution of an Integral Equation That Arises in the Design of Magnetic Field Coils

We have investigated the use of calculus of variations to design magnetic field coils that have minimum stored energy. In particularly, we have considered the problem of computing the winding density along a cylindrical surface that will minimize the stored energy, while at the same

time producing a magnetic field with certain desired characteristics. These desired characteristics, corresponding to the uniformity of magnetic field, are prescribed as constraints on various coefficients in the spherical harmonic expansion of the magnetic field.
The problem reduces to solving a singular integral equation. For the cases of short coils, the dominant part of the kernel reveals a logarithmic singularity and, hence, permits an approximate analytic solution. The analysis leads to some practical designs.

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An Algorithm for Hamiltonian Cycles in the Square of K1, 3-free Graphs

Fleischner proved that the square of a 2-connected graph is hamiltonian. This resolved a long standing conjecture due independently to Nash-Williams and to Beinede and Plummer. His proof is a deep inductive argument which is not constructive. Later, Kleitman presented an algorithm for finding hamiltonian cycles in certain graphs whose maximal degree is three. In this paper we present an algorithm, with order proportional to the number of edges in the graph, for finding hamiltonian cycles in the squares of a much larger class of graphs, the K1, 3-free graphs. The algorithm constructs a certain breath first search tree and then links the sons up to form the hamiltonian cycle in the square. The algorithm may also be used to construct a cycle of any length containing any vertex in the square of a K1, 3-free graph.

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The Kernel of the Operating System of a Multi-Microprocessor Prototype

The paper illustrates the kernel of the operating system of a parallel MIMD prototype (the ALPAR system). The operating system of such a machine controls the management of task level in a multitasking single user environment whose characteristic aspects are the following ones: synchronisation and priority: among tasks to access to a resource and among sequential and parallel branches of program user; concurrency: among processes to exchange information; asynchronism: some events may happen in a very unexpected moment (interrupt from an I/O device) and need to be synchronized with the system functions dedicated to their management. The kernel consists, essentially, of a program, called scheduler, that manages processors and tasks, of a set of primitives for synchronisation and communications among tasks, and of utility routines for user software applications. The use of such a system may be seen useful, besides experimenting the characteristics of algorithms structured in a parallel way rather than in a sequential way, also to real-time environment where more processes must be executed in the same time (that is in an industrial environment to control processes.)

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Finite Element Solution of the Navier-Stokes Equations for Compressible Viscous Fluids

We present a combination of finite element, least squares and alternating direction methods which makes possible the numerical solution of the Navier-Stokes equations for compressible viscous fluids. Various mathematical models are tested, including one with constant enthalpy and the corresponding numerical results are compared to experimental one showing a good agreement.

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Exploiting Parallelism in Symbolic Mathematical Computation

A computer algebra system provides a programming environment with facilities such as differentiation, integration and factorization, where the input and output are exact mathematical expressions.
In this paper we examine how to exploit the mathematical structure of computer algebra problems in order to best take advantage of a given fixed number of processors. By dividing the problem up at a very high level, the tasks to be performed are quite substantial so the overhead of process management and inter-process communication is small in comparison. These methods are applied to a problem that is central to the construction of a computer algebra system - determining the greatest common divisor of a pair of polynomials.

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On The Flow of Real Compressible Fluids

In 'computational aerodynamics,' air is generally considered to be a perfect gas except where shocks occur in the flow. By contrast, many nonaerodynamic flows involve fluids whose thermodynamic properties cannot be so easily characterized. Examples include the flow of high temperature combustion gas mixtures in rocket nozzles; the flow of steam through ejectors and safety valve systems in power plants and the flow of flashing liquids through valves and pipes.

This presentation traces some of the methods used over the past 25 years beginning with manual methods using charts and tables. The impact of digital computers--from microcomputer to maxi-computer is emphasized. Even using a pocket calculator, the data contained in NACA 1135-- a basic early reference for the aerodynamicist--can be easily reproduced.

Basic industrial flows of interest include those in nozzles, ducts, across normal shocks and across abrupt enlargements. The approach to including the properties of real compressible fluids in the models of these flows is described.

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Unsteady Flow Development of the Wake Behind an Impulsively Started Circular Cylinder at Reynolds Number 9500

The initial unsteady flow around an impulsively started circular cylinder at Reynolds number 9500 is simulated using a hybrid random vortex numerical method. We are interested in the relationship of the creation, diffusion and convection of vorticity (both inside and outside the boundary layer) to the complex and unstable flow structures of the recirculating zone behind the cylinder. In our simulation, we focus on the initial development of the wake behind the cylinder. Our numerical soultion gives insight into the mechanism that control changes in length, width, size and shape of the wake, illuminates the evolution of the main flow characteristics in the recirculating zone, and exhibits an accurate velocity and vorticity field. Functionals, such as lift and drag coefficients, points of reattachment of the streamlines behind the cylinder, the velocity distribution on the wake axis et cetera, are computed & analyzed, and compare well to experimental studies. Furthermore, this hybrid numerical method is sensitive to changes in Reynolds numbers. The success of our simulation lies in the ability of the numerical method to accurately model the vorticity field.

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Vectorized, Three-Dimensional Flow Field Computations With Application To The Space Shuttle Orbiter

The introduction of vector-processing computers has provided a tool for computing three-dimensional flow fields about complex aerodynamic shapes. In particular, a code HALIS, designed to generate the inviscid flow field about shuttle-like vehicles at high angle of attack and written for use on the CDC Cyber 203 system will be discussed. The structure and organization of the code will be detailed as they relate to the requirements and constraints of vector processing. Also, the performance of the code when operating in a 32-bit word vector-processing mode will be noted.

Some comparisons of computed windward surface pressures with Shuttle Orbiter flight data will be shown. These comparisons indicate regions of the flow field which require greater resolution than allowed by current CPU storage constraints. An estimate will be made of the storage requirements necessary to determine a well-defined flow field about these types of configurations and the computational speeds necessary to generate these solutions in a timely manner.

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Conversion of Two-Point Boundary Value Problems to Parametrized Integral Equations

Construction of solutions for two-point b.v.p.(s) governed by 3rd or 4th order o.d.e.(s) is sought. The types of equations are exemplified by equations which arise from similarity type transforms applied to b.v.p.(s) in fluid mechanics. The approach we use is to first write the equation as a second order system. Multiples of linear terms are added to both sides and the linear part of the operator is inverted to form an integral equation system with a Green's function kernel.

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Stiffness Characteristic and the Application of the Method of Lines on Nonuniform Grids

The method of lines is a technique for the solution of partial differential equations which is relatively simple to apply compared to finite difference methods. The technique is applied in a time-space domain by discretizing the space variables, treating the time variables as a continum and integrating the resulting system of ordinary differential equations.

This paper describes the application of the method of lines technique on nonuniform grids and the associated stiffness characteristics. The specific problem considered is solutions of the incompressible form of Navier-Stokes equations using a nonuniform grid distribution. These equations are expressed in terms of the stream function and vorticity and are transformed to boundary-fitted coordinates system. Solutions are obtained for flow in horizontal ducts, curved-wall diffusers, and driven cavity.

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Uniform Finite-Difference Schemes for Singularly Perturbed Ordinary Differential Equations

This paper is concerned with the numerical approximation by finite differences of differential equations of the form

$$-\varepsilon u'' + a(x)u' + b(x)u = f(x).$$

Standard approximations behave poorly when the mesh size h is large compared to ε. This has led several authors to seek schemes that have a certain order of accuracy uniformly in ε, i.c.,

$$\| u - u_h \| \leq ch^p$$

where c is independent of ε. Here we use a truncation error analysis based on a local perturbation-like series for u to construct and analyze uniform schemes via the HODIE Method of Lynch and Rice [Math. Comp. 34 (80) 333-72].

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The Fast-Time Instability of Diffusion Flames

A diffusion flame burns with varying intensity if the pressure is varied, and the nonlinear steady-state response is typically S-shaped; that is, multiple solutions exist for some range of pressure. The physically relevant branch can only be determined by unsteady analyses, and in this paper we discuss the stability of a large class of diffusion flames when the activation energy characterizing the reaction rate is large. Specifically, we examine the evolution from the stationary solution on a time scale so short that changes are confined to the thin flame sheet where all the reaction occurs. In this region time derivatives are added to the steady state equations, which otherwise describe a balance between diffusion and chemical reaction. The stability problem is then reduced to the determination of the spectrum of Schrodinger's Equation, defined on the infinite interval, with a potential that is not of one sign on this interval. In this way certain conclusions about extinction are drawn and certain past misconceptions are clarified.

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Solution of Two-Dimensional Elliptic Equations Via a Strongly Implicit Procedure with Optimal Iteration Parameter

The strongly implicit procedure (SIP) is a form of approximate LU-decomposition introduced by Stone (SIAM J. Numer. Anal. 5,530,1968). Various subsequent studies have demonstrated its superior convergence properites compared with usual SOR and ADI methods, especially for problems with any of variable (and not necessarily smooth) coefficients, mixed derivatives, or complicated boundary conditions. Stone's original version of SIP required specification of a sequence of iteration parameters (as in ADI) leading to a nonstationary iteration procedure. Here we present a modified form of SIP in which only a single iteration parameter is needed. Hence, the method is stationary; and this significantly reduces the arithmetic per iteration. We develop a computationally efficient procedure for selecting a (nearly) optimal iteration parameter and show the influence of this parameter on convergence rate; and we present an implementation of this version of SIP which also includes a partial multi-grid scheme. We then compare total computational work of this algorithm with that of SOR and ADI for several test problems which range in difficulty from very simple constant coefficient to quite difficult variable coefficient with mixed derivative.

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Aerodynamic Coefficients from Free Flight Test Data - Improvements to Chapman and Kirk

The differential corrections technique of Chapman and Kirk is a standard method for determining aerodynamic coefficients for free flight projectiles. The current implementations of Chapman and Kirk for radar range, yaw-sonde, and sparkrange data are reviewed as to their mathematical soundness and computational efficiency. The existing codes are compared with improved versions being implemented by the U.S. Army at its Picatinny Arsenal. Of particular interest are the increase in stability and the use of non-linear techniques to accelerate convergence. Also discussed is the data managements system created to control the data flow through these programs. This system is designed for ease of use and ease of maintenance.

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Aeroacoustic Computation From Vortex-Pair Merging

Recent work has demonstrated the feasibility of aeroacoustic computations from direct simulation of fluid flows past two dimensional bluff bodies (e.g., cylinders). Accurate computation for the complimentary problem of shear flow (e.g., free jet) is complicated by the need to calculate quadrupole noise sources dependent upon second time derivatives of the fluctuating fluid variables. Results are presented for the noise produced by the merging of a pair of like signed vortices. The nonlinear, two dimensional, unsteady, incompressible Navier-Stokes equations are Fourier transformed and solved using the "infinite order" accurate Orszag-Patterson Galerkin spectral technique on a 128 x 128 computational grid. Periodic boundary conditions are imposed and time marching is performed via an explicit predictor-corrector method. The simulation is implemented using a highly vectorized code designed to run efficiently on the CYBER-203 (STAR) computer at NASA/LaRC. Results from the present simulation are compared with the analytical solution obtained from point vortices in inviscid flow. The computations indicate that the primary sound generation occurs during the close interaction phase before the vortices actually merge.

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Acoustical wave propagation in slender wave-guides and resonant cavities

A general method is presented to determine the propagation of acoustical waves in slender wave-guides and resonant cavities. For large frequencies, the solution is represented as the product of a rapidly varying exponential factor and an amplitude factor. The first few terms are obtained in the asymptotic expansion of the solution as the slenderness ratio ϵ of the body approaches zero. Both hard and soft boundary conditions are treated. For wave numbers which are $O(1)$ when compared to the body length, the solution is represented as a formal power series in ϵ . The method is applied to wave-guides with circular and square cross-sections. For the special case of the spheroid, there is excellent agreement for the resonant frequencies between the asymptotic results and reported numerical results.

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FEEDBACK STABILIZATION OF RETARDED AND NEUTRAL DELAY-DIFFERENTIAL SYSTEMS WITH NONCOMMENSURABLE DELAYS

We consider a class of neutral delay differential systems with finitely many noncommensurable point delays in state and control, and D-operator satisfying a strong stability condition, which we call formal stability. This class includes retarded systems as a special case. We model any system from this class as a so-called generalized linear dynamical system $\Sigma = (F,G)$ over a ring R of delay operators $z_1, \ldots, z_k$ consisting of rational functions of the z_i which are regular on the unit polydisk $X \subset C^k$. Let B(R) denote the feedback or Brunovsky group of transformations defined on R-reachable pairs, i.e., B(R) sends a reachable pair (F,G) to $(F',G') = (T^{-1}(F-GK)T, T^{-1}GL)$, where T,K,L are matrices over R of suitable dimensions, with T and L unimodular. We show that the action of B(R) has a natural interpretation in the context of delay systems and give a sufficient condition, which we call resolvability, based on the solution of an associated algebraic Riccati equation, for a neutral or retarded delay system to be equivalent under the action of B(R) to a stable system.

