The Twentieth International Conference on Domain Decomposition Methods

San Diego Supercomputer Center
La Jolla, California 92093

February 7–11, 2011

Version Date: February 9, 2011

International Scientific Committee

Sponsors (click on image)

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Session Index

Schedule

M T W T F	Monday, February 7, 2011			
7:45-8:00	Opening Remarks: Chancellor Marye Anne Fox, Dean Mark Thiemens			
	Plenary P1 (Chair: Ralf Kornhuber)			
8:00-8:45	Harry Yserentant			
8:45-9:30	Thomas Hou			
9:30-10:00	Coffee Break			
10:00-12:00	Mini M8 B211-B212	Mini M15 B210	Mini M7 B143-B144	
	P. F. Antonietti B. Ayuso de Dios A. Barker E.-H. Park	M. Gander A. Sandu J. Diaz R. Haynes	E. P. Stephan R. Hiptmair G. Of M. Windisch	
12:00-1:30	Lunch			
	Plenary P2 (Chair: David Keyes)			
1:30-2:15	Charbel Farhat			
2:15-2:45	Coffee Break			
2:45-4:45	Mini M3 B211-B212	Mini M15 B210	Mini M6 B143-B144	Contributed C1 B145
	J. Xu J. Kraus J. Adler Y. Zhu	J. Rodríguez V. Lisitsa F. Haeberlein L. Halpern	H. Zhang R. Tezaur M. Guddati D. Neklyudov	D. Keyes P. Gosselet D. N. Wakam T. Dufaud M. B. Tran P. Krzyzanowski
5:15-6:30	Reception and Poster Session			

Author Index Session Index

M T W T F	Tuesday, February 8, 2011			
	Plenary P3 (Chair: Rob Falgout)			
8:00-8:45	Yvon Maday			
8:45-9:30	John Bell			
9:30-10:00	Coffee Break			
10:00-12:00	Mini M3 B211-B212	Mini M17 B210	Mini M10 B143-B144	Contributed C2 B145
	R. Hiptmair T. Kolev L. Grasedyck S. Zhang	D. Samaddar J. Salomon M. Gander B. Ong	Y. Courvoisier J.-F. Lee V. Dolean M. Huber	S. Zampini O. Steinbach C. Japhet Y. Wu M. Garbey M. Garbey
12:00-1:30	Lunch			
	Plenary P4 (Chair: Jeff Remmel)			
1:30-2:00	Michael Norman			
2:00-2:30	Richard C. J. Somerville			
2:30-3:00	J. Andrew McCammon			
3:00-3:30	Coffee Break			
3:30-5:30	Mini M3 B211-B212	Mini M17 B210	Mini M9 B143-B144	Contributed C3 B145
	J. Chen J. W. L. Wan G. Xue X. Hu	Y. Maday M. L. Minion S. Guettel X. Dai	A. St-Cyr S. Loisel F.-X. Roux X. Tu	S. Thirunavukkarasu C. Rey S. Beuchler A. Patel T. Dickopf Y. Boubendir

Author Index Session Index

M T W T F	Wednesday, February 9, 2011			
	Plenary P5 (Chair: Jinchao Xu)			
8:00-8:45	Robert Scheichl			
8:45-9:30	Long Chen			
9:30-10:00	Coffee Break			
10:00-12:00	Mini M3 B211-B212	Mini M12 B210	Mini M11 B143-B144	Contributed C4 B145
	G. Wittum Y. Chen R. Szypowski J.-H. Kimn	R. Krause T. Kouzbek J. Kruis J. Lee	Y. Vassilevski J. Willems A. Matsokin J. Galvis	I. Prokopyshyn S. Quraishi L. Marcinkowski F.-N. Hwang L. Laayouni L. F. Pavarino
12:00-1:30	Lunch			
	Plenary P6 (Chair: Ulrich Langer)			
1:30-2:15	Clark Dohrmann			
2:15-2:45	Coffee Break			
2:45-4:45	Mini M3 B211-B212	Mini M12 B210	Mini M11 B143-B144	Contributed C5 B145
	R. Falgout U. Yang Y. Chen J. Gaidamour	D. Lukáš A. Markopoulos A. Popp V. Vondrák	U. Langer L. Zikatanov C. Pechstein S. Nepomyaschikh	T.Huyen Dao M. Belonosov X.-C. Cai F. Lemarie M. Neumüller H. Berninger

Author Index Session Index

M T W T F	Thursday, February 10, 2011			
	Plenary P7 (Chair: Olof Widlund)			
8:00-8:45	Zdeněk Dostál			
8:45-9:30	Jun Zou			
9:30-10:00	Coffee Break			
10:00-12:00	Mini M2 B211-B212	Mini M14 B210	Mini M16 B143-B144	Mini M13 B145
	A. Alonso Rodriguez H. Li J. Gopalakrishnan R. Hoppe	A. Klawonn D.-S. Oh O. Rheinbach O. Widlund	V. Martin J. Ryan T. Arbogast O. Sander	R. Brower K. Kahl J. Cohen K. Kahl
12:00-1:30	Lunch			
	Plenary P8 (Chair: Harry Yserentant)			
1:30-2:15	Wolfgang Dahmen			
2:15-2:45	Coffee Break			
2:45-5:05	Mini M2 B211-B212	Mini M1 B210	Mini M16 B143-B144	Contributed C6 B145
	M. Sarkis Y. Huang L. Chen H. Nguyen	F. Nataf R. Tuminaro I. Yamazaki E. Agullo	R. Kornhuber L. Gastaldi P. Gervasio M. Discacciati	J. Leskinen V. Martin R. Chen E. Chacon Vera T. Sassi H. H. Kim B. Eguzkitza
7:00-10:00	Banquet			

Author Index Session Index

M T W T F	Friday, February 11, 2011			
	Plenary P9 (Chair: Petter Bjørstad)			
8:00-8:45	Victorita Dolean			
8:45-9:30	Xuejun Xu			
9:30-10:00	Coffee Break			
	Mini M2	Mini M5	Mini M18	Mini M19
10:00-12:00	B211-B212	B210	B143-B144	B145
	K. Wang	D. Barajas	X.-C. Cai	F. Kwok
	L.-Y. Sung	E. Rosseel	A. Nägel	M.-B. Tran
	P. Sun	W. Subber	C. Groß	O. Sander
	Y. Zhu	E. Ullmann	B. Gmeiner	K. Santgini
12:00	Close of Conference			

Author Index   Session Index

Plenary Lectures P1

Schedule Author Index Session Index

Date: Monday, February 7
Time: 8:00-9:30
Location: SDSC Auditorium
Chairman: Ralf Kornhuber

8:00-8:45 : Harry Yserentant
Multi-level decompositions of electronic wave functions
Abstract

8:45-9:30 : Thomas Hou
A Data-Driven Stochastic Multiscale Method
Abstract

Multi-level decompositions of electronic wave functions

Session Schedule Author Index Session Index

Harry Yserentant
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Abstract

The electronic Schrödinger equation describes the motion of N electrons under Coulomb interaction forces in a field of clamped nuclei and is of fundamental importance for our understanding of atoms and molecules. The solutions of this equation, the electronic wave functions, depend on $3N$ variables, three spatial dimensions for each electron. Approximating them is thus inordinately challenging, and it is conventionally believed that a reduction to simplified models, such as those of the Hartree-Fock method or density functional theory, is the only tenable approach. We indicate why this conventional wisdom need not to be ironclad: the unexpectedly high regularity of the solutions, which increases with the number of electrons, the decay behavior of their mixed derivatives, and their antisymmetry enforced by the Pauli principle contribute properties that allow these functions to be approximated with an order of complexity which comes arbitrarily close to that for a system of two electrons. The approximation schemes are based on multi-level decompositions of the corresponding function spaces, similar to those used in sparse grid methods. It is even possible to reach almost the same complexity as in the one-electron case adding a simple regularizing factor that depends explicitly on the interelectronic distances.

A Data-Driven Stochastic Multiscale Method

Session Schedule Author Index Session Index

Thomas Hou
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Abstract

We introduce a data-driven stochastic multiscale method to solve stochastic PDEs. The main idea is to find a sparse representation of the stochastic solution by constructing multiscale stochastic basis from limited samples of the stochastic solutions obtained by Monte Carlo simulations. For multiscale problems with small correlation lengths in some localized regions, we first partition the physical domain into appropriate subdomains so that the stochastic solution has a comparable correlation length within each of these subdomains. This multiscale method effectively reduces the dimension of the stochastic PDEs. As a consequence, we reduce the high dimensional stochastic problem to a relatively small number of coupled deterministic PDEs for the coefficients. Statistic property of the solution can be recovered from the solutio sof these coupled deterministic PDEs. One important advantage of this method is that the stochastic basis obtained in the offline computation can be used repeatedly in online computation for a large class of stochastic problems with different deterministic forcing coefficients or boundary conditions. Some numercal results will be presented to demonstrate the effectiveness of the method. This is a joint work with Mulin Cheng and Mike Yan.

Plenary Lectures P2

Schedule Author Index Session Index

Date: Monday, February 7
Time: 1:30-2:15
Location: SDSC Auditorium
Chairman: David Keyes

1:30-2:15 : Charbel Farhat
A Domain Decomposition Method with a Proper Orthogonal Decomposition-Based Augmented Conjugate Gradient Algorithm for Nearby Problems
Abstract

A Domain Decomposition Method with a Proper Orthogonal Decomposition-Based Augmented Conjugate Gradient Algorithm for Nearby Problems

Session Schedule Author Index Session Index

Charbel Farhat
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Abstract

A novel domain decomposition (DD) method is presented for the fast solution of consecutive linear or linearized systems of equation of the form $A_i x_i = b_i$, where A_i are nearby symmetric positive definite matrices. Such systems arise in many engineering applications, particularly in optimization. This DD method is based on a preconditioned conjugate gradient algorithm where the usual Krylov subspace is augmented with a proper orthogonal decomposition subspace which approximately minimizes the orthogonal projection error of the solution, thereby accelerating convergence. This proposed methodology is effectively a model reduction scheme, as it efficiently computes approximate states and sensitivities in the sum of two subspaces. The resulting reduced-order model is well-suited for optimization settings because its accuracy is continually improved as the optimum is approached. The scalable performance of the proposed DD method is demonstrated with a direct sensitivity analysis of a parameterized V-22 tiltrotor wing panel.

Plenary Lectures P3

Schedule Author Index Session Index

Date: Tuesday, February 8
Time: 8:00-9:30
Location: SDSC Auditorium
Chairman: Rob Falgout

8:00-8:45 : Yvon Maday
Parareal Algorithm, Basics and New Contributions
Abstract

8:45-9:30 : John Bell
Parallel Algorithms for Multiphysics Adaptive Mesh Refinement
Abstract

Parareal Algorithm, Basics and New Contributions

Session Schedule Author Index Session Index

Yvon Maday
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Abstract

The parareal algorithm is a domain decomposition like method where the "domain" is the related to time. It leads to the definition of different independent initial value evolution problems that are solved over each time subdomain and the challenge is to discover the proper initial conditions so that a global propagation is simulated. These proper initial conditions are discovered iteratively through a predictor corrector procedure. In this talk we shall introduce the parareal algorithm, the basics feature, the weaknesses and the different contributions that have been proposed recently to circumvent them. We shall give extensive details on the adaptation of the algorithm for long time propagation of Hamiltonian systems and on the coupling of the parareal with Schwarz type algorithms in the construction of a global space time domain decomposition method. We shall also give some illustrations of some of the presentations that will be detailed in the minisymposium on the subject that is organized latter in the day.

Parallel Algorithms for Multiphysics Adaptive Mesh Refinement

Session Schedule Author Index Session Index

John B. Bell
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Abstract

Adaptive Mesh Refinement (AMR) is an effective tool for the solution of partial differential equations, often requiring far fewer computational resources than equivalently resolved non-adaptive approaches. Block-structured AMR algorithms, originally developed for gas dynamics, are now used in a number of multiphysics applications. In this talk we will outline a basic framework for discretizing PDEs on a block-structured adaptive mesh and discuss how to use those building blocks to develop more complex applications. We will then describe a hybrid parallelization strategy for these types of algorithms that combines MPI to distribute large blocks of data to nodes with a thread-based model for fine-grained parallelism within each block. Additional issues involving load balancing, data distribution and non-numerical metadata manipulations will also be discussed. Illustrations for the methodology will be drawn from combustion, astrophysics and subsurface flow.

Plenary Lectures P4

Schedule Author Index Session Index

Date: Tuesday February 8
Time: 1:30-3:00
Location: SDSC Auditorium
Chairman: Jeff Remmel

1:30-2:00 : Michael Norman
Extreme Scale AMR for Hydrodynamic Cosmology
Abstract

2:00-2:30 : Richard C. J. Somerville
Evaluating a Global Climate Model with Superparameterized Clouds
Abstract

2:30-3:00 : J. Andrew McCammon
Computer-aided Drug Discovery: From the Molecule to the Cell
Abstract

Extreme Scale AMR for Hydrodynamic Cosmology

Session Schedule Author Index Session Index

Michael L. Norman
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Abstract

Cosmological simulations present well-known difficulties scaling to large core counts because of the large spatial inhomogeneities and vast range of length scales induced by gravitational instability. These difficulties are compounded when baryonic physics is included which introduce their own multiscale challenges. In this talk I review efforts to scale the Enzo adaptive mesh refinement hydrodynamic cosmology code to $O(10^5)$ cores, and I also discuss Cello–an extremely scalable AMR infrastructure under development at UCSD for the next generation of computer architectures which will underpin petascale Enzo.

Evaluating a Global Climate Model with Superparameterized Clouds

Session Schedule Author Index Session Index

Richard C. J. Somerville
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Abstract

Like many computationally challenging problems in the physical sciences, climate modeling involves a very wide range of characteristic scales. The effects of small-scale phenomena and processes, such as those associated with clouds, are critical to the large-scale climate. Hence, climate modelers have long sought a Holy Grail in the form of statistical parameterizations, which are algorithms for representing the ensemble effects of these small-scale processes, calculable as explicit functions of the large-scale computed fields of variables such as winds, humidities and temperatures. The parameterizability assumption that adequate parameterizations of this type exist is unproven. We show that an alternative formulation, the Multiscale Modeling Framework (MMF) approach to climate modeling, results in improved simulations of important aspects of climate variability. The MMF approach relies on the use of superparameterizations, which involve running a small number of limited-domain cloud-resolving models inside the GCM. An MMF is thus a conventional Global Climate Model (GCM) in which high-resolution superparameterizations replace conventional statistical parameterizations. In other words, MMFs represent sub-grid cloud and boundary layer processes using a one- or two-dimensional array of nested cloud-resolving models located in each large-scale GCM grid volume. The MMF and GCM compared in this study are identical except for this difference. They were developed under CMMAP, the Center for Multiscale Modeling of Atmospheric Processes, an NSF Science and Technology Center. See www.cmmap.org for more information. Only a few MMFs exist. They are invariably not yet tuned for optimal realism, and their development is still in its infancy. MMFs are expensive computationally, typically about 200 times more demanding than a conventional GCM of the same large-scale spatial resolution. Nevertheless, this novel approach to climate modeling has a very promising future.

Computer-aided Drug Discovery: From the Molecule to the Cell

Session Schedule Author Index Session Index

J. Andrew McCammon
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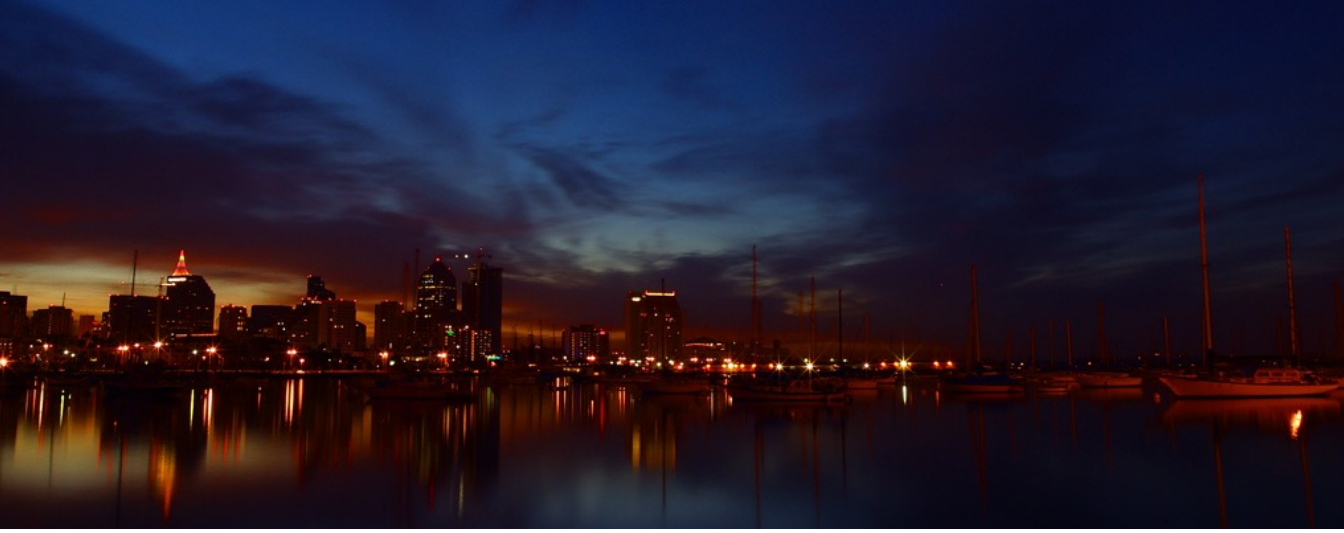
Abstract

The selective character of the binding and reactivity of key biological molecules is essential for life. Properly understood, such selectivity can be exploited in the design of drugs, novel antibodies or enzymes, sensors, or a host of other materials or devices. While early work in computational sructural biology focused largely on one or two molecules at a time, advances in theory and computers increasingly allow for larger-scale simulations of cellular activity. In particular, computational structural biology at the supramolecular level can be extended to large scales of space and time by the use of continuum models for biomolecules and their solvent surroundings. Models based on the Poisson-Boltzmann equation have been very successful in the analysis of electrostatic contributions to biomolecular recognition and assembly. Brownian dynamics and direct numerical solution of the diffusion equation allow for the simulation of time-dependent properties, such as molecular binding and conformational change, and transport within and among cells. Several examples of such studies will be presented, with special reference to neuronal activity.



Plenary Lectures P5

Schedule Author Index Session Index

Date: Wednesday February 9
Time: 8:00-9:30
Location: SDSC Auditorium
Chairman: Jinchao Xu

8:00-8:45 : Robert Scheichl
Weighted Poincare Inequalities and Applications in Multigrid/DD Analysis
Abstract

8:45-9:30 : Long Chen
Optimal Delaunay Triangulation
Abstract

Weighted Poincare Inequalities and Applications in Multigrid/DD Analysis

Session Schedule Author Index Session Index

Robert Scheichl
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Abstract

Poincaré type inequalities play a central role in the analysis of domain decomposition and multilevel iterative methods for second-order elliptic problems. When the diffusion coefficient varies within a subdomain or within a coarse grid element, then standard condition number bounds for these methods based on classical Poincaré inequalities are in general overly pessimistic. In this talk I will present new, weighted Poincaré type inequalities that lead to significantly sharper bounds, independent of any possible large variation in the coefficients. The Poincaré constants depend on the topology and the geometry of the coefficient variation, and we will study these dependencies in detail. The theoretical results provide a recipe for designing (hierarchies of) coarse spaces such that the condition number of the preconditioned system does not depend on the coefficient variation or on any mesh parameters (even in the case of standard geometric multigrid and for large variations of the coefficient within coarse grid elements). Numerical results illustrate the sharpness of the theoretical bounds and the necessity of the technical assumptions.

Optimal Delaunay Triangulation

Session Schedule Author Index Session Index

Long Chen
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Abstract

Optimal Delaunay triangulations (ODTs) are optimal meshes minimizing the interpolation error to a convex function in Lp norm. We shall present several application of ODT.

1. Mesh smoothing. Meshes with high quality are obtained by minimizing the interpolation error in a weighted L1 norm.
2. Anisotropic mesh adaptation. Optimal anisotropic interpolation error estimate is obtained by choosing anisotropic functions. The error estimate is used to produce anisotropic mesh adaptation for convection-dominated problems.
3. Sphere covering and convex polytope approximation. Asymptotic exact and sharp estimate of some constant in these two problems are obtained from ODT.
4. Quantization. Optimization algorithms based on ODT are applied to quantization to speed up the processing.

Plenary Lectures P6

Schedule Author Index Session Index

Date: Wednesday, February 9
Time: 1:30-2:15
Location: SDSC Auditorium
Chairman: Ulrich Langer

1:30-2:15 : Clark Dohrmann
Two Domain Decomposition Algorithms for Problems in H(curl)
Abstract

Two Domain Decomposition Algorithms for Problems in H(curl)

Session Schedule Author Index Session Index

Clark R. Dohrmann
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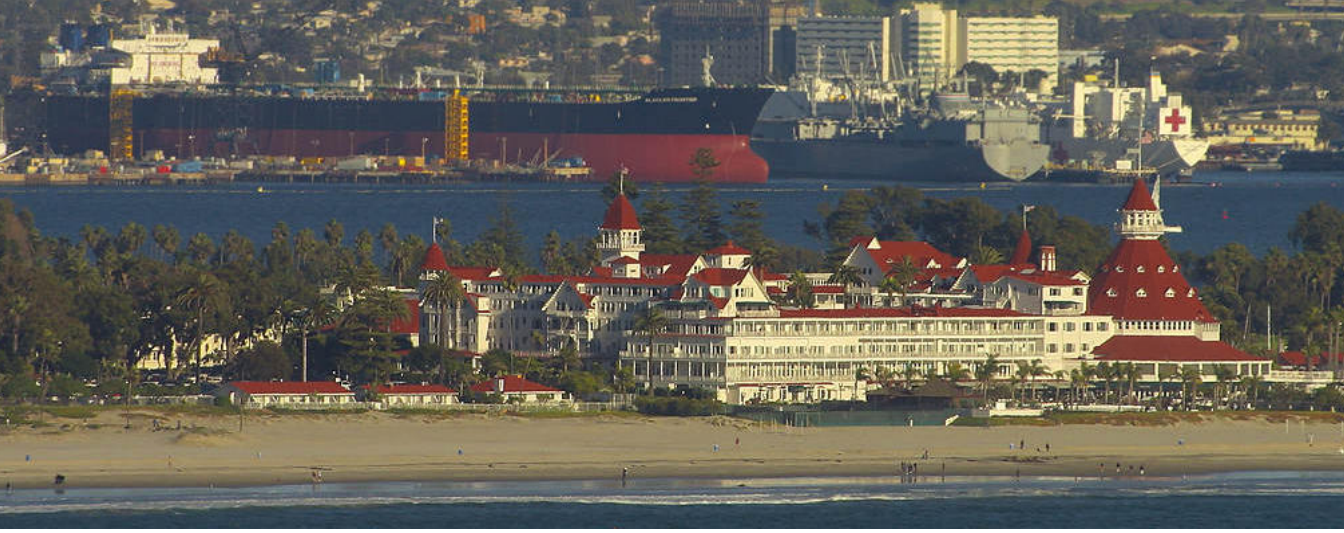
Abstract

We present two different domain decomposition algorithms for problems in the space $H(\text{curl};\Omega)$. The first one is for two-dimensional (2D) problems, and is similar to classical iterative substructuring approaches. It is defined in terms of a coarse space and local subspaces associated with individual edges of the subdomains into which the domain of the problem has been subdivided. The algorithm differs from others in three basic respects. First, it can be implemented in an algebraic manner that does not require access to individual subdomain matrices or a coarse discretization of the domain. Second, favorable condition number bounds can be established over a broader range of subdomain material properties than in previous studies. Third, we are able to develop theory for quite irregular subdomains and establish bounds for the condition number of our preconditioned conjugate gradient algorithm, which depend only on a few geometric parameters. The second algorithm presented is for three-dimensional (3D) problems. Like the first algorithm, it does not require individual subdomain matrices or a coarse discretization of the domain. The theory for the 3D algorithm is less comprehensive than its 2D counterpart, but a collection of numerical experiments indicates very good performance even for cases not covered by the theory. Numerical results are presented for both algorithms which confirm the theory and demonstrate the usefulness of the algorithms for a variety of mesh decompositions and distributions of material properties. The results presented in this talk were obtained in collaboration with Olof Widlund.



Plenary Lectures P7

Schedule Author Index Session Index

Date: Thursday February 10
Time: 8:00-9:30
Location: SDSC Auditorium
Chairman: Olof Widlund

8:00-8:45 : Zdeněk Dostál
Scalable FETI Based Algorithms for Contact Problems: Theory, Implementation, and Numerical Experiments
Abstract

8:45-9:30 : Jun Zou
Non-overlapping DD Preconditioners for Maxwell and PML Maxwell Systems in Non-homogeneous Media
Abstract

Scalable FETI Based Algorithms for Contact Problems: Theory, Implementation, and Numerical Experiments

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Abstract

We report the results of our research in development of the algorithms with both numerical and parallel scalability for the solution of contact problems of elasticity. Our talk covers 2D and 3D problems discretized by the finite element or boundary element method, possibly with "floating" bodies, including the multibody frictionless problems, both static and dynamic, and the problems with a given (Tresca) friction. A common feature of all the problems considered in our talk is a strong nonlinearity due to the interface conditions. Since even the algorithms for the solution of linear problems have the linear complexity at least, it follows that a scalable algorithm for contact problems has to treat the nonlinearity in a sense for free.

