Induced Dimension Reduction method for solving linear matrix equations

Reinaldo Astudillo - Delft University of Technology
The fortieth Woudschoten Conference

IDR(s) was originally developed for solving:

\[ Ax = b. \]

We generalized the IDR(s) method to solve:

- \( AX + XA^T = C \)
- \( Ax = b \) and \( A^T \bar{x} = \bar{x} \)
- \( AXB = C \)
- \( AX + XB = C \)
- \( AX + BXD = C \)
- \( "u" = f " \)

- Including preconditioning.
- Examples from CFD and Helmholtz equation.
- Implementation in Fortran, Matlab, Python, and Julia.
A generalization of the Proper Orthogonal Decomposition method for nonlinear model-order reduction

Manuel Baumann, Jan Heiland, Michael Schmidt
Analytical solutions describing tidal conversion over ocean ridges

Felix Beckebanze, Mathematical Institute, Utrecht University

Diagram showing barotropic tidal flow and internal waves propagating away.
I told you!

Use **SIMULATED ANNEALING**
and
**SPLITTING**

BLACKOUT!!
Fast solvers for fluid-structure interaction

David Blom
Delft University of Technology
Validated Exponential Analysis

Exploit Aliasing

Advantages:
- Smaller Parallel Systems
- Better Conditioning
- Frequency Validation
- Noise Subspace Separation

Some possible applications of Sub-Nyquist sampling:
- Nuclear Magnetic Resonance Spectroscopy
- Harmonics Separation in Audio Signal Processing
- Vibration Analysis

Matteo Briani
Annie Cuyt
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hpGEM: Software Library for Discontinuous and Conforming Finite Element Methods

Freekjan Brink, Anthony Thornton, Jaap van der Vegt
University of Twente

hpGEM offers:

• Fast and efficient implementation of finite element methods,
• Coupling with mesh generation and plotting software,
• Mixed mesh support,
• Applications: Water waves, Maxwell equations, granular flows, etc.

Source code, detailed information and full authors list available at hpGEM.org
Accurate Modeling of Light Propagation inside Photonic Crystals

Devashish¹,², Freekjan Brink¹, Willem L. Vos², Jaap van der Vegt¹
¹ = Mathematics of Computational Science (MACS), University of Twente
² = Complex Photonic Systems (COPS), University of Twente

Aim
To develop a fast and parallelized discontinuous Galerkin finite-element (DGFEM) eigenvalue solver for the time-harmonic Maxwell equations.

Photonic Crystals
◆ Natural or artificial materials with spatial periodicity in the dielectric coefficient.
◆ Light propagation inside photonic crystals is described by the time-harmonic Maxwell equations.
Physics-based preconditioners for large-scale subsurface flow simulation.

Gabriela Berenice Díaz Cortés

Prof. Kees Vuik
Prof J.D. Jansen

TU Delft

SPE 10
Optimization of Chaotic systems

Calculate sensitivity of statistical averages of chaotic systems

Example: Lorenz system

\[ \langle z \rangle \propto \rho \]

Using variational equations:

Using least squares shadowing:
Efficient CFD simulations of vortex generator induced flow phenomena

**Problem:**

Body-fitted mesh simulations infeasible due to large scale difference

→ **Mimic effect of vortex generator on flow by source term in governing equations**

- Analysis of existing model
- Calculation of optimal source term with adjoint approach
- Turbulence models (RANS)

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Fig: Vorticity contours colored according to turbulent kinetic energy levels.
Approximating $\|f(A)\|_2$

with inexact Lanczos bidiagonalization

Sarah W. Gaaf
TU/e
Numerical methods for decoupled forward-backward SDEs in finance

Z. van der Have    C.W. Oosterlee

Delft University of Technology, Delft
Centrum Wiskunde & Informatica, Amsterdam

October 7-9, 2015
Block preconditioner for finite volume methods used in maritime CFD

Xin He and Kees Vuik

Delft Institute of Applied Mathematics, Delft University of Technology, Netherlands

Pressure coefficient obtained on model scale tanker
Elephant Herd Algorithm for multi-modal optimization