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A Multi-microprocessor System for Parallel Solution of ODE's

The development of a multi-micro processor system for continuous system simulation is presented. The approach is based on the use of a block implicit predictor-corrector method for solving the ordinary differential equations of the system model in a parallel manner without the need for partitioning. Each pass through the algorithm simultaneously produces k equally-spaced solution values where k is the block size. The formulas for generating these k values are independent of each other even though they refer to successive time steps. By allocating each of these formulas to a different processor a speed-up ratio of k can be realized. We have extended the basic formula for k=2 which has appeared in the literature, to higher values of k and have adapted the process to a variable step-size format. The method will be implemented on N processors (where k=iN, i a positive integer) communicating through an N*N matrix of low cost memory blocks. The blocks of a row are connected in parallel. All processors can write their data simultaneously into their designated areas resulting in instantaneous exchange of data among processors. Thus there is virtually no overhead and an efficient implementation of the method is achieved.

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A Fast QR Algorithm For Any Arbitrary Matrix In Parallel

It is shown that Cholesky's factorization of a symmetric positive definite matrix and QR decomposition of an arbitrary nonsingular matrix A of order n can be implemented in $O(\log^2 n)$ steps in parallel using an arbitrary number of processors.

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Smooth External Patched Grid Generation

Often in the application of grid generation methods to compute metric information to be used in the solution of partial differential equations, it is necessary to patch a new grid onto a previously defined grid. This paper describes an application of the multi-surface method for grid generation with embedded exponential functions for patched grids. The method uses the boundary and neighboring grid points of the original grid to determine a patched grid in which the elements of the Jacobian matrix are continuous across the boundary between the original grid and the patched grid. Several examples are presented.

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HIGHER-ORDER VORTEX PANEL METHOD FOR WINGS HAVING LEADING-AND SIDE-EDGE SEPARATIONS

A nonlinear, higher-Order Vortex panel method is developed to solve for the distributed aerodynamics loads and wake shape of wings with highly swept leading and trailing edges. The method uses triangular vortex panels with linear vorticity distributions on each panel, the vorticity is expressed in terms of the vorticity components at the global panel nodes. The induced velocity field of these distributions is calculated by using closed form expressions. In the far field, the distributed vorticity is lumped into vortex filaments and Biot-Savart's law is used to calculate the velocity field. The problem is solved iteratively by satisfying the boundary conditions successively on the wing and the wake. The method converges in a few iteration cycles. The computed results show that the method is highly reliable and efficient.

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BOUNDARY CONDITIONS FOR NAVIER STOKES SOLUTIONS MERGING WITH BOUNDARY LAYER AND POTENTIAL SOLUTIONS

In the flow field near a body, there can be local region(s) where the flow is governed by the Navier Stokes (NS) equations instead of the boundary layer (BL) equations. Numerical solution of NS equations has to be constructed for a bounded region for which boundary conditions have

to be imposed. We consider first a two dimensional problem for which the NS solution is bounded by the body from below and merges on the top side with a potential solution and on the upstream and downstream sides respectively with two BL solutions, which may not be similarity solutions. The upstream BL solution provides the boundary data on the upstream side. The appropriate boundary conditions on the top and the downstream sides are formulated. In general, the thickness of the region has to be sufficiently larger than the BL thickness since the downstream BL is unknown a priori. The required modifications on the boundary conditions are then stated. Boundary conditions for the merging of a NS solution with either a three dimensional BL or wakes are formulated respectively.

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A Semi-Inverse Method for the Design of Subcritical and Shock-Free Supercritical Slender Bodies of Revolution

A numerical procedure is presented for the design of subcritical and shock-free supercritical slender bodies of revolution. In addition to the free-stream conditions, the input to the design procedure includes a prescription of the subsonic portion of the pressure distribution and to an arbitrary continuous function representing the unstretched radial coordinate of the body (or portions of the body wetted by subsonic flow and sonic line for supercritical designs.) The stretching function and the supercritical pressures being determined as part of the solution.

The procedure relies on the fact that for small disturbances a hodograph-like transformation (not known aporiori) can be applied to the axisymmetric potential equation. The result being a set of two coupled Poisson equations defined on a common rectangular domain. In the special variables we use, the system of coupled equatinns is solved iteratively using a fast Poisson solver, for the subsonic portion of the flow. This in turn defines the mapping of the subsonic boundary to the physical plane. For supercritical flows, the supersonic portion of the flow is calculated using an axisymmetric characteristic calculation. This then is followed by a map to the physical plane to determine the shape of the body under the sonic bubble. Examples of subcritical and shock-free supercritical slender body designs are presented. They show good agreement with the direct computation of the flow past the designed slender bodies.

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Error Analysis of the G-algorithm for the Weighted Linear Least Squares Problem

The G-algorithm of Bareiss (1982) for solving the weighted linear least squares problem has the advantage that it is a square root free algorithm and is more suitable for pivoting than the fast Givens algorithm of Gentleman (1972). In this talk it will be shown that these two algorithm produce the same upper triangular matrix within a diagonal matrix factor and that this upper triangular matrix is also within a diagonal factor of that produced by the standard orthogonal decomposition methods such as Householder, Givens, or modified Gram-Schmidt. The main subject of this talk, however, is the error analysis of the G-algorithm. It is shown here exactly how instability in the algorithm can occur even when row and column pivoting are used. This instability can be prevented by a row scaling technique that preserves the square root free nature of the algorithm.

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Hybrid Adaptive Excitation Control of a Turbogenerator System

The paper describes the development of a hybrid adaptive excitation control scheme of a turbogenerator system. The system comprises a synchronous generator connected to a large power grid via a transformer and transmission line. A linearized model of the system is employed in this simulation study.
The adaptation algorithm is based on the minimization of the error between the process output, which is selected to be the generator terminal voltage, and the output of a reference model which contains the desired control specifications. The latter are defined in terms of specified positions of the system eigenvalues. The controller provides continuous control to the system, but the feedback gains are apdated at every sampling interval. The stability of the closed-loop system is guaranteed, and implementation of the controller requires the measurement of the readily available output and input signals. Simulation results are presented to show the effecacy of this control strategy in improving the turbogenerator performance.

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Bricklayering Approximation

This paper presents a direct exponential approximation to the sine function, leading to a geometrical figure that has the appearance of a bricklayered structure. The summation formula obtained is generalized for sine-type functions - functions admitting different gradients and deformations while belonging to the same topological class, e.g. quadratics with simple sigle maxima. The need for this approximation arises in perception theory and physicochemical pattern problems, where it is often necessary to consider details of wave forms and their changes, e.g. fine perceptory resolution of intensities. In physicochemical processes, it facilitates fine resolution of the evolution of shock fronts, of interfaces in separation processes, and in perception theory, the analogy is provided by wave descriptions of perception of edges. (An important unifying theme is provided by discontinuous boundary value problems). The presentation is devoted to showing how manipulations of this approximation facilitates the generation of different wave forms.

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Numerical Solution of Trajectory Path Control Problems by the Backward Difference Method

This paper discusses a numerical method for solving differential-algebraic equations (DAEs) encountered in trajectory prescribed path control (TPPC) problems. A typical TPPC problem prescribes a drag acceleration profile for the reentry of a space vehicle. Traditionally, the control variables are held constant while solving the state equations of motion. Next a control model, developed for each TPPC problem, instantaneously corrects the control variables so the vehicle will approximately follow the given path profile. This paper's approach is to consider the state and path equations as a DAE system. If the path equations can be solved for the control variables, the corresponding index one DAE system can be numerically integrated by the k-step backward difference formulas (BDFs). Numerical results have also been obtained for higher index TPPC problems where the path equations do not contain the controls. While this method may be unstable on fully-implicit DAEs, it does converge globally to $O(h^k)$ after k + 1 steps for linear, variable coefficient, semi-explicit systems modelled from the TPPC problems.

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SOME APPLICATIONS OF THE METHOD OF LINES TO ELLIPTIC PARTIAL DIFFERENTIAL EQUATIONS

The Method of Lines reduces an elliptic partial differential equation, defined on a rectangle, to a system of two point boundary value problems. The first application discussed is joint work with L. Xanthis on the treatment of singularities of an antiplane crack problem. Computational results are presented for the model problem in Wait and Mitchell (J. of Comp. Physics 8, 45-52). The second application is to a class of nonlinear elliptic equations possessing multiple solutions. All the solutions can be obtained numerically using software for nonlinear two point boundary value problems.

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Isospectral Flows and the Power Method

The Toda flow is a dynamical system whose dependent variables may be viewed as the entries of a symmetric, tridiagonal matrix. The spectrum of the matrix is invariant in time and, as $t \to \infty$, the off-diagonal entries tend to zero, exposing the eigenvalues on the main diagonal. In this talk we will consider generalizations of the Toda flow, some old and some new, and argue that the easiest way to understand the convergence properties of these flows is to identify them with the continuous analogue of the power method for calculating eigenvalues and eignevectors.

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FFT Noise Analysis with Recommendations for Scaling Procedures

We have ascertained the effects of computational noise on the results of an FFT calculation in a pipelined structure. This report indicates the factors which a designer must taken into account. The architecture which was considered in the study is one employing radix 2, decimation in time. However, the results may be extrapolated to other forms.

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Age Distribution Function for a Catalyst in Fluidized Systems Under a Discrete Addition

It is presented a modification of the age-distribution function developed by Minkovski in order to represent operating conditions following in FCC units at Mexico. Catalyst addition and addition periods on Catalyst's activity can be evaluated. It is presented different age distribution inventory under the FCC plant.

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Sparse Matrix-Vector Multiplication Software for a Vector Computer

A number of important numerical algorithms for linear systems of equations require repeated multiplication of a matrix A by a vector x (e.g., conjugate gradient, Lanczos). This work has been directed toward the development of a storage/computational scheme which will perform this operation efficiently on a vector processor such as the CYBER-203 when the matrix A is sparse and symmetric.

Given several compact storage schemes for a "line" of information from a sparse matrix such as a row, column, or diagonal, the selection of the most desirable mode of storage involves a trade-off between the resulting storage and CPU time. The options afforded by a computer which has both scalar and vector processing, a bit addressable memory, and associated hardware instructions further complicates the selection. Software has been written for the CYBER-203 which estimates these resource requirements for each method on each line and makes the selection based upon the user's goal for efficiency.

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A Constructive Method for Optimal Control of Radiating Structures

We consider the problem of optimizing the far field radiation pattern of a smooth radiating structure (antenna) Γ in $\mathbb{R}^2$ by choice of appropriately constrained boundary control functions in $L^2(\Gamma)$. These far field patterns arise as asymptotic forms of outgoing solutions of the Helmholtz equation in the unbounded domain exterior to the surface Γ. We give a precise formulation of the boundary value problem and show how the use of complete families of such solutions leads in one important case to a Galerkin procedure for constructing the optimal control and resulting far field pattern. Computational results will be described.

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Parallel Splitting of a Matrix

When the alternating direction method, or the finite element method with assembly by elements are used, the system matrix may be "split" into a sum matrices. These splittings give rise to algorithms whose parts may be done simultaneously. In order to study their convergence properties, the concepts of parallel splitting and dissolution of a matrix are introduced. Convergence results will be given for both linear and nonlinear (a parallel Newton method) problems. A comparison of computing "lengths" for sequential and parallel algorithms will be presented.

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Adapting the NAG Library to vector-processing architectures

Selected routines from the NAG Library of numerical and statistical subroutines have been adapted to achieve high execution speeds on a variety of vector-processing and pipeline computers (eg Cray 1, Cyber 205, FPS AP-164). For linear algebra computations the strategy has been to replace in-line code, or calls to inner-product routines, by calls to auxiliary routines for performing operations "of order n^2", such as various matrix-vector products and the solution of triangular systems of equations. These auxiliary routines (which are simple, and few in number) have then been tuned, where necessary, for each specific architecture. Figures for performance improvements will be quoted, including in many cases improved performance on scalar-processing machines. Finally the implications for design and management of a transportable subroutine library will be discussed.

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Parallelizability Degree of Synchronous and Asynchronous Parallel Programs

The parallelizability degree, PD(Prg), of a repetition free program Prg (relatively to its multiset, Mu, of instructions) is the minimal number of processors (of a MIMD machine) needed for the shortest execution time of Prg, when with each $v \in Mu$ its execution time, $et(v) > o$, is associated. A parallelization (in the instruction level) is allowed by the flow of data. A set $Step_i = \{v_{1,i}, \dots v_{qi,i}\}$ of compatible instructions requires q_i processors to be executed in parallel. A synchronous execution sequence $SYES = (Step_1, \dots, Step_k)$ requires $\max_{1 \leq i \leq k} q_i$ processors. The execution time $et(Step_i) = \max_{1 \leq j \leq q_i} et(v_{j,i})$, and $et(SYES) = \sum_{i=1}^{k} et(Step_i)$. Some estimates of PD(Prg) are given. A sequence, $Stream_j = (v_{j,1}, \dots, v_{j,k_i})$, of instructions from Mu may be provided with a wait instruction. An asynchronous execution sequence, ASES, is a set of p streams, $Stream_j$, which can be executed on p processors. The execution time $et(Stream_i) = \sum_{h=1}^{k_i} et(v_{i,h})$, and $et(ASES) = \max_{1 \leq i \leq p} et(Stream_i)$.
Theorem: $\forall$ SYES $\exists$ ASES($et(ASES) \leq et(SYES)$) for a given p.