After introducing the variational inequalities that describe the equilibrium of a system of elastic bodies in mutual contact under the interface conditions considered in our talk, we briefly review the TFETI (total finite element tearing and interconnecting) based domain decomposition methodology adapted to the solution of contact problems of elasticity, including optimal estimates. Recall that TFETI differs from the classical FETI or FETI2 as introduced by Farhat and Roux by imposing the prescribed displacements by the Lagrange multipliers and treating all subdomains as "floating". Then we present our in a sense optimal algorithms for the solution of the resulting quadratic programming and QPQC (quadratic programming - quadratic constraints) problems. A unique feature of these algorithms

is their capability to solve the class of such problems with homogeneous equality constraints and separable inequality constraints in $O(1)$ matrix-vector multiplications provided the spectrum of the Hessian of the cost function is in a given positive interval [1], [2].

Finally we put together the above results to develop scalable algorithms for the solution of the above problems [3], [4],[5], [6], [7]. A special attention is paid to the construction of an initial approximation which is not far from the solution, so that the above results guarantee that the cost of the solution increases nearly proportionally with the dimension of the discretized problem and to effective implementation of generalized inverse matrices of floating subdomains. We illustrate the results by numerical experiments and by the solution of difficult real world problems, such as analysis the roller bearings in Figure 1 with 73 bodies under nonsymmetric loading. We conclude by a brief discussion of other results [8] and current research.

Figure 1. *Roller bearings of wind generator*

1. Z. Dostál, *Optimal Quadratic Programming Algorithms, with Applications to Variational Inequalities*, 1st edition, Springer US, New York 2009, SOIA 23.

2. Z. Dostál and T. Kozubek, *An optimal algorithm with superrelaxation for minimization of a quadratic function subject to separable spherical constraints with applications*, submitted.

3. Z. Dostál, T. Kozubek, V. Vondrák, T. Brzobohatý, A. Markopoulos, *Scalable TFETI algorithm for the solution of multibody contact problems of elasticity.* International Journal for Numerical Methods in Engineering, 82, No. 11, 1384-1405 (2010).

4. J. Bouchala, Z. Dostál, M. Sadowská, *Scalable Total BETI based algorithm for 3D coercive contact problems of linear elastostatics*, Computing, 85(2009) 189-217. IF 0.881

5. M. Sadowská, Z. Dostál, T. Kozubek, J. Bouchala, and A. Markopoulos, *Scalable Total BETI based solver for 3D multibody frictionless contact problems in mechanical engineering.* Submitted.

6. Z. Dostál, T. Kozubek, A. Markopoulos, T. Brzobohatý, V. Vondrák, P. Horyl, *Scalable TFETI algorithm for two dimensional multibody contact problems with friction*, accepted in Journal of Computational and Applied Mathematics.

7. Z. Dostál, T. Kozubek, A. Markopoulos, T. Brzobohatý, V. Vondrák, P. Horyl, *Theoretically supported scalable TFETI algorithm for the solution of multibody 3D contact problems with friction*, submitted.

8. V. Vondrák, T. Kozubek, Z. Dostál, *Parallel solution of contact shape optimization problems based on Total FETI domain decomposition method*, Engineering Optimization, accepted.

Non-overlapping DD Preconditioners for Maxwell and PML Maxwell Systems in Non-homogeneous Media

Session Schedule Author Index Session Index

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Abstract

In this talk we will discuss some new non-overlapping DD preconditioners for three-dimensional Maxwell systems and PML Maxwell systems in non-homogeneous media. Conditioning estimates of the preconditioned systems will be addressed, and some novel technical tools will be introduced for the analysis. Numerical experiments are also presented to demonstrate the effectiveness of the preconditioners in terms of the finite element mesh size and subdomain size as well as the jumps of material coefficients. This is a joint work with Qiya Hu (Chinese Academy of Sciences) and Shi Shu (Xiangtan University).

Plenary Lectures P8

Schedule Author Index Session Index

Date: Thursday February 10
Time: 1:30-2:15
Location: SDSC Auditorium
Chairman: Harry Yserentant

1:30-2:15 : Wolfgang Dahmen
Robust Preconditioners for DG-Discretizations with Arbitrary Polynomial Degrees on Locally Refined Meshes
Abstract

Robust Preconditioners for DG-Discretizations with Arbitrary Polynomial Degrees on Locally Refined Meshes

Session Schedule Author Index Session Index

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Martin Campos Pinto
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Abstract

Attractive features of Discontinuous Galerkin (DG) discretizations are their applicability for a variety of different problem types as well as their flexibility regarding local mesh refinement and even locally varying polynomial degrees. While initially the main focus has been on transport problems like hyperbolic conservation laws considerable interest has meanwhile shifted towards diffusion problems. This talk is therefore concerned with DG discretizations for elliptic boundary value problems. In particular, we focus on the efficient solution of the linear systems of equations arising from the Interior Penalty Discontinuous Galerkin method. The central objective is to develop preconditioners that, under mild grading conditions, give rise to uniformly bounded condition numbers even for locally refined grids with hanging nodes and arbitrary polynomial degrees. In particular, spectral discretizations on a fixed partition are covered as a special case. As a conceptual framework we employ the auxiliary space method in combination with techniques from spectral element methods. The main difficulties turn out to be caused by varying polynomial degrees around a hanging node. We indicate some of the ideas how to overcome these obstructions. The performance of the key ingredients are illustrated by first numerical experiments.

Plenary Lectures P9

Schedule Author Index Session Index

Date: Friday February 11
Time: 8:00-9:30
Location: SDSC Auditorium
Chairman: Petter Bjørstad

8:00-8:45 : Victorita Dolean
Preconditioning Methods for PDE Systems Using Algebraic Tools
Abstract

8:45-9:30 : Xuejun Xu
Local Multilevel Method and Its Applications
Abstract

Preconditioning Methods for PDE Systems Using Algebraic Tools

Session Schedule Author Index Session Index

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Abstract

The purpose of this work is the use of algebraic and symbolic techniques such as Smith normal forms and Grobner basis techniques in order to develop new Schwarz algorithms and preconditionners for linear systems of partial differential equations (PDEs). This work is motivated by the fact that in some sense these methods applied systems of partial differential equations (such as Stokes, Oseen, linear elasticity) are less optimal than the domain decomposition methods for scalar problems. Indeed, in the case of two subdomains consisting of the two half planes it is well known, that the Neumann-Neumann preconditioner is an exact preconditioner for the Schur complement equation for scalar equations like the Laplace problem. A preconditioner is called exact, if the preconditioned operator simplies to the identity. Unfortunately, this does not hold in the vector case. In order to achieve this goal we use algebraic methods developed in constructive algebra, D-modules (differential modules) and symbolic computation such as the so-called Smith or Jacobson normal forms and Grobner basis techniques for transforming a linear system of PDEs into a set of independent scalar PDEs. Decoupling linear systems of PDEs leads to the design of new numerical methods based on the effcient techniques dedicated to scalar PDEs (e.g., Laplace equation, advection- diffusion equation). Moreover, these algebraic and symbolic methods provide important intrinsic information (e.g., invariants) about the linear system of PDEs to solve which need to be taken into account in the design of new numerical methods which can supersede the usual ones based on a direct extension of the classical scalar methods to the linear systems.

Local Multilevel Method and Its Applications

Session Schedule Author Index Session Index

Xuejun Xu
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Abstract

In this talk, we present a local multilevel algorithm for solving the linear algebraic systems arising from the adaptive continuous and discontinuous finite element methods. The abstract Schwarz theory is applied to analyze the mul- tilevel method with Jacobi or Gauss-Seidel smoother performed on local nodes on each level. It is shown that the local multilevel method is optimal, which means that the convergence rate is independent of the mesh sizes and mesh levels. Furthermore, we will explore the local multilevel method for solving convection-diffusion equation and time-harmonic Maxwell equation. This talk is based on a joint work with Huangxin Chen and R. H. W. Hoppe.

Mini Symposium M1

Parallel Preconditioning Techniques Based on Algebraic Domain Decomposition

Schedule Author Index Session Index

Date: Thursday, February 10
Time: 2:45–4:45
Location: B210
Chairman: Luc Giraud, Jean Roman, Stéphane Lanteri

2:45-3:15 : Frederic Nataf
A Two Level Domain Decomposition Preconditionner Based on Local Dirichlet to Neumann Maps
Abstract

3:15-3:45 : Ray Tuminaro
A Quasi-Algebraic Multigrid Approach to Fracture Problems Based on Extended Finite Elements
Abstract

3:45-4:15 : Ichitaro Yamazaki
A Parallel Schur Complement Based Hybrid Solver for Highly-Indefinite Systems
Abstract

4:15-4:45 : Emmanuel Agullo
Algebraic Schwarz Preconditioning for the Schur Complement: Application to the Time-Harmonic Maxwell Equations Discretized by a Discontinuous Galerkin Method
Abstract

Abstract

One possible route to the design of high-performance, scalable solvers for large sparse linear systems is to combine iterative and direct methods. Such a hybrid iterative-direct approach exploits the advantages of both direct and iterative methods. The iterative component allows to use a small amount of memory and is naturally amenable to parallel implementation. The direct part provides its favorable numerical properties. Besides, this algorithmic hybridization also calls for a

hierarchical parallelization, combining a distributed memory oriented SPMD strategy for the iterative part, with a multi-threaded scheduling of the direct part. This minisyposimum will present some recent developements on hybrid iterative-direct solvers relying on domain decomposition principles but only exploiting the sparsity structure and entry magnitude of the matrix associated with the linear system to be solved. The talks in this minisymposium will address parallel preconditioning techniques for the Schur complement as well as algebraic Schwarz approaches.

A Two Level Domain Decomposition Preconditionner Based on Local Dirichlet to Neumann Maps

Session Schedule Author Index Session Index

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Abstract

Coarse grid correction is a key ingredient in order to have scalable domain decomposition methods. In this work we construct the coarse grid space using the low frequency modes of the subdomain DtN (Dirichlet-Neumann) maps, and apply the obtained two-level preconditioner to the linear system arising from an overlapping domain decomposition. Our method is suitable for the parallel implementation and its efficiency is demonstrated by numerical examples on problems with high heterogeneities.

A Quasi-Algebraic Multigrid Approach to Fracture Problems Based on Extended Finite Elements

Session Schedule Author Index Session Index

Ray Tuminaro
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Abstract

The modeling of discontinuities arising from fracture or damage poses a number of significant computational challenges. The extended finite element method provides an attractive alternative to standard finite elements in that they do not require fine spatial resolution in the vicinity of discontinuities nor do they require repeated re-meshing to properly address propagation of cracks. They do, however, give rise to linear systems requiring special care within an iterative solver method.

An algebraic multigrid method is proposed that is suitable for the linear systems associated with modeling fracture via extended finite elements. The new method follows naturally from an energy minimizing algebraic multigrid framework. The key idea is the modification of the prolongator sparsity pattern to prevent interpolation across cracks. This is accomplished by accessing the standard levelset functions used during the discretization process. Numerical experiments illustrate that the resulting method converges in a fashion that is relatively insensitive to mesh resolution and to the number of cracks or their location.

A Parallel Schur Complement Based Hybrid Solver for Highly-Indefinite Systems

Session Schedule Author Index Session Index

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Abstract

We introduce the Parallel Domain decomposition Schur complement method based Linear solver, or PDSLin for short. The code has been used to solve highly-indefinite linear systems of equations arising from large-scale simulations on thousands of processors, where a parallel direct or iterative solver often suffers from large memory or slow convergence. In this talk, we discuss techniques used in PDSLin to address the challenges when solving large-scale highly-indefinite linear systems.

Algebraic Schwarz Preconditioning for the Schur Complement: Application to the Time-Harmonic Maxwell Equations Discretized by a Discontinuous Galerkin Method

Session Schedule Author Index Session Index

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Abstract

We study parallel algebraic additive Schwarz preconditioning techniques for the Schur complement in the context of frequency domain electromagnetics. For that purpose, the system of 2D and 3D time-harmonic Maxwell equations in first order form is discretized using a discontinuous Galerkin method formulated on an unstructured tetrahedral mesh. The resulting large sparse non-Hermitian complex coefficient linear system is solved by a parallel algebraic domain decomposition method. More precisely, we consider numerical techniques based on a non-overlapping decomposition of the graph associated with the sparse matrix to solve a condensed system. Although the Schur complement system is usually more tractable than the original problem by an iterative Krylov subspace technique, preconditioning is still required. The numerical and parallel performances of several variants of parallel algebraic additive Schwarz preconditioners for the Schur complement will be illus-

trated. Furthermore, preliminary comparisons of this purely algebraic approach with a Schwarz algorithm tailored for the Maxwell equations will be presented.

Mini Symposium M2P1

Theory and Application of Adaptive and Multilevel Methods

Schedule Author Index Session Index

Date: Thursday, February 10
Time: 10:00-12:00
Location: B211-B212
Chairman: Blanca Ayuso, Long Chen, Jun Hu, and Ludmil Zikatanov

10:00-10:30 : Ana Alonso Rodriguez
Domain Decomposition Methods for Maxwell Equations
Abstract

10:30-11:00 : Hengguang Li
FEMs and MG Methods for Axisymmetric Problems on Polygonal Domains
Abstract

11:00-11:30 : Jay Gopalakrishnan
A Convergent Multigrid Algorithm for the HDG Method
Abstract

11:30-12:00 : Ronald Hoppe
Adaptive Finite Element Methods for Control and State Constrained Elliptic Optimal Control Problems
Abstract

Part II

Part III

Abstract

Multilevel and adaptive methods are two distinct classes of modern numerical methods for solving partial differential equations. The theories for both types of methods have been studied, essentially independently, for several decades. The studies of both these methods have been done to a large extend separately, but striking similarities in both the methodology and the analysis have begun to emerge. The goal of the mini-symposium is to bring together experts in adaptive finite element method or multigrid methods to discuss new questions at the foundation, overlap and application of these two research fields.

Domain Decomposition Methods for Maxwell equations

Session Schedule Author Index Session Index

Ana Alonso Rodriguez
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Abstract

The aim of the talk is to review some domain decomposition methods for the finite element approximation of the eddy current model in electromagnetism. Particular attention will be pay to the case of a non simply connected conductor. We will analyze formulations that consider as main unknown the same field in all the subdomains and also hybrid formulations that use different unknowns in different subdomains.

FEMs and MG Methods for Axisymmetric Problems on Polygonal Domains

Session Schedule Author Index Session Index

Hengguang Li
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Abstract

We shall discuss finite element and multigrid techniques solving the axisymmetric Poisson's equation and the azimuthal Maxwell problem on polygonal domains with possible singular solutions. In particular, we establish the well-posedness and regularity in some weighted Sobolev space for these problems and in turn, construct special finite element spaces (graded meshes) to approximate the solutions in the optimal rate. With a careful formulation, we also obtain uniform convergence of the MG methods on these meshes. These estimates can also be used to show the stability of the Taylor-Hood elements for the axisymmetric Stokes problem.

A Convergent Multigrid Algorithm for the HDG Method

Session Schedule Author Index Session Index

Jay Gopalakrishnan
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Abstract

The hybridizable discontinuous Galerkin (HDG) method is a relatively new DG method with favorable properties. But it does not fit into the unified theory of DG methods. We study the condition number of a condensed system arising from the HDG method and design a V-cycle solver yielding a uniform contraction. Along the way, we identify an abstract class of problems for which the non-nested V-cycle converges with one smoothing step even when the prolongation norm is greater than one.

Adaptive Finite Element Methods for Control and State Constrained Elliptic Optimal Control Problems

Session Schedule Author Index Session Index

Ronald H.W. Hoppe
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Abstract

We consider adaptive finite element methods for the numerical solution of optimal control problems for second order elliptic boundary value problems with pointwise constraints on the controls and/or the states. The mesh adaptivity is taken care of by both residual-type a posteriori error estimators and those derived by the application of the goal oriented dual weighted approach. The error estimation gives rise to residuals with respect to the associated optimality system, i.e., residuals associated with the state and the adjoint state as well as a primal-dual mismatch in complementarity which can be assessed via the computed finite element approximations. Numerical results are given to illustrate the performance of the suggested approaches.

The presented results are based on joint work with M. Hintermueller, M. Hinze, and M. Kieweg.

Mini Symposium M2P2

Theory and Application of Adaptive and Multilevel Methods

Schedule Author Index Session Index

Date: Thursday, February 10
Time: 2:45-4:45
Location: B211-B212
Chairman: Blanca Ayuso, Long Chen, Jun Hu, and Ludmil Zikatanov

2:45-3:15 : Marcus Sarkis
Robust Parameter-Free Multilevel Preconditioner for Boundary Elliptic Control Problems
Abstract

3:15-3:45 : Yunqing Huang
The Lower Bounds for Eigenvalues of Elliptic Operators By Nonconforming Finite Element Methods
Abstract

3:45-4:15 : Long Chen
Adaptive Finite Element Methods for H(curl) and H(div) Problems
Abstract

4:15-4:45 : Hieu Nguyen
Mesh Regularization in Parallel *hp*-Adaptive Meshing
Abstract

Part I

Part III

Abstract

Multilevel and adaptive methods are two distinct classes of modern numerical methods for solving partial differential equations. The theories for both types of methods have been studied, essentially independently, for several decades. The studies of both these methods have been done to a large extend separately, but striking similarities in both the methodology and the analysis have begun to emerge. The

goal of the mini-symposium is to bring together experts in adaptive finite element method or multigrid methods to discuss new questions at the foundation, overlap and application of these two research fields.

Robust Paramenter-Free Multilevel Preconditioner for Boundary Elliptic Control Problems

Session Schedule Author Index Session Index

Marcus Sarkis
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Etereldes Goncalves

Abstract

We propose and analyze a multilevel preconditioner for a linear-quadratic elliptic control problem. For the problem considered here, the control variable corresponds to the Neumann data on the boundary of a convex polygonal domain. The control variable is chosen such that the harmonic extension approximates an specified target. The main goal is to develop robust negative-norm multilevel splitting for a nonconforming discretization associated to this problem.

The Lower Bounds for Eigenvalues of Elliptic Operators By Nonconforming Finite Element Methods

Session Schedule Author Index Session Index

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Abstract

Finding eigenvalues of partial differential operators is important in the mathematical science. Since the exact eigenvalues are almost impossible, many papers and books investigate their bounds from above and below. It is well known that the variational principle (including the conforming finite element methods) provides the upper bounds, while there are no general theories to provide the lower bounds. The talk is to introduce a new systematic method that can produce the lower bounds for eigenvalues. More precisely, under three hypothesis on the nonconforming finite element spaces we first show the abstract error estimates of approximate eigenvalues and eigenfunctions. Subsequently, we propose a condition and prove that it is sufficient to guarantee the nonconforming finite element methods to produce the lower bounds for eigenvalues of the symmetric elliptic operators. We show that this condition holds for the most used nonconforming elements, e.g., the Wilson element, the nonconforming linear element by Crouzeix and Raviart, the nonconforming rotated Q_1 element by Rannacher and Turek, and the enriched nonconforming rotated Q_1 element by Lin, Tobiska and Zhou for the second order elliptic operators, the Morley element, the Adini element and the enriched Adini element by Hu and Shi for the fourth order elliptic operators, and the Morley-Wang-Xu element for the $2m$-th order elliptic operator. Whence they will give lower bounds for eigenvalues of these operators. Moreover, we follow the sufficient condition to propose two new classes of nonconforming elements for the second order elliptic operators and prove that they will yield the lower bounds for eigenvalues.

Adaptive Finite Element Methods for H(curl) and H(div) Problems

Session Schedule Author Index Session Index

Long Chen
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Abstract

We design adaptive finite element methods (AFEMs) for variational problems posed in the Hilbert spaces H(div) and H(curl) in two and three dimensions. The main difficulty is the large null space of curl or div operators and we solve it by using discrete regular decompositions and a novel stable and local projection operator. As a result, we obtain convergence and optimal complexity of our adaptive algorithms.

Mesh Regularization in Parallel hp-Adaptive Meshing

Session Schedule Author Index Session Index

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Randolph E. Bank
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Abstract

In 2003, Bank and Holst proposed a new parallel adaptive meshing paradigm that requires low communication and allows existing sequential adaptive finite element codes to run in parallel environment without much effort in recoding. In this approach, each processor is initially provided with the same coarse mesh of the whole domain, and then focuses its adaptive enrichment in its own subregion. In the end, the final solution is computed using a domain decomposition solver on the union of the refined partitions contributed by all the processors. As the adaptive enrichment is performed independently on each processor, local meshes need to be regularized to match to each other along their fine interfaces. When hp-adaptive meshing is used, the regularization need to be done in both h (geometry) and p (degree). In this talk, we will discuss how to make the local meshes conforming in both h and p along their interfaces. We will also discuss some regularization for the coarse parts of local meshes that help to improve the convergence of the domain decomposition solver.

Mini Symposium M2P3

Theory and Application of Adaptive and Multilevel Methods

Schedule Author Index Session Index

Date: Friday, February 11
Time: 10:00-12:00
Location: B211-B212
Chairman: Blanca Ayuso, Long Chen, Jun Hu, and Ludmil Zikatanov

10:00-10:30 : Kening Wang
An Iterative Substructuring Algorithm for C^0 Interior Penalty Methods
Abstract

10:30-11:00 : Li-Yeng Sun
Fast Solvers for the Biharmonic Problem with Boundary Conditions of the Cahn-Hilliard Type
Abstract

11:00-11:30 : Pengtao Sun
An Overlapping Domain Decomposition Method for a Polymer Exchange Membrane Fuel Cell Model
Abstract

11:30-12:00 : Yunrong Zhu
Convergence of Adaptive Finite Element for the Poisson-Boltzmann Equation
Abstract

Part I

Part II

Abstract

Multilevel and adaptive methods are two distinct classes of modern numerical methods for solving partial differential equations. The theories for both types of methods have been studied, essentially independently, for several decades. The studies of both these methods have been done to a large extend separately, but striking

similarities in both the methodology and the analysis have begun to emerge. The goal of the mini-symposium is to bring together experts in adaptive finite element method or multigrid methods to discuss new questions at the foundation, overlap and application of these two research fields.

An Iterative Substructuring Algorithm for C^0 Interior Penalty Methods

Session Schedule Author Index Session Index

Kening Wang
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Abstract

We study the Bramble-Pasciak-Schatz preconditioner for C^0 interior penalty methods for fourth order elliptic boundary value problems and show that the condition number of the preconditioned system can be bounded by $C(1 + \ln(H/h))^2$, where H and h are mesh sizes and the positive constant C is mesh-independent.

Fast Solvers for the Biharmonic Problem with Boundary Conditions of the Cahn-Hilliard Type

Session Schedule Author Index Session Index

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Thirupathi Gudi
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Abstract

In this talk we will discuss C 0 interior penalty methods for the biharmonic equation $\Delta^2 u = f$ with prescribed boundary values for $\partial u/\partial n$ and $\partial(\Delta u)/\partial n$. Such boundary conditions appear for example in the Cahn-Hilliard model for phase separation. We will also present adaptive methods and multigrid methods for the resulting discrete problems.

An Overlapping Domain Decomposition Method for a Polymer Exchange Membrane Fuel Cell Model

Session Schedule Author Index Session Index

Pengtao Sun
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Abstract

The structure of channels, material and operation parameters are usually implemented in different ways from anode to cathode in the actual work to seek better performance for PEMFC. However, the asymmetrical structure of this specific PEMFC design often leads to non-matching grids especially for structured grids. Besides, different mesh sizes are often used in the simulation for anode and cathode in order to obtain high accuracy. In this paper, an overlapping domain decomposition is designed to deal with the non-matching grids for two-dimensional single-phase PEMFC model. Numerical experiments demonstrate that our methods are able to deal with the non-matching grids with fast convergence but lower mass balance error.

Convergence of Adaptive Finite Element for the Poisson-Boltzmann Equation

Session Schedule Author Index Session Index

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Yongcheng Zhou
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Abstract

In this talk, we consider the design of an effective and reliable adaptive finite element method (AFEM) for the nonlinear Poisson-Boltzmann equation (PBE). We examine a three-term regularization technique which can be shown to be less susceptible to numerical instability. We establish a priori estimates and other basic results for the continuous regularized problem, as well as for Galerkin finite element approximations. We then design an AFEM scheme for the new regularized problem, and show that the resulting AFEM scheme is accurate and reliable, by proving a contraction result for the error. This result, which is one of the first results of this type for nonlinear elliptic problems, is based on using continuous and discrete a priori L^∞ estimates. The convergence and accuracy of the overall AFEM algorithm is also illustrated by numerical approximation of electrostatic solvation energy for an insulin protein.

Mini Symposium M3P1

Optimal Solvers from Multi-grid and Two-grid to One-grid and No-grid

Schedule Author Index Session Index

Date: Monday, February 7
Time: 2:45-4:45
Location: B211-B212
Chairman: Randolph E. Bank, Michael Holst, Jinchao Xu, Yunrong Zhu, Ludmil Zikatanov

2:45-3:15 : Jinchao Xu
An Overview of Optimal Solvers from Multi-grid and Two-grid to One-grid and No-Grid
Abstract

3:15-3:45 : Johannes Kraus
Auxiliary Space Preconditioner for Finite Element Elasticity Systems Obtained by Reduced Integration
Abstract

3:45-4:15 : James Adler
Multigrid Methods for Complex Fluids
Abstract

4:15-4:45 : Yunrong Zhu
Multilevel Preconditioners for Crouzeix-Raviart Discretization of Second Order Elliptic Equations with Jump Coefficients and Application to Discontinuous Galerkin Discretizations
Abstract

Part II

Part III

Part IV

Part V

Abstract

Multigrid methods are among the most efficient algorithms in solving large scale algebraic equations arising from discretized PDEs. They offer the possibility of optimal, with storage and work (nearly) linearly proportional to the number of unknowns, solution to a large class of problems. One drawback of the classic multigrid methods is that they may not be so user-friendly, namely they need the hierarchal space structure (or hierarchy of grids) which is usually unavailable in many applications.