Ajinkya Kadu, Mritunjay Prasad, R. P. Shimpi
Parallel time integration of nonlinear partial differential equations

Gijs L. Kooij*
Mike A. Botchev
Bernard J. Geurts

Burgers’ equation \((u_t + uu_x = \nu u_{xx})\)

![Graph showing speedup versus time-parallel processes](image)

**Time**

**Space**

- Process 1
- Process 2
- Process 3
- \(\ldots\)
A nearly optimal Chebyshev method for inertial waves

Anna Kruseman, Utrecht University
Computation of Interface Velocities in the incompressible Navier-Stokes equations using Local BVPs

Nikhil Kumar, Jan ten Thije Boonkkamp, Barry Koren

Centre for Analysis, Scientific computing and Applications
Department of Mathematics and Computer Science
Eindhoven University of Technology
Data assimilation: finding a compromise between observations and current model state estimates

Usually consists of cleverly weighted averaging

However, model geometry influences statistics

We want to improve data assimilation methods using model geometry, such as conservation laws and dynamical structure
We developed a Parallel Variable Block Algebraic Recursive Multilevel solver for distributed memory computers.

Excellent performance and strong parallel scalability of our solver were achieved from solving Computational Fluid Dynamics applications matrices.
Optics on phase space and Liouville's equation

- Much light is wasted!
- Need better optics.
- Ray tracing is slow (and boring).
- Idea: use Liouville's equation.

Bart van Lith
An Uzawa smoother for the multigrid method has been introduced.

LFA analysis helps to determine each component of multigrid method.

To improve the convergence performance, acceleration of multigrid by iterant recombination scheme is taken into account.
Temporal Oscillations in the simulation of Foam Enhanced Oil Recovery

Jakolien van der Meer¹, Matthias Möller¹, Hans Kraaijevanger², Hans Groot², Johan Romate², Jan Dirk Jansen¹,
¹TU Delft, ²Shell Rijswijk

Figure: Oscillations due to generation of foam for different grid resolutions.
An Implicit Earth System Model of Intermediate Complexity

Erik Mulder
IMAU
Drift-diffusion-reaction model for the electron beam interaction with dielectric samples

Behrouz Raftari, Neil Budko and Kees Vuik

Delft Institute of Applied Mathematics
Delft University of Technology
Delft, the Netherlands

Woudschoten Conference 2015

\[-\nabla \cdot (\varepsilon \nabla V) = \frac{q}{\varepsilon_0} (p + p_t - n - n_t)\]

\[\frac{\partial n}{\partial t} + \nabla \cdot (-D_n \nabla n + \mu_n n \nabla V) = U + S_n - \frac{\partial n_t}{\partial t} = \sigma_n v_{th}(N_n - n_t)(n - n_i) - \gamma_n n_t\]

\[\frac{\partial p}{\partial t} + \nabla \cdot (-D_p \nabla p - \mu_p p \nabla V) = U + S_p - \frac{\partial p_t}{\partial t} = \sigma_p v_{th}(N_p - p_t)(p - n_i) - \gamma_p p_t\]
Fast, High Volume Infiltration

Menel Rahrah

Fred Vermolen

Kees Vuik

Delft University of Technology
Multilevel Monte Carlo Methods for Problems in Uncertainty Quantification

Pieterjan Robbe
A Regularization Method For Phase Contrast Computed Tomography

We solve the resulting linear system via Tikhonov regularization:

$$\min_x \| b - Ax \|^2_2 + \lambda \| x \|^2_2$$

$\lambda$ is chosen iteratively based on the discrepancy principle.

$A$ is the product of a finite difference operator & the original projection matrix for absorption contrast tomography.

Can lead to higher contrast reconstructions in various applications.
Anticipatory interaction scheme for moving rigid bodies in free-surface flow

The response of the ship is anticipated in the boundary conditions of the fluid

ir. Henk Seubers
Johann Bernoulli Institute

Rijksuniversiteit Groningen
Symmetry-preserving subgrid-scale models for large-eddy simulation of turbulent flows

- Continuous level
- Discrete level
A Highly Parallel Code for Strongly Coupled Fluid-Transport Equations
W. Song (RUG & DLR), F. W. Wubs (RUG), J. Thies (DLR)

Hybrid direct/iterative multi-level linear solver:
Parallel, scalable, robust...