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Efficient Feeding of Small Organisms: The Generation of Scanning Currents in Stokes Flow

Many small, free-swimming organisms feed on still smaller particles of plankton, which are captured from the surrounding water through the use of a number of feeding appendages. The question we wish to address is how should a small free-swimming organism, endowed with a set of moveable appendages, wave these about so as to "scan" (in some appropriate sense) a fixed volume of water per unit time, with minimal power? We will explore a number of different models of increasing complexity in which a Stokes flow of prescribed amplitude is generated with minimum power, as determined by the viscous dissipation within the flow. Finally, conclusions will be drawn concerning the relationship between our model problems and real organisms.

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A Multi-Grid Continuation Method for Elliptic Problems with Turning Points

We introduce a new multi-grid continuation method for computing solutions of nonlinear ellipic eigenvalue problems which contain turning (limit) points. Our method combines the frozen tau technique of Brandt with pseudo arc-length continuation and correction on the coarsest grid. This method uses no large Jacobians, can treat multiple turning points, and is simpler and more robust than the methods of Chan and Keller, Mittlemann, and Meis, Lehmann and Michael. We provide numerical results for fourth-order approximations to the two-dimensional stationary reaction-diffusion problems:

$$\Delta u + \lambda \exp\left(u/(1+\alpha u)\right) = 0$$

The convergence rate is observed to be independent of the occurence of limit points.

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INTEGRAL EQUATION FORMULATION FOR COMPUTATIONAL TRANSONIC FLOWS ABOUT AIRCRAFT IN ARBITRARY MOTION

An integral formulation for nonlinear wave equation with a boundary surface having arbitrary motion is presented. The frame of reference itself may have arbitrary motion (e.g., an airplane in maneuvering). Application of the method to the analysis of unsteady transonic flows is then presented along with the numerical algorithm. Numerical validation of the formulation is included. The formulation extends the work of Tseng and Morino (Ch. XV of Transonic Aerodynamics, Vol. 81, Progress in Astronautics and Aeronautics, Ed. D. Nixon, 1982) which is limited to steady transonic flows. The derivation of the integral equation is based upon a rigorous use of the theory of distribution. The numerical algorithm is obtained using a finite-element method for integral equations.

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Spin Mode Acoustic Radiation From a Thick Wall Duct

A mathematical model of spin mode acoustic radiation has been developed based on an experimental setup designed by Richard Silcox of the Noise Control Branch at NASA LRC. This model is formulated using singular integral equations. Predicted reflection coefficients and far field patterns are compared with experimental results.

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Cubic Spline Based Approximation Schemes for the Identification of Parabolic Systems

We consider approximation schemes for the identification of systems governed by a class of semilinear parabolic partial differential equations. The methods are based upon cubic spline and Pade rational function approximation. A sequence of approximating finite dimensional discrete parameter identification problems which can be solved using standard techniques and readily available software is constructed. The convergence of solutions to the approximating problems to a solution to the original infinite dimensional identification problem is demonstrated. Numerical results including the application of the schemes to problems arising in the modeling of biofurbation in deep-sea sediment cores and air quality in the laboratory, both involving actual experimental data, is discussed.

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Solution of Steady-State Euler Equations in the Presence of Arbitrary Boundary Surfaces: An Extension of the PAN AIR System of Programs

An optimal control formulation of the steady-state Euler equations will be described which treats arbitrary boundary surfaces. The fundamental unknowns are a scalar and vector potential (which define the velocity), the enthalpy and the entropy. The equations are solved iteratively on a rectangular grid with interior jump conditions specified on boundary surfaces defined within the rectangular grid. Multiply-preconditioned conjugate gradient techniques are used to substantially accelerate convergence. Preconditioners include a small disturbance Euler solver for exterior domains. The exterior solver allows the boundary of the rectangular grid to be quite close to the configuration boundary. The combination of choice of unknowns and the rectangular grid allows second order accuracy in the entropy growth throughout the computational domain. This avoids "false" entropy generation inherent in some approaches. Fast direct methods (Fast Fourier Transforms) are extensively used in the preconditioners. Special techniques for coupling the interior jump surface to the rectangular grid will be described. These permit solution of the equations for complex configuration geometry.

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Legendre-Tau Approximations for Functional Differential Equations, Part II; The Linear Quadratic Optimal Control Problem

In this paper we consider the both finite and infinite interval regulator problems for hereditary differentral systems. A method based upon Legendre-tau approximation to compute feedback gain operators is proposed. Various numerical examples are presented; comparison with other methods is made.

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Spatial eigenfunction expansions of disturbances originating in the free stream

Some years ago we showed how, given the form of a disturbance in a boundary layer at some distance downstream of the leading edge, to expand it in terms of the discrete and continuum spatial eigenfunctions of the Orr-Sommerfeld equation (Salwen & Grosch, 1981). One of the major cases of interest is that of a disturbance originating in the free stream, for example, an oscillation in the amplitude of the free stream flow. Stuart (1982) pointed out that our expansion technique cannot be applied to this case because we assumed that the energy of the disturbance was finite and a free stream oscillation, in a frame of reference fixed to the body, has infinite energy. Therefore, our set of expansion function functions could not possibly be complete for this class of disturbances. We show here that there is a simple, exact solution of the Orr-Sommerfeld equation for the spatial stability case which completes the set of expansion functions for this class of disturbances. We give this solution, discuss its application to the boundary layer receptivity problem for flows past bodies of semi-infinite extent in the flow direction, and, finally, discuss the physical implication of this result.

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Rotational Supersonic Flow Using a Clebsch Velocity Decomposition

A Clebsch velocity decomposition $\bar{V}=\nabla\phi+\lambda\nabla\mu$ is used to formulate inviscid supersonic flow problems. Rotational flow effects due to entropy gradients at curved shocks and due to leading edge vortex separation are both considered. A finite-difference procedure is developed and applied to several conical supersonic flowfields.

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Computing Stokes Flow by Longitudinal Partitioning

When optical fibers are drawn through a coating applicator filled with coating fluid, the resulting pressure and velocity fields are described by Stokes flow. To solve for the flow and subsequently, the forces on the fiber, a linear combination of basis solutions can be found that satisfies the boundary conditions on the sloping boundary in the least square sense. It will be shown that the number of these basis elements required can be greatly reduced by partitioning the flow region along the fiber and enforcing the continuity conditions in the least square sense.

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Modal Control of a Class of Non Self-Adjoint Systems

This work examines the extent to which normal modes exist in linear dynamic systems described by partial differential equations defined on a Hilbert space. Normal modes, as defined here, refer to the existence of a complete set of eigenfunctions associated with the operators defining the class of systems considered. It is shown that a certain class of non self-adjoint operators can be defined as being self-adjoint with respect to a given self-adjoint operator. These product operators are then used to define eigenfunction expansions and to perform standard modal control. An example of the feedback control of a non self-adjoint distributed structure is given (a damped Pflüger's column).

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Estimation of Discontinuous Coefficients in Parabolic Distributed Systems

We present our findings for the problem of estimating discontinuous coefficients in distributed systems. In particular, we focus on the problem of estimating $q = q(x)$ in the parabolic partial differential equation

$$\frac{\partial}{\partial x}\left(q\,\frac{\partial u}{\partial x}\right) = f;$$

here we use observations of u to locate points of spatial discontinuity as well as to approximate the overall shape of the spatially-varying parameter. We discuss a theoretical framework for the estimation problem, present numerical findings, and indicate a motivating example from the area of reservoir engineering. For this particular application, the problem of estimating points of spatial discontinuity in q is closely related to the problem of locating physical changes (such as layering) in rock characteristics underground.

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A Numerical Study of Taylor Vortex Flows

Results will be presented of finite difference computations for steady Taylor vortex flows. The computations have been performed with the same range of Reynolds number and aspect ratio as used by T. B. Benjamin in his experiments (Proc. R. Soc. Lond. A. 359, 27-43 (1978)). The numerically determined bifurcation points for two-cell and four-cell flows agree well with Benjamin's experimentally determined values. There are, however, some differences in interpretation, particularly with regard to the two-cell/four-cell hysteresis and the anomalous modes. The flows were computed using regularized central differences with uniform grid spacing. The flows were assumed to be axisymmetric so that the computation required only two spatial dimensions although it required that all three velocity components as well as pressure be computed.

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A Highly Compact High Order Multi-grid Method for Nonlinear Elliptic Problems

A highly compact multi-grid scheme is presented to solve nonlinear elliptic problems. Tau-extrapolation is combined with residual minimizing prolongation to simplify the program structure. The scheme is particularly suitable for three dimensional problems on vector and parallel processor computers.

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AN AUTOMATIC MESH GENERATOR WHICH CHANGES DENSITY IN TWO DIRECTIONS SIMULTANEOUSLY

An automatic mesh generating algorithm for CAD systems is described. The surface is parameterized as

$$(x(r,s),y(r,s),z(r,s)) \quad \text{with } 0\le r,s\le 1.$$

The mesh is defined in the parameter space and lifted to the surface. The number of nodes on each edge is prescribed: if

$$\left.\begin{array}{l} n_0 \\ n_1 \\ k_0 \\ k_1 \end{array}\right\} \text{is the number of elements on the } \left\{\begin{array}{l} r=0 \\ r=1 \\ k=0 \\ k=1 \end{array}\right\} \text{edge}$$

and

$$\max\{n_0/n_1,\ n_1/n_0\} \le \min\{k_0,k_1\},$$

and

$$\max\{k_0/k_1,\ k_1/k_0\} \le \min\{n_0,n_1\},$$

a mesh is generated.

The algorithm has been implemented on G-PRIME and produces reasonable looking meshes. It can be extended to a similiar algorithm in three dimensions.

Slides of the computer generated meshes will appear.

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Some Effects of Three Dimensional Nonorthogonal, Curvilinear Coordinate Systems on the Calculation of the Bow Shock

First, a brief review of the use of conformal transformations with body location dependent parameters to produce a three dimensional curvilinear coordinate system is given. The resulting transformation is usually nonorthogonal. Several examples of the types of grids that can be generated are presented for some simple configurations. Second, due to the fact that in many CFD calculations the coordinate system is transformed but the velocity vectors are not, certain problems can arise in advancing the bow shock position under the above transformations. Two formulations associated with the problem are discussed. In one formulation, a differential/algebraic system is used to advance the shock position, while in the second, a simple differential equation system similar to that for, say, the cylindrical coordinate system, is used for advancement of the shock.

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Two Strategies for Root Finding on Multiprocessor Systems

The problem of finding the roots of a single nonlinear equation on an MIMD (multiple instruction stream-multiple data stream) computer system is considered. Two globally convergent strategies for exploiting the parallelism in the computer system are investigated and compared. In one strategy a serial root finding algorithm is used, with the parallel computation capabilities of the system being used to speed up the necessary function evaluations. For a given function this increase in speed is determined by a known speed-up function S_p, which relates the number of processors available to function evaluation time. Linear and logarithmic speed-up functions are investigated. In the second strategy a parallel root finding algorithm is used. Function evaluations are performed serially, one function evaluation being performed on each processor. Two parallel root finding algorithms based on a contraction mapping and on Halley's method are presented and their convergence properties examined. Expressions for comparing the two strategies are derived and decision curves are presented.

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A Smoother Interpolant for DE/STEP,INTRP

One advantage of the Adams methods for the solution of the initial value problem $y'(x)=f(x,y)$, $a\le x\le b$, $y(a)$ given, is that there is a natural polynomial interpolant which can be evaluated to approximate $y(x)$ and its derivative(s) between mesh points. In point of fact there are several possibilities which differ mainly in their smoothness as a global approximation to $y(x)$. For example, in the well known suite of codes DE/STEP,INTRP the derivative of the interpolant is globally continuous, but the solution has a jump at the mesh points which is comparable in size to the error tolerance. This can be troublesome in some applications such as root finding. We examine several choices for an improved interpolant (globally C^1) and show how the implementation aspects are important to achieve the desired behavior. Some numerical comparisons will be presented.

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NUMERIC DIFFERENTIATORS FOR PSEUDO-SPECTRAL METHODS

The heart of the pseudospectral (collocation) method for solving mixed initial-boundary value problems [1, 2] is a numeric differentiator based on Chebyshev polynomials and Fast Fourier Transforms. Other numeric differentiators are available, and this paper investigates the tradeoffs among them as applied to the one-dimensional convection-diffusion equation, using test problems originating in reservoir modelling.

[1] Borasky, M. Edward (1982), Adapting Spectral Methods to the FPS-164, Proceedings, 1982 ARRAY Conference, FPS, Inc., Beaverton, OR

[2] Gottlieb, David and Orszag, Steven A. (1977), Numerical Analysis of Spectral Methods, CBMS - NSF # 26, SIAM, Philadelphia, PA

[3] Peaceman, Donald W. (1977), Fundamentals of Numerical Reservoir Simulation, Elsevier, New York.

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Boundary Feedback Stabilization of Parabolic PDE's Using Finite Memory

We consider the parabolic PDE (*) $u_t = u_{xx} + f(u)$ in which interaction (observation, control) can occur only at the boundary: x=0,1. Under suitable hypotheses on the function $f(\cdot)$ it is shown that stabilizing control laws of a 'generalized feedback type' can be constructed which use only on-line computation with finite memory.