The algebraic multigrid (AMG) methods, which often requires no-grid at all, are designed to overcome this drawback, because they use only the information from the algebraic equations. But due to the lack of geometric and analytic information from the underlying discretization, the efficiency and applicability of the gridless AMG are sometimes limited. One class of methods, which will fall into the category of one-grid method here, are to make use of geometric especially on the grid) and analytic (such as the qualitative PDE and discretization properties) information that are often readily available for the underlying discrete problems.

The classic domain decomposition (with or without overlapping) may fall into the category of two-grid or two-level methods in our teminology here. The two-grid methods also include techniques that can be used to facilitate the use of classic multigrid method, the gridless AMG method or one-grid method.

The purpose of this mini-symposium is to bring together experts in these four areas to discuss the design of algorithms and analysis of optimal solvers for a wide range of problems.

An Overview of Optimal Solvers from Multi-grid and Two-grid to One-grid and No-Grid

Session Schedule Author Index Session Index

Jinchao Xu
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Abstract

In this talk, I will give an overview of classic geometric "multi-grid" methods, "two-grid" methods for linearization, parallelization, decoupling and domain decomposition, "one-grid" methods for solving unstructured grid problems with (nearly) optimal computational complexity, and finally algebraic multigrid (AMG) methods that make use of "no-grid".

Auxiliary Space Preconditioner for Finite Element Elasticity Systems Obtained by Reduced Integration

Session Schedule Author Index Session Index

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Ludmil Zikatanov
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Abstract

In this talk we consider a stable finite element method of the equations of linear elasticity that has been introduced by R. Falk (R. Falk, Nonconforming finite element methods for the equations of linear elasticity. Math. Comp., 57(196), 1991, pp. 529550). This method uses so-called reduced integration techniques in order to overcome locking effects as they are observed when applying standard low(est) order conforming finite element methods to problems with incompressible materials. The focus of this work is on constructing uniform preconditioners for the linear systems arising from this discretization scheme. We introduce an auxiliary space method which consists in solving an auxiliary problem that involves a bilinear form on a larger auxiliary space. We discuss the details of the construction, derive spectral equivalence results based on the fictitious space lemma, and present numerical experiments.

Multigrid Methods for Complex Fluids

Session Schedule Author Index Session Index

James Adler
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Abstract

Complex fluid problems involve multi-physics and multi-scale phenomena that require advanced techniques in scientific computing in order to be solved efficiently. The complex fluid systems, such as multiphase flow and magnetohydrodynamics (MHD) yield time-dependent nonlinear systems of partial differential equations that couple a fluid with other internal properties (magnetic field in MHD and phase function in multiphase flow). In this talk, I will discuss the applications of various discretization methods and multilevel solvers to solve such systems of equations. The goal is to solve the systems as efficiently as possible, while approximating the physical properties of the system accurately. To accomplish this, tools such as nested iteration and adaptive refinement are used. In addition, the energetics of the system are considered in order to develop a more physically-tractable scheme. Finally, examples of solving various multiphase flow problems and, if time, MHD test problems using these methods will be given.

Multilevel Preconditioners for Crouzeix-Raviart Discretization of Second Order Elliptic Equations with Jump Coefficients and Application to Discontinuous Galerkin Discretizations

Session Schedule Author Index Session Index

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Ludmil Zikatanov
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Abstract

Efficient solvers for the Crouzeix-Raviart (CR) discretization are one of the main ingredients in designing solvers for DG discretizations of second order elliptic equations. In this talk, we propose simple preconditioners (both additive and multiplicative) for solving the CR discretization of second order elliptic equations with discontinuous coefficients. We simply decompose the CR space into conforming P_1 spaces and the remaining high frequencies in CR space, so the preconditioners are boiled down to a smoother on CR and conforming solvers. By construction, any robust and efficient solvers designed for conforming approximation could be used as a preconditioner here. We prove nearly optimal convergence and robustness (with respect to both the mesh size and the coefficient) for these preconditioners (up to a logarithmic term depending on the mesh size). We also present some numerical experiments to verify our theoretical results.

Mini Symposium M3P2

Optimal Solvers from Multi-grid and Two-grid to One-grid and No-grid

Schedule Author Index Session Index

Date: Tuesday, February 8
Time: 10:00-12:00
Location: B211-B212
Chairman: Randolph E. Bank, Michael Holst, Jinchao Xu, Yunrong Zhu, Ludmil Zikatanov

10:00-10:30 : Ralf Hiptmair
Auxiliary Space Methods for Edge Elements
Abstract

10:30-11:00 : Tzanio Kolev
Parallel Algebraic Multigrid for Electromagnetic Diffusion
Abstract

11:00-11:30 : Lars Grasedyck
Algebraic Multigrid Based on Clustering
Abstract

11:30-12:00 : Shuo Zhang
Poisson-based Optimal Solvers for Biharmonic Problems
Abstract

Part I

Part III

Part IV

Part V

Abstract

Multigrid methods are among the most efficient algorithms in solving large scale algebraic equations arising from discretized PDEs. They offer the possibility of

optimal, with storage and work (nearly) linearly proportional to the number of unknowns, solution to a large class of problems. One drawback of the classic multigrid methods is that they may not be so user-friendly, namely they need the hierarchal space structure (or hierarchy of grids) which is usually unavailable in many applications.

The algebraic multigrid (AMG) methods, which often requires no-grid at all, are designed to overcome this drawback, because they use only the information from the algebraic equations. But due to the lack of geometric and analytic information from the underlying discretization, the efficiency and applicability of the gridless AMG are sometimes limited. One class of methods, which will fall into the category of one-grid method here, are to make use of geometric especially on the grid) and analytic (such as the qualitative PDE and discretization properties) information that are often readily available for the underlying discrete problems.

The classic domain decomposition (with or without overlapping) may fall into the category of two-grid or two-level methods in our teminology here. The two-grid methods also include techniques that can be used to facilitate the use of classic multigrid method, the gridless AMG method or one-grid method.

The purpose of this mini-symposium is to bring together experts in these four areas to discuss the design of algorithms and analysis of optimal solvers for a wide range of problems.

Auxiliary Space Methods for Edge Elements

Session Schedule Author Index Session Index

Ralf Hiptmair
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Abstract

Auxiliary space preconditioning targets elliptic boundary value problems discetized by means of finite elements. The idea is to use a related discrete boundary value problem, whose solution is less expensive, as a preconditioner. The connection between both problems is established by means of a suitable prolongation operator. This idea can be adapted to H(curl)-elliptic variational problems dis- cretized by means of edge finite elements. Two variants will be examined:

1. an auxiliary space built upon a semi-structured grid [1],

2. a method employing a nodal finite element discretization of an H 1 - elliptic variationall problem on the same mesh [2, 3].

The focus will be on theoretical analysis, which, in both cases, heavily relies on regular decomposition results for H(curl) in order to show key stability estimates of the abstract theory of auxiliary space preconditioning. Theory clearly highlights the importance of taking care of the kernel of the curl- operator. If this is done properly, asymptotic optimality of the methods can be established.

References

1. R. Hiptmair, G. Widmer, and J. Zou, Auxiliary space precondition- ing in H0 (curl,), Numer. Math., 103 (2006), pp. 435-459.

2. R. Hiptmair and J. Xu, Nodal auxiliary space preconditioning in H(curl) and H(div) spaces, SIAM J. Numer. Anal., 45 (2007), pp. 2483- 2509.

3. , Auxiliary space preconditioning for edge elements, IEEE Trans. Magnetics, 44 (2008), pp. 938-941.

Parallel Algebraic Multigrid for Electromagnetic Diffusion

Session Schedule Author Index Session Index

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Thomas Brunner
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Abstract

Recently, there has been a significant activity in the area of auxiliary-space methods for linear systems arising in electromagnetic diffusion simulations. Motivated by a novel stable decomposition of the Nedelec finite element space due to Hiptmair and Xu, we implemented a scalable solver for second order (semi-)definite Maxwell problems, which utilizes several internal Algebraic Multigrid (AMG) V-cycles for scalar and vector nodal Poisson-like matrices. In this talk we describe this Auxiliary-space Maxwell Solver (AMS) by reviewing the underlying theory, demonstrating its numerical performance, and presenting some new developments in its theory and implementation for new classes of electromagnetic problems.

Algebraic Multigrid Based on Clustering

Session Schedule Author Index Session Index

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Abstract

In this talk we present recent work on the construction of coarse grids for geometric multigrid on unstructured grids. The framework that we use is the auxiliary space multigrid scheme [ASMG] with local subspace correction. We present the construction of the grids as well as the multigrid method itself for the Dirichlet and the Neumann problem. Our construction allows for a setup and solution in almost optimal complexity, i.e. optimal up to one additional logarithm during the setup, cf. the following table for the Dirichlet problem:

DOFS	Setup (seconds)	Solve (seconds)	Steps
n4 = 737, 933	45.2	12.4	(5)
n5 = 2, 970, 149	124	40.2	(5)
n6 = 11, 917, 397	414	125.9	(5)
n7 = 47, 743, 157	1360	544.9	(5)

We will present numerical examples that underline the practicability of our approach. There is a strong relation to composite finite elements [CFE, CFE2]. In contrast to algebraic multigrid methods [AMG] we require geometry information (the given unstructured grid). Knowledge of the discretisation scheme and the underlying partial differential operator is beneficial but not necessary.

References

ASMG Jinchao Xu: The auxiliary space method and optimal multigrid preconditioning techniques for unstructured grids. Computing 56(3):215-235, 1996.

CFE Stefan Sauter and Wolfgang Hackbusch: Composite finite elements for the approximation of PDEs on domains with complicated micro-structures. Numerische Mathematik 75(4):447-472, 1997.

CFE2 Dirk Feuchter, Ingo Heppner, Stefan Sauter, Gabriel Wittum: Bridging the gap between geometric and algebraic multi-grid methods. Computing and Visualization in Science 6(1):1-13, 2003.

AMG Klaus Stüben: A review of algebraic multigrid. Journal of Computational and Applied Mathematics 128(1-2): 281-309, 2001.

Poisson-based Optimal Solvers for Biharmonic Problems

Session Schedule Author Index Session Index

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Abstract

This talk is devoted to the study of preconditioning methods for linear system arising from the finite element discretization discretization of the biharmonic equation in two and three dimensions. Using the framework of the Fast Auxiliary Space Preconditioning (FASP) method, the solution to the linear system from the discretization by conforming or nonconforming element is transformed to the solution of the Ciarlet-Raviart mixed finite element system together with some elementary point relaxation iterative methods (such as Jacobi and Gauss Seidel methods) for the original system. The Ciarlet-Raviart finite element system is further decoupled to systems of Poisson equations through a boundary operator equation. Again by the FASP framework, this boundary operator can be preconditioned by a discrete Poincaré-Steklov operator, and finally Poisson solvers. Therefore, an nearly optimal solver for the the discrete biharmonic system is obtained in terms of a number of Poisson solvers. Numerical examples are reported to support the theoretical results.

Mini Symposium M3P3

Optimal Solvers from Multi-grid and Two-grid to One-grid and No-grid

Schedule Author Index Session Index

Date: Tuesday, February 8
Time: 3:30-5:30
Location: B211-B212
Chairman: Randolph E. Bank, Michael Holst, Jinchao Xu, Yunrong Zhu, Ludmil Zikatanov

3:30-4:00 : Jinru Chen
Mixed and Nonconforming FEMs with Nonmatching Meshes for A Coupled Stokes-Darcy Model
Abstract

4:00-4:30 : Justin W.L. Wan
Multigrid Time Stepping Method for Systems of Hyperbolic PDEs
Abstract

4:30-5:00 : Guangri Xue
A Preconditioning Technique for Mixed Finite Element Formulations of Elliptic Problems with Full Tensor Coefficients
Abstract

5:00-5:30 : Xiaozhe Hu
Fast Solvers for Reservoir Simulation
Abstract

Part I

Part II

Part IV

Part V

Abstract

Multigrid methods are among the most efficient algorithms in solving large scale algebraic equations arising from discretized PDEs. They offer the possibility of optimal, with storage and work (nearly) linearly proportional to the number of unknowns, solution to a large class of problems. One drawback of the classic multigrid methods is that they may not be so user-friendly, namely they need the hierarchal space structure (or hierarchy of grids) which is usually unavailable in many applications.

The algebraic multigrid (AMG) methods, which often requires no-grid at all, are designed to overcome this drawback, because they use only the information from the algebraic equations. But due to the lack of geometric and analytic information from the underlying discretization, the efficiency and applicability of the gridless AMG are sometimes limited. One class of methods, which will fall into the category of one-grid method here, are to make use of geometric especially on the grid) and analytic (such as the qualitative PDE and discretization properties) information that are often readily available for the underlying discrete problems.

The classic domain decomposition (with or without overlapping) may fall into the category of two-grid or two-level methods in our teminology here. The two-grid methods also include techniques that can be used to facilitate the use of classic multigrid method, the gridless AMG method or one-grid method.

The purpose of this mini-symposium is to bring together experts in these four areas to discuss the design of algorithms and analysis of optimal solvers for a wide range of problems.

Mixed and Nonconforming FEMs with Nonmatching Meshes for A Coupled Stokes-Darcy Model

Session Schedule Author Index Session Index

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Abstract

In this paper, we study numerical methods for a coupled Stokes-Darcy model. This model is composed by a Stokes equations in fluid domain, a Darcy's equation in porous media domain, coupling together through certain interface conditions. By introducing a Lagrange multiplier, the coupled model is formed into a saddle point problem. A nonconforming mixed finite element method with nonmatching meshes is proposed to solve this coupled problem. The wellposedness of the discrete problem is proved. Moreover, we derive the a priori error estimate of the proposed finite element method. Numerical examples are also given to confirm the theoretical results.

Multigrid Time Stepping Method for Systems of Hyperbolic PDEs

Session Schedule Author Index Session Index

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Abstract

In this talk, we present a multigrid time stepping method for computing the steady state solution of systems of partial differential equations. Due to the CFL condition, the small time step size may lead to a long computational time. Multigrid methods have been exploited extensively for solving scalar convection dominated problems. The main idea of these approaches is linked to the "upwinding" concept for discretizing hyperbolic PDEs. However, in the system case, the upwinding or the characteristic directions of the unknown quantities are not as apparent as in the scalar case. We propose an interpolation method which is constructed by solving an appropriately defined local Riemann problem. We determine the upwinding direction for interpolation from the Riemann problem solution which is easy to compute. The restriction operator is defined similarly. We demonstrate the effectiveness of the multigrid time stepping method by numerical examples including the Euler equations.

A Preconditioning Technique for Mixed Finite Element Formulations of Elliptic Problems with Full Tensor Coefficients

Session Schedule Author Index Session Index

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Abstract

In this talk, we consider mixed finite element methods for the second order elliptic problems with full tensor coefficients. Mixed finite element methods are locally conservative and have accurate approximations for the flux variable. The mixed finite elements considered in this work are RT0, BDM1, BDDF1 on simplicies, parallelograms, and parallelpipeds. The approximation space of the scalar variable in these spaces is piecewise constant. The focus of this work is constructing a uniform preconditioner for the Schur complement of the discrete system. We choose a multipoint flux approximation scheme for the scalar variable as a preconditioner. We discuss the details of the preconditioner. In particular how it behaves uniformly w. r. t. the full tensor coefficient. Finally we present numerical experiments.

Fast Solvers for Reservoir Simulation

Session Schedule Author Index Session Index

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Abstract

The most time consuming part of the modern reservoir simulation is solving a sequence of highly coupled, nonsymmetric and indefinite linear Jacobian systems, which are obtain by discretizing the mathematical formulation of multiphase flow in porous media by fully implicit Euler scheme and Newton's method. In this work, based on the different physical properties of the equations and unknowns, we propose a fast preconditioning technique to solve these ill-conditioned Jacobian systems. Numerical tests show that the fast solver is robust to practical problems.

Mini Symposium M3P4

Optimal Solvers from Multi-grid and Two-grid to One-grid and No-grid

Schedule Author Index Session Index

Date: Wednesday, February 9
Time: 10:00-12:00
Location: B211-B212
Chairman: Randolph E. Bank, Michael Holst, Jinchao Xu, Yunrong Zhu, Ludmil Zikatanov

10:00-10:30 : Gabriel Wittum
Multi-grid Methods and Domain Decomposition for Large Scale Simulations
Abstract

10:30-11:00 : Yanping Chen
Analysis of Two-Grid Methods for Nonlinear Reaction Diffusion Equations by Mixed Finite Element Methods
Abstract

11:00-11:30 : Ryan Szypowski
Two-Grid Methods for Semilinear Interface Problems
Abstract

11:30-12:00 : Jung-Han Kimn
Overlapping Balancing Domain Decomposition Methods for the Helmholtz Equation
Abstract

Part I

Part II

Part III

Part V

Abstract

Multigrid methods are among the most efficient algorithms in solving large scale

algebraic equations arising from discretized PDEs. They offer the possibility of optimal, with storage and work (nearly) linearly proportional to the number of unknowns, solution to a large class of problems. One drawback of the classic multigrid methods is that they may not be so user-friendly, namely they need the hierarchal space structure (or hierarchy of grids) which is usually unavailable in many applications.

The algebraic multigrid (AMG) methods, which often requires no-grid at all, are designed to overcome this drawback, because they use only the information from the algebraic equations. But due to the lack of geometric and analytic information from the underlying discretization, the efficiency and applicability of the gridless AMG are sometimes limited. One class of methods, which will fall into the category of one-grid method here, are to make use of geometric especially on the grid) and analytic (such as the qualitative PDE and discretization properties) information that are often readily available for the underlying discrete problems.

The classic domain decomposition (with or without overlapping) may fall into the category of two-grid or two-level methods in our teminology here. The two-grid methods also include techniques that can be used to facilitate the use of classic multigrid method, the gridless AMG method or one-grid method.

The purpose of this mini-symposium is to bring together experts in these four areas to discuss the design of algorithms and analysis of optimal solvers for a wide range of problems.

Multi-Grid Methods and Domain Decomposition for Large Scale Simulations

Session Schedule Author Index Session Index

Gabriel Wittum
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Abstract

Multigrid and domain decompostion are well known methods with optimal complexity. Both methods are widely used in parallel computing environments. In the near future, computers with 10^6 CPUs will be available. To use these computers efficiently, new scaling concepts for solvers are required. In the talk, we present scaling concepts and results of simulations with a toolbox called ASIL.

Analysis of Two-Grid Methods for Nonlinear Reaction Diffusion Equations by Mixed Finite Element Methods

Session Schedule Author Index Session Index

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Abstract

We present two efficient methods of two-grid scheme for the approximation of two-dimensional semilinear reaction-diffusion equations using an expanded mixed finite element method. To linearize the discretized equations, we use two Newton iterations on the fine grid in our methods. Firstly, we solve an original non-linear problem on the coarse grid. Then we use twice Newton iterations on the fine grid in our first method, and while in second method we make a correction on the coarse grid between two Newton iterations on the fine grid. These two-grid ideas are from Xu's work (SIAM J. Sci. Comput. 1994; 15:231; SIAM J. Numer. Anal. 1996; 33:17 59) on standard finite element method. We extend the ideas to the mixed finite element method. Moreover, we obtain the error estimates for two algorithms of two-grid method. It is showed that coarse space can be extremely coarse and we achieve asymptotically optimal approximation as long as the mesh sizes satisfy $H = O(h^{1/4})$ in the first algorithm and $H = O(h^{1/6})$ in second algorithm.

Two-Grid Methods for Semilinear Interface Problems

Session Schedule Author Index Session Index

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Abstract

In this talk we propose two-grid finite element methods for solving semilinear elliptic interface problems. In particular, we are interested in problems with discontinuous diffusion coefficients, such as the nonlinear Poisson-Boltzmann equation and its regularizations. The algorithm consists of a coarse grid solver for the original nonlinear problem, and a fine grid solver for the linearized problem. Both theoretical analysis and numerical evidence show that we may choose a coarse grid with much larger meshsize than the fine grid.

Overlapping Balancing Domain Decomposition Methods for the Helmholtz Equation

Session Schedule Author Index Session Index

Jung-Han Kimn
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Abstract

We will present the numerical results and the Restrict Overlapping Balancing methods and Restrict Coarse Space for the Helmholtz equations. This approach is based on Overlapping Balancing Methods which can be considered as an extension of the Balancing Domain Decomposition Methods. Combinations of two ideas produce efficient algorithms. The choice of the best combination will be discussed.

Mini Symposium M3P5

Optimal Solvers from Multi-grid and Two-grid to One-grid and No-grid

Schedule   Author Index   Session Index

Date: Wednesday, February 9
Time: 2:45-4:45
Location: B211-B212
Chairman: Randolph E. Bank, Michael Holst, Jinchao Xu, Yunrong Zhu, Ludmil Zikatanov

2:45-3:15 : Rob Falgout
Compatible Relaxation Techniques for Parallel Coarsening in Algebraic Multigrid
Abstract

3:15-3:45 : Ulrike Yang
Recent Developments in the Design of Algebraic Multigrid Methods for Multicore Architectures
Abstract

3:45-4:15 : Yao Chen
An AMG Algorithm Based on Matching of Graphs
Abstract

4:15-4:45 : Jeremie Gaidamour
A General AMG Strategy for Addressing the Near Null-space Based on Energy Minimization
Abstract

Part I

Part II

Part III

Part IV

Abstract

Multigrid methods are among the most efficient algorithms in solving large scale algebraic equations arising from discretized PDEs. They offer the possibility of optimal, with storage and work (nearly) linearly proportional to the number of unknowns, solution to a large class of problems. One drawback of the classic multigrid methods is that they may not be so user-friendly, namely they need the hierarchal space structure (or hierarchy of grids) which is usually unavailable in many applications.

The algebraic multigrid (AMG) methods, which often requires no-grid at all, are designed to overcome this drawback, because they use only the information from the algebraic equations. But due to the lack of geometric and analytic information from the underlying discretization, the efficiency and applicability of the gridless AMG are sometimes limited. One class of methods, which will fall into the category of one-grid method here, are to make use of geometric especially on the grid) and analytic (such as the qualitative PDE and discretization properties) information that are often readily available for the underlying discrete problems.

The classic domain decomposition (with or without overlapping) may fall into the category of two-grid or two-level methods in our teminology here. The two-grid methods also include techniques that can be used to facilitate the use of classic multigrid method, the gridless AMG method or one-grid method.

The purpose of this mini-symposium is to bring together experts in these four areas to discuss the design of algorithms and analysis of optimal solvers for a wide range of problems.

Compatible Relaxation Techniques for Parallel Coarsening in Algebraic Multigrid

Session Schedule Author Index Session Index

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Abstract

Algebraic multigrid (AMG) is an important method for solving the large sparse linear systems that arise in many PDE-based scientific simulation codes. A major component of algebraic multigrid methods is the selection of coarse grids and the construction of interpolation. The idea of compatible relaxation (CR) was introduced by Brandt as a cheap method for measuring the quality of a coarse grid. In this talk, we will review the theory behind CR, describe our serial CR-based coarsening algorithm, and discuss our efforts to develop a robust parallel variant of this coarsening algorithm. We will also discuss CR's ability to predict the convergence behavior of the AMG method and ideas for improving the accuracy of its predictions.

Recent Developments in the Design of Algebraic Multigrid Methods for Multicore Architectures

Session Schedule Author Index Session Index

Ulrike Yang
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Abstract

Sparse iterative linear solvers are a critical part of many simulation codes and often account for a significant fraction of their total run times. Therefore, their performance and scalability on modern multicore machines is of great importance for enabling large-scale simulations on these new high-performance architectures. On distributed-memory architectures, current optimal sparse linear solvers, e.g. multigrid preconditioned Krylov methods, are generally weakly scalable. However, the new generation of large scale systems with an ever increasing number of nodes, which includes multiple cores sharing the bus and several caches, presents new challenges for algorithm designers and programmers. In particular, algorithms need to have good data locality, a minimal number of synchronization conflicts, and increased small grain parallelism to perform well on this new high-performance architecture. At the same time their scalability needs to be preserved and/or improved in order to efficiently deal with the much larger number of processors. This presentation d iscusses challenges and solutions for the design and implementation of algebraic multigrid solvers on massively parallel multicore architectures.

An AMG Algorithm Based on Matching of Graphs

Session Schedule Author Index Session Index

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Abstract

We introduce an algebraic multilevel method based on matching of graphs. We show that the resulting piecewise constant coarse spaces and an appropriately chosen Algebraic Multilevel Iteration (or AMLI) method yield an uniformly convergent solver. In addition, we introduce a new polynomial smoother and theory for estimating its performance in practice.

A General AMG Strategy for Addressing the Near Null-space Based on Energy Minimization

Session Schedule Author Index Session Index

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Abstract

The basic idea of multigrid methods is to use coarse grid correction to handle the error which have not been eliminated by the smoothing process. In Smoothed Aggregation multigrid, the knowledge of near-kernel components is explicitly used to define inter-grid operators that capture efficiently the remaining error. But the number of degrees of freedom per grid point grows with the number of near-kernel components, and costs can become unacceptable for problems involving large number of near-kernel components.

We have developed a new algorithm for generating grid transfers based on energy minimization. A key to the new algorithm is to still achieve accurate interpolation of the near-kernel components with the same number of coarse degrees of freedom per node as on the fine level while minimizing the energies of the transfer matrices. Our algorithm allows explicit control of the grid transfer operators' sparsity patterns. This ensures low cost while tailoring performance for anisotropic problems. In this talk, comparative results on anisotropic 3D linear elasticity will be presented.