-Eigen pairs computation
-Bifurcation analysis
Block GMRES-DR method for linear systems with multiple shifts and multiple right-hand sides

Dong-Lin Sun (UESTC, RUG), Ting-Zhu Huang (UESTC), Yan-Fei Jing (UESTC), Bruno Carpentieri (RUG)

- We proposed a new shifted block GMRES method for solving linear systems with multiple shifts and multiple right-hand sides.

- In our method, we augment the space with directions associated with some approximations of selected eigenvalues and solve the multiple linear systems simultaneously.

- Moreover, the seed selection strategy is employed to improve the performance of our method.
Speeding Up Monte Carlo Simulation Using An Emulator

A.K. Tyagi, W.H.A. Schilders, X. Jonsson, T.G.J. Beelen

Center for Analysis, Scientific Computing and Applications (CASA),
Mentor Graphics®, Grenoble (FR)
Let us consider the following controlled HJB PDE [Avellaneda et al. 1995]

$$\frac{\partial V}{\partial t} - \inf_{\sigma \in [\sigma_{\text{min}}, \sigma_{\text{max}}]} \left( \frac{\sigma^2}{2} S^2 \frac{\partial^2 V}{\partial S^2} + (r - D) S \frac{\partial V}{\partial S} \right) + rV = 0, (S, t) \in R_+ \times (0, T]$$

with butterfly payoff: $h(S) = \max(S - K_1, 0) - 2 \max(S - K, 0) + \max(S - K_2, 0)$

Formally differentiate with respect to $S$ and arrive at the BSB Delta PDE

$$\frac{\partial W}{\partial t} - \frac{\partial}{\partial S} \left( \inf_{\sigma \in [\sigma_{\text{min}}, \sigma_{\text{max}}]} \left( \frac{\sigma^2}{2} S^2 \frac{\partial W}{\partial S} + (r - D) SW \right) \right) + rW = 0, (S, t) \in R_+ \times (0, T]$$

with “digital” (disc.) payoff: $h(S) = H(S - K_1) - 2H(S - K) + H(S - K_2)$

where $W := V_S$ is the “Delta” Greek and $H(x)$ is the Heaviside function

Numerical analysis
BSB “Delta” PDE
Fitted finite volume scheme
Strong-stability preserving [1]

- Spatial discretization by fitted flux optimization
- Higher-order monotone Runge-Kutta time-marching
- Monotonicity and consistency analysis
- Generalized to the case of uncertain dividend yield and a general FVM [2]
- Comprehensive computational results

The battle of

Continuous
implicit,
larger time step,
global mass matrix,
impose symmetry of $T$

Discontinuous
explicit,
smaller time step,
local mass matrices,
exploit symmetry of $T$

finite elements to simulate elastic waves

\[
C^{-1} : \ddot{T} = 0.5 \left( \nabla \mathbf{v} + (\nabla \mathbf{v})^T \right)
\]

\[
\rho \ddot{\mathbf{v}} = \nabla \cdot \mathbf{T} + \mathbf{f}
\]

Steven Vandekerckhove, Hannes Vandecastelee
Automated parameters via outlier detection

Thea Vuik

Hyperbolic conservation, DG, Multiwavelets, Troubled cells, Limiting
Understanding Flow Slides in Flood Defences (MPM-Flow)

Lisa Wobbes

Więckowski (2013)
Convergence analysis of the Modified Craig–Sneyd scheme in 2 dimensions for nonsmooth initial data

40º Woudschoten Conferentie, October 2015

No Rannacher time stepping

Rannacher time stepping with four half–timesteps

Universiteit Antwerpen
Illumination Optics: Optimal Transport for Optical Design

N.K. Yadav, J.H.M. ten Thije Boonkkamp, W.L. IJzerman
VORtech

scientific software engineers, mathematical consultants

• A challenging environment for talented scientific software engineers, applied math.,
• Providing advanced knowledge and services to the market,
• Stimulating the development and application of computational science.