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A Rotationally Biased Upwind Difference Scheme for the Euler Equations

In a previous paper, the author has derived a first order upwind finite difference scheme for the Euler equations which resolves steady two-dimensional shocks that cross the computing grid at an oblique angle. This was accomplished by locating the angle at which the shock might be expected to cross the computing grid and then constructing separate finite difference formulas for the flux components normal and tangential to this direction.

In this paper we discuss an extension of this method which is second order accurate in regions of smooth flow and which preserves monotonicity. Numerical examples illustrate the performance of this new method.

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Acoustic Shocks in a Variable Area Duct Containing Near Sonic Flows

In this talk we consider acoustic shock waves in a variable area duct which contains near sonic flows. The problem we treat here is modelled after an aero engine inlet. It is known experimentally that area variation of the duct and high Mach number mean flows can reduce acoustic energy yielding a substantial noise reduction. One possible reason for this sound attenuation is acoustic shocks. We describe use of an explicit numerical method which is very accurate and also captures shocks reasonably well. Comparisons of the results are made with an existing asymptotic theory for Mach numbers close to unity. When shock occurs the reduction of sound pressure levels are shown by examples.

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Stability of Difference Approximations for Hyperbolic Initial-Boundary-Value Problems

If a difference approximation to an initial-boundary-value problem (IBVP) on a finite domain is written in vector-matrix form as $u^{n+1} = Cu^n$, then Lax-Richtmyer stability requires a uniform bound on C^n in some norm for $n\Delta t \le T$. Here both the "analytical" and "numerical" boundary conditions are included in the operator C. We give numerous examples illustrating the difficulty of establishing uniform bounds for matrix operators associated with discrete hyperbolic IBVP's. Both explicit and implicit schemes are considered. The relation between Lax-Richtmyer stability and the stability theory developed by Godunov, Kreiss, Osher, Gustafsson and Sundstrom is considered. In practical computational problems, both theories can be deficient since the stability definitions allow exponential growth if the mesh interval Δt or Δx is not sufficiently small for a fixed value of $\Delta t/\Delta x$.

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The effect of smoothing filters on solutions to the Euler Equations

A feature of many codes which solve the Euler equations using central differences is the presence of some form of filtering to remove unwanted oscillations. This lends stability and robustness to the code, and hopefully does not unduly alter the solution. We quantitatively study the effects of one form of widely used smoothing in a Euler code. The quantity of smoothing is varied, and so is the grid on which the calculation is being done. The interaction between grid choice and this smoothing filter is shown to have a substantial effect on an example solution.

This work was supported by NASA contract #NAS2-11555

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Local Uniform Mesh Refinement with Moving Grids for Time Dependent Problems

Numerical dispersion is a serious problem in the solution of many hyperbolic PDE's. A number of techniques have been developed to deal with this problem, but most either depend on special features in the problem or on significant grid refinement. We propose a different method which takes advantage of the fact that numerical dispersion can be viewed as the result of motion of the solution across grid points. We show how to use locally uniform grids (for efficiency and vectorizability) which move with the solution to substantially reduce numerical dispersion at little additional computational cost. Examples will be presented in both 1 and 2 dimensions.

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Mathematical Modelling and Stabilization of Flexible Spacecrafts

In this paper we present a rigorous mathematical model of flexible spacecrafts giving an interesting system of coupled hyperbolic partial differential equations and ordinary differential equations. We propose feedback controls for the satellite body and the flexible beam that can be easily implemented. The proposed control makes the system asymptotically stable with respect to the rest state in the sense that all the motions of the satellite and the beam including beam deformations eventually decay to zero. Very interesting numerical simulation results will be presented.

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Performance of Various Computers Using Standard Linear Equations Software in a Fortran Environment

In this note we compare a number of different computer systems for solving dense systems of linear equations using the LINPACK software in a Fortran environment. There are about 50 computers compared, ranging from a Cray X-MP to the 68000 based systems such as the Apollo and the SUN workstations.

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The NYU Ultracomputer

The architecture of the NYU Ultracomputer is outlined. This is a proposed "MIMD" parallel machine comprising thousands of independently programmable fast processing elements connected to a large shared memory by a switching network. The latter has the geometry of an Omega-network, with switches each having enough memory and processing power to yield a bandwidth proportional to the number of processors. The network, which is pipelined, also supports the parallel execution of the "fetch-and-add" primitive important for process coordination. Questions relating to operating systems, programmability, and efficiency of applications codes are also discussed.

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EVALUATION OF A BUS NETWORK PARALLEL PROCESSING ARCHITECTURE

This paper discusses a generalized interconnection scheme for medium through large scale applications, including those in scientific computing and robotics. Two modules are defined, a high speed bus and a bi-directional link of matching bandwidth. Arbitrary graphs of buses and links may be constructed to match the communication pattern of the application. Any kind of processing or storage elements may be included as long as it conforms to the bus's simple deadlock-free protocol. For scientific applications processing elements would include Von Neumann processors, systolic array and array processors. Devices should be grouped so that those that interact most are physically on the same bus. Locality of access is common in programs and highly advantageous in systems with global communication at linear cost. Two approaches for analyzing the bus network's performance are under development. One uses a program designed to simulate arbitrary bus networks. The second is a generalized 'soft testbed' simulation for distributed systems. Initial results indicate good performance, full bus bandwidth is utilized and shared fairly, while links only incur a linear time cost. Quantitative results are presented.

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Mapping Approximate Factored Algorithms Onto Concurrent Processing Computers

Certain approximate factored algorithms have properties well suited for parallel processing. A method for implementing these codes on concurrent processing computers is presented which involves solving the explicit portion of the code concurrently and the implicit portion through approximate factorization. The approximate factorization decouples "pencils" of data which can then be processed in parallel. A benchmark three dimensional Navier-Stokes code, which allows for a turbulent boundary layer, is discussed for illustration and results from the NASA-Ames Research Center MIMD (Multiple Instruction/Multiple Data stream) test facility are presented. Some of the principle steps in modifying the code to run concurrently are discussed as well as the resulting timing and memory mapping problems. The speedup for the two processor facility exceeds 1.9 with a typical CFD implementation of the Navier-Stokes code run on an otherwise quiescent system.

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An Application Of Concurrent Processing To Flows About Multiple Bodies

A "Chimera" grid scheme* has been implemented on the NASA-Ames Research Center MIMD (Multiple Instruction/Multiple Data stream) test computer. This scheme, which uses overset grids, was developed as a method for solving flow about complex geometries. The chimera scheme is an ideal candidate for parallel processing because it uses a minimum amount of shared data with few synchronizations. The specific geometry studied is a two dimensional airfoil/flap configuration and is implemented with one processor solving the major grid (airfoil) and the second processor solving the minor grid (flap) in parallel. Results have been obtained using two different algorithms: a stream function solution and a compressible potential solution. A discussion of the mapping onto a concurrent processing system and the passing of boundary conditions and a review of the scheme is presented.

*Steger, J. L.; Dougherty, F. C.; and Benek, J. A.; "A Chimera Grid Scheme"; Submitted to the ASME Mini-symposium on 'Advances in Grid Generation'; Houston, Texas; June, 1983.

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Two-Dimensional Fast Fourier Transform: New Algorithm and Architecture

A new Two-dimensional Fast Fourier Transform algorithm has been derived. Based on this algorithm we devise the architecture to emulate the window operations associated with the new development algorithm. Some variations of our architecture and the VLSI implementations are presented in this paper. Our architecture gets rid of the matrix transpose problem and the data traffic problem between main memory and the secondary memory. These two problems are the bottleneck of two-dimensional Fast Fourier Transform. In our architecture, the data can be driven into the arithmetic processors continuously such that the processors have very high utilization rate.

KEY WORDS:
Bit Serial Arithmetic, Butterfly, Image Enhancement, Matrix Transpose, Parallel, Parallel Arithmetic, Perfect Shuffle, Pipeline, Radar, Radix-2 by Radis-2, Signal Processing, Tomography, Two-dimensional Fast Fourier Transform, VLSI, Window Operations.

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Performance of Multicomputer Architectures

The increasing number of multicomputer architectures and advances in integrated circuits have necessitated the emergence of design tools which can assess the performance of scheduling real time problems to existing architectures. This paper presents a scheduling technique for matching an algorithm to a multicomputer architecture. The performance of such an assignment has been evaluated in terms of speed-up, processor utilization, communication channel utilization, and the cardinality. Constraints imposed by memory requirement have been excluded to simplify the model. Various architectures have been considered for both synchronous and asynchronous (in a limited sense) modes of operation. Throughput and turnaround time of multiprocessor systems have been shown to be influenced by their architectures. A suboptimal $O(N^2)$ time scheduling algorithm, which can be adapted for either communication — or computation — intensive applications, has also been reported.

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A Mathematical Computer Architecture to Vectorize Resursive Algebra

Many algorithms include an algebraic calculation which is recursive. One example (Gauss elimination) is to solve a set of simultaneous linear equations using the LU factorization. In particular, the solution of a tridiagonal system first order recursive algebraic sequences. Such equations are frequently referred to as being "not vectorizable" on such multimillion dollar super computers as the Cray-1 or Star 100. The conclusion of the present paper is that, by combining both pipelined computation and parallel processing together with internal data movement architecture, algebraic recursion can be efficiently vectorized.

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A Parallel Algorithm for On-line Bin Packing

A modification of the best-fit rule for on-line one-dimensional bin packing is given. This approach, best-fit with replacement (left BFR) is described, and its implementation as a multiprocessor algorithm is given. This algorithm employs parallelism to increase packing efficiency rather than to speed up the packing process.

The performance of this algorithm is simulated using a class of lists that can elicit worst-case behavior in other on-line algorithms. The improvements in packing efficiency for the multiprocessor algorithm are discussed as a function of the number of utilized processors. Finally, a formal description of the structural properties of the algorithm that produced these improvements in performance is given.

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A Study of the Relationship Between MIMD Architectures and Computational Fluid Dynamics

Effective implementation of MIMD computers can help satisfy the demand of computational physicists for supercomputers of ever-increasing speed. Identifying and exploiting the concurrency available in an algorithm can be an arduous task, however, unless the computer used provides an environment conducive to MIMD computing. This paper documents an effort to identify architectural characteristics, operating system facilities and language features which promote productive program development and efficient program execution on an MIMD computer.

Three computational fluid dynamics codes (Navier-Stokes, full potential, and large eddy simulation) are implemented on an MIMD testbed consisting of two VAX 11/780 minicomputers linked by an MA780 shared memory unit. Issues addressed include memory management, synchronization, interprocess communication, and performance analysis. Facilities for handling these tasks are implemented in a FORTRAN pre-compiler. Common bottlenecks in code performance are identified, and proposals made for architecture and operating system features which could help eliminate these problems.

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Digit On-Line Arithmetic for Solving Ordinary Differential Equations

Speed is an important consideration when solving stiff ordinary differential equations, since methods for solving them usually involve systems of non-linear equations. Digit on-line arithmetic is particularly well suited to this type of problem.

In digit on-line arithmetic, the operands of an arithmetic operation are introduced a digit at a time. After a brief delay called the "on line-delay", the result digits begin to appear a digit at a time. Taking advantage of the radically different manner in which these algorithms operate, can yield some very powerful pipeline architectures. These architectures in turn, can be used to solve ordinary differential equations very quickly.

This talk will present some properties of digit on-line algorithms and how these properties can be exploited to solve ordinary differential equations and other problems in numerical analysis.

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Parallel Game-Tree Search

While sequential versions of the alpha-beta algorithm are efficient, the tree examined is still exponential with depth. Simple parallel solutions to this search problem have limited efficiency, since one processor must search at least the minimal tree. To alleviate this difficulty we have proposed the Principal Variation Splitting method. [T.A. Marsland and M. Campbell, "Parallel Search of Strongly Ordered Game Trees." *Computing Surveys*, vol. 14, no. 4, Dec. 1982.] Our preliminary experimental results with an implementation of PV splitting will be compared to previous simulation results and contrasted favorably with the experimental work of others.

The essence of PV splitting hinges on the use of a successive refinement method to identify candidate PV's. Initially, all the processors are applied recursively to this variation. Subsequently, the work of examining the balance of the tree is assigned to individual processors. The efficiency of the method is also dependent on how the new alpha bound is made available. A refutation table of primary lines, updated at the start of each iteration, guides the search. Experiments with a global hash table of key nodes have also been carried out. The final phase of the project involves coordinating processors to assist in the search of a new candidate. Since little inter-unit communication and coordination is required, our PV splitting implementation results in low processor idle time. Although the system consists of identical loosely coupled processors with homogeneous software, heterogeneous units can be used.

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Classifying Parallel Sorting Algorithms

When a number of equivalent algorithms are found, they can be classified using a hierarchy of design decisions, reflecting the various ways in which mathematical properties can be exploited to fulfil the conditions of a specification. One purpose of such an organization is to examine the differences in resources required; this depends crucially upon the available instruction set. Algorithm comparison, in terms of space/time/processor trade-offs, is only possible once assumptions have been made about the primitive operations provided by a machine architecture.