Mini Symposium M5

Efficient Solvers for Stochastic PDEs

Schedule Author Index Session Index

Date: Friday, February 11
Time: 10:00-12:00
Location: B210
Chairman: Victorita Dolean and Robert Scheichl

10:00-10:30 : David Barajas
Random Data-Driven Domain Decompositions for Stochastic PDEs
Abstract

10:30-11:00 : Eveline Rosseel
Multigrid Solvers for Stochastic PDEs with Application to Biological Reaction-Diffusion Problems
Abstract

11:00-11:30 : Waad Subber
Domain Decomposition of Stochastic PDEs
Abstract

11:30-12:00 : Elisabeth Ullmann
Efficient Iterative Solvers for Stochastic Galerkin Discretizations of the Lognormal Diffusion Problem
Abstract

Abstract

Quantifying uncertainty for large scale systems has found an increasing interest in the scientific community in recent years. New approximation methods, especially adapted for stochastic partial differential equations and for partial differential equations with random inputs, have been developed, but the solution of the resulting high-dimensional integration problems is computational extremely challenging. As in deterministic simulations, domain decomposition and multigrid/multilevel/multiscale methods are among the most promising methods to tackle these challenges efficiently. In this mini-symposium we would like to present some recent advances in this rapidly growing and exciting new field.

Random Data-Driven Domain Decompositions for Stochastic PDEs

Session Schedule Author Index Session Index

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Abstract

Although it has long been recognized that simulations of most physical systems are fundamentally stochastic, this fact remains overlooked in most practical applications. Even essentially deterministic systems must be treated stochastically when their parameters, boundary and initial conditions, or forcing functions are under-specified by data. Data-driven random domain decompositions provide a novel approach to dealing with the kinds of spatially heterogeneous random processes that typically appear in realistic simulations of physical systems. The method is based on a doubly stochastic model in which the problem domain is decomposed according to stochastic geometries into disjoint random fields. The stochastic decomposition is determined by variations in the parameter space based on additional (uncertain) geometric information that can be derived from new characterization techniques and also from expert knowledge. The outputs of different characterizations can be combined and the decomposition model modified using Bayesian updating techniques. Previous work has tended to concentrate on spatially homogeneous parametrizations, or at most on heterogeneous parameter fields whose geometry is assumed known with certainty. This is almost never the case in natural systems. On the other hand, random domain decomposition allows us to estimate system states when heterogeneous parametrizations depend on realistic geometric uncertainty.

Multigrid Solvers for Stochastic PDEs with Application to Biological Reaction-Diffusion Problems

Session Schedule Author Index Session Index

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Abstract

Partial differential equations (PDE) containing random coefficients can be efficiently solved by applying a stochastic Galerkin finite element method. This method avoids the large computational cost of performing Monte Carlo simulations and it leads to high-order accurate stochastic solutions. It converts a stochastic PDE into a coupled system of deterministic PDEs. The main challenge lies then in solving this coupled system of equations. In this talk, we will show that very efficient multigrid solvers can be constructed for stochastic Galerkin finite element discretizations.

We consider a system of time-dependent nonlinear reaction-diffusion problems with stochastic coefficients. This system models the conversion of starch into sugars in growing apples, which provides information on the quality of apples during development, maturation and ripening. A stable and high-order discretization of the PDE system is obtained by combining a stochastic Galerkin finite element discretization with a fully implicit Runge-Kutta time discretization. An algebraic Newton-multigrid solver is proposed to solve the high-dimensional algebraic systems. A point-based coarsening and smoothing strategy is key to its performance. Numerical results demonstrate the convergence properties, robustness and efficiency of the proposed multigrid solvers.

Domain Decomposition Methods of Stochastic PDEs

Session Schedule Author Index Session Index

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Abstract

For uncertainty quantification in many practical engineering problems, the application of stochastic finite element method (SFEM) may be computationally challenging. In SFEM, the size of the algebraic system grows rapidly with the spatial mesh resolution and the size of the stochastic dimension. In this paper, non-overlapping domain decomposition methods are proposed to tackle the large-scale linear system arising in the context of the finite element discretization of SPDEs. The methodology is based on domain decomposition in the spatial domain and a functional decomposition in the stochastic space using polynomial chaos expansion. In particular, we first describe a primal version of iterative substructuring methods of SPDEs in order to formulate a two-level scalable preconditioner. In the proposed preconditioner, the continuity of the solution field is strictly enforced on the corner nodes of the interface boundary, but weakly satisfied over the remaining interface nodes. This approach naturally leads to a coarse grid connecting the subdomains globally and provides a mechanism to exchange information across the subdomains which makes the algorithm scalable. In the second part of the paper, a dual-primal iterative substructuring method is introduced for SPDEs. In this approach, the continuity condition on the corner nodes is strictly satisfied and Lagrange multipliers are used to weakly enforce the continuity on the remaining nodes of the interface boundary. For numerical illustrations, a two dimensional elliptic SPDE with non-Gaussian random coefficients is considered. The numerical results demonstrate the scalability of both the algorithms with respect to the mesh size, subdomain size, fixed problem size per subdomain, order of polynomial chaos expansion and level of uncertainty in the system parameters. The numerical experiments are performed on a Linux cluster using MPI and PETSc parallel libraries.

Efficient Iterative Solvers for Stochastic Galerkin Discretizations of the Lognormal Diffusion Problem

Session Schedule Author Index Session Index

Elisabeth Ullmann
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Abstract

Many physical processes occuring in different areas of science, engineering and industry are modelled by partial differential equations (PDEs). The numerical simulation of such processes requires input data which are, however, often subject to considerable uncertainty. Quantitative statements on the effect of these data uncertainties are therefore desirable for the evaluation of simulation results.

Stochastic Galerkin methods are a well-established discretization tool for PDEs with un- certain data modelled in terms of random fields. The method couples physical degrees of freedom arising from standard finite element discretizations with stochastic degrees of free- dom. For this reason the number of unknowns in the Galerkin equations grows rapidly: stochastic Galerkin equations can involve up to 10,000 times more unknowns than determin- istic Galerkin equations. Consequently, the design of efficient and robust iterative solvers for these huge linear systems of equations is essential for the numerical simulation with uncertain data.

Specifically, we are concerned with a model problem arising from steady-state ground- water flow calculations where the permeability of the rock is often modelled as a lognormal random field. Mathematically, this problem can be formulated as diffusion equation where the diffusion coefficient is a nonlinear function of a fixed number of statistically independent Gaussian random variables. We consider primal and mixed stochastic Galerkin finite element discretizations of our model problem and present an overview of iterative solution strategies. In particular, we discuss structural and spectral properties of the associated Galerkin matrices and outline the resulting computational challenges together with proposed preconditioners for the Galerkin system (see [1], [2]).

References

1. E. Ullmann: A Kronecker Product Preconditioner for Stochastic Galerkin Finite Element Discretizations. SIAM J. Sci. Comput. 32(2), pp. 923-946, 2010.

2. C. E. Powell, E. Ullmann: Preconditioning Stochastic Galerkin Saddle Point sys- tems, MIMS EPrint 2009.88, School of Mathematics, University of Manchester, ISSN 1749-9097. To appear in SIAM J. Matrix Anal. Appl., 2010.

Mini Symposium M6

Domain Decomposition Methods for Helmholtz Problems

Schedule Author Index Session Index

Date: Monday, February 7
Time: 2:45:4:45
Location: B143-B144
Chairman: Martin J. Gander and Hui Zhang

2:45-3:15 : Hui Zhang
Extensive Numerical Tests of Domain Decomposition Methods for the Helmholtz Equation Representing a Geophysical Model
Abstract

3:15-3:45 : Radek Tezaur
The Discontinuous Enrichment Method and its Domain Decomposition Solver for the Helmholtz Equation
Abstract

3:45-4:15 : Murthy Guddati
Improving the Convergence Rate of Optimized Schwarz Methods for Time-Harmonic Wave Propagation Problems
Abstract

4:15-4:45 : Dmitry Neklyudov
An Iterative Method for Elastic Wave Equation in the Frequency Domain with No Use of Finite-Difference Approximations
Abstract

Abstract

The Helmholtz equation modeling wave phenomena has many applications, such as geophysics, which have great demands for parallel preconditioners and large scale computing. However, the indefiniteness of the equation causes domain decomposition methods that were developed for symmetric positive definite problems to loose optimality, scalability, and sometimes they are not even convergent any more. To cure these problems, Robin-type transmission conditions and plane waves have

been introduced. However, to keep the optimality with respect to the wavenumber, the subdomain size needs to be sufficiently small, inversely proportional to the wavenumber, which leads to larger and larger coarse problems. In addition, it is not clear how good current domain decomposition methods are for heterogeneous media, in which case we do not have plane wave solutions. A further interesting topic is domain decomposition methods which use more accurate discretizations, such as DG and spectral element methods with local plane wave basis functions. This mini-symposium will bring researchers working on this topic together to discuss theoretical analysis, numerical experiments and further directions.

Extensive Numerical Tests of Domain Decomposition Methods for the Helmholtz Equation Representing a Geophysical Model

Session Schedule Author Index Session Index

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Abstract

We present a numerical study of domain decomposition methods for the solution of the Helmholtz equation defined on the geophysical model SEG_SALT. We extensively tested the FETI-DP methods, the BDDC methods and the optimized Schwarz methods, and we present comprehensive results of our numerical experiments. In particular, we evaluate the performance of some components in these methods such as plane waves and Robin transmission conditions. It is seen that all the methods converge much more slowly in the presence of medium heterogeneity.

The Discontinuous Enrichment Method and its Domain Decomposition Solver for the Helmholtz Equation

Session Schedule Author Index Session Index

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Abstract

The Discontinuous Enrichment Method (DEM) is a discretization method designed for an efficient solution of multi-scale problems. It is based on a hybrid variational formulation with Lagrange multipliers. In addition to an optional polynomial field, it employs free-space solutions of the governing differential equation for approximating large gradients or highly oscillatory components of the solution. It relies on Lagrange multipliers to enforce a weak form of the inter-element continuity of the solution. In this talk, recent applications of DEM to the solution of acoustic scattering and structural dynamics problems in the medium frequency regime are first discussed. Then, a nonoverlapping domain decomposition method is presented for the solution of Helmholtz/structural dynamics problems discretized by DEM with and without the optional polynomial field. In this domain decomposition method, the primal subdomain degrees of freedom are eliminated by local static condensations to obtain an algebraic system of equations formulated in terms of the interface Lagrange multipliers only. As in the FETI-H and FETI-DPH domain decomposition methods for continuous Galerkin discretizations, this system of Lagrange multipliers is iteratively solved by a Krylov method equipped with both a local preconditioner based on subdomain data, and a global one using a coarse space. Numerical experiments performed for two- and three-dimensional acoustic problems demonstrate the scalability of the method with respect to the size of the global problem and the number of subdomains.

Improving the Convergence Rate of Optimized Schwarz Methods for Time-Harmonic Wave Propagation Problems

Session Schedule Author Index Session Index

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Abstract

Utilizing the recently developed concept of Perfectly Matched Discrete Layers (PMDLs), we propose a new non-overlapping domain decomposition (DD) method that converges faster than existing optimized Schwarz methods. Optimized Schwarz Methods utilize polynomial approximation of the half-space DtN map to accelerate the convergence of the Schwarz method. The improved convergence of the proposed method is due to the fact that PMDLs are high-order rational approximations of half-space DtN maps. The proposed DD method is easy to implement due to a simple link to well-known Perfectly Matched Layers, and can be easily incorporated into standard finite element and finite difference implementations. This talk includes the basic theory of PMDL-based interface conditions, convergence analysis, implementation details, and numerical examples illustrating improved convergence rate with minimal increase in computational cost per iteration.

An Iterative Method for Elastic Wave Equation in the Frequency Domain with No Use of Finite-Difference Approximations

Session Schedule Author Index Session Index

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Abstract

A preconditioned iterative method for solving frequency domain elastic wave equations is presented. Its distinctive feature is the use of a right preconditioner, obtained as a solution of the damped elastic wave equations in a vertically heterogeneous medium. We represent the actual differential operator as a perturbation of preconditioner. As a result, a matrix-by-vector multiplication of the preconditioned system is effectively evaluated via the fast Fourier transform in horizontal direction(s) followed by the solution of a number of ordinary differential equations in the vertical direction. To solve these equations we introduce a piecewise constant 1D background medium and search for the exact solution in the 1D medium as a superposition of upgoing and downgoing waves. The method has excellent dispersion properties because it does not use any finite-difference approximation of derivatives and converges reasonably fast. We discuss advantages of this approach for solving the 3D formulation on the base of domain decomposition.

This study is done in cooperation with Schlumberger Moscow Research and partially supported by RFBR grants 10-05-00233, 11-05-00947.

Mini Symposium M7

Domain Decomposition Methods in Computational Electromagnetics

Schedule Author Index Session Index

Date: Monday, February 7
Time: 10:00-12:00
Location: B143-B144
Chairman: Ulrich Langer, Olaf Steinbach

10:00-10:30 : E. P. Stephan
Fast Solvers for the hp Version Boundary Element Method and Applications in Electromagnetics
Abstract

10:30-11:00 : R. Hiptmair
Multiple Traces Boundary Integral Formulations for Helmholtz Transmission Problems
Abstract

11:00-11:30 : G. Of
Direct and Indirect Boundary Element Methods for Magnetostatic Field Problems
Abstract

11:30-12:00 : M. Windisch
Robust Boundary Element Domain Decomposition Methods for Electromagnetic Scattering
Abstract

Abstract

The main focus of this minisymposium is on new boundary element domain decomposition and related techniques for a robust and efficient solution of challenging problems in electromagnetics. This covers direct, indirect, and combined boundary integral formulations for acoustic and electromagnetic scattering, fast boundary element methods, hp techniques, and adaptive methods.

Fast Solvers for the hp-Version Boundary Element Method and Applications in Electromagnetics

Session Schedule Author Index Session Index

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Abstract

We present new results from [1, 2] on various Schwarz methods for the h and p versions of the boundary element method applied to prototype first kind integral equations on surfaces. When those integral equations (weakly/hypersingular) are solved numerically by the Galerkin boundary element method, the resulting matrices become ill-conditioned. Hence, for an efficient solution procedure appropriate preconditioners are necessary to reduce the numbers of CG-iterations. In the p version where accuracy of the Galerkin solution is achieved by increasing the polynomial degree the use of suitable Schwarz preconditioners (presented in the paper) leads to only polylogarithmically growing condition numbers. For the h version where accuracy is achieved by reducing the mesh size we present a multi-level additive Schwarz method which is competitive with the multigrid method. Applications are given in electromagnetics when solving the eddy current problemor the electrical field integral equation using FEM and BEM.

References

1. Heuer, N., Leydecker, F., Stephan, E.P.: Iterative substructering method for the p-version of the BEM on triangular meshes. Num. Meth. PDE 23 (2007):879-903

2. Maischak, M., Leydecker, F., Stephan, E.P. : Some Schwarz methods for integral equations on surfaces- h and p versions, Computing and Visualization in Science 8 (2005):211-216

Multiple Traces Boundary Integral Formulations for Helmholtz Transmission Problems

Session Schedule Author Index Session Index

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Abstract

We present a novel boundary integral formulation of the Helmholtz transmission problem for bounded composite scatterers (that is, piecewise constant material parameters in subdomains) that directly lends itself to operator preconditioning via Caldero n projectors. The method relies on local traces on subdomains and weak enforcement of transmission conditions. The variational formulation is set in Cartesian products of standard Dirichlet and special Neumann trace spaces for which restriction and extension by zero are well defined. In particular, the Neumann trace spaces over each subdomain boundary are built as piecewise H1/2-distributions over each associated interface. Through the use of interior Caldero n projectors, the problem is cast in variational Galerkin form with an operator matrix whose diagonal is composed of block boundary integral operators associated with the subdomains. We show existence and uniqueness of solutions based on an extension of Lions projection lemma for non-closed subspaces. We also investigate asymptotic quasi-optimality of conforming boundary element Galerkin discretization. Numerical experiments in 2-D confirm the efficacy of the method and a performance matching that of another widely used boundary element discretization. They also demonstrate its amenability to different types of preconditioning.

Boundary Element Methods for Transmission Problems

Session Schedule Author Index Session Index

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Abstract

We consider transmission problems in magnetostatics. Using scalar potential formulations, one ends up with transmission problems of the potential equation with piecewise constant coefficients. We compare a class of global indirect boundary integral formulations to a domain decomposition approach to solve these transmission problems by fast boundary element methods, e.g., the Fast Multipole Method. We discuss the pros and cons of the considered formulations and compare the performance, the accuracy and the stability of the approaches for several numerical examples of industrial applications.

BETI-methods for Maxwell equations

Session Schedule Author Index Session Index

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Abstract

In this talk we want to present basic ideas for a Tearing and Interconnecting approach for electromagnetic scattering, using boundary integral equations on the local subdomains. The Tearing and Interconnecting approach is normally used for partial differential equations which lead to elliptic bilinear forms. Nevertheless, C. Farhat introduced the FETI also for the Helmholtz equation (using FEM instead of BEM on the local subdomains), now called FETI-H. In former talks we presented a numerical analysis to use this method with boundary instead of finite elements. In this talk now we describe ideas, how this approach can be used for the even more complicated electromagnetic scattering problem. Instead of standard transmission boundary conditions of Dirichlet and Neumann type we may use Robin type interface conditions, which result in a stable formulation which is robust to possible spurious modes.

Mini Symposium M8

Domain Decomposition for Discontinuous Galerkin Methods

Schedule Author Index Session Index

Date: Monday, February 7
Time: 10:00-12:00
Location: B211-B212
Chairman: Blanca Ayuso de Dios, Susanne C. Brenner

10:00-10:30 : Paola F. Antonietti
Schwarz Preconditioners for the hp-Version of the Discontinuous Galerkin Method
Abstract

10:30-11:00 : Blanca Ayuso de Dios
Multilevel Preconditioners for Interior Penalty Discontinuous Galerkin Discretizations of Elliptic Problems with Jump Coefficients
Abstract

11:00-11:30 : Andrew Barker
Additive Schwarz Preconditioners for the Local Discontinuous Galerkin Method Applied to Convection-Diffusion Problems
Abstract

11:30-12:00 : Eun-Hee Park
A Nonoverlapping Domain Decomposition Preconditioner for a Weakly Over-Penalized Symmetric Interior Penalty Method
Abstract

Abstract

Based on a totally discontinuous Finite element spaces, discontinuous Galerkin (DG) methods are extremely versatile and have numerous attractive features: local conservation properties; flexibility in handling non-matching grids and in designing hp-refinement strategies; weak approximation of boundary conditions and built-in parallelism which permits coarse-grain parallelization. DG methods can deal robustly with partial differential equations of almost any kind, as well as with equations whose type changes within the computational domain. However, their use

has been often limited due to the much larger number of degrees of freedom as compared with other classical discretization methods. In recent years, domain decomposition (DD) methods for the design of efficient and robust preconditioners for DG discretizations is becoming increasingly popular. This includes both the use of classical strategies and the development of new techniques. The aim of this minisymposium is to bring together experts in the field to discuss and identify the most relevant aspects of the current development of DD techniques for DG methods.

Schwarz Preconditioners for the hp-Version of the Discontinuous Galerkin Method

Session Schedule Author Index Session Index

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Abstract

In the hp-version of the finite element method convergence is achieved by a suitable combination of h-refinements (dividing elements into smaller ones) and p-refinements (increasing the polynomial approximation order). It is well known that the discontinuous Galerkin (DG) method can handle non-conforming/hybrid meshes as well as variable approximation orders, making the DG method well suited for the design of hp-adaptive solution strategies. In this talk we address the problem of efficiently solving the algebraic linear systems of equations arising from the discretization of a symmetric, elliptic boundary value problem using hp discontinuous Galerkin finite element methods. We introduce a class of domain decomposition preconditioners based on the Schwarz framework, and prove bounds on the condition number of the resulting iteration operators. Numerical results confirming the theoretical estimates are also presented.

Multilevel Preconditioners for Interior Penalty Discontinuous Galerkin Discretizations of Elliptic Problems with Jump Coefficients

Session Schedule Author Index Session Index

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Abstract

We present two-level and multi-level methods for the family of Interior Penalty (IP) Discontinuous Galerkin (DG) discretization of second order elliptic problems with rough (with large jumps across interfaces) coefficients. The methods are based on a decomposition of the DG finite element space that inherently hinges on the diffusion coefficient of the problem.

The analysis of the proposed preconditioners is presented for symmetric and non-symmetric IP schemes. Robustness with respect to the jump in the coefficient and nearly-optimality with respect to the mesh size is shown. Numerical results are included to verify the theory and illustrate the performance of the suggested methods.

Additive Schwarz Preconditioners for the Local Discontinuous Galerkin Method Applied to Convection-Diffusion Problems

Session Schedule Author Index Session Index

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Abstract

We present and analyze a two-level additive Schwarz preconditioner for the local discontinuous Galerkin discretization. For the Poisson problem, we show that the condition number of the preconditioned system is independent of the discretization size and the number of subdomains, and we present numerical examples illustrating these results and showing the parallel scalability of our implementation. Additionally, numerical results indicate that this preconditioner is also effective for the non-symmetric convection-diffusion problem.

A Nonoverlapping Domain Decomposition Preconditioner for a Weakly Over-Penalized Symmetric Interior Penalty Method

Session Schedule Author Index Session Index

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Abstract

The weakly over-penalized symmetric interior penalty (WOPSIP) method, which belongs to the family of discontinuous Galerkin methods, was introduced for second order elliptic problems by Brenner et al. in 2008. We will discuss a preconditioner for the WOPSIP method that is based on balancing domain decomposition by constraints (BDDC). Theoretical results on the condition number estimate of the preconditioned system will be presented along with numerical results. This is joint work with Susanne C. Brenner and Li-yeng Sung.

Mini Symposium M9

Domain Decomposition and Massively Parallel Computation

Schedule Author Index Session Index

Date: Tuesday, February 8
Time: 3:30-5:30
Location: B143-B144
Chairman: Felix Kwok, Sébastien Loisel

3:30-4:00 : Amik St-Cyr
Two-Level Spectral Elements Optimized Schwarz Preconditioning for MHD Simulations
Abstract

4:00-4:30 : Sébastien Loisel
Optimized Domain Decomposition Methods that Scale Weakly
Abstract

4:30-5:00 : Francois-Xavier Roux
Strategies for Massively Parallel Implementation of FETI
Abstract

5:00-5:30 : Xuemin Tu
The Fourth Talk in This Mini Symposium
Abstract

Abstract

Domain decomposition methods are a natural way of parallelizing the solution of boundary value problems. In order to solve larger problems, one must use techniques that scale well to large numbers of processors. Large scale problems present some special difficulties, such as the need for a coarse grid correction and special handling of cross points. In this minisymposium, we will discuss how these issues impact the analysis of domain decomposition algorithms and how a proper implementation can improve their performance and scalability in large-scale applications.

Two-Level Spectral Elements Optimized Schwarz Preconditioning for MHD Simulations

Session Schedule Author Index Session Index

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Abstract

We present a new two-level preconditioner for a "pseudo-Laplacian" operator that emerges from an explicit spectral-element discretization of the incompressible magnetohydrodynamics equations. Extending work in JCP,133:84(1997), we use new overlap stenciling and corner communication for the fine grid whose preconditioner utilizes a theoretical result enabling trivial conversion to an optimized overlapping Schwarz method. Results are presented for the (pseudo-)Poisson equation, and for magnetohydrodynamics simulations of Orszag-Tang vortex.

Optimized Domain Decomposition Methods that Scale Weakly

Session Schedule Author Index Session Index

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Abstract

In various fields of application, one must solve very large scale boundary value problems using parallel solvers and supercomputers. The domain decomposition approach partitions the large computational domain into smaller computational subdomains. In order to speed up the convergence, we have several "optimized" algorithm that use Robin transmission conditions across the artificial interfaces (FETI-2LM). It is known that this approach alone is not sufficient: as the number of subdomains increases, the number of iterations required for convergence also increases and hence the parallel speedup is lost. A known solution for classical Schwarz methods as well as FETI algorithms is to incorporate a "coarse grid correction", which is able to transmit low-frequency information more quickly across the whole domain. Such algorithms are known to "scale weakly" to large supercomputers. A coarse grid correction is also necessary for FETI-2LM methods. In this talk, we will introduce and analyze coarse grid correction algorithms for FETI-2LM domain decomposition methods.

Strategies for Massively Parallel Implementation of FETI

Session Schedule Author Index Session Index

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Abstract

The optimal number of subdomains of FETI for real problems is never very large and is close to the point where the time spent in the initial factorization and in the successive forward-backward substitutions of the FETI iterations is the same. Massively parallel systems feature SMPs nodes, so coupling FETI with local parallel sparse direct solvers using OpenMP seems a relevant strategy. The available parallel sparse direct solvers focus on the factorization phase and exhibit lower performance on single forward-backward substitution phase. To tackle this issue we have developed a sparse direct solver based on nested bisection, taking into account the specific block structure of the factorized matrix to optimize the forward-backward substitution. We also try to compute several search directions at the same time, to increase the performance of the local direct solver and to decrease the cost of the global data exchange in the orthogonalization phases of FETI.

Scalability study for exact and inexact BDDC algorithms in large scale computation

Session Schedule Author Index Session Index

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Abstract

Balancing domain decomposition by constraints (BDDC) algorithms are non-overlapping domain decomposition methods for solutions of large sparse linear algebraic systems arising from the discretization of boundary value problems. They are suitable for parallel computation. The coarse problem matrix of BDDC algorithms is generated and factored by a direct solver at the beginning of the computation. It will become a bottleneck when the computer systems with a large number of processors are used. The inexact BDDC algorithms solve the coarse problem inexactly and help to remove the bottleneck. In this talk, numerical experiments on exact and inexact BDDC algorithms for large scale computation are presented. Numerical results show that the scalability for inexact solver is reserved for large scale computation but not for the exact BDDC solvers.