The development of system software libraries for parallel computers depends upon the ability to categorize performance in terms of families of architectures. Sorting algorithms provide a simple but non-trivial example for examination and comparison using a few abstract machine models (including pipelined, arrayed, and distributed processors). Optimal algorithms differ significantly over the various architectures, and also differ within a given architecture at different levels.

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Parallel Implementation of LOD Methods for Partial Differential Equations

This paper discusses several aspects of the practical implementation of Parallel Alternating Locally One Dimensional methods for the numerical solution of parabolic partial differential equations on parallel computers. The optimum use of parallelism is considered with a) solution of the linear system arising out of the method, b) incorporating of boundary conditions and c) imhomogeneous problems. Tuning and storage problems are also discussed, with specific reference to a SIMD computer (ICL DAP) and a vector computer (CRAY). Comparative timings for different stages of the method using test problems of varying sizes and types are reported for the DAP, CRAY and selected fast serial computers. The approximate LOD solution on a rectangular grid is also compared with results obtained from fast Poisson solvers and similar exact schemes.

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Multiprocessing Applied to FORTRAN Applications

Experimental software has been developed to multiprocess individual FORTRAN applications on multiple CYBER 200s. The goal is to build a testbed for studing multiprocessor design tradeoffs both in architecture and software for future supercomputer products. We have made multiprocessing available in FORTRAN requiring no new language extensions and minimal charges to the application code. Several applications have been partitioned successfully and run on a dual CYBER 205 configuration with a shared file system. Performance improvement is highly application dependent and ranges from 1.5 to 2.0 times single processor speed. Measurements allowing estimates for 3 and 4 processor configurations have also been made. Recent results and impact on multiprocessor design will be discussed.

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Communication Times for Grid Computations on the Mago Tree Machine

The Mago tree machine is a cellular computer, that executes the FFP languages of Backus. The machine consists of a network of cells connected as a complete binary tree. The FFP program is stored in the leaf cells of the tree, one symbol per cell. Execution of the program consists of rewriting the program by replacing inner-most expressions with their values. Since each inner-most application can be reduced simultaneously, the tree machine has great potential for parallel execution.
In algorithms for the iterative solution of differential equations on a grid of points, the tree machine has order (n) communication time in straight-forward implementations. This is a severe disadvantage when compared to array processor systems, however the tree machine compensates for this by offering tremendous flexibility. The grid does not have to be a certain shape and can be dynamically modified in subregions to improve convergence. In solving a grid problem on the tree machine one must insert the nodes of the grid into the lead cells in come order. For row major order the communication time is order (n). In this paper we show that no other arrangement produces better communication times.

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LINEAR SYSTOLIC ARRAYS FOR TOEPLITZ AND SINGULAR VALUE PROBLEMS

We are interested in the real-time solution of two important signal processing problems. A promising approach is the use of linear systolic arrays. First, we show how an n×n Toeplitz system of linear equations can be solved using O(n) processors, O(n) time, and O(n) storage, i.e. constant storage per systolic processor. Second, we describe a Jacobi-like algorithm for computing the singular value decomposition of an m×n matrix (m≥n) using O(n) processors and O(mnS) time, where S is the number of sweeps required for convergence.

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Strict and Stochastic Redundancy for Fault Tolerant Computational Networks

In this paper, we consider parallel computational networks for solving recursive filtering problems. We analyze the network design constraints necessary to meet both speed up and fault tolerance requirements. Two approaches are considered. The first one is based on the use of strict redundancy for meeting the fault detection and fault location requirements. This approach is general in nature because it does not depend on the specific properties of recursive filtering problems, but its implementation requires a great deal of hardware. In contrast, the second approach, based on the concept of stochastic redundancy, depends heavily on the specific properties of recursive filtering problems. We show that although the scope of this approach is limited to a particular class of problems, considerable hardware gains are achieved.

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Parallel Locally One-Dimensional Schemes

A method is developed for the implementation of alternating locally one-dimensional (ALOD) schemes for forced linear differential equations. The schemes are implicit and are based on the splitting $\exp\tau(L_1+L_2)=0.5(\exp\tau L_1\exp\tau L_2+\exp\tau L_2\exp\tau L_1)+O(\tau^3)$. Representative schemes are applied to the linear heat-conduction equation $u_t= u_{xx}+ u_{yy}$ with time-dependent Dirichlet boundary conditions. Reasonable conditions are established for which the schemes produce numerical solutions for such boundary conditions, with time-step τ, with the accuracy of $O(\tau^2)$. Results for $u_t=u_{xx}+u_{yy}+u_{zz}$ are presented.

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(SEE INDIVIDUAL TABLE DISPLAY)

Future SIAM Meetings and Conferences

June 12-14, 1984 at
Boulder, Colorado

Conference on numerical optimization.

July 16-20, 1984 at
Seattle, Washington

1984 National Meeting.

August 20-22, 1984 at
Stanford, California

Conference on applied linear algebra.

October 22-24, 1984 at
Boston, Massachusetts

Conference on frontiers in computational statistics (ASA-IASC-SIAM).

November 12-14, 1984 at
Boston, Massachusetts

Second conference on VLSI devices.

January 21-24, 1985 at
Houston, Texas

Conference on mathematical, statistical, and computational methods in petroleum engineering--exploration and extraction.

April 29-May 2, 1985 at
Raleigh, North Carolina

Conference on applied linear algebra.

June 24-26, 1985 at
Pittsburgh, Pennsylvania

1985 National Meeting.

October 28-30, 1985 at
Tempe, Arizona

1985 Fall Meeting.

SIAM Conference on Parallel Processing for Scientific Computing

November 10–11, 1983

SYMPOSIA SESSIONS

THURSDAY, NOVEMBER 10

SYMPOSIUM ON SCIENTIFIC COMPUTING AND PARALLEL PROCESSING

8:30-9:15 AM	K.W. Neves
9:15-10:00 AM	O.M. Lubeck

SYMPOSIUM ON PARALLEL NUMERICAL ALGORITHMS I

1:15-1:45 PM	C.B. Moler
1:45-2:15 PM	P.N. Swarztrauber
2:15-2:45 PM	L. Kaufman
2:45-3:15 PM	B. Smith

SYMPOSIUM ON PARALLEL NUMERICAL ALGORITHMS II

3:45-4:15 PM	J.S. Kowalik
4:15-4:45 PM	A. Lichnewsky
4:45-5:15 PM	M.H. Schultz

FRIDAY, NOVEMBER 11

SYMPOSIUM ON EXPERIENCE WITH ARRAYS OF PROCESSORS I

8:30-9:00 AM	L.M. Adams
9:00-9:30 AM	J.C. Browne
9:30-10:00 AM	D. Gannon

SYMPOSIUM ON EXPERIENCE WITH ARRAYS OF PROCESSORS II

10:30-11:00 AM	M.L. Patrick
11:00-11:30 AM	G.W. Stewart
11:30-12:00 PM	J.W. Moore

ALL SESSIONS ARE HELD IN THE POPLAR ROOM.

TIMETABLE

THURSDAY, NOVEMBER 10

TIME (MORNING)	C/P 1A (Poplar Room)	C/P 1B (York Room)	POSTER 1 (International Promenade)
10:30	W.G. Poole	O.O. Storaasli* R.E. Fulton J.B. Ransom	10:30AM-12:00N J.L. Gustafson S.W. Bostic D.C. Fisher E. Montagne M.A. Abidi A. Wilson H.D. Simon
10:45	M.J. Kascic, Jr. S.E. Follin*	M.R. Leuze	
11:00	J. Natvig* B. Nour-Omid B.N. Parlett	G.S.J. Bowgen H.M. Liddell*	
11:15	L.J. Hayes P. Devloo*	J.S. Kowalik Y.K. Bushnaq*	
11:30	L.J. Hayes* P. Devloo	P-H. Ang* M. Morf	
11:45	E.N. Houstis J.R. Rice*	K. Tanabe	

FRIDAY, NOVEMBER 11

TIME (PM)	C/P 2A (Poplar Room)	C/P 2B (York Room)
1:15	D. Hicks,* J. Middleton A. Stokes	J. Oliger,* P.H. Worley
1:30	G. Alaghband,* H.F. Jordan	E.R. Ducot
1:45	C.C. Hsiung,* W. Butscher	V.C. Klema
2:00	J.R. Baumgardner, P.O. Frederickson*	M. Gokhale
2:15	M.E. Borasky	J.R. Allen
2:30	S.L. Johnsson	F.J. Burkowski
2:45	R.G. Grimes, J.G. Lewis*	R. Bernecky

*Speaker, when there are two or more authors.

C/P = Contributed Papers

SIAM Conference on Parallel Processing for Scientific Computing
November 10–11, 1983
Final Program

THURSDAY, NOVEMBER 10

7:30 AM - 5:00 PM
REGISTRATION (**International Promenade**)

9:00 AM - 5:00 PM
BOOK EXHIBITS (**International Promenade**)

8:20 - 8:30 AM
OPENING SESSION (**Poplar Room**)
Welcome Remarks. Robert G. Voigt (Conference Chairman), ICASE

8:30 - 10:00 AM
Invited Speakers. Scientific Computing and Parallel Processing. (Poplar Room)
Chairman: Albert M. Erisman, Boeing Computer Services Co.

8:30 - 9:15
Vector Algorithms as a Function of Hardware Architecture, Kenneth W. Neves, Boeing Computer Services Company

9:15 - 10:00
Experiences with the Denelcor HEP, Olaf M. Lubeck, Los Alamos National Laboratory

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10:00 - 10:30 AM
INTERMISSION

10:30 AM - 12:00 PM
Contributed Papers 1A. Algorithm Performance on Vector Computers. (Poplar Room)
Chairman: Paul N. Swarztrauber, National Center for Atmospheric Research

10:30-10:42
The Effectiveness of Vector Computers on Numerical Computations, William G. Poole, Jr., Pacific Analysis & Computing

10:45-10:57
Shooting Poisson's Equation on a Vector Processor, Michael J. Kascic, Control Data Corporation, and S. E. Follin,* University of Minnesota

11:00-11:12
Comparison of Lanczos and Subspace Iteration on Vector Computers, Jon Natvig,* Bahram Nour-Omid, and Beresford N. Parlett, University of California, Berkeley

11:15-11:27
A Fast, Vector Algorithm for a Matrix Vector Multiply, Linda J. Hayes, and Philippe Devloo,* The University of Texas, Austin

11:30-11:42
An Overlapping Block Iterative Scheme for Finite Element Methods, Linda J. Hayes,* and Philippe Devloo, The University of Texas, Austin

11:45-11:57
Toward a Vectorized Ellpack, Elias N. Houstis, University of Thessaloniki, and John R. Rice,* Purdue University

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10:30 AM - 12:00 PM
Contributed Papers 1B. Algorithm Development for Parallel Arrays. (York Room)

Chairman: Joseph Oliger, Stanford University

10:30-10:42
An Application of Parallel Computing to Nonlinear Structural Analysis, Olaf O. Storaasli,* Robert E. Fulton, and Jonathan B. Ransom, NASA Langley Research Center

10:45-10:57
Gaussian Elimination on the Finite Element Machine, Michael R. Leuze, Vanderbilt University

11:00-11:12
The Solution of N Linear Equations on a P-Processor Parallel Computer, G.S.J. Bowgen, and Heather M. Liddell,* Queen Mary College

11:15-11:27
Parallel Solution of Banded Linear Equations, J. S. Kowalik, Boeing Computer Services, Inc., and Y. K. Bushnaq,* University of Texas, Dallas

11:30-11:42
A Doubling Algorithm for Eigenvalue Decomposition and Its Array Implementation, Peng-Huat Ang,* and Martin Morf, Stanford University

11:45-11:57
A New Algorithm for Parallel Iteration Towards All the Zeros of a Complex Polynomial, Kunio Tanabe, The Institute of Statistical Mathematics, Tokyo

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10:30 AM - 12:00 PM
Poster Session 1. (International Promenade)

Solution of Linear Systems Using Inner Product Architecture, John L. Gustafson, Floating Point Systems, Inc.

Solution of Tridiagonal Systems of Equations on the Finite Element Machine, Susan W. Bostic, NASA Langley Research Center

Numerical Computations on Multiprocessors with Only Local Connections, David C. Fisher, University of Maryland

Vivaldi II: Array Handling in Data Flow Systems, Lic. Euripides Montagne, McGill University

*Indicates the presenter of the paper when more than one author is given.

THURSDAY (Continued)

An Efficient Minimum Stage Multistage Interconnection Network, Mohammad A. Abidi, SUNY - Buffalo

Parallel Processing in the Next Fortran, Alan Wilson, International Computers Limited

Eigenvalue Computations on the CRAY-1S, Horst D. Simon, Boeing Computer Services Co.

12:00 - 1:15 PM
Lunch

1:15 - 3:15 PM
Invited Speakers. Parallel Numerical Algorithms I. (Poplar Room)
Chairman: Garry Rodrigue, Lawrence Livermore National Laboratory

1:15 - 1:45
Mathematical Software for Vector Computers, Cleve Moler, University of New Mexico

1:45 - 2:15
Vector FFT Algorithms, Paul N. Swarztrauber, National Center for Atmospheric Research

2:15 - 2:45
Vector Eigenvalue Algorithms, Linda Kaufman, Bell Laboratories

2:45 - 3:15
Proposed Array Processing Features for Fortran 8x: Are They Suitable for Scientific Computation on Parallel Processors?, Brian Smith, Argonne National Laboratory

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3:15 - 3:45
INTERMISSION

3:45 - 5:15 PM
Invited Speakers. Parallel Numerical Algorithms II. (Poplar Room)
Chairman: Jack Dongarra, Argonne National Laboratory

3:45 -4:15
Examples of Multiple-instruction Multiple-data (MIMD) Computations, Janusz S. Kowalik, Boeing Computer Services, Inc.