Mini Symposium M10

Domain Decomposition Methods for Maxwell Equations

Schedule Author Index Session Index

Date: Tuesday, February 8
Time: 10:00-12:00
Location: B143-B144
Chairman: Victorita Dolean, Martin J. Gander, Stéphane Lanteri

10:00-10:30 : Y. Courvoisier
Time Domain Maxwell Equations Solved with Schwarz Waveform Relaxation Methods
Abstract

10:30-11:00 : Z. Peng
Domain Decomposition Method for Combined Field Integral Equations in Computational Electromagnetics
Abstract

11:00-11:30 : Victorita Dolean
Optimized Schwarz Methods for the Conductive Time-Harmonic Maxwell Equations
Abstract

11:30-12:00 : Martin Huber
Hybrid Domain Decomposition Solvers for Scalar and Vectorial Wave Equations
Abstract

Abstract

Electromagnetic devices are ubiquitous in present day technology. Although the principles of electromagnetics are well understood, solving Maxwell's equations is a challenge, both for time-domain and time-harmonic formulations. For practical applications, the solution of such problems is further complicated by the detailed geometrical features of scattering objects, the physical properties of the propagation medium and the characteristics of the radiating sources. In addition, because the

wavelength is often short, the algebraic systems resulting from the discretization of Maxwell's equations can be extremely large. Domain decomposition principles are thus ideally suited for the design of efficient and scalable solvers for such systems. This mini-symposium will discuss some recent developments on domain decomposition methods for the solution of the system of Maxwell equations.

Time Domain Maxwell Equations Solved with Schwarz Waveform Relaxation Methods

Session Schedule Author Index Session Index

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Abstract

The Maxwell equations are widely analyzed in their harmonic variant, and Schwarz algorithms have been mainly applied to the harmonic formulation. We consider in this work the time domain Maxwell equations to which we apply the Schwarz Waveform Relaxation (SWR) method, and provide a global analysis of the algorithm.

We propose a convergence result in a finite number of steps for an overlapping SWR algorithm with arbitrary geometry and characteristic transmission conditions. In addition, for a non-overlapping situation, we show convergence using energy estimates. These results set the stage for the analysis and justify a deeper look at the method.

The slow speed of convergence of the method using characteristic transmission conditions suggests that one should look for better transmission conditions. Therefore, we propose transmission conditions which are approximations of the transparent boundary conditions. They yield a contraction factor for the method having the same form as the one of the wave equation. This resemblance will provide optimization results leading to faster solvers for the time domain electromagnetic wave equations. We illustrate the theory with numerical experiments.

Domain Decomposition Method for Combined Field Integral Equations in Computational Electromagnetics

Session Schedule Author Index Session Index

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Abstract

The integral equation (IE) method is commonly utilized to model time-harmonic electromagnetic (EM) problems. One of the greatest challenges in its applications arises in the solution of the resulting dense matrix equation. Techniques such as FMM and FFT have been developed to speed up the matrix-vector multiplication, however, the convergence of the resulting matrix equations still relies on the availability of a robust preconditioner. Here, we introduce a new domain decomposition (DD) based iterative method for solving the combined field integral equation (CFIE) formulation for closed non-penetrable targets. It decomposes the original problem domain into smaller disjoint closed sub-domains, in which local sub-problems are to be solved. Adjacent sub-domains are coupled to one another via Stratton-Chu representation formulas. There are two major ingredients in the proposed IE-DDM: (a) the method is a type of non-overlapping DD method and provides a computationally efficient and effect preconditioner for the dense matrix equation. (b) The proposed method is very suitable for dealing with multi-scale EM problems. Each sub-domain has its own characteristics length and will be meshed independently from others. For example, an apache helicopter, see Fig. 1, operated at 500 MHz is simulated by using the proposed IE-DDM.

Optimized Schwarz Methods for the Conductive Time-Harmonic Maxwell Equations

Session Schedule Author Index Session Index

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Abstract

We are interested here in solving the time-harmonic Maxwell equations. The space discretization of these equations leads to the resolution of a linear system. For the problems we consider, this system can be of a very large dimension and it cannot reasonably be solved using direct factorization methods. Moreover, the matrix of this system is sparse, complex and non-hermitian. This structure makes difficult the resolution of the system with an iterative method. In this context, it is essential to develop efficient iterative methods that are easily parallelizable. The Schwarz-type domain decomposition methods are very well suited for parallel computation. We focus of this paper is the case where electric conductivity is non-zero. We present here a first analysis of optimized transmission conditions for Maxwell's equations with non-zero electric conductivity. We study in detail a two dimensional model problem, and obtain the optimized transmission conditions for one particular class of optimized Schwarz methods. We illustrate our analysis with numerical experiments.

Hybrid Domain Decomposition Solvers for Scalar and Vectorial Wave Equations

Session Schedule Author Index Session Index

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Abstract

In this talk we discuss hybrid domain decomposition solvers for scalar and vectorial wave equations. The presented hybrid finite element methods are equivalent to a discontinuous Galerkin method, based on the ultra weak variational formulation (UWVF) by Cessenat and Despres. When solving a scalar or vectorial wave equation with hybrid finite elements the continuity of the scalar field and the tangential continuity of the vector valued field, respectively, is broken accross element interfaces and reinforced again by introducing hybrid variables, which are supported only on the element facets. Using this technique, coupling between degrees of freedom belonging to the interior of different elements is avoided, and the large number of unknowns on the element can be eliminated easiliy. Consequently, the linear system of equations needs only to be solved for the introduced facet degrees of freedom. It is shown by numerical experiments, that iterative solvers using Schwarz preconditioners have good convergence properties for these systems of equations.

Mini Symposium M11P1

Domain Decomposition Methods for Multiscale Heterogeneous Problems

Schedule Author Index Session Index

Date: Wednesday, February 9
Time: 10:00-12:00
Location: B143-B144
Chairman: Sergey Nepomnyaschikh, Juan Galvis

10:00-10:30 : Yuri Vassilevski
Hybrid DDM for the Diffusion Equation with Heterogeneous Coefficient
Abstract

10:30-11:00 : Joerg Willems
Robust Additive Schwarz Preconditioners for Abstract Symmetric Positive Definite Operators
Abstract

11:00-11:30 : A. Matsokin
Domain Decomposition Preconditioning for Well Models for Reservoir Problems
Abstract

11:30-12:00 : Juan Galvis
Spectrally Constructed Coarse Spaces
Abstract

Part II

Abstract

Multiple scales and high contrast are present in many applications, such as porous media, material sciences and others. It is known that heterogeneities and disparity in media properties make it dicult to design robust preconditioning techniques and coarse multiscale approximations. In particular, the variations within coarse regions need to be taken into account carefully in order to obtain preconditioners that converge independent of physical parameters. A main interest of this minisymposium is to development techniques for construction of algorithms which are

robust with respect to both the grid and the heterogeneous property of problems. In this session, we will bring together experts working on domain decomposition methods for multiscale problems.

Hybrid DDM for the Diffusion Equation with Heterogeneous Coefficient

Session Schedule Author Index Session Index

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Abstract

A two-level black-box preconditioner based on the hybrid Domain Decomposition (DD) technique is presented. The preconditioner is a combination of an additive Schwarz preconditioner and a special smoother. The smoother removes dependence of the condition number on the number of subdomains and variations of the diffusion coefficient and leaves minor sensitivity to the problem size. The algorithm is parallel and pure algebraic which makes it a convenient framework for the construction parallel black-box preconditioners on unstructured meshes.

Robust Additive Schwarz Preconditioners for Abstract Symmetric Positive Definite Operators

Session Schedule Author Index Session Index

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Abstract

A framework for constructing robust additive Schwarz preconditioners for SPD problems is presented. The term "robust" refers to the property of the condition numbers of the preconditioned systems being independent of mesh parameters and problem parameters. Important instances of such problem parameters are e.g. (highly varying) conductivities and permeabilities. The core of this method is the construction of the coarse space based on the solution of local generalized eigenvalue problems. The framework only requires assumptions which are naturally satisfied by SPD operators resulting from partial differential equations and is thus applicable to a wide range of problems. Some numerical examples are presented to illustrate the properties of the method. Departing from the two-level additive Schwarz framework we also address the possibility of extending the algorithm to a multilevel procedure. In addition the possibilities of applying the framework to construct preconditioners for saddle point problems such as Brinkman's equations are addressed.

Domain Decomposition Preconditioning for Well Models for Reservoir Problems

Session Schedule Author Index Session Index

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Abstract

Well models for reservoir simulation play very important role. A special property of the considered problem is that an operator of this problem inside small subdomains, which correspond to wells, is unknown. The purpose is the design of an effective preconditioner for the iterative solution of the problem. The construction of the preconditioner consists of two steps. The first step is auxiliary. In this step we suggest a preconditioning operator for a problem with small holes. The holes correspond to subdomains with wells. The construction of a preconditioner for the first step is based on the multilevel decomposition and the fictitious space method. The second step of the construction is more important. The design of the preconditioning operator is based on few domain decomposition methods using the additive Schwarz method. Trace theorem in Sobolev spaces is a very important in a construction of domain decomposition preconditioners. Corresponding theorems were proved for small domains for the cases of Sobolev spaces and its finite element subspaces. Using these theorems, optimal preconditioners with respect to condition numbers and arithmetic cost for the case of small coefficients in holes can be constructed.

Spectrally Constructed Coarse Spaces

Session Schedule Author Index Session Index

Juan Galvis
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Abstract

Many problems in applied sciences occur in the media that contains multiple scales and have a high contrast in the properties. In this talk, new robust preconditioners for multiscale high-contrast problems are investigated. We consider elliptic equations with highly varying coefficients. We design and analyze two-level domain decomposition preconditioners that converge independent of the contrast in the media properties. The coarse spaces are constructed using selected eigenvectors of a local spectral problem. Our new construction enriches any given initial coarse space to make it suitable for high-contrast problems. Via judicious choice of the initial space, we reduce the dimension of the resulting coarse space. Numerical experiments are presented. The new construction presented here can handle tensor coefficients. We will also look at the coarse approximation properties of the coarse solver. If time allows we will present the extension of our methods to a multilevel framework and other equations.

Mini Symposium M11P2

Domain Decomposition Methods for Multiscale Heterogeneous Problems

Schedule Author Index Session Index

Date: Wednesday, February 9
Time: 2:45-4:45
Location: B143-B144
Chairman: Sergey Nepomnyaschikh, Juan Galvis

2:45-3:15 : Ulrich Langer
Parameter-Robust and Almost Optimal Solvers for Eddy Current Problems in the Frequency Domain
Abstract

3:15-3:45 : Ludmil T. Zikatanov
Energy Minimizing Coarse Spaces with Functional Constraints
Abstract

3:45-4:15 : Clemens Pechstein
Analysis of FETI and FETI-DP Methods for Highly Varying Coefficients Within Subdomains
Abstract

4:15-4:45 : Sergey Nepomnyaschikh
Trace Theorems and Domain Decomposition Preconditioners in the Case of Subdomains with Jumps in Coefficients of Elliptic Problems
Abstract

Part I

Abstract

Multiple scales and high contrast are present in many applications, such as porous media, material sciences and others. It is known that heterogeneities and disparity in media properties make it dicult to design robust preconditioning techniques and coarse multiscale approximations. In particular, the variations within coarse regions need to be taken into account carefully in order to obtain preconditioners

that converge independent of physical parameters. A main interest of this minisymposium is to development techniques for construction of algorithms which are robust with respect to both the grid and the heterogeneous property of problems. In this session, we will bring together experts working on domain decomposition methods for multiscale problems.

Parameter-Robust and Almost Optimal Solvers for Eddy Current Problems in the Frequency Domain

Session Schedule Author Index Session Index

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Abstract

In many practical applications, for instance, in computational electromagnetics, the excitation is time-harmonic. Due to the time-harmonic excitation, we can switch from the time domain to the frequency domain. At least in the case of linear problems this allows us to replace the expensive time-integration procedure by the solution of a simple linear elliptic system for the amplitudes belonging to the sine- and to the cosine-excitation. The fast solution of the corresponding linear system of finite element equations is crucial for the competitiveness of this method. J. Schöberl and W. Zulehner (2007) proposed a new parameter-robust MinRes preconditioning technique for saddle point problems. This method allows us to construct a parameter-robust preconditioned MinRes solver for linear time-harmonic eddy current problems in electromagnetics. Due to the non-trivial kernel of the curl operator we have to perform an exact regularization of the frequency domain equations in order to provide the basis for the application of the MinRes preconditioner. The block-preconditioner contains blocks which can be replaced by multigrid or domain decomposition preconditioners proposed by D. Arnold, R. Falk, and R. Winther (2000) and by Q. Hu, and J. Zou (2005, 2009), respectively. The robustness is obtained with respect to the reluctivity, the frequency, and conductivity, where the conductivity can degenerate into zero in non-conducting regions. Finally, we discuss the application of this solver to linear initial-boundary value problems with non-harmonic excitation and to non-linear problems including non-linear eddy current problems in the framework of the multiharmonic approach.

The authors acknowledge the support by the Austrian Science Fund (FWF) under the grants P19255 and DK W1214.

Energy Minimizing Coarse Spaces with Functional Constraints

Session Schedule Author Index Session Index

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Panayot Vassilevski
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Robert Scheichl
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Abstract

We will report on the construction of energy minimizing coarse spaces built by patching solutions to appropriate saddle point problems. We first set an abstract framework for such constructions, and then we give an example of constructing coarse space and stable interpolation operator for the two level Schwarz method. We apply the theoretical results in the design of coarse spaces for discretizations of PDE with large varying coefficients. The stability and approximation bounds of the constructed interpolant are in a weighted norm and are independent of the variations in the coefficients. Such spaces can be used in two level overlapping Schwarz algorithms for elliptic PDEs with large coefficient jumps generally not resolved by a standard coarse grid. This is a joint work with Robert Scheichl (University of Bath, UK) and Panayot S. Vassilevski (Lawrence Livermore National Lab).

Analysis of FETI and FETI-DP Methods for Highly Varying Coefficients Within Subdomains

Session Schedule Author Index Session Index

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Abstract

In the standard analysis of non-overlapping DD methods the PDE coefficient is often assumed to be constant in each subdomain. However, there is growing interest in multiscale problems where this assumption cannot be fulfilled in practice, at least not with a coarse space of reasonable size. A straightforward generalization of the standard analysis to varying coefficients easily results in far too pessimistic condition number bounds.

In this talk we present a refined analysis of FETI and FETI-DP methods where large scale coefficient variation is allowed in each subdomain. Using a generalized concept of quasi-monotonicity and new weighted Poincare inequalities, robustness can be achieved for a large class of varying coefficients. It is even sufficient that the quasi-monotonicity holds only in the subdomain boundary layers, which allows any type of variation in the subdomain interiors. We note that some adaptions of the FETI-DP coarse space are needed to succeed with a robust behavior. Finally, we show some numerical results, in particular for a problem stemming from nonlinear magnetostatics.

This research has been supported by the Austrian Science Fund (FWF) under grants P19255 and DK W1214.

Trace Theorems and Domain Decomposition Preconditioners in the Case of Subdomains with Jumps in Coefficients of Elliptic Problems

Session Schedule Author Index Session Index

Sergey Nepomnyaschikh
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Abstract

The theorems on traces of functions from Sobolev spaces play an important role in studying boundary value problems of partial differential equations. These theorems are commonly used for a priori estimates of stability with respect to boundary conditions, and also play very important role in constructing and studying effective domain decomposition methods. In some practical cases it is necessary to split original domains into subdomains in such a way that interfaces between subdomains and interfaces where there are jumps in coefficients can have intersections. It means that inside subdomains norms in Sobolev spaces involve weight functions with jumps. For this case corresponding norms of traces are defined, trace theorems are proved, optimal domain decomposition solvers are suggested.

Mini Symposium M12P1

Optimal Algorithms for Contact Problems

Schedule Author Index Session Index

Date: Wednesday, February 9
Time: 10:00-12:00
Location: B210
Chairman: Zdeněk Dostál, Rolf Krause

10:00-10:30 : Rolf Krause
Monotone Multigrid Methods Based on Parametric Finite Elements
Abstract

10:30-11:00 : Tomáš Kozubek
Scalable TFETI Based Algorithm for Transient Contact Problems with Preconditioning by Conjugate Projector
Abstract

11:00-11:30 : Jaroslav Kruis
Modelling Imperfect Interfaces in Composite Materials
Abstract

11:30-12:00 : Jungho Lee
A Comparison of Two Domain Decomposition Methods for a Linearized Contact Problem
Abstract

Part II

Abstract

The minisymposium is concerned with effective methods for the solution of unilateral contact problems in elasticity, in particular the ones that can exhibit optimal complexity, either theoretically or by numerical experiments. Important part of the minisymposium will be innovative applications, solution of complex industrial problems, and results related to the existing algorithms that can concerns their better understanding, effective implementation, and improved performance.

Monotone Multigrid Methods Based on Parametric Finite Elements

Session Schedule Author Index Session Index

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Abstract

In the numerical simulation of elastic contact problems, the treatment of the non-penetration conditions at the potential contact boundary is of particular importance for both the quality of a finite element approximation and the overall efficiency of the algorithms. A vital challenge is to achieve an accurate description of geometric features, e. g., of warped surfaces, often incorporated in three-dimensional models from computer-aided design (CAD). In this talk, we investigate a new connection of different numerical methods, namely modern discretization techniques for PDEs on complex geometries on the one side and fast multilevel solvers for constrained minimization problems on the other side.

The perspective we offer here is a monotone multigrid method based on parametric finite elements. To obtain multilevel parametric finite element spaces in 3D, we use a full-dimensional parameterization, constructed by tetrahedral transfinite interpolation of CAD data, to lift standard Lagrange elements to the computational domain. After all, the long-term objective lies in an increased flexibility of hp-adaptive methods for contact problems.

Scalable TFETI Based Algorithm for Transient Contact Problems with Preconditioning by Conjugate Projector

Session Schedule Author Index Session Index

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Abstract

The TFETI based domain decomposition method is adapted to implement the time step of the Newmark scheme for the solution of dynamic contact problems without friction. If the time steps and the ratio of the decomposition and discretization parameters are kept uniformly bounded, then the cost of the time step is proved to be proportional to the number of nodal variables. The algorithm uses our in a sense optimal MPRGP algorithm for the solution of strictly convex bound constrained quadratic programming problems with preconditioning by the conjugate projector to the subspace defined by the trace of the rigid body motions on the artificial subdomain interfaces. The proof of optimality combines our theory of preconditioning by conjugate projector for nonlinear problems with the classical results by Farhat, Mandel, and Roux on scalability of FETI for linear problems. The results are confirmed by numerical solution of 2D and 3D dynamic contact problems.

Modelling of Imperfect Interfaces in Composite Materials

Session Schedule Author Index Session Index

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Abstract

Modelling of imperfect interfaces in composite materials will be based on modification of the FETI method. The interface conditions, which represent the continuity conditions in the classical FETI method, are modified and slip between composite constituents is introduced. It results in slight modification of the coarse problem where the compliance matrix is enriched by the compliance matrix of the interface.

In the second part of the talk, we apply this procedure to simulate progressive delamination within a variational framework based on incremental energy minimization. The interfacial description is based on energetic reformulation of the Camacho-Ortiz constitutive law, complemented with surface-related dissipation function. At each time increment, the alternating minimization strategy is adopted, in which we iteratively update the internal variables and displacement-based quantities using the FETI-based method. Performance of the algorithm is demonstrated by case studies of mixed-mode delamination in laminated structures and debonding in fibre-reinforced composites.

A Comparison of Two Domain Decomposition Methods for a Linearized Contact Problem

Session Schedule Author Index Session Index

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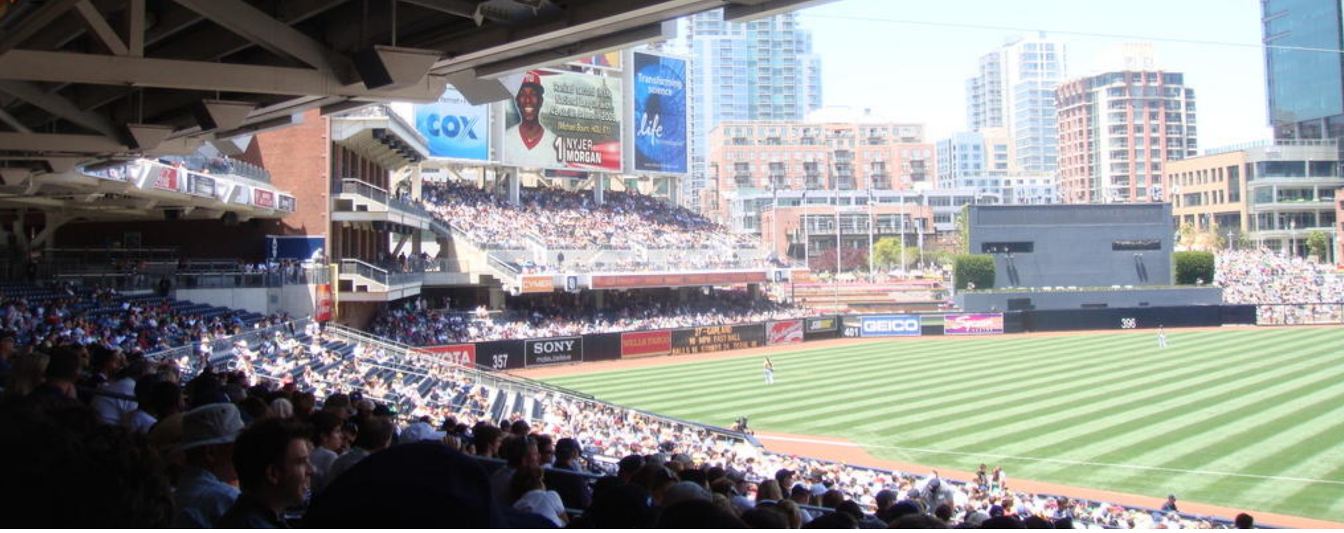
Abstract

We compare two domain decomposition methods for a linearized contact problem. The first method we consider has been used in an engineering community; we provide theoretical and numerical evidence that this method is not scalable with respect to the number of subdomains (processors). We propose a scalable alternative and analyze its properties, both theoretically and numerically. We also solve a model problem using a combination of a primal-dual active set method, viewed as a semismooth Newton method, and the scalable alternative.



Mini Symposium M12P2

Optimal Algorithms for Contact Problems

Schedule Author Index Session Index

Date: Wednesday, February 9
Time: 2:45-4:45
Location: B210
Chairman: Zdeněk Dostál, Rolf Krause

2:45-3:15 : Dalibor Lukáš
Scalable TBETI Algorithms for Contact Problems of Elasticity
Abstract

3:15-3:45 : Alexandros Markopoulos
Solution of Complex Engineering Problems by Scalable TFETI/TBETI
Abstract

3:45-4:15 : Alexander Popp
The Mortar Method with Dual Lagrange Multipliers: Application to 3D Finite Deformation Contact and Quadratic Elements
Abstract

4:15-4:45 : Vít Vondrák
Contact Shape Optimization with Scalable TFETI Algorithms
Abstract

Part I

Abstract

The minisymposium is concerned with effective methods for the solution of unilateral contact problems in elasticity, in particular the ones that can exhibit optimal complexity, either theoretically or by numerical experiments. Important part of the minisymposium will be innovative applications, solution of complex industrial problems, and results related to the existing algorithms that can concerns their better understanding, effective implementation, and improved performance.

Optimal TBETI for Multi-Body Contact Problems

Session Schedule Author Index Session Index

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Abstract

We consider a multi-body elastic contact problem with Tresca friction. The linear elastic problem with mixed boundary conditions is formulated as a boundary integral equation in terms of the Steklov-Poincare (SP) operator. We employ Galerkin boundary element discretization and the Total-BETI domain decomposition approach, which leads to a minimization problem with both linear equality and inequality constraints and the objective functional involving a dissipative Tresca term. Applying the duality concept, the linear inequality constraints transfer to simple bound constraints and the nonlinear Tresca friction term translates to additional separable quadratic constraints. When solving the problem in parallel, each slave process is responsible for actions of its local SP operator and the pseudoinverse. This results in CG-iterations additionaly preconditioned by the projector to the rigid body modes. We document performance of the method on numerical results for real-life engineering benchmark problems.

Solution of complex engineering problems by scalable TFETI/TBETI

Session Schedule Author Index Session Index

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Abstract

We present the MatSol library developed at the Department of Applied Mathematics, VSB-Technical University of Ostrava. This MATLAB based library is designed for research in development of effective algorithms for solving large-scale mechanical engineering problems and their application to the real-world problems. An important part of the library is the interface to some commercial packages (COMSOL, ANSYS, ANSA) . The MatSol library implements effective our scalable algorithms for the solution of contact problems of elasticity, including the problems with friction, both static and dynamic, and contact shape optimization. The main topics of our presentation are engineering benchmarks comprising both static and dynamic problems and the results of numerical experiments which demonstrate the scalability of our algorithms. As the discretization scheme, the finite and boundary element methods are used.

The Mortar Method with Dual Lagrange Multipliers: Application to 3D Finite Deformation Contact and Quadratic Elements

Session Schedule Author Index Session Index

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Abstract

We propose a mortar formulation of finite deformation frictional contact using dual Lagrange multiplier spaces in combination with a consistently linearized semi-smooth Newton scheme for constraint enforcement. Advantageous properties of the devised algorithms include superior robustness as compared with traditional node-to-segment schemes, the absence of any user-defined parameter (e.g. penalty parameter), the integration of all types of nonlinearities (including finite deformations, nonlinear material behavior and active set search) into one single nonlinear iteration loop and the possibility to easily condense the discrete Lagrange multipliers from the global system of equations. Special focus will be set on second-order finite element interpolation in 3D. By introducing a local basis transformation, we obtain dual Lagrange multiplier shape functions suitable for mortar contact analysis with quadratic (tri6, quad8 and quad9) surface elements from the usual biorthogonality condition. Furthermore, a novel dynamic load balancing strategy assuring optimal parallel scalability of the contact algorithms will be presented.

Contact shape optimization with scalable TFETI algorithms

Session Schedule Author Index Session Index

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Abstract

The contact shape optimization problems is one of the computationally most challenging problems. The reason is that not only the cost function is a nonlinear implicit function of the design variables, but that its evaluation requires also a solution of the highly nonlinear variational inequality which describes the equilibrium of a system of elastic bodies in mutual contact. Since the cost function must be evaluated many times in the solution process, it is obvious that the solution of contact problem is a key ingredient of any effective algorithm for the solution of contact shape optimization problems. The approach that we propose here is based on the Finite Element Tearing and Interconnecting (FETI) domain decomposition method, which was originally proposed by Farhat and Roux for parallel solving of the linear problems described by elliptic partial differential equations. If the FETI procedure is applied to an elliptic variational inequality, the resulting quadratic programming problem has not only the equality constraints, but also the non-negativity constraints.

In this talk, we exploit the parallel implementation of our scalable algorithm for contact problem to the minimization of the the compliance of the system elastic bodies subject the volume constraint and some additional constraints. We start our exposition by recalling some theoretical results and formulae for derivatives of the solution with respect to the design variables. In particular, it turns out that the derivatives of the solution may be evaluated by the solution of variational inequalities with the same operator as the state problem. After identifying the subdomains with the bodies of the system and discretization, we describe our Total

FETI (TFETI, also all floating) based domain decomposition algorithm for the solution of the resulting variational inequalities in two steps. First, using the duality theory, the problem to find the minimum of the energy functional subject to the kinematically admissible displacements is reduced to the contact interface. Then we exploit an efficient algorithm for the solution of the quadratic programming problems with simple bounds and possibly some equalities. An especially attractive feature of this approach is not only high precision of the gradient, but also the fact that relatively expensive decomposition of the stiffness matrices of the subdomains is carried out only once for each update of the design variables. Moreover, the decomposition update concerns only the subdomains affected by the update and we usually have good initial approximations for the solution. The efficiency of the proposed algorithms will be demonstrated on the compliance minimization of selected practical problem.

Mini Symposium M13

Domain Decomposition and Multigrid Methods for Lattice QCD

Schedule Author Index Session Index

Date: Thursday, February 11
Time: 10:00-12:00
Location: B145
Chairman: James Brannick, Richard Brower

10:00-10:30 : Richard Brower
Overview of LQCD
Abstract

10:30-11:00 : Karsten Kahl
Multigrid Methods for Lattice QCD
Abstract

11:00-11:30 : Jonathan Cohen
Domain Decomposition on GPUs
Abstract

11:30-12:00 : Karsten Kahl
Domain Decomposition Methods for LQCD
Abstract

Abstract

The focus of the proposed minisymposium is on the development and implementation of Domain Decomposition and Algebraic Multilevel algorithms for the solution of large scale linear systems arising in Lattice Quantum Chromodynamics. Large scale computing in lattice Quantum Chromodynamics (LQCD) is undergoing a critical transition. Dedicated Petascale facilities and a deeper theoretical understanding of this quantum field theory allow one for the first time to explore the full non-linearities of the theory and confront experimental data with ab initio predictions. Although these theoretical, software, and hardware advances have resulted in substantial improvements to LQCD simulations, further advances in algorithms are still needed.

Over the last decade or more, applied mathematics has also made tremendous progress developing more robust and efficient algorithms based on domain decomposition and multilevel (Multigrid) methods for scientic computing. Together, these mathematical advances, better formulations of the QCD theory on a lattice, and the signicant growth in computer power offer new opportunities for algorithm advances in LQCD. The minisymposium will highlight these advances in LQCD theory, algorithms, and hardware and further expose challenges in exploiting them in actual simulation code.

Exploiting Multi-scale Lattice QCD

Session Schedule Author Index Session Index

Richard Brower
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Abstract

Extreme scale computing for lattice QCD present both an opportunity to resolve more accurately multiple scales and a challenge to redesign algorithm to exploit them. At the same time extreme scale architectures are becoming increasingly heterogeneous with demand to localize and reduce memory traffic. An overview of the problem and potential avenues for confronting multi-scales in lattice field theory will be presented.

Multigrid Methods for Lattice QCD

Session Schedule Author Index Session Index

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James Brannick
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Abstract

We give an overview of the Dirac system of Lattice QCD and discuss the features which make it difficult to solve this system using iterative solvers. We then discuss recent progress in developing adaptive MG for these systems.

Domain Decomposition on GPUs

Session Schedule Author Index Session Index

Jonathan Cohen
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Abstract

Modern GPUs are highly efficient massively parallel general purposes processors. A single high-end GPU from NVIDIA can achieve several hundred GFLOPS/s in double precision arithmetic. Because of their inherently parallel and high-throughput nature, they are a natural fit for domain decomposition and multilevel methods. I will give a brief technical overview of NVIDIA's CUDA platform for GPU computing, and present initial work to develop sparse linear solvers using CUDA.

Domain Decomposition Methods for LQCD

Session Schedule Author Index Session Index

Karsten Kahl
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Abstract

Solving the linear systems arising in Lattice QCD (LQCD) computations is the main bottleneck of LQCD simulations and remains one of the great challenges for the development of efficient and scalable algorithms. While a lot of effort in the last decade has been spent in the investigation of Krylov-subspace type methods and it has been shown that adaptive multigrid methods are applicable to these problems, Domain Decomposition methods, despite being well-understood and broadly used in many applications arising in PDE simulations, were just recently getting attention in the LQCD community which lead to first basic DD methods. In order to improve these methods we examine the challenges posed by these linear systems and analyze possible remedies using advanced DD principles. Furthermore we connect the development of DD methods with the development of efficient multigrid algorithms and give an outlook on the implementation of such methods on exascale architectures.

Mini Symposium M14

Advances in Domain Decomposition Methods for Almost Incompressible Elasticity and Problems Posed in H(div) and H(curl)

Schedule Author Index Session Index

Date: Thursday, February 10
Time: 10:00-12:00
Location: B210
Chairman: Olof Widlund

10:00-10:30 : Axel Klawonn
A Hybrid FETI-DP Method for Almost Incompressible Elasticity
Abstract

10:30-11:00 : Duk-Soon Oh
An Overlapping Schwarz Algorithm for Raviart–Thomas Vector Fields
Abstract

11:00-11:30 : Oliver Rheinbach
Newton-Krylov-FETI and the Augmented Lagrange Method in the Simulation of Biological Soft Tissue
Abstract

11:30-12:00 : Olof Widlund
Advances in Domain Decomposition Algorithms for H(curl)–Problems
Abstract

Abstract

The mini symposium will focus on results on new variants of overlapping Schwarz, FETI-DP, and BDDC algorithms for finite element methods for almost incompressible elasticity and problems posed in H(div) and H(curl).

A Hybrid FETI-DP Method for Almost Incompressible Elasticity

Session Schedule Author Index Session Index

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Abstract

In contrast to classical FETI-1 methods, which use projections, the coarse problem of FETI-DP methods is constructed by using partial assembly in certain primal variables. It is well known that standard coarse spaces are not robust with respect to almost incompressible elasticity. In this talk a framework using projections is presented which allows to enhance a given FETI-DP coarse space such that robustness is achieved.

An Overlapping Schwarz Algorithm for Raviart–Thomas Vector Fields

Session Schedule Author Index Session Index

Duk-Soon Oh
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Abstract

In this talk, we provide a two-level overlapping Schwarz method for Raviart-Thomas vector fields. While many iterative substructuring methods for H(div) or H(curl) problems have been studied for variable coefficients cases, there has been no supporting theory for the overlapping Schwarz methods until recently. This is because traditional coarse space methods are sensitive to the large jumps of the coefficients. In order to overcome this, we introduce an alternative method. The coarse part of the preconditioner is based on the energy-minimizing extensions and the local parts are based on traditional solvers on overlapping subdomains.

Newton-Krylov-FETI and the Augmented Lagrange Method in the Simulation of Biological Soft Tissue

Session Schedule Author Index Session Index

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Abstract

Biological soft tissue is often modelled as a highly nonlinear, anisotropic and almost incompressible elastic material. We apply a FETI domain decomposition method within a nonlinear structural mechanics simulation environment. In order to cope with the almost incompressibilty constraint we use an augmented Lagrange approach. We show that this approach considerably improves the properties of the linearized systems.

Advances in Domain Decomposition Algorithms for H(curl)–Problems

Session Schedule Author Index Session Index

Olof Widlund
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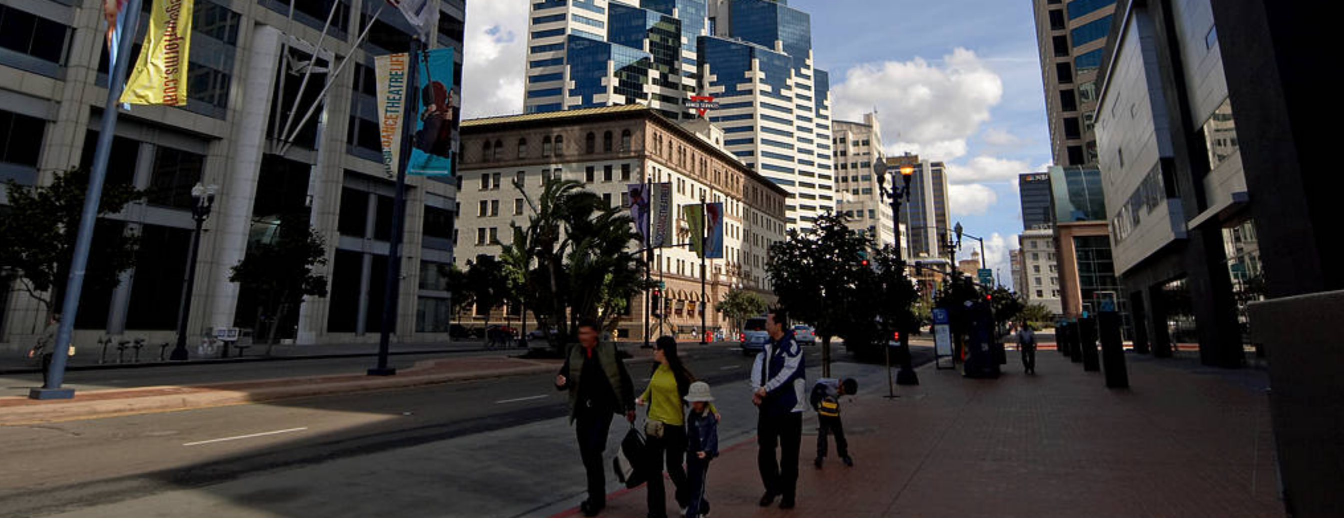
Abstract

In recent years, new hybrid domain decomposition methods have been developed which combine algorithmic ideas from two-level overlapping Schwarz methods and primal iterative substructuring methods. These methods are well defined for arbitrarily shaped subdomains and allow performance bounds which are independent of coefficient jumps across the interface between the subdomains. The local subproblems are defined on a set of overlapping subdomains. In spite of that by a choice of a hybrid Schwarz method residuals and iterates need only to be saved on the interface. Earlier work was focused on almost incompressible elasticity but the efforts are now concentrated on two- and three dimensional problems formulated in H(curl) and discretized using edge elements. All this work is joint with Clark Dohrmann of the Sandia National Laboratories.



Mini Symposium M15P1

Space-time Adaptive Methods

Schedule Author Index Session Index

Date: Monday, February 7
Time: 10:00-12:00
Location: B210
Chairman: Martin J. Gander, Laurence Halpern

10:00-10:30 : Martin J. Gander
Techniques for Locally Adaptive Timestepping Developped Over the Last Two Decades
Abstract

10:30-11:00 : Adrian Sandu
Recent Developments in Multirate Time Integration
Abstract

11:00-11:30 : Julien Diaz
Explicit hp-Adaptive Time Scheme for the Wave Equation
Abstract

11:30-12:00 : Ron Haynes
Equidistributing Grids via Domain Decomposition
Abstract

Part II

Abstract

Local mesh adaptation is an area of active research, and several well developed techniques exist for steady problems. When solving evolution problems however, often a uniform time discretization across all the spatial domain is used, and locally adaptive techniques are then only used in space. This approach often leads to unnecessarily fine time steps in areas of the domain where the spatial grid is coarse, and substantial unnecessary computational cost. The purpose of this minisymposium is to have experts of locally time adaptive methods to present the different techniques that have been developed to solve evolution problems adaptively both in space and time. Such techniques include local time sub-stepping and interpolation, discontinuous Galerkin formulations in time, space-time domain decomposition methods and local specialized explicit or implicit coupling schemes.

Techniques for Locally Adaptive Timestepping Developped Over the Last Two Decades

Session Schedule Author Index Session Index

Martin J. Gander
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Laurence Halpern
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Abstract

While adaptive mesh refinement techniques (AMR) have been well established for space discretizations, both mathematically and in applications, local adaptation in the time direction is not yet widely used. This is probably due to the fact that the time direction is special, and time marching schemes tend to impose a uniform time step over the entire domain in the simulation.

We present in this talk an overview over the different techniques developed over the last two decades which permit the use of locally adapted time steps. Topics include multirate time integrators for systems of ordinary differential equations, local time substepping using interpolation, projection or energy conservation, one-way and two-way coupling methods from atmospheric and oceanic sciences, and space-time decomposition methods, which permit the use of completely different methods in different space-time domains.

Recent Developments in Multirate Time Integration

Session Schedule Author Index Session Index

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Abstract

We discuss multirate discretization methods that allow efficient solutions to problems that have components with different dynamics. The presentation includes strong stability preserving Runge Kutta and Linear Multistep methods, and extrapolation methods. Strong stability multirate methods are suited for hyperbolic PDEs solved on adaptive grids, as they allow different time steps to be used in different parts of the domain. The extrapolation approach is suited for the time integration of multiscale ordinary and partial differential equations and provides highly accurate discretizations. We analyze the linear stability properties of the multirate explicit and linearly implicit extrapolated methods. Numerical results illustrate the theoretical findings.

Explicit hp-Adaptive Time Scheme for the Wave Equation

Session Schedule Author Index Session Index

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Abstract

We present a new hp-adaptive time scheme for solving the wave equation. This scheme does not only allow for the use of small time steps in the locally-refined cells and large time steps elsewhere, but also for the adaptation of the order of time discretization to the order of the space discretization. This last property is particularly useful to consider Discontinuous Galekin Methods (DGM) with meshes composed of cells of various order. The scheme is totally explicit and it conserves exactly a discrete energy. It can be extended to deal with hierarchical local time-stepping (i.e., when the fine mesh contains itself a very fine mesh). The numerical results illustrate the efficiency of the methods and in particular its ability to handle very strong ratio between coarse and fine cells (from 1 to 100).

Equidistributing Grids via Domain Decomposition

Session Schedule Author Index Session Index

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Abstract

Adaptively choosing an underlying grid for computation has proven to be a useful, if not essential, tool for the solution of boundary value problems and partial differential equations. One way of generating adaptive meshes is through the so-called equidistribution principle (EP). In one spatial dimension the required mesh can be obtained through the solution of a nonlinear BVP. In this talk I will review the idea of EP and consider the solution of the resulting BVP via domain decomposition including classical, optimized and optimal Schwarz iterations.

Mini Symposium M15P2

Space-time Adaptive Methods

Schedule Author Index Session Index

Date: Monday, February 7
Time: 2:45-4:45
Location: B210
Chairman: Martin J. Gander, Laurence Halpern

2:45-3:15 : Jerónimo Rodríguez
Coupling Discontinuous Galerkin Methods and Retarded Potentials for Transient Wave Propagation on Unbounded Domains
Abstract

3:15-3:45 : Vadim Lisitsa
Local Low-Reflection Space-Time Mesh Refinement for Finite-Difference Simulation of Seismic Waves
Abstract

3:45-4:15 : Florian Haeberlein
Krylov Subspace Accelerators for Non-Overlapping Schwarz Waveform Relaxation Methods Applied to Coupled Nonlinear Reactive Transport Systems in the Context of CO2 Geological Storage Simulation
Abstract

4:15-4:45 : Laurence Halpern
Space-time Refinement for the 1-D Wave Equation
Abstract

Part I

Abstract

Local mesh adaptation is an area of active research, and several well developed techniques exist for steady problems. When solving evolution problems however, often a uniform time discretization across all the spatial domain is used, and locally adaptive techniques are then only used in space. This approach often leads to unnecessarily fine time steps in areas of the domain where the spatial grid is coarse, and substantial unnecessary computational cost. The purpose of this minisymposium is

to have experts of locally time adaptive methods to present the different techniques that have been developed to solve evolution problems adaptively both in space and time. Such techniques include local time sub-stepping and interpolation, discontinuous Galerkin formulations in time, space-time domain decomposition methods and local specialized explicit or implicit coupling schemes.

Coupling Discontinuous Galerkin Methods and Retarded Potentials for Transient Wave Propagation on Unbounded Domains

Session Schedule Author Index Session Index

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Abstract

This work deals with the numerical simulation of wave propagation on unbounded domains with localized heterogeneities. To do so, we propose to combine a discretization based on a discontinuous Galerkin method in space and explicit finite differences in time on the regions containing heterogeneities with the retarded potential method to account the unbounded nature of the computational domain. The coupling formula enforces a discrete energy identity ensuring the stability under the usual CFL condition in the interior. Moreover, the scheme allows to use a smaller time step in the interior domain yielding to quasi-optimal discretization parameters for both methods. The aliasing phenomena introduced by the local time stepping are reduced by a post-processing by averaging in time obtaining a stable and second order consistent coupling algorithm.We show some numerical experiments on academic problems that show the feasibility of the whole discretization procedure.

Local Low-Reflection Space-Time Mesh Refinement for Finite-Difference Simulation of Seismic Waves

Session Schedule Author Index Session Index

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Abstract

We develop the finite-difference techniques for simulation of seismic waves propagation through 3D heterogeneous elastic media with microstructure. The method uses grids with local refinement in time and space and possesses extremely low level of artificial reflection - about 0.0001/0.0005 of incident amplitude. This feature is undisputed for reliable numerical modeling of scattered waves and is provided in main by:
1) Implementation of refinement in time and space on two different embedded surfaces embracing target area filled with microheterogeneities;
2) Time stepping is free from any kind of interpolation and, so, from any kind of induced inaccuracy;
3) Fast Fourier Transform based interpolation sewing different grids in space has exponential accuracy and is unbeatable in computational effectiveness.
We justify stability of the method both theoretically and numerically and present results of numerical simulation for realistic 3D heterogeneous multiscale media with performed with the use of grids locally refined in seven times in time and space. This research is done under partial support of RFBR grants 10-05-00233, 11-05-00238, 11-05-00947.

Krylov Subspace Accelerators for Non-Overlapping Schwarz Waveform Relaxation Methods Applied to Coupled Nonlinear Reactive Transport Systems in the Context of CO2 Geological Storage Simulation

Session Schedule Author Index Session Index

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Anthony Michel
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Abstract

Krylov subspace methods are widely used in the context of non-overlapping Schwarz waveform relaxation methods for linear problems in order to accelerate the convergence speed independently of the parameter chosen for the Robin transmission condition. In this work, we propose to extend this technique to nonlinear problems. We present two approaches which differ in the order of combination of Newton's method and the Schwarz algorithm. In both approaches, the arising linear systems are treated by an in exact Krylov-type method. Numerical tests in 2D studying the influence of the parameter of the Robin transmission condition prove that both approaches provide a considerable acceleration of the convergence speed compared to the standard approach. We provide also results in 3D for a two species nonlinear coupled reactive transport system in the context of CO2 geological storage simulation.

Space-time Refinement for the 1-D Wave Equation

Session Schedule Author Index Session Index

Laurence Halpern
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Abstract

Optimized Schwarz waveform relaxation algorithms are versatile and powerful tools to perform local mesh refinement in both time and space. This is particularly useful for wave equation, as explicit schemes are commonly used to avoid inverting a matrix at each time step. As a draw-back, they impose a CFL condition of the type ct/x. If the velocity c presents large discontinuities, or if one wants to zoom in some region (i.e. reduce x), the time step t has to be reduced accordingly. Domain decomposition is therefore a very relevant approach to the separation of zones with velocities of the same order of magnitude. But it is important to be able to keep for the full process the order of accuracy of the scheme. In this presentation we show a proof of such analysis for the one-dimensional wave equation.

References

1. L. Halpern. Non conforming space-time grids for the wave equation: a new approach. Monogr. Semin. Mat. Garca Galdeano, 31, Prensas Univ. Zaragoza, Zaragoza, 479-495, 2004.

2. L. Halpern. Local space-time refinement for the one dimensional wave equation. Journal of Computational Acoustics, vol.13, pp 153-176, 2005.

Mini Symposium M16P1

Heterogeneous Domain Decomposition

Schedule Author Index Session Index

Date: Thursday, February 10
Time: 10:00-12:00
Location: B143-B144
Chairman: Veronique Martin, Ralf Kornhuber, Oliver Sander, Alfio Quarteroni

10:00-10:30 : Veronique Martin
Historical Review of Methods for Coupling Different Models
Abstract

10:30-11:00 : Juliette Ryan
Euler - Navier-Stokes Coupling for Aeroacoustics Based on a Schwarz Waveform Technique
Abstract

11:00-11:30 : Todd Arbogast
Multiscale Mortar Methods for Flow in Heterogeneous Porous Media
Abstract

11:30-12:30 : Oliver Sander
Nonlinear Coupling between a Cosserat Rod and an Elastic Continuum
Abstract

Part II

Abstract

Coupled heterogeneous phenomena are not an exception but the rule in advanced numerical simulations of fluid dynamics, hydrodynamics, haemodynamics, biomechanics or acoustics. Mathematical understanding of coupling conditions in connection with the development, analysis and implementation of substructuring methods becomes more and more important. The aim of this minisymposium is to bring together scientists working in this field to report about recent developments.

Historical Review of Methods for Coupling Different Models

Session Schedule Author Index Session Index

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Abstract

In many applications the viscous terms become only important in parts of the computational domain. A typical example is the flow of air around the wing of an airplane. It can then be interesting to use an expensive viscous model only where the viscosity is essential for the solution and an inviscid one elsewhere. This leads to the interesting problem of coupling partial differential equations of different types. In this talk we propose to give an historical overview of coupling techniques from the last 20 years. Different strategies have namely been proposed. A first one, proposed by Glowinski et al in 1988, consists in solving a least squares problem in the overlapping region in order to minimize the distance between the solutions of the two models. A second strategy proposed by Brezzi et al in 1989 is to introduce a non-linear function of the diffusion, which makes this term zero as soon as it becomes small enough, thus providing a smooth, auto- matically detected transition between the viscous and inviscid regions. Finally, the coupling can be achieved using transmission conditions that are built in different manners (limiting process for small viscosity, see Quarteroni et al in 1989, absorbing boundary condition theory and factorization of the operator, see Dubach 1993, and finally using asymptotic corrections, see Wendland et al in 2000). We will show a numerical comparison of these techniques for a simple model problem.

Euler - Navier-Stokes Coupling for Aeroacoustics Based on a Schwarz Waveform Technique

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Abstract

A new method of coupling between aerodynamics and acoustics was proposed in [1] which is independent of boundary location. This work is a natural extension of activities on optimized Schwarz waveform relaxation for advection - diffusion - reaction, including semi-linear equations, developed around M. Gander and L. Halpern (see DD 11 to 19). This method consists in solving Euler and Navier-Stokes alternatively in each subdomain, and transmitting the necessary information through differential interface boundary conditions, globally in time windows. Optimized parameters make it possible to reduce the number of iterations necessary for convergence. It has been implemented with a new discontinuous Galerkin method developed at ONERA by M. Borrel and J. Ryan (see ICOHASOM 2009). New developments including time-space interpolation allowing for multi-scale simulations will be presented. The present method will be evaluated on 2D laminar configurations such as the low-Reynolds subsonic flow around a cylinder.

References

1. M. Borrel, L. Halpern, J. Ryan : *Euler - Navier-Stokes coupling for Aeroacoustics problems*, ICCFD 2010, St Petersburg.

Multiscale Mortar Methods for Flow in Heterogeneous Porous Media

Session Schedule Author Index Session Index

Todd Arbogast
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Abstract

We consider a second order elliptic problem with a heterogeneous coefficient written in mixed form. We view the domain decomposition method as a multiscale method with restricted degrees of freedom on the interfaces. We devise an effective but purely local multiscale method that incorporates information from homogenization theory. We also use this decomposition method approach to devise effective preconditioners that incorporate exact coarse-scale information to iteratively solve the full fine-scale problem.

Nonlinear Coupling between a Cosserat Rod and an Elastic Continuum

Session Schedule Author Index Session Index

Oliver Sander
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Abstract

We investigate the coupling between a geometrically exact Cosserat rod and a nonlinearly elastic continuum. Due to the nonlinear nature of the rod configuration space the coupling conditions have to be formulated on the tangent bundle of the group of rigid body motions SE(3). We give the formulation in terms of Steklov–Poincaré operators and show existence of a solution in a special case. We then propose various solution algorithms for the nonlinear coupled problem that follow from the Steklov–Poincaré formulation. These algorithms are compared numerically. As a practical application we compute solutions of a model of the human knee, where Cosserat rods are used to model the ligaments.