4:15 -4:45
Some Vector and Parallel Implementation for Linear Systems Arising in PDE Problems, Alain Lichnewsky, Universite de Paris-Sud, and INRIA

4:45 - 5:15 PM
Solving Partial Differential Equations on Array Processors, Martin H. Schultz, Yale University

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FRIDAY, NOVEMBER 11

8:00 AM - 2:00 PM
REGISTRATION (**International Promenade**)

9:00 AM - 12:00 PM
BOOK EXHIBITS (**International Promenade**)

8:30 - 10:00 AM
Invited Speakers. Experience with Arrays of Processors I. (Poplar Room)
Chairman: Robert G. Voigt, ICASE

8:30 - 9:00
Experiences Using the Finite Element Machine, Loyce Mae Adams, ICASE

9:00 - 9:30
Parallel Algorithms for a Dynamically Reconfigurable Computer Architecture, James C. Browne, University of Texas, Austin

9:30 - 10:00
Restructuring SIMPLE for the CHiP System, Dennis Gannon,* and Jairo Panetta, Purdue University

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10:00 -10:30 AM
INTERMISSION

10:30 AM - 12:00 PM
Invited Speakers. Experience with Arrays of Processors II. (Poplar Room)
Chairman: Terrence W. Pratt, University of Virginia

10:30 - 11:00
Some Matrix Algorithms on the Boolean Vector Machine, Robert A. Wagner, and Merrell L. Patrick,* Duke University

11:00 - 11:30
Data Flow Algorithms for Parallel Matrix Computations, G. W. Stewart, University of Maryland, College Park

11:30 - 12:00
PuPS: Parallel Microprocessor System, James W. Moore, Los Alamos National Laboratory

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12:00 - 1:15 PM
Lunch

1:15 - 3:00 PM
Contributed Papers 2A. Scientific Applications on Parallel Systems. (Poplar Room)
Chairman: C. E. Grosch, Old Dominion University

1:15-1:27
Hydrocodes on the HEP, Darrell Hicks,* Michigan Technological University; John Middleton, and Alan Stokes, Denelcor

*Indicates the presenter of the paper when more than one author is given.

FRIDAY (Continued)

1:30-1:42
Parallelization of the MA28 Sparse Matrix Package for the HEP, Gita Alaghband,* and Harry F. Jordan, University of Colorado, Boulder

1:45-1:57

A New Numerical Seismic 3-D Migration Model on the CRAY X-MP, Christopher C. Hsiung,* CRAY Research, Inc., and Werner Butscher, CRAY Germany

2:00-2:12
Parallel Three-Dimensional Computation of the Earth's Free Oscillations, John R. Baumgardner, University of California, Los Angeles; and Paul O. Frederickson,* Los Alamos National Laboratory

2:15-2:27
Rapid Elliptic Solvers for Attached Processors, M. Edward Borasky, Floating Point Systems, Inc.

2:30-2:42
Some Ensemble Architecture Algorithms for the Conjugate Gradient Method and for Tridiagonal Systems of Equations, S. Lennart Johnsson, California Institute of Technology

2:45-2:57
Vectorizing Direct Sparse Linear Equation Solvers, Roger G. Grimes, and John G. Lewis,* Boeing Computer Services Company

1:15 - 3:00 PM
Contributed Papers 2B. Exploitation of Parallelism. (York Room)
Chairman: Loyce Mae Adams, ICASE

1:15-1:27
Algorithm Independent Topological Requirements for Numerical Simulations, Joseph Oliger,* and Patrick H. Worley, Stanford University

1:30-1:42
TRAMP: An Experimental Facility for the Development of Concurrent Algorithms, Elizabeth R. Ducot, Massachusetts Institute of Technology

1:45-1:57
How TRAMP Is Used, Virginia C. Klema, Massachusetts Institute of Technology

2:00-2:12
Generating Parallel Programs from Nonprocedural Specifications, Maya Gokhale, University of Delaware

2:15-2:27
Automatic Program Transformations to Enhance Performance on Parallel Machines, John Randal Allen, Rice University

2:30-2:42
A Data Flow Computer Architecture for Vector Processing Applications, Forbes J. Burkowski, University of Waterloo

2:45-2:57
Parallel Processors and APL, Robert Bernecky, I.P. Sharp Associates Limited

*Indicates the presenter of the paper when more than one author is given.

SIAM Conference on Parallel Processing for Scientific Computing
Author Index

SYMBOLS:
- P/S = Poster Session
- I/S = Invited Speaker
- C/P = Contributed Paper
- M/S = Minisymposium

NOTE: Where the session is left blank, it indicates that the person listed is a co-author of an invited speaker.

SIAM Conference on Parallel Processing for Scientific Computing
Abstracts: Invited Speakers

Experiences Using the Finite Element Machine

The Finite Element Machine under construction at NASA Langley Research Center is an asynchronous array of microprocessors. Each microprocessor is connected locally to its eight nearest neighbors and globally to other microprocessors and the controller. In addition, each processor is connected to eight different hardware flag networks and to a circuitry for computing global summations and maximum values.

In this talk, we describe the software for the controller and the individual microprocessors in enough depth to show how the numerical analyst must view the machine (architecture plus software). We then show how this view has influenced the development of new parallel algorithms. We conclude by giving speedup and execution time breakdown results as the number of processors increases from one to eight.

Loyce Mae Adams
ICASE
Mail Stop 132C
NASA Langley Research Center
Hampton, VA 23666

Parallel Algorithms for a Dynamically Reconfigurable Computer Architecture

This talk will show by example how dynamically reconfigurable computer architecture may be exploited to give computationally efficient parallel formulations of significant algorithms for linear algebra, signal processing and pattern recognition. Many algorithms have several distinct phases which are characterized by different unit computations and different communication topologies. The ability of a reconfigurable architecture to realize the computational structures required by the different phases lets them be efficiently mapped to the architecture.

James C. Browne
Department of Computer Science
University of Texas
Austin, TX 78712

Restructuring SIMPLE for the CHiP System

The SIMPLE program is a two dimensional Lagrangian hydrodynamics code released by Lawrence Livermore Laboratories to provide computer architects and language designers with a simple example of a common type of fluid computation. Since its release, it has served as a standard benchmark for a variety of high speed computer designs. This paper will describe the organization of the underlying algorithms and show how the program can be restructured to run on a configurable, MIMD array of 64 processors constructed as a prototype of the CHiP computer. In addition to basic machine performance, we consider algorithmic changes designed to increase parallelism.

Professor Dennis Gannon
Department of Computer Science
Purdue University
West Lafayette, Indiana 47907

Mr. Jairo Panetta
Department of Computer Science
Purdue University
West Lafayette, Indiana 47907

Vector Eigenvalue Algorithms

On serial machines the number of floating point operations is the primary measure of the computational complexity for numerical algorithms. With the emergence of vector machines, that measure alone is no longer sufficient to indicate whether a particular algorithm is faster than another on all machines. In this talk we will consider several types of eigenvalue problems. On vector machines we will show that it often pays to consider the possibility of reworking algorithms and implementations to use vector operations. Sometimes the original algorithm appears serial in nature and only upon closer examination does one realize that many of the operations are independent and vector operations can be used. In particular, for banded matrices most of the algorithms for finding eigenvalues are "chasing" schemes in which unwanted elements are flushed out the bottom of a matrix using planar transformations. We show that it is possible to chase several elements simultaneously down the matrix and use vector-like operations to compute and apply the transformations.

Linda Kaufman
Computing Mathematics Research Department
Bell Laboratories
600 Mountain Avenue
Murray Hill, NJ 07974

Examples of Multiple-instruction Multiple-data (MIMD) Computations

The most common ways of introducing parallelism to computer architecture are

(a) pipelining,
(b) processor replication,
(c) functional replication.

In the second category we distinguish between SIMD (single-instruction single-data) and MIMD (multiple-instruction multiple-data) computers.

In the former configuration the processors work in lock-step, in the later the processors can execute independent streams of instructions. Examples of algorithms for an MIMD machine and related implementation issues will be presented and discussed.

Janusz S. Kowalik
Boeing Computer Services, Inc.
Advanced Technology Applications Division
P. O. Box 24346
Mail Stop 7A-03
Seattle, WA 98124

Experiences with the Denelcor HEP

Four Fortran codes, each typical of a class of physical problems at Los Alamos National Laboratory, have been converted to execute on the Denelcor HEP. The codes are 1) PIC, a particle-in-cell code; 2) SIMPLE, a 2-dimensional hydrodynamics program; 3) GAMTAB, a Monte Carlo application; and 4) TRAC, a nuclear reactor simulation. The algorithmic nature of the concurrency and specific HEP features for each code are discussed. Speedups as a function of number of processes are given.

Olaf M. Lubeck
Los Alamos National Laboratory
Computer Research and Applications Group
Mail Stop B265
Los Alamos, NM 87545

MATHEMATICAL SOFTWARE FOR VECTOR COMPUTERS

We review recent work on the developments of mathematical software intended to perform efficiently on vector and parallel computers. We concentrate the primary components of a mathematical software library -- elementary functions and matrix calculations.

Computation of elementary functions involves the development of algorithms which can operate simultaneously on all the components of a vector. Two approaches are possible. One avoids piecewise approximations which depend upon the actual numerical values of the input arguments. The other makes use of a table of stored values.

The matrix software packages LINPACK and EISPACK must be modified if they are to realize the full potential of vector computers. We examine the performance of the current versions of these

Professor Cleve Moler
Chairman, Department of Computer Science
University of New Mexico
Albuquerque, NM 87131

PuPS: Parallel Microprocessor System

The Parallel Microprocessor System (PuPS) is an experimental multiprocessor system consisting of two types of processors, Execution processors and Data Transfer processors. The system can be dynamically configured to a variety of architectures from shared memory systems to network configurations. We will discuss the intended uses, hardware configuration, and current operational status of the machine.

James W. Moore
Mail Stop B265
Los Alamos National Laboratory
Los Alamos, NM 87545

VECTOR ALGORITHMS AS A FUNCTION OF HARDWARE ARCHITECTURE

The subject of algorithms for vector computers is by no means new. It is fairly well accepted that efficient use of vector machines often requires algorithm reformulation. In this work, we examine a generic model of vector computers such as the CRAY-1, CRAY X-MP, and CYBER-205. The above machines and more recent entries into the "supercomputer" market exploit the pipeline form of parallelism in the floating point arithmetic units in order to achieve maximal computational rates. The characteristics of these pipeline units and memory access can vary between machines, even within a manufacturer line (e.g., CRAY-1 and CRAY X-MP). The relationship between efficient vector algorithms and computer architecture is by no means trivial. In fact, some vector computers as depicted by design diagrams seem almost transparently similar. Yet we find that subtle design differences can lead to striking performance differences on a given algorithm. In this paper we discuss four major architectural areas in which most vector computers differ: 1) Memory size and access, 2) Buffer/register characteristics, 3) Scalar and vector performance characterstics, and 4) Instruction sequencing. Examples will be given.

Kenneth W. Neves
Boeing Computer Services Company
Energy Technology Applications Division
565 Andover Park West, M/S 9C-01
Tukwila, Washington 98188

Solving Partial Differential Equations on Array Processors

Inexpensive, fast peripheral array processors have been available for many years and have been successfully applied to signal processing applications. We discuss the application of these processors to the numerical solution of partial differential equations with special emphasis on algorithm formulation, analysis, and testing.

Professor Martin H. Schultz
Yale University, Dept. of Comp. Sci.
P.O. Box 2158 Yale Station
New Haven, Ct. 06520

Proposed Array Processing Features for Fortran 8x: Are They Suitable for Scientific Computation on Parallel Processors?

In this presentation, we briefly review the array processing features proposed by Fortran Standard Committee X3J3 for the next Fortran standard. We discuss these features from the point of view of preparing Fortran programs for scientific computation involving arrays on parallel processors. Although the use of such array facilities will make many computations easier to program, and easier for compilers to generate efficient code, further facilities are needed to effectively implement algorithms for scientific computation.

Brian T. Smith
Mathematics and Computer Science Division
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

Data Flow Algorithms for Parallel Matrix Computations

This talk is divided into two parts. In the first, a class of algorithms for parallel matrix computations is described. The algorithms have the property that the computations are synchronized by the flow of data between processors, which eliminates the need for global control of the system. Most of the standard algorithms in numerical linear algebra have implementations of this form.

In the second part of the talk we describe an operating system to implement data flow algorithms. The system is designed to run on the ZMOB, a parallel computer currently being built at the University of Maryland.