Mini Symposium M16P2

Heterogeneous Domain Decomposition

Schedule Author Index Session Index

Date: Thursday, February 10
Time: 2:45-4:45
Location: B143-B144
Chairman: Veronique Martin, Ralf Kornhuber, Oliver Sander, Alfio Quarteroni

2:45-3:15 : Ralf Kornhuber
Numerical Simulation of Coupled Surface and Saturated/Unsaturated Ground Water Flow
Abstract

3:15-3:45 : Lucia Gastaldi
Finite Elements for the Immersed Boundary Method
Abstract

3:45-4:15 : Paola Gervasio
Virtual Controls and Extended Variational Formulation for Hyperbolic/Elliptic Couplings
Abstract

4:15-4:45 : Marco Discacciati
A Domain Decomposition Framework for Modeling Dimensionally Heterogeneous Problems
Abstract

Part I

Abstract

Coupled heterogeneous phenomena are not an exception but the rule in advanced numerical simulations of fluid dynamics, hydrodynamics, haemodynamics, biomechanics or acoustics. Mathematical understanding of coupling conditions in connection with the development, analysis and implementation of substructuring methods becomes more and more important. The aim of this minisymposium is to bring together scientists working in this field to report about recent developments.

Numerical Simulation of Coupled Surface and Saturated/Unsaturated Ground Water Flow

Session Schedule Author Index Session Index

Ralf Kornhuber
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Abstract

In lowland areas the surface and the subsurface catchment may vary considerably in time and space, because precipitation "excess" is partly flowing directly into rivers and lakes by surface runoff, and partly is diverted to these water bodies by surface infiltration, ground water recharge, and ground water leakage. Our approach to the mathematical modelling of these highly nonlinear, heterogeneous processes is based on Richhards equation for saturated/unsaturated ground water flow which is coupled to the shallow water equations or simple compartement models for surface water by suitable transmission conditions. The seepage along river beds and lakes is described by Signorini-type boundary conditions. We will present Poincare-Steklov formulations of the coupled problem and an iterative solver of Dirichlet-Neumann-type taking the multiple time scales of ground and surface water flow into account. The Richards equation is discretized in space by a novel, solver-friendly multidomain discretization allowing for fast and robust solution of the resulting large-scale nonlinear nonsmooth systems by domain decomposition and multigrid. The shallow water equations are treated by discontiuous Galerkin methods. We present numerical simulations of some typical scenarios and illustrate the performance of the building blocks of our algorithm by numerical experiments.

Finite Elements for the Immersed Boundary Method

Session Schedule Author Index Session Index

Lucia Gastaldi
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Abstract

In the resolution of fluid-structure interaction systems, one has usually to face the problem of the strong coupling between the equations modeling the dynamics of the fluid and the structure. This coupling can be expressed, for example, through transmission conditions along the interface separating the fluid and the structure domain. Numerical strategies for computing the solution are based on different approaches. Among them, the Immersed Boundary Method (IBM), designed by Peskin for the modeling and the numerical approximation of fluid-structure interaction problems, has been successfully used in order to simulate the blood dynamic in the heart (see [4]). In this approach, the Navier-Stokes equations are considered everywhere and the presence of the structure is taken into account by means of a source term which depends on the unknown position of the structure. These equations are coupled with the condition that the structure moves at the same velocity of the underlying fluid.

Recently, a finite element version of the IBM has been developed (see [1, 2, 3]), which offers interesting features for both the analysis of the problem under consideration and the robustness and flexibility of the numerical scheme. The numerical procedure to compute the solution is based on a semi-implicit scheme. We present a stability analysis showing that the time-step and the discretization parameters are linked by a CFL condition, independently of the ratio between the densities of fluid and solid. Moreover, we also compare different finite element spaces for the approximation of velocity and pressure, in order to better enforce the conservation of mass across the immersed boundary.

References

1. D. Boffi and L. Gastaldi, A finite element approach for the immersed boundary method, Comput. & Structures 81 (2003), no. 8-11, 491501, In honour of Klaus-Jrgen Bathe.

2. u D. Boffi, L. Gastaldi, and L. Heltai, On the CFL condition for the finite element immersed boundary method, Comput. & Structures 85 (2007), no. 11-14, 775783.

3. D. Boffi, L. Gastaldi, L. Heltai, and Charles S. Peskin, On the hyper-elastic formulation of the immersed boundary method, Comput. Methods Appl. Mech. Engrg. 197 (2008), no. 25-28, 22102231.

4. C. S. Peskin, The immersed boundary method, Acta Numerica 2002, Cambridge University Press, 2002.

Virtual Controls and Extended Variational Formulation for Hyperbolic/Elliptic Couplings

Session Schedule Author Index Session Index

Paola Gervasio
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Abstract

We address the coupling between advection and advection-diffusion equations, for solutions featuring boundary layers. We consider both non-overlapping and overlapping domain decompositions and we face up the heterogeneous problem by different approaches. Starting from a rigorous variational analysis, the aim of this research is to investigate if other approaches may be considered to formulate this heterogeneous problem, for a possible extension to more general couplings. In particular we will consider the virtual control approach, based on the optimal control theory, and an extend variational formulation recently proposed for geometric multiscale problems.

A Domain Decomposition Framework for Modeling Dimensionally Heterogeneous Problems

Session Schedule Author Index Session Index

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Abstract

In the last decade, there has been an increasing interest in the use of dimensionally heterogeneous representations of different physical systems. This so-called geometrical multiscale modeling has been applied successfully to represent physical phenomena arising in different fields such as, e.g., fluid-dynamics and structural modeling. The appealing aspect of such an approach is that it is possible to account for the interactions between different geometrical scales in a given system. For instance, in the context of the cardiovascular system, this allows for the integrated modeling of the blood flow, taking into account the interplay between the global systemic dynamics and the complex local blood flow behavior. In this talk we present a general theoretical framework for coupling dimensionally heterogeneous partial differential equations and we provide some guidelines for the abstract well-posedness analysis of such problems both in the continuous and in the discrete cases. Moreover, we show how to construct suitable partitioning methodologies in the context of domain decomposition methods. In particular, we discuss some alternative possibilities to those encountered in the classical domain decomposition literature, specifically devised for the dimensionally-heterogeneous case. Finally, we present some numerical results to illustrate the effectiveness of our approach.

Mini Symposium M17P1

Time-Domain Decomposition Methods for the Solution of ODEs and PDEs

Schedule Author Index Session Index

Date: Tuesday, February 8
Time: 10:00-12:00
Location: B210
Chairman: Martin J. Gander, Stefan Guettel, Yvon Maday

10:00-10:30 : Debasmita Samaddar
A New Approach to Turbulence Simulations: Temporal Parallelization by Application of the "Parareal Algorithm"
Abstract

10:30-11:00 : Julien Salomon
Time Parallelization for Optimal Control
Abstract

11:00-11:30 : Martin J. Gander
A Parareal Schwarz Waveform Relaxation Algorithm
Abstract

11:30-12:00 : Benjamin Ong
Distributed Parallel Time Integrators
Abstract

Part II

Abstract

Time-domain decomposition methods are a means of employing the ever increasing number of cores in today's supercomputers when parallelization in space is saturated or real-time approximations to the solution at future time steps are required before all previous time steps are available to full accuracy. Algorithms such as parareal, parallel deferred corrections or parallel exponential integrators show promising applicability for large-scale computations and are currently an active research topic. Our minisymposium brings together experts in these methods, to discuss recent developments and to spread the message that time-parallelism can indeed be very efficient.

A New Approach to Turbulence Simulations: Temporal Parallelization by Application of the "Parareal Algorithm"

Session Schedule Author Index Session Index

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Abstract

Understanding turbulence and turbulent transport is of fundamental importance for the study of fusion plasmas. Turbulence simulations are extremely computationally intensive as the turbulence and the profiles of the quantities of interest have to be evolved over transport (long) time scales. Studying long time dynamics for turbulence simulations has been very difficult even with the fastest computers available now or in the near future.

Parallelizing the space domain to computationally solve partial differential equations has been the most common approach so far. This work presents a new way of simulating turbulence by using the Parareal Algorithm which parallelizes the time domain. The algorithm has been successfully applied to relatively simpler problems, but not to a system as high dimensionally chaotic as turbulence (to the best of our knowledge).Time parallelization of a fully developed turbulent system is a new application and has been found to significantly reduce the computational wall time. If efficiently applied, this algorithm will allow study of the turbulent transport dynamics on transport time scales - something that has heretofore been very difficult.

In this talk, the results of applying the Parareal Algorithm to turbulence simulations of primarily fusion plasma are presented. These turbulent systems are in many ways similar to neutral fluid turbulence models. In fact, a successful treat-

ment of a highly complex system such as turbulence with this algorithm expands the prospect of applicability to other complex initial value problems. This talk also presents the results of a modification to the algorithm and a model to study and predict the parameters governing the convergence of the scheme is explored.

Time Parallelization for Optimal Control

Session Schedule Author Index Session Index

Julien Salomon
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Abstract

In this talk, we present and analyze two methods that enable to combine an optimization algorithm and a time parallelization procedure to tackle some optimal control problems. Even if the resulting schemes are quite different, they both make use of intermediate targets to achieve the time parallelization. Numerical experiments show the efficiency of our approach.

A Parareal Schwarz Waveform Relaxation Algorithm

Session Schedule Author Index Session Index

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Rong-Jian Li
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Abstract

Following a suggestion made by Yvon Maday in his presentation at DD17, we present a new space-time parallel algorithm. The algorithm uses an overlapping spatial decomposition, and also a decomposition of the time domain into non-overlapping time intervals. We then solve in parallel in all the space-time sub domains local problems, for which the initial value is provided by a Parareal correction iteration, and the boundary values are provided by a Schwarz waveform relaxation iteration. We present a convergence proof of the method for the case of the heat equation, and also show numerical experiments.

Distributed Parallel Time Integrators

Session Schedule Author Index Session Index

Benjamin Ong
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Abstract

We present on-going research in developing a family of high order parallel time integrators based on defect correction, known as Revisionist Integral Defect Correction (RIDC). RIDC methods are particularly promising because they can be potentially coupled with existing legacy codes to add parallelism in the time direction, thereby increasing the scalability. In this talk, we hope to present the results and issues related to implementing our RIDC algorithm in a heterogeneous computing environment (open-mp/cuda, open-mpi/cuda, open-mp/open-mpi).

Mini Symposium M17P2

Time-Domain Decomposition Methods for the Solution of ODEs and PDEs

Schedule Author Index Session Index

Date: Tuesday, February 8
Time: 3:30-5:30
Location: B210
Chairman: Martin J. Gander, Stefan Guettel, Yvon Maday

3:30-4:00 : Yvon Maday
Some Practical and Numerical Aspects of the Parareal in Time Algorithm Related to Exascale Simulations
Abstract

4:00-4:30 : Michael L. Minion
The Parallel Full Approximation Scheme in Space and Time
Abstract

4:30-5:00 : Stefan Guettel
A Time-Parallel Rational Krylov Integrator for Linear ODEs
Abstract

5:00-5:30 : X. Dai
Parareal Algorithm for Convection Type Equation
Abstract

Part I

Abstract

Time-domain decomposition methods are a means of employing the ever increasing number of cores in today's supercomputers when parallelization in space is saturated or real-time approximations to the solution at future time steps are required before all previous time steps are available to full accuracy. Algorithms such as parareal, parallel deferred corrections or parallel exponential integrators show promising applicability for large-scale computations and are currently an active research topic. Our minisymposium brings together experts in these methods, to discuss recent developments and to spread the message that time-parallelism can indeed be very efficient.

Some Practical and Numerical Aspects of the Parareal in Time Algorithm Related to Exascale Simulations

Session Schedule Author Index Session Index

Yvon Maday
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Abstract

The parareal algorithm was introduced as a method to take advantage of time – the "fourth dimension" that exists in non stationary PDE's, and the only that exists for differential systems – for parallelizing codes on the current generation of architectures that are available and those new that will soon been proposed and match the exascale simulations. Many of the ideas on which the algorithm is built, the theoretical capabilities and the variants that can be proposed to cope with the drawbacks of the initial implementation will be given in my invited talk. Here some technical point on the implementation explaining why we think that this type of algorithm may have interesting aspects regarding asynchronism, failure and memory access that are not so much presented will be discussed.

The Parallel Full Approximation Scheme in Space and Time

Session Schedule Author Index Session Index

Michael Minion
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Abstract

I will discuss a strategy for the parallelization of numerical methods for partial differential equations in both the spatial and temporal directions. The method is based on an iterative multilevel approach whereby spectral deferred correction sweeps are applied to a hierarchy of discretizations at different spatial and temporal resolutions. Connections to the parareal algorithm and space-time multigrid methods will be discussed, and the parallel efficiency and speedup for three dimensional problems will be presented.

A Time-Parallel Rational Krylov Integrator for Linear ODEs

Session Schedule Author Index Session Index

Stefan Guettel
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Abstract

In this talk we discuss a new time-parallel variant of a rational Krylov exponential integrator. It provides almost perfect speedup in the number of processors for linear ODEs $u'(t) = A * u(t) + f(t)$, where A is a large sparse or structured matrix and $u(t)$ and $f(t)$ are vectors depending on time. Our approach is based on the fast propagation of the linear part over the whole time domain and the parallel integration of the possibly highly oscillating source term $f(t)$ over disjoint time-intervals. For more complicated (i.e., semilinear or nonlinear) problems we discuss variants of the parareal algorithm where both the fine and coarse integrators are based on Krylov techniques. We show how to tune the parameters of these methods.

Parareal Algorithm for Convection Type Equation

Session Schedule Author Index Session Index

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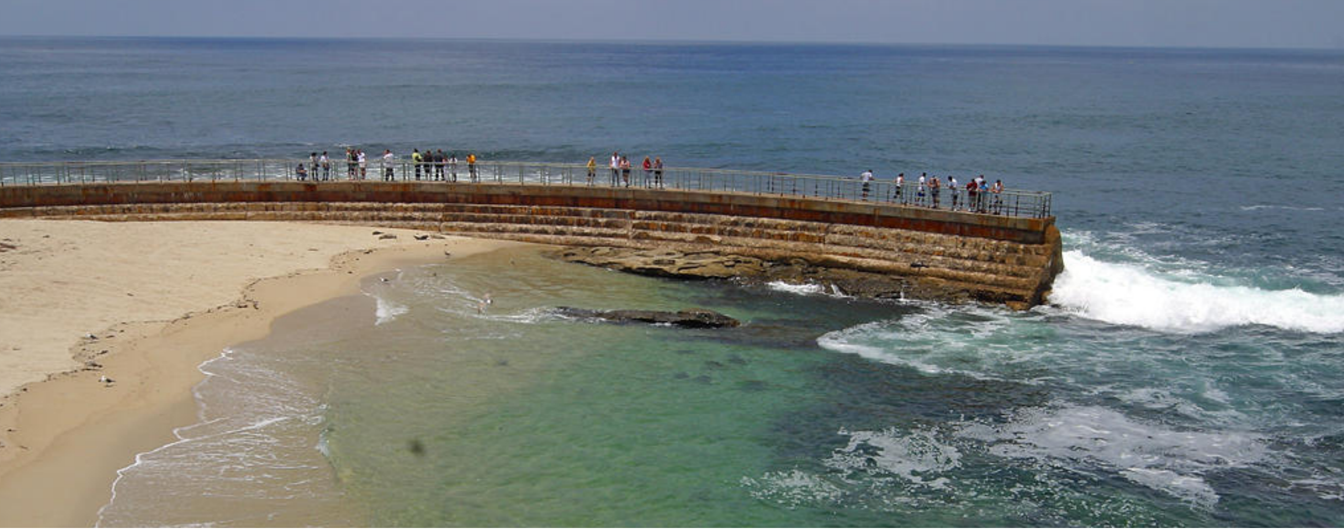
Abstract

The parareal algorithm allows to use efficiently parallel computers for the simulation of time dependant problems. It is based on a decomposition of the time propagation interval, into subintervals, and the propagation over each subinterval is done concurrently on the different processors. Parareal method has obtained great success in many applications. However, when applied to some hyperbolic equation (e.g. wave equation) or convection-diffusion problems with highly dominant convection (e.g. Burgers equation with small viscosity), the plain parareal method encounters some instabilities. In this presentation, we explain some strategies to overcome this stability issue. These are quite easy to implement. We illustrate the good behavior of this new scheme by some numerical examples. This is a joint work with Yvon Maday.



Mini Symposium M18

Domain Decomposition Methods for Non-smooth Quadratic and Nonlinear Programming Problems

Schedule Author Index Session Index

Date: Friday, February 11
Time: 10:00-12:00
Location: B143-B144
Chairman: Rolf Krause, Christian Groß

10:00-10:30 : Xiao-Chuan Cai
Newton-Krylov-Schwarz for Some PDE-Constrained Optimization Problems
Abstract

10:30-11:00 : Arne Nägel
Filtering AMG Solvers for Systems of PDEs
Abstract

11:00-11:30 : Christian Groß
Parallel Multiscale Optimization Techniques in Nonlinear Mechanics
Abstract

11:30-12:00 : Björn Gmeiner
Multigrid for Finite Elements on 290,000 Compute Cores: Scalability Experiments
Abstract

Abstract

The solution of smooth and non-smooth quadratic and nonlinear programming problems is of paramount importance for many applications in computational sciences, for example computational fluid dynamics or computational mechanics. In return, in addition to well established solution strategies as Krylov space methods and trust region or linesearch methods, also domain decomposition oriented techniques have emerged during the last decades, such as Krylov-Schwarz and Newton-Krylov-Schwarz methods, nonlinear multigrid methods, or nonlinear additive Schwarz methods.

Since for large and realistic applications only parallel computers provide the necessary computational resources, the solution of quadratic and nonlinear programming problems will more and more be carried out on distributed systems. By design, domain decomposition and subspace correction methods are a natural approach for achieving this goal. But moreover, domain decomposition methods also allow for exploiting concurrency for the local resolution of nonlinearities, thus providing a sound basis for developing new solution approaches for complex problems.

Therefore, the focus of this mini-symposium will be on presenting advances in methodological approaches for domain decomposition and multiscale techniques for the solution of quadratic and nonlinear programming problems on parallel computers and, in particular, on HPC systems.

Newton-Krylov-Schwarz for Some PDE-Constrained Optimization Problems

Session Schedule Author Index Session Index

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Abstract

We consider some optimization problems constrained by linear or nonlinear partial differential equations. Most of the popular approaches are "block Gauss-Seidel type", with three large blocks representing the constraints, the Lagrange multipliers, and the objective variables. These approaches are relatively easy to implement, but the convergence is sometimes slow or hard to obtain. We investigate the so-called one-shot approach in which all three components are solved at once with a fully coupled Newton-Krylov-Schwarz method. We show the robustness and parallel scalability of the one-shot approach for several classes of problems including inverse problems, boundary control of incompressible flows, and shape optimization problems.

Filtering AMG Solvers for Systems of PDEs

Session Schedule Author Index Session Index

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Abstract

One well-known standard strategy to solve non-linear equations is to employ variants of Newton's method and hence to decompose the problem into a sequence of linear sub-problems. In this case efficient preconditioning strategies for the solution of the resulting linear systems remain one of the key challenges.

Algebraic multigrid methods are one useful tool to cope with this problem with almost optimal computational complexity. In this talk we comment on the Filtering Algebraic Multigrid method and introduce its generalization for systems of coupled PDEs. In this class of methods the interpolation operator for coarse grid correction is constructed, such that the norm of the two-grid operator is minimized in an approximate sense. At the same time, additional filter conditions for certain test vectors can be imposed in order guarantee an exact interpolation of the near null space.

The developed method is finally applied to the problem class of density driven flow in porous media. This includes a fully nonlinear formulation as well as a simplified approximation of Boussinesq-type. In both cases additional challenges for the linear solver arise from anisotropies, discontinuous coefficients and fluctuations in the velocity profiles. We present a robust preconditioning strategy within a point-block-setting. This comprises the choice of appropriate smoothers, a pre-processing in the setup phase and modifications for the choice of strong connections.

Parallel Multiscale Optimization Techniques in Nonlinear Mechanics

Session Schedule Author Index Session Index

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Abstract

The parallel numerical solution of realistic mechanical problems, such as large-deformation contact between an elastic body and a rigid obstacle, often gives rise to nonlinear and possibly non-convex optimization problems. Thus, in order to succeed in computing a local minimizer of such optimization problems their solution is most oftenly carried out employing globalization strategies, i.e., Trust-Region and Linesearch methods.

As is well-known, the paradigm of globalization strategies is to compute and to damp a search direction in order to achieve a descent in the value of a given objective function. Usually, search directions are computed as the solution of constrained quadratic programming problems. But, even if these quadratic programming problems are solved exactly, the damping of the search directions might yield a slow convergence of the overall scheme. Unfortunately, this effect often increases with the size of the optimization problem.

Therefore, we present a class of nonlinear preconditioning strategies where a possible slow convergence is bypassed by computing search directions in parallel. In particular, the paradigm of these strategies is to locally solve certain nonlinear programming problems employing either Trust-Region or Linesearch methods. But, since these globalization strategies *asynchronously* compute local corrections, we must furthermore take care of the overall convergence of the method. As it turns out, this can be done by employing global control strategies yielding globally convergent, inherently parallel Linesearch (APLS) and Trust-Region (APTS) strategies.

In this talk, we will review the concept of nonlinear additively preconditioned globalization strategies and focus on the application of such strategies to the parallel solution of large-scale nonlinear optimization problems arising from the discretization of large deformation contact problems.

Multigrid for Finite Elements on 290,000 Compute Cores: Scalability Experiments

Session Schedule Author Index Session Index

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Abstract

While multicore architectures are becoming usual on desktop machines, supercomputers are approaching million cores. The amount of memory and compute power on current clusters enable us e.g. to obtain a resolution of in excess $(10000)^3 = 10^{12}$ degrees of freedom. However, on the downside we are forced to partition our domain into extremely many sub-problems. Portions of the algorithm that do not permit such degrees of parallelism can easily become a bottleneck. Additionally the performance analysis and debugging of programs at this scale become challenging tasks in themselves.

The Hierarchical Hybrid Grids (HHG) framework is designed to close the gap between flexibility of Finite Element's (FE) and the performance of geometric Multigrid's (MG) by using a compromise between structured and unstructured grids. A coarse input FE mesh is split into the grid primitives vertices, edges, faces, and volumes. The primitives are then refined in a structured way, resulting in semi-structured meshes. The regularity of the resulting meshes may be exploited in such a way that it is no longer necessary to explicitly assemble the global discretization matrix. It permits an efficient matrix-free implementation. This approach allows to solve elliptic partial differential equations with a very high resolution.

In our presentation, we will address the scalability problems and communication overhead created by the coarsest grids in a multigrid hierarchy. Surprisingly, a careful implementation can result in excellent scalability results, i.e. the coarse grids do not seriously effect overall parallel performance. To this end we will explore and analyze the weak scaling of numerical experiments with up to 10^{12} unknowns. A strong scaling will investigate the possibilities to solve parabolic equations in real-time by an implicit scheme. To achieve real time behavior, strong scaling is necessary, i.e. for a fixed problem size more and more processors must be used. There the parallel efficiency on current architectures reaches its limits. This will be analyzed in the talk.

Mini Symposium M19

Schwarz Methods: Analysis and Applications

Schedule Author Index Session Index

Date: Friday, February 11
Time: 10:00-12:00
Location: B145
Chairman: Felix Kwok, Kevin Santugini

10:00-10:30 : Felix Kwok
Optimized Schwarz Method for Problems with Cross Points
Abstract

10:30-11:00 : Minh Binh Tran
Convergence Proofs of Domain Decomposition Algorithms
Abstract

11:00-11:30 : Oliver Sander
Domain Decomposition Algorithms for the Heterogeneous Richards Equation
Abstract

11:30-12:00 : Kevin Santugini
Explicit Constants for the Condition of the Continuous Additive Schwarz Preconditioned Operator with a Coarse Grid
Abstract

Abstract

Schwarz methods are domain decomposition methods in which subdomains communicate with each other using either classical (Dirichlet) or optimized (Robin or higher-order) transmission conditions along the inteface. Schwarz methods are an attractive way to parallelize PDE solvers, since the implementation of various boundary conditions require only modest changes to existing PDE codes. However, the convergence rate of such methods depends crucially on which transmission conditions are used and whether a coarse grid correction is used to propagate information over long distances. In this minisymposium, we will study the effect of coarse grid correction for a continuous Schwarz method, analyze the effect of optimized conditions in the presence of curved interfaces and cross points, and show how a Schwarz method with nonlinear interface conditions can be used to solve Richards equation, a nonlinear PDE that models unsaturated subsurface flow.

Optimized Schwarz Method for Problems with Cross Points

Session Schedule Author Index Session Index

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Abstract

When performing large-scale physical simulations, one often encounters linear systems that are so large that the they must be subdivided and solved in parallel using many processors. In optimized Schwarz methods, this is done by dividing the computational domain into many subdomains, solving the smaller subdomain problems in parallel, and iterating until one obtains a global solution that is consistent across subdomain boundaries. Fast convergence can be obtained if Robin conditions are used along subdomain boundaries, provided that the Robin parameters p are chosen correctly. It is well known that for two-subdomain problems with no overlap, the optimal choice is $p = O(h^{-1/2})$ (where h is the mesh size), with the resulting method having a convergence factor of $\rho = 1-O(h^{1/2})$. However, when cross points are present, i.e., when several subdomains meet at a single point, this choice leads to a divergent method. In this work, we use a simple model problem to show that convergence can only occur if $p = O(h^{-1})$ at the cross point. In addition, this choice of p allows us to recover the $1 - O(h^{1/2})$ convergence factor in the resulting method.