G. W. Stewart
University of Maryland, College Park
Department of Computer Science
College Park, MD 20742

VECTOR FFT ALGORITHMS

The FFT algorithms are parallel algorithms in the sense that it is easy to envision how to interconnect n processors and distribute the computation so that the computing time would be proportional to log n. However, on a vector or pipeline computer, the time remains proportional to n log n, just as it is on a scalar computer. The advantage of the vector computer is that the constant of proportionality can be made quite small if the computation can be formulated in terms of vectors.

There are a number of different algorithms for computing the FFT, and although the result is always the same, they differ in the way that intermediate results are computed and stored. It is these differences that make one or the other more attractive on a vector computer. Since these algorithm considerations differ from those on a parallel computer, we are led to distinguish between vector and parallel algorithms.

Dr. Paul N. Swarztrauber
Scientific Computing Division
National Center for Atmospheric Research
P. O. Box 3000
Boulder, CO 80307

Some Matrix Algorithms on the Boolean Vector Machine

The Boolean Vector Machine (BVM) is a large network of extremely small processors with very small memories operating in SIMD mode using bit-serial arithmetic. Individual processors communicate via a hardware implementation of the Cube Connected Cycles (CCC) network. A prototype BVM with 2048 processing elements, each with 128 binary bits of memory, is currently being built using VLSI technology.

The BVM's bit-serial arithmetic and the small memories of individual processors are apparently a drawback to its effectiveness when applied to large numerical problems. In this paper we relate our experiences in implementing basic matrix algorithms on the BVM. Particular attention is given to matrix multiplication for very large and sparse (not just banded) matrices.

Robert A. Wagner
And
Merrell L. Patrick
Department of Computer Science
Duke University
Durham, NC 27706

SOME VECTOR AND PARALLEL IMPLEMENTATIONS FOR LINEAR SYSTEMS ARISING IN P.D.E. PROBLEMS

Our first topic deals with some adaptations of the Conjugate Gradient Method for parallel and vector architectures. Since most of the algorithm consists of matrix multiplications, and vector operations which can be performed efficiently in parallel, we consider the resolution of the linear system used as Preconditionning operator. Our technique is based on renumberings of the unknowns, while imposing a sparsity structure on the linear system. This gives variants suitable for Vector or MIMD architectures, which are effective in practice, as shown by performance data.

Our second topic deals with Fast Poisson Solvers on Finite Difference meshes on SIMD architectures which involve an Omega or Shuffle-Exchange interconnection networks. By requiring conflict free access only for a subset of translations of the access pattern which is not a group, implantation rules due to W.Jalby overcome some restrictions of the classical results by H.D.Shapiro. Furthermore, these rules are compatible with practical permutation selection and generation schemes, which include those due to J.Lenfant.

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and
I.N.R.I.A.
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An efficient minimum stage multistage interconnection network

This paper provides a very systematic procedure to configure a minimum stage non-blocking multistage interconnection network. The overall aim of the paper is to minimize the overall processing time in a SIMD or MIMD computer system by decreasing the access time required for processing elements to communicate with memory. The GEMINE, which is an 'n'stage, $N=2^n$ input/output multistage interconnection network, provided a simple mathematical model. As an 'n' stage GEMINE is blocking in nature, its model was extended to develop a simple mathematical model of a non-blocking EXtended GEMINE (EXGEMINE). This study is different and superior to other similar studies in that it does not restrict itself to one configuration like Benes, reverse-exchange, Omega networks etc., but it first determines the minimum number of stages required for a non-blocking network, comes up with the necessary and sufficient conditions to configure an EXGEMINE and then selects simplest of the control algorithms. The matehmatical rules of control algorithm are incorporated in the model equation of EXGEMINE and then the configuration of the EXGEMINE is determined. Thus, the extended multistage interconnection network so generated has simpler control algorithm incorporated inherently. A better bound of (2n-2) stages is achieved.

Dr. Mohammad A. Abidi
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Parallel Processors and APL

Glueing additions onto scalar-oriented languages in order to allow a user to efficiently utilize a parallel architecture is like building a space shuttle from buggy whips. A better way to achieve effecient use of such architectures is to use a language with inherent parallelism, such as APL. Arrays are the primitive data objects of APL, and functions apply directly to entire arrays. Operators in APL allow concise specification of a large family of derived functions (such as reduction, and inner and outer products) which may be implemented directly on SIMD architectures. The advent of new operators (such as the RANK operator of SHARP APL), offer explicit control over the subarrays to which a function is applied, giving the user an unprecedented amount of control over function application. Certain operators and functions in APL (some old, some new) are examined to show how they lend themselves to efficient implementation on parallel architectures, and how the parallel nature of APL allows even von Neumann architectures to take some advantage of parallelism.

Robert Bernecky
APL Development Group
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Parallel Processing in the Next Fortran

The ANSI Fortran Standards Committee X3J3 is considering a set of extensions to the language suitable for parallel computation on Fortran arrays of whatever dimensionality. These extensions are designed to provide in a simple and efficient Fortran form much of the array handling power that has hitherto only been available in more complex and less efficient languages such as APL.

The new array features will be described and their use illustrated.

Alan Wilson
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England

Eigenvalue Computations on the CRAY-1S

In the process of vectorizing EISPACK subroutines, several standard algorithms for eigenvalue computations were implemented for comparison purposes making maximal use of existing vectorized Basic Linear Algebra Subroutines. Comparisons of execution time and accuracy show a surprisingly good performance of some algorithms considered to be noncompetitive on scalar computers.

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A Doubling Algorithm for Eigenvalue Decomposition and Its Array Implementation

In this paper, we present the following:

(1) a new "doubling" algorithm for eigenvalue composition

(2) comparison of this with existing algorithms

(3) An array architecture to implement this algorithm using CORDIC-type elements

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Hydrocodes on the HEP

On the HEP, a computer with MIMD architecture, we have been investigating parallel algorithms for hydrocodes in general and also with some specific applications in mind. One specific application is two-phase flow hydrocodes (such as RELAP) for simulating water-cooled nuclear reactors. We began our investigation by considering concurrent computations for some classical hydrocode schemes such as, for example, the von Neumann-Richtmyer scheme. We divided hydrocode schemes into two cases: explicit and implicit. Case 1 (Exlicit): The solution to the problem of constructing parallel algorithms for explicit schemes is very straightforward; it is easy to divise schemes with top-down, zone-by-zone parallelization. Case 2: (Implicit): Implicit schemes (in 1-D) usually involve the inversion of a tridiagonal matrix. These tridiagonal matrices submit to an a priori, symbolic inversion. Thereby we essentially reduce the problem to the previously solved case.

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Gaussian Elimination on the Finite Element Machine

A task that arises frequently in the solution of finite element problems is that of solving an nxn system of equations Ax=b, where A is symmetric, positive definite, and generally sparse. The Finite Element Machine (FEM), consisting of a number of identical independent processors, each with its own associated memory, was designed specifically for finite element problems. Early attempts to solve the system Ax=b by direct methods on the FEM have been based on decomposition of banded matrices. In this paper, on the other hand, a Gaussian elimination algorithm for the FEM which attempts to take advantage of all zeros in the coefficient matrix is presented. The algorithm allows the elimination process to proceed in parallel at different locations in the coefficient matrix when possible and works well for systems with randomly sparse coefficient matrices.

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SOLUTION OF TRIDIAGONAL SYSTEMS OF EQUATIONS ON THE FINITE ELEMENT MACHINE

The Finite Element Machine (FEM) is a multiple-instruction, multiple-data (MIMD) array processor under development at NASA Langley Research Center. At the present stage, eight processors are operating concurrently, and work is underway to extend the system to 16 processors.

In the present research, two methods for solving tridiagonal systems of equations are evaluated for MIMD machines through implementation on FEM. One method is iterative and the other is direct. The iterative method is the Accelerated Parallel Gauss method developed by Heller, Stevenson, and Traub. The direct method is the Buneman algorithm, a variant of cyclic reduction. (Grosch, C.E.: Performance Analysis of Poisson Solvers on Array Computers. Supercomputers, Vol. 2, Jesshope, C.R.; and Hockney, R.W., Ed., pp. 149-181).

A comparison between the performances of the two algorithms will be presented. Results of varying the number of equations in the system and the number of processors used for each method will be analyzed.

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A NEW NUMERICAL SEISMIC 3-D MIGRATION MODEL ON THE CRAY X-MP

The emergence of multiprocessor vector machines, like the CRAY X-MP, along with large, relatively inexpensive, secondary memory, like the CRAY SSD, provides immense potential for simulating large, complex, 3-dimensional problems.
An implicit numerical scheme is developed to solve a 3-D seismic migration problem with 200 x 200 traces, 1024 time samples per trace. The particular model is an approximation of the original accostic wave equation. The 30^{0} operator, a parabolic equation, is solved through downward continuation. No constraints on the velocity function is required. A depth level of 1000 is used in our experimenting model. The code is developed to run on the 2-processor X-MP under multiprocessing mode. The total number of floating point operations performed is around 1.5×10^{12}.
With a 2-MW X-MP and a 32-MW SSD, the 40BW of I/O time were totally masked with CPU calculations. The elapsed time for the 1-processor model is about 3.8 hours, versus 24 hours for the disk-only version. The 2-processor model has an elapsed time of around 2 hours, a speedup of 11-12 times over the disk version.

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Generating Parallel Programs from Nonprocedural Specifications

A nonprocedural specification is a form of problem description free of the assignment statement and procedural control statements. The MODEL nonprocedural language has only two kinds of statement: data definition and assertion. The assertions enumerate the relationships among the data.[1]

This paper discusses a system which derives a parallel program from a MODEL specification. The parallel program is composed of iterative, parallel or simple blocks.

The system first builds a data dependency graph from the specification, the array graph, and checks the array graph for inconsistency or incompleteness. During the next phase, nodes in the array graph are coalesced into larger graph components. Each component becomes a block in the parallel program. In the final phase, the actual parallel program is generated. The present MODEL System generates parallel programs in the Manchester Dataflow Language for the Manchester University Dataflow Machine.

The system is illustrated with the example of matrix multiplication.

[1] Prywes, N. and Pneuli, A., "Compilation of Nonprocedural Specifications into Computer Programs", IEEE Transactions on Software Engineering, May 1983.

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TRAMP: An Experimental Facility for the Development of Concurrent Algorithms

TRAMP (Tasking RAM in Parallel) is a multiple microprocessor system dedicated to numerical algorithmic research. Intel components are used throughout, configured initially so that an 8086 central processor, an 8087 numeric data co-processor and 256k bytes of configurable memory are placed on each multifunction board. The hardware will be described briefly and the hardware/software mechanisms that permit memory allocation and interprocessor communication and coordination will be indicated. The tasking primitives for depicting concurrency within the algorithm and for designating the movement of code and data during execution will be presented.

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How TRAMP Is Used

Since TRAMP (Tasking RAM in Parallel) consists of multiple Intel 8630 boards with IEEE floating point arithmetic (draft 8.0), many programming constraints required for other floating point arithmetics can be relaxed. Computation of matrix factorizations for statistical applications in this concurrent computing environment is emphasized. In particular, the solution of ordinary least squares problems using the normal equations will be compared with solutions from orthogonal factorizations using standard Givens transformations. The potential for using this environment for robust estimation, jack knife, and bootstrap, will be described.

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Parallel Solution of Banded Linear Equations

The problem of solving tridiagonal systems of linear algebraic equations on parallel computer is considered. A new partitioning method suitable for MIMD machines will be presented. The basic algorithm can be extended to banded systems.

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A FAST, VECTOR ALGORITHM FOR A MATRIX-VECTOR MULTIPLY

In the finite element solution of time-dependent problems, the right hand side calculations which must be done at each time step involve one or more matrix-vector multiplies. A very efficient vector algorithm is presented which can be used when the matrix is derived from a finite element grid.

The proposed method is especially suited for computations on a vector computer. The number of vector operations needed to perform the multiply is independent of the number of finite elements in the grid and of the bandwidth of the assembled global stiffness matrix. Instead of assembling the element stiffness matrices into a global coefficient matrix, the multiplication is performed at an element level. The assembly is then performed after the multiplication.

Iterative methods based on this algorithm have proven to be much faster (3 to 10 times faster) than comparable iterative methods with classical multiplication algorithms, even for small problems.

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An Overlapping Block Iterative Scheme for Finite Element Methods

The finite element stiffness matrix corresponding to large physical problems can be very sparse. In these cases, iterative methods for solving the linear system of equations become more efficient than direct methods. A new, overlapping block iterative method is presented which is based on using elements as the iterative blocks. This method converges for positive definite, symmetric matrices.

In this method, the global stiffness matrix is assembled in the usual way. Then the equations are grouped into blocks which correspond to the nodes in each finite element. Nodes which are in several elements will appear in several groups and different solutions may be obtained for these nodes. The solutions obtained from these overlapping blocks are averaged to obtain the solution for a given iteration. This method is especially suited for vector processing. A timing of this method has been performed on the CDC vector computer CYBER 205 at Colorado State University, and the execution times have been compared to other standard iterative methods.

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Vivaldi II: Array handling in data flow systems

The efficient handling of array operation in data flow machines is considered a main drawback. A data flow processor with array processing capabilities is described. The data flow model of computing is used for scalar processing under low degree of parallelism, and also as a control mechanism. On the other hand, we take the advantages of a processor array to handle array operations and reduce the traffic of tokens through the system. The proposed architecture is a step forward to integrate some of the existing approaches for high speed computing in a more conventional data flow supercomputer.

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RAPID ELLIPTIC SOLVERS FOR ATTACHED PROCESSORS

Hockney and Eastwood [1] describe seven methods for high-speed solution of some important elliptic problems. These rapid elliptic solvers form the basis of the particle-mesh approach to computational physics, which is especially useful in plasma and electronic device modelling. Many of these algorithms were developed and hand-optimized for "supercomputers" and may not perform acceptably on a conventional minicomputer or a multi-user mainframe. This paper investigates another approach: a high-speed scientific processor attached to a super-minicomputer, with the rapid elliptic solver in the attached processor.

[1] Hockney, Roger W., and Eastwood, James W. (1981), Computer Simulation Using Particles, McGraw-Hill, Inc., New York

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The Effectiveness of Vector Computers on Numerical Computations

Vector computers, such as the CRAY-1 and the CYBER 205, are becoming common at scientific and engineering computer centers. A new generation of vector computers is now becoming available. Manufacturers of these vector computers advertise them as having potential speeds of hundreds of millions of floating-point operations per second. However, not all numerical computations are executed at these maximum rates. In fact, very few computations can be executed at the maximum potential rate.

This talk will describe some of the types of computations which have the potential for maximum execution rates and how different implementations of the same algorithm on the same vector computer yield significantly different execution rates. Examples will include several commonly-encountered numerical algorithms used in scientific and engineering computations.

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Numerical Computations on Multiprocessors with only Local Connections

How quickly can the sum of N numbers be computed with sufficiently many processors? The traditional answer is $t = O(\log N)$. However, if the processors are to be situated in R^d (usually $d \leq 3$), addition time and processor volume are bounded away from zero, and transmission speed and processor length are bounded above, I will show $t \geq O(N^{1/d+1})$.

Suppose P processors are arranged in a grid with only local connections. Let N(k,P) be the maximum number of numbers that can be summed in k steps. (A step is one addition and one transmission.)

Then N(k,P) will be computed for various grids (linear, square, cubic, triangular, etc). Since $N(k,\infty) = O(k^{d+1})$ for these grids, $t = O(N^{1/d+1})$ is obtainable.

Finally, N(k,P) gives lower bounds on the number of steps needed for algorithms where at least one result depends on all inputs. I will describe algorithms for solving several common linear algebraic problems with time requirements of the same magnitude as these lower bounds

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The Solution of N Linear Equations on a P-processor Parallel Computer

Various direct methods have been developed for solving a dense system of N linear equations on a P-processor parallel SIMD computer. For $N^2 = P$ it has been shown that the Gauss-Jordan strategy is preferable to Gauss Elimination. For $N^2>P$ a hybrid Gauss Elimination/Gauss Jordan technique is employed. Special methods which have been developed for the cases where $N^3 = P$ and for solving multiple systems when $N^4 \leq P$ will also be described. Most of these methods have been implemented in the DAP subroutine library and tested on a 64 x 64 DAP, and the performance compared with the best serial routines available.

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Parallelization of the MA28 Sparse Matrix Package for the HEP

The MA28 package from the AERE establishment at Harwell, England, is a sparse linear system solver. First an LU decomposition is performed on a sparse matrix and second forward and back substitution are performed with one or more right hand side vectors. The most time consuming portions of the decomposition phase, namely the Markowitz search for a pivot and the reduction of non-pivot rows, have been parallelized. The parallelized version of the MA28 is written and tested on the HEP computer (Heterogeneous Element Processor, built by Denelcor, Inc.). Numerical results concerning the effective parallelism and the speed up of the algorithm are obtained. Difficulties in parallelizing the package are discussed, and some suggestions to make it suitable to an MIMD machine are given. Indications are that, although the package has been fairly effectively parallelized for execution on one HEP process execution module, much better results can be obtained by revising the underlying data structures and pivoting strategy. This work gives a solid basis for the parallelization of the sparse linear system foundation of the semi-conductor circuit simulation program, SPICE2, which is the key to efficient execution of the rest of the algorithm on an MIMD processor.

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TOWARD A VECTORIZED ELLPACK

We present the general specifications of a vectorized implementation of the ELLPACK system for solving elliptic PDEs. Vector ELLPACK will contain only modules that seem most promising to benefit from vectorization; the initial effort is to include vectorized implementation Hermite collocation, FFT9, Spline collocation, band Gauss elimination and methods from the ITPACK project. Performance data will be presented for the CDC Cyber 205.

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Shooting Poisson's Equation on a Vector Processor

An essential requirement for many linear and non-linear equation solvers is the efficient solution of Poisson's equation. The performance of a Poisson solver on a vector processor depends both on the operation count and the degree of vectorization.

For three-dimensional problems, FFT algorithms have an operation count of $0(N^3 \log N)$ and good vector structure. This report describes the theory and performance of a highly vectorized $O(N^3)$ Poisson solver. The algorithm is based on the Marching Method, as described in (1), which is here generalized to three-dimensional problems.

The algorithm was used to solve Poisson's equation on a 63x64x64 grid, with Dirichlet boundary data in one direction and periodic boundary conditions in the other two. It has been implemented on a CDC CYBER 205 using 64-bit precision. The computational time achieved is under 100 msec., and is, to the authors' knowledge, the best yet attained for this problem.

1. Bank, R. E. and Rose, D. J., Marching Algorithms for Elliptic Boundary Value Problems. I: The Constant Coefficient Case. SIAM J. NUMER. ANAL. Vol. 14, No. 5, October 1977.

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AN APPLICATION OF PARALLEL COMPUTING TO NONLINEAR STRUCTURAL ANALYSIS

The solution of many physical problems, such as complex structural analysis, lend themselves to a parallel solution strategy. Since parallel computers are not yet commercially available, solutions must be obtained via serial calculations on sequential computers. This research investigates the improvements provided by parallel asynchronous calculations for nonlinear transient response solutions. Sample results are obtained for nonlinear response of a shallow arch subjected to dynamic loading. Results were obtained using a research computer denoted the Finite Element Machine (FEM) (see NASA TM 78912 and NASA CP 2245, p. 1, 1982). The FEM is a multiple instruction, multiple-data (MIMD) array processor currently under development at NASA Langley Research Center. Currently, 8 processors are operating concurrently and work is underway to extend the system to 16 processors. Results are obtained using 1, 2, 4, and 8 processors to solve the arch problem. Tradeoff issues pertinent to multiprocessor systems, as well as a summary of the assets and liabilities of parallel processing for this class of problems, will be discussed.

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Comparison of Lanczos and Subspace Iteration on Vector Computers

Lanczos algorithm and the subspace iteration method are designed to solve the general eigenvalue problem, $(A-\lambda M)z=0$. In previous work it has been demonstrated that Lanczos is more efficient, by an order of magnitude, than subspace iteration on serial computers. The purpose of the present study is to determine if Lanczos can maintain this edge in a parallel computation environment.
A number of test problems from structural dynamic analysis were produced by the general purpose finite element program, FEAP. The two methods were then used to solve these problems. All computations were carried out on a CYBER 205 computer. We report the results of our comparisons and evaluate the performance of each method.

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Parallel Three-Dimensional Computation of the Earth's Free Oscillations

We have constructed software for computing the earth's free oscillation eigenmodes based on a fast multigrid elliptic solver. The hierarchy of nested grids is derived from the regular icosahedron. The software is written as ten communicating processes, each process being highly vectorizable. With all ten processes executing on the Cray-1, it is fast enough to evaluate a cluster of 19 eigenvalues and associated eigenfunctions, each with 17,334 degrees of freedom in less than two minutes, and to refine this cluster on a grid with 130,662 degrees of freedom in another three minutes. The software accommodates variable coefficient operators and is being used to investigate the character of the eigenmode splitting in fully three-dimensional earth models.

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Automatic Program Transformations to Enhance Performance on Parallel Machines

Although much attention has been focused on the development of pipelined and parallel architectures, relatively little attention has been focused on the development of software to utilize this hardware. Specifically, existing programs in languages such as standard Fortran are unable to directly use vector facilities without a translation process. This process can be very tedious and time consuming, because there are very subtle differences between loops that can be correctly executed in parallel and those that cannot.

The semantic differences between parallel statements and sequential loops is precisely captured by data dependence. This theory has been incorporated into the Parallel Fortran Converter (PFC), a program developed at Rice University to translate Fortran programs into equivalent Fortran 8x programs with explicit parallelism.

Exposure of parallel operations is only one of the applications of data dependence. Dependence also forms the basis of other reordering transformations such as loop interchange, loop reversal, loop splitting, and loop fusion. Using these transformations, PFC is able to vastly improve the performance of programs on parallel machines.

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Some ensemble architecture algorithms for the conjugate gradient method and for tridiagonal systems of equations

There are many possible architectures for parallel processing systems. The term ensemble architecture denotes machines having a large number of processing elements, often in the order of a thousand or more. The larger the number of processing elements is, the smaller is in general each of them, and the more primitive is the programming environment and the operating system. A few ensemble architecture algorithms for the conjugate gradient method and for tridiagonal systems of equations are discussed. The ensembles consist of processing elements interconnected as binary trees, or as Boolean n-cubes. The algorithms only use storage local to each processing element, and the control is distributed. Limitations on performance due to sequence requirements inherent in the solution methods, as well as limitations introduced by the processor interconection scheme are discussed.

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VECTORIZING DIRECT SPARSE LINEAR EQUATION SOLVERS

Sparse Gaussian elimination codes typically vectorize poorly. They usually demonstrate much lower computation rates than those achieved by dense elimination codes. Still, in many cases, standard serial algorithms are more efficient than existing alternative algorithms for vector computers. We discuss three means for improving the efficiency of standard Gaussian elimination codes: replacing critical loops with assembly language functions, changing to different orderings which make more use of the vector hardware, and modifying implementations to acquire or use dense data structures. We use our experience with seven different ordering algorithms on a CRAY-1 computer to demonstrate the power and the limitations of these approaches. We also discuss techniques whereby the effects of any of these enhancements can be predicted for other vector and parallel computer architectures. This provides a general framework for adapting serial sparse Gaussian elimination algorithms to vector machines. As such, this talk illustrates a systematic application of some of the ideas discussed in the invited presentation by Neves.

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A Data Flow Computer Architecture for Vector Processing Applications

This research deals with the design and implementation of an array processor that handles vector data using an approach that is typical of static data flow architectures. The processor embodies a packet communication architecture. An instruction packet in a memory block becomes enabled or completed when it has received its operands and various acknowledge signals. Enabled packets travel through small switching networks to functional units that produce result operands. These operands are sent to incomplete instruction packets in the memory blocks by passing through a large distribution network. When these packets are completed, the cycle continues. Extensive parallel execution can result when many packets are concurrently active.

While high performance should be achievable using data flow design principles, it is undeniable that there is a significant amount of execution time, memory space and machine complexity that must be devoted to the processing of the various enabling conditions done prior to the execution of the instruction packets. If this overhead activity must be carried out for each individual operation (treated as a scalar operation), then it is difficult to achieve cost effective performance unless one has "fat" data flow graphs (i.e., a high amount of algorithmic concurrency).

In the proposed design, the data flow principle is applied to vector operations, scalars being handled in a more conventional fashion. This has two immediate benefits. Vectors are processed using the latest and relatively inexpensive, floating point chips and using data flow principles, most of the concurrent vector processing in an algorithm can be efficiently handled, overhead activity being amortized over the many elements of the vector.

Finally, this presentation will discuss the facilities that will allow interconnections of many processor "nodes" to create larger systems for large scientific applications.

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A new algorithm for parallel iteration towards all the zeros of a complex polynomial

A new parallel algorithm is given for obtaining simultaneously all the zeros of a complex polynomial. The convergence of the algorithm is of order 3 for simple zeros. By taking advantage of the special property of the algorithm, a method is obtained for accelerating the slow convergence in the case of multiple zeros. It is proved that the acceleration procedure will produce almost as rapid convergence as in the case of simple zeros. The numerical performance of the method is compared with those of the existing parallel algorithms such as the Durand-Kerner method and the Aberth method and it is shown that the new method is much more advantageous in both accuracy and speed over the other methods.

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Algorithm Independent Topological Requirements For Numerical Simulations

Algorithm independent topological requirements for the computation of approximate solutions to partial differential equations will be presented. Finite domains of dependence exist and can be estimated if a finite error tolerance is explicitly introduced. Computation required directional data flow rates can then be computed. In terms of these quantities lower bounds for "optimal algorithms" can be computed, optimal data transmission capability for given processor power can be estimated, and the best way to dissect a problem for concurrent or vector processing can be identified.

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Solution of Linear Systems Using Inner Product Architecture

Solution of large sets of simultaneous equations using conventional Gaussian elimination is limited in speed by memory references rather than adds and multiplies on high-speed parallel machines designed for fast vector inner products. This paper describes a method for removing this limitation by using a variant of LU factorization to obtain highly efficient use of a parallel-pipeline inner product architecture. An implementation of this method is discussed in which profile sparsity is exploited, and disk storage functions as a user-transparent extension of memory. Examples are given demonstrating that a factor of from 2 to 5 speedup is obtainable compared with conventional methods on the same machine.

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