Convergence Proofs of Domain Decomposition Algorithms

Session Schedule Author Index Session Index

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Abstract

In this talk, we present some of our results about the convergence of domain decomposition methods. We introduce new techniques to prove that classical overlapping domain decomposition methods always converge when being applied to semilinear elliptic and parabolic equations, while overlapping domain decomposition methods with Robin transmission conditions only converge for semilinear parabolic equations, but not for semilinear elliptic ones. We then provide some conditions so that overlapping domain decomposition methods with Robin transmission conditions converge for semilinear elliptic equations. (This is a part of my PhD thesis being done under the guidance of Professor Laurence Halpern, at the University Paris 13, France.)

Domain Decomposition Algorithms for the Heterogeneous Richards Equation

Session Schedule Author Index Session Index

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Ralf Kornhuber
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Abstract

We consider the Richards equation for saturated–unsaturated porous media flow. The domain is assumed to be subdivided such that the permeability and saturation functions are independent of space on each subdomain. Applying the Kirchhoff transformation leads to a set of semilinear subproblems coupled by nonlinear transmission conditions. Each subproblem can be solved efficiently using a truncated nonsmooth Newton multigrid. The coupled problem can be approached with various nonlinear nonoverlapping Schwarz methods. Comparison with the linear case shows that many desirable properties are retained in the nonlinear setting. We discuss algorithmic aspects of this approach and present an implementation based on the Dune libraries.

Explicit Constants for the Condition of the Continuous Additive Schwarz Preconditioned Operator with a Coarse Grid

Session Schedule Author Index Session Index

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Abstract

The classical convergence result for the additive Schwarz preconditioner with coarse grid is based on a stable decomposition. The result holds for discrete versions of the Schwarz preconditioner, and states that the preconditioned operator has a uniformly bounded condition number that depends only on the number of colors of the domain decomposition, and the ratio between the average diameter of the subdomains and the overlap width. Constants are usually non explicit and are only asserted to depend on the "shape regularity" of the domain decomposition.

The classical Schwarz method was however defined at the continuous level, and similarly, the additive Schwarz preconditioner can also be defined at the continuous level. We provide in this talk a continuous analysis of the additive Schwarz preconditioned operator with a coarse grid in two dimensions. We provide completely explicit constants for the stable decomposition of the continuous additive Schwarz operator with a completely explicit definition of shape regularity. The advantage of having explicit constants is that it opens the way to deal with non shape regular domain decompositions.

Contributed Talks C1
DD Based Solvers and Preconditioners

Schedule Author Index Session Index

Date: Monday, February 7
Time: 2:45-4:45
Location: B145
Chairman: Ryan Szypowski

2:45-3:05 : David Keyes
Inexact Schwarz-AMG Preconditioners for Crack Problems Modeled by XFEM
Abstract

3:05-3:25 : Pierre Gosselet
An Exact Non-Intrusive Submodeling Technique Based on Domain Decomposition
Abstract

3:25-3:45 : Désiré Nuentsa Wakam
Deflated GMRES with Multiplicative Schwarz Preconditioner: A Challenge of Robustness and Parallelism
Abstract

3:45-4:05 : Thomas Dufaud
Aitken Restricted Additive Schwarz 2 Preconditioning Technique Using Coarse Approximations on the Interface
Abstract

4:05-4:25 : Minh Binh Tran
A Domain Decomposition Method for Forward-Backward SDEs
Abstract

4:25-4:45 : Piotr Krzyzanowski
Block Preconditioning for Systems of Equations Originating From PDEs
Abstract

Inexact Schwarz-AMG Preconditioners for Crack Problems Modeled by XFEM

Session Schedule Author Index Session Index

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Abstract

Traditional algebraic multigrid (AMG) preconditioners are not well suited for crack problems modeled by extended finite element methods (XFEM), which embed discontinuous fields through special degrees of freedom. These DOFs are not properly handled in typical AMG coarsening processes, which may lead to slow convergence. We propose a Schwarz approach that retains AMG advantages on otherwise well behaved domains by avoiding the coarsening of enriched DOFs. The physical domain is partitioned into "healthy" (or unfractured) and "cracked" subdomains. The "healthy" subdomain containing only standard degrees of freedom, is solved approximately by one AMG V-cycle, accompanied by direct solves of "cracked" subdomains, whose DOFs are relatively small in number. This strategy alleviates the redesign of AMG coarsening strategies for XFEM discretizations. Numerical examples on various crack problems illustrate the superior performance of this approach over a brute force AMG preconditioner applied directly to the linear system.

An Exact Non-Intrusive Submodeling Technique Based on Domain Decomposition

Session Schedule Author Index Session Index

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Abstract

Solvers based on domain decomposition have shown their ability to handle most mechanical problems. Unfortunatly commercial CAD and FEA softwares lag behind to incorporate them, and industrialists hardly use these powerful methods. Our study aims at porting the benefits of DD methods within an industrial context by a "non-intrusive" approach. The targeted applications are large structures which evolve linearly except in localized nonlinear (eg. plastic or damaging) zones; they are commonly handled using (error-prone) submodeling techniques. Our strategy consists in introducing a sequence of correcting loadings to the classical linear data setting for the commercial solver, which are deduced from independent nonlinear analyses conducted on a subdomain including the critical zone. We propose two approaches inspired from primal (BDD) and mixed (Robin-based with a two scale approximation of the Schur complement) non-overlapping domain decomposition methods. Assessments conducted on industrial problems show that not only this approach enables to reach the exact solution and brings versatility but it can also be computationaly advantageous.

Deflated GMRES with Multiplicative Schwarz Preconditioner: A Challenge of Robustness and Parallelism

Session Schedule Author Index Session Index

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Abstract

We consider the GMRES method preconditioned by one iteration of the classical multiplicative Schwarz method in which the matrix operator is algebraically decomposed in block-diagonal form. The general observation is that the number of iterations in GMRES tends to increase with the number of domains. To limit this effect, we introduce a deflation process in GMRES. This deflation is based either on a preconditioning technique or an augmented Krylov subspace approach. We show on real test cases that these approaches can reduce the overall number of iterations and prevent stagnation on large number of subdomains.

Aitken Restricted Additive Schwarz 2 Preconditioning Technique Using Coarse Approximations on the Interface

Session Schedule Author Index Session Index

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Abstract

A two-level preconditioning technique based on the Aitken's acceleration of the convergence of the Restricted Additive Schwarz (RAS) domain decomposition method is derived. When it is applied to linear problems, the RAS has a pure linear rate of convergence/divergence that can be enhanced with optimized boundary conditions giving the ORAS method based on the underlying PDE. The RAS method's linear convergence allows its acceleration of the convergence by the Aitken's process. In this new two level algebraic preconditioner technique named ARAS2, the coarse grid operator uses only parts of the artificial interfaces contrary to the patch substructuring method. In this way, it can be seen as similar as the SchurRAS method but it differs because the discrete Steklov-Poincar operator connects the coarse artificial interfaces of all the subdomains. Numerical results of the good properties of the ARAS2 preconditioning are provided on industrial problems with no knowledge of the underlying equations.

A Domain Decomposition Method for Forward-Backward SDEs

Session Schedule Author Index Session Index

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Abstract

Motivated by the idea of imposing paralleling computing on solving stochastic differential equations (SDEs), we introduce a new domain decomposition scheme to solve forward-backward stochastic differential equations (FBSDEs) parallely. We reconstruct the four step scheme by Jin Ma, Philip Protter, and Jiong Min Yong with some different conditions and then associate it with the idea of domain decomposition methods. We also introduce a new technique to prove the convergence of domain decomposition methods for systems of quasilinear parabolic equations and use it to prove the convergence of our scheme for the FBSDEs. (This is a part of my thesis under the guidance of Professor Laurence Halpern, at the University Paris 13, France.)

Block Preconditioning for Systems of Equations Originating From PDEs

Session Schedule Author Index Session Index

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Abstract

We discuss a range of block preconditioners for symmetric problems obtained fromdiscretization of certain PDEs. This approach allows to reuse efficient solvers or preconditioners for simpler, elliptic problems. We provide eigenvalue bounds and a set of conditions under which a uniform convergence rate of the conjugate residuals method with respect to the mesh size can be obtained. Application areas include generalized saddle point problems.

Contributed Talks C2
Applications in the Sciences

Schedule Author Index Session Index

Date: Tuesday, February 8
Time: 10:00-12:00
Location: B145
Chairman: Ari Stern

10:00-10:20 : Stefano Zampini
Exact and Inexact BDDC Methods for Spectral Element Discretizations of Almost Incompressible Elasticity in Three Dimensions
Abstract

10:20-10:40 : Olaf Steinbach
All Floating Finite Element Tearing and Interconnceting Methods for the Simulation of Biological Tissues
Abstract

10:40-11:00 : Caroline Japhet
Optimized Schwarz Waveform Relaxation for Porous Media Applications
Abstract

11:00-11:20 : Yuqi Wu
Scalable Parallel Methods for Modeling Blood Flows in 3D
Abstract

11:20-11:40 : Marc Garbey
Simulation of Breast Conservative Therapy
Abstract

11:40-12:00 : Marc Garbey
From Ultrasound Video to Hemodynamic Simulation with Moving Walls
Abstract

Exact and Inexact BDDC Methods for Spectral Element Discretizations of Almost Incompressible Elasticity in Three Dimensions

Session Schedule Author Index Session Index

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Abstract

BDDC algorithms are constructed and analyzed for the system of almost incompressible elasticity discretized with Gauss-Lobatto-Legendre spectral elements in three dimensions. The almost incompressible elasticity system is first discretized with mixed spectral elements and then a positive definite reformulation is obtained by eliminating all pressure degrees of freedom. With appropriate sets of primal constraints associated with the substructures vertices, edges and/or faces averages, BDDC methods for the resulting displacements have a fast convergence rate independent of the almost incompressibility of the material. A convergence rate bound can be proved for a suitable set of primal constraints in the compressible case with, in addition, a no net flux condition across the boundary of each substructure. In particular, the condition number of the BDDC preconditioned operator is shown to depend only weakly on the polynomial degree n, the ratio H/h of substructures and element diameters and the inverse of the inf sup constant related to the underlying mixed formulation and to the aspect ratio of the and of jumps in Poisson ratio and Young's modulus of the material considered (robustness) aligned with the interface. These results also apply to the related FETI-DP algorithms defined by the same set of primal constraints. Numerical experiments carried out on parallel computing systems confirm these results and illustrate the effects of the choice of the primal constraints. A new three-level inexact approach is also considered for the positive definite reformulation of the displacements, for which usual AMG based black-box solvers fail. In particular, BDDC Dirichlet and saddle point Neumann problems are replaced with the action of local BDDC preconditioners for the related problems, using a finer decomposition of each substructure; moreover, such a new approach would exploit the local scalability of BDDC preconditioners and ideally map into modern shared-memory architectures using an hybrid MPI-OpenMP

paradigm. Numerical experiments for such a new approach are presented for a pure MPI formulation.

All Floating Finite Element Tearing and Interconnceting Methods for the Simulation of Biological Tissues

Session Schedule Author Index Session Index

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Abstract

In this talk we consider the modeling of the nonlinear elastic behavior or arterial walls. For an efficient numerical solution of the linearized equations we use a finite element tearing and interconnecting approach which considers all subdomains as floating. While for the solution of the local subproblems direct methods are applied, the solution of the global Schur complement system is done by using appropriatly preconditioned iterative schemes. Numerical examples are given.

Optimized Schwarz Waveform Relaxation for Porous Media Applications

Session Schedule Author Index Session Index

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Abstract

We consider domain decomposition strategies with as final objective the solving, on parallel platforms, of heterogeneous advection-diffusion-reaction equation modeling radionuclide flow transport in the underground, in the context of nuclear waste repos itories. The coefficients are functions of the space variable, piecewise smooth, since such repositories are highly heterogeneous due to the variety of materials involved. Moreover, the waste package is a meter-sized object embedded in a hectometer or kilometer-sized domain of computation. These issues lead us to consider numerical methods that allow for the use of nonconforming space-time grids, so as to match the local space and time scales, while at the same time simplifying the parallel generation and adaptation of meshes. Schwarz waveform relaxation algorithms are a class of such methods, based on domain decomposition and on iterations which converge quickly and require communications only once per iteration, at the end of the time interval. The transmission conditions are approximations of the best operators related to transparent boundary operators. They can be found using Fourier analysis in the two half-spaces case. However, this approach is not adapted for domains with high variability of sizes.

In the present work, we propose a new approach that takes into account this variability. We focus on a model problem to show the effect of subdomains with widely differing sizes. We determine optimal non-local, and optimized transmission conditions, taking into account the size of the waste package when it becomes small with respect to the size of the surrounding clay subdomains. Numerical results in 2D illustrate the method on an example inspired from nuclear waste disposal simulations.

This work is partially supported by GNR MoMaS.

Scalable Parallel Methods for Modeling Blood Flows in 3D

Session Schedule Author Index Session Index

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Abstract

We introduce and study a scalable domain decomposition method for the simulation of three-dimensional blood flows in arteries. To cope with the deformation of the computational domain, we model the fluid using the incompressible Navier-Stokes equations in the arbitrary Lagrangian Eulerian framework. The nonlinear system of PDEs is discretized with a stabilized finite element method on unstructured moving meshes and a fully-implicit temporal scheme. The nonlinear algebraic systems are solved by a Newton-Krylov algorithm preconditioned with an overlapping Schwarz method. We study the performance of the Schwarz type preconditioner for solving the Jacobian systems as well as the scalability of the Newton-Krylov-Schwarz algorithm.

Keywords: blood flow, incompressible Navier-Stokes equations, arbitrary Lagrangian Eulerian, stabilized finite element, domain decomposition, additive Schwarz, parallel computing

Simulation of Breast Conservative Therapy

Session Schedule Author Index Session Index

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Abstract

The complex interplay between mechanical forces due to gravity, constitutive law of breast tissue distribution, and internal stress generated by the healing process play dominant roles in determining the success or failure of lumpectomy. The mechanical and physiological response of breast tissue following lumpectomy affects the healing process, results in volume reduction, in esthetically suboptimal outcomes up to 30and is a significant factor in quality of life [1, 3] . The purpose of this project is to define the impact of tissue removal on breast deformation as a function of these processes and to develop a mathematical model for assessing and predicting the effect of lumpectomies on postsurgical cosmesis - see [2] chapter 1 and 15. We will present an image based domain decomposition method coupling the mechanical model of the breast tissue with a model simulating the healing. Two models of tissue healing with increasing complexity will be presented.

References

1. Clough K, Cuminet J, Fitoussi A, Nos C, Mosseri V. Cosmetic sequelae after con- servative treatment for breast cancer: classification and results of surgical correction, Ann Plast Surg. 1998;41:471-481.

2. M.Garbey, B. Bass, M. De Matelin, C. Collet and R. Tran Son Tay, Computational Surgery and Dual Training, Springer Verlag, 2010, XVI, 315 p., Hardcover, ISBN: 978-1- 4419-1122-3

3. Veiga DF, Veiga-Filho J, Ribeiro LM, Archangelo-Junior I, Balbino PF, Caetano LV, Novo NF, Ferreira LM. Quality-of-life and self-esteem outcomes after oncoplastic breast-conserving surgery. Plast Reconstr Surg. 2010;125:811-817.

From Ultrasound Video to Hemodynamic Simulation with Moving Walls

Session Schedule Author Index Session Index

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Abstract

Accurate hemodynamic simulations enable different modalities of cardiovascular measurements and alter the design and protocols of intravascular interventions. Numerous researches focused on improving the quality of the fluid-structure interaction simulations, correlated with the constitutive law of the artery wall and its surrounding tissue.

Our study consists in achieving hemodynamic simulations starting from the image segmentation of time dependent medical imaging data, such as ultrasound. We present a domain decomposition technique with immersed boundary conditions adapted to the problem of long vessel structure with time dependent image acquisition. This technique is a generalization of an image based L2 penalty method applied to Navier Stokes. We show the difficulty of combining Navier Stokes flow simulation and image segmentation adapted to noisy video stream while ensuring mass conservation. We discuss the limitations of the method, the sources of numerical uncertainties and the impact of wall motion on the calculation of shear stress indicators.

Contributed Talks C3
Finite Element and DD Theory

Schedule Author Index Session Index

Date: Tuesday, February 8
Time: 3:30-5:30
Location: B145
Chairman: Melvin Leok

3:30-3:50 : Senganal Thirunavukkarasu
Domain Decomposition Method for Concurrent Multiscale Modeling
Abstract

3:50-4:10 : Christain Rey
A Fully Parallel A Posteriori Error Estimation for Nonoverlapping Domain Decomposition Methods
Abstract

4:10-4:30 : Sven Beuchler
Quasioptimal Additive Schwarz Based Solvers for hp-FEM Discretizations in 3D
Abstract

4:30-4:50 : Ajit Patel
Stabilized Nitsche's Mortaring Element Method for Elliptic Interface Problems
Abstract

4:50-5:10 : Thomas Dickopf
Non-Nested Meshes in Multilevel Methods
Abstract

5:10-5:30 : Yassine Boubendir
New Non-overlapping Domain Decomposition Algorithm for Helmholtz Equation
Abstract

Domain Decomposition Method for Concurrent Multiscale Modeling

Session Schedule Author Index Session Index

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Abstract

We consider a fine-scale problem defined on a small region embedded in a much larger coarse-scale domain, and propose an efficient solution technique based on the domain decomposition framework. Specifically, we develop a non-overlapping Schwarz method with two important features that aid in fast convergence of the method: (a) the use of semi-local Dirichlet-to Neumann (DtN) map for the interface conditions, and (b) the utilization of inherent scale separation in developing these interface conditions. In this talk, we present the basic idea behind the proposed method, followed by precise formulation and convergence analysis for the Laplace equation. The effectiveness of the method will be further illustrated using appropriate numerical examples.

A Fully Parallel A Posteriori Error Estimation for Nonoverlapping Domain Decomposition Methods

Session Schedule Author Index Session Index

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Abstract

we present a strategy for a posteriori error estimation for substructured problems solved by nonoverlapping domain decomposition methods. We focus on global a posteriori error estimates obtained through the error in constitutive relation for linear elasticity problems. Our method allows to compute error estimate in a fully parallel way for both primal (BDD) and dual (FETI) approaches of non-overlapping domain decomposition whatever the state (converged or not) of the associated iterative solver. It yields a guaranteed upper bound on the error measured in the energy norm. One key point is a costless build of continuous displacement and balanced trac- tion fields using properties of the preconditioners involved in domain de- composition solvers. We then consider adaptative strategies based on either sequential or parallel remeshing.

Quasioptimal Additive Schwarz Based Solvers for hp-FEM Discretizations in 3D

Session Schedule Author Index Session Index

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Abstract

In this talk we investigate the discretization of an elliptic boundary value problem in 3D by means of the hp-version of the finite element method using a mesh of hexahedrons. The corresponding linear system is solved by a preconditioned conjugate gradient method. The construction of the preconditioner is based on an inexact additive overlapping Schwarz method which was suggested by Pavarino. The remaining subproblems are treated by a tensor product based preconditioner. This preconditioner uses a basis transformation into a basis which is stable in L^2 and H^1. The construction is based on interpretations of the p-FEM mass and stiffness matrix as weighted h-FEM matrices and a simultaneous diagonalization of these matrices using wavelets. The preconditioner is implemented into the finite element program *SpCAdHp* for hp-discretizations of scalar elliptic and linear elasticity problems using hexahedral elements with hanging nodes. In the main part of the talk, we illustrate the efficiency of the presented quasioptimal hp-solver on several numerical examples.

Stabilized Nitsche's Mortaring Element Method for Elliptic Interface Problems

Session Schedule Author Index Session Index

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Abstract

In this article, we discuss a stabilized Lagrange multiplier method for finite element solution of multi-domain elliptic initial-boundary value problem with non-matching grid across the subdomain interfaces. The stability of the method is achieved without using the inf-sup (well known as LBB, i.e., Ladyzhenskaya-Babuska-Brezzi) condition. The proposed method is consistent with the original problem. Optimal error estimates in both weighted H1-norm and L2 norm are derived for second order elliptic problems. The results of numerical experiments support the theoretical results obtained in this article.

Non-Nested Meshes in Multilevel Methods

Session Schedule Author Index Session Index

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Abstract

This talk is about multilevel methods for an efficient solution of partial differential equations in complicated domains. Our particular purpose is to provide additional insight into the design of coarse spaces in case of unstructured finite element meshes. We study an approach of semi-geometric preconditioning based on non-nested mesh hierarchies, a concept with rather weak requirements (yet still in a variational setting) compared with other geometry-based methods. The use of non-nested meshes in this context raises new questions. Apart from a brief outline of the analysis of the devised multilevel algorithms in the framework of subspace correction methods, we present new results on the actual information transfer between finite element spaces associated with non-nested meshes. Both intuitive and more elaborate mappings are examined in a novel study combining theoretical, practical and experimental considerations.

New Non-overlapping Domain Decomposition Algorithm for Helmholtz Equation

Session Schedule Author Index Session Index

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Christophe Geuzaine
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Abstract

In this talk, we present a new non overlapping domain decomposition method where the transmission conditions are defined using suitable representation of Dirichlet to Neumann operator. Following a general overview of the method, we explain the approximation procedure of these operators and discuss convergence properties of the iterative method. Numerical results, both in 2D and 3D, are presented and show that the effective convergence is quasi-optimal.

Contributed Talks C4
Applications in Engineering

Schedule Author Index Session Index

Date: Wednesday, February 9
Time: 10:00-12:00
Location: B145
Chairman: Li-Tien Cheng

10:00-10:20 : Ihor I. Prokopyshyn
Robin-Robin Type Domain Decomposition Schemes for Frictionless Multibody Contact Problems
Abstract

10:20-10:40 : Sarosh Quraishi
Catmull Clark Subdivision Based Iso-geometric Analysis on Meshes with Arbitrary Topology
Abstract

10:40-11:00 : Leszek Marcinkowski
A Neumann-Dirichlet Preconditioner for FETI-DP Method for Mortar Discretization of a 4th Order Problem
Abstract

11:00-11:20 : Feng-Nan Hwang
A Parallel Polynomial Jacobi-Davidson Approach for Dissipative Acoustic Eigenvalue Problems
Abstract

11:20-11:40 : Lahcen Laayouni
Optimized Schwarz Methods for Bi-harmonic Differential Equations in Two-Dimension
Abstract

11:40-12:00 : Luca Pavarino
Robust BDDC Preconditioners for Reissner-Mindlin Plate Problems and MITC Elements
Abstract

Robin-Robin Type Domain Decomposition Schemes for Frictionless Multibody Contact Problems

Session Schedule Author Index Session Index

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Abstract

A class of parallel Robin-Robin type domain decomposition schemes which are based on the penalty method for elliptic variational inequalities and stationary or nonstationary iterative methods for nonlinear variational equations is proposed for solution of 3D frictionless multibody contact problems of elasticity.

We consider the variational formulation of the multibody contact problem in the form of elliptic variational inequality at closed convex set. The penalty method is used to reduce the variational inequality to an unconstrained minimization problem which is equivalent to the nonlinear variational equation in the whole space. The unique existence of solution of the penalty variational problem is shown and strong convergence of this solution to the solution of initial variational problem is proved.

For solution of nonlinear penalty variational equations for contact problems, we propose such stationary and nonstationary iteration schemes, which lead to the domain decomposition. At each step of these schemes we have to solve in parallel linear variational equations in subdomains which correspond to elasticity problems with Robin boundary conditions on possible contact areas. The strong convergence of these schemes is proved on continuous level. It is shown that the convergence rate of stationary Robib-Robin schemes in some energy norm is linear.

Numerical investigations of presented domain decomposition schemes are made for several plane frictionless two-body and three-body contact problems with the use of finite element and boundary element approximations. Numerical examples demon-

strate the effectiveness of this approach and confirm the theoretical results about convergence of these schemes.

Catmull Clark Subdivision Based Iso-geometric Analysis on Meshes with Arbitrary Topology

Session Schedule Author Index Session Index

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Abstract

In this paper we design a new iso-geometric analysis (IGA) based on Catmull Clark subdivision. The element matrices are constructed using subdivision masks without requiring exact parameterization of Catmull Clark basis functions. Unlike the original NURBS based IGA which is valid only on tensor product domains, then newly proposed subdivision based IGA can be applied over complicated, unstructured domains. Several examples will be presented to illustrate this method. We will solve a plate bending problem by using Catmull Clark subdivision based IGA.

A Neumann-Dirichlet Preconditioner for FETI-DP Method for Mortar Discretization of a 4th Order Problem

Session Schedule Author Index Session Index

Leszek Marcinkowski
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Abstract

In the talk we discuss a parallel preconditioner for a FETI-DP problem arising from a discretization of a model fourth order problem with discontinuous coefficients on nonmatching grids. Locally in the subdomains, independent triangulations are introduced and in subdomains reduced Hsieh-Clough-Tocher macro element spaces are used. The global discrete space is constructed using a mortar approach. The local interior variables are eliminated and next a Feti-dp problem is introduced. Finally we construct and analyze a parallel preconditioner for the Feti-dp problem. We show that the preconditioner is quasi-optimal, i.e. the number of PCG iterations grows logarithmically with respect to the sizes of the local meshes.

A Parallel Polynomial Jacobi-Davidson Approach for Dissipative Acoustic Eigenvalue Problems

Session Schedule Author Index Session Index

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Abstract

We consider a rational algebraic large sparse eigenvalue problem arising in the discretization of the finite element method for the dissipative acoustic model in the pressure formulation. The presence of nonlinearity due to the frequency-dependent impedance poses a challenge in developing an efficient numerical algorithm for solving such eigenvalue problems. In this talk, we reformulate the rational eigenvalue problem as a cubic eigenvalue problem and then solve the resulting cubic eigenvalue problem by a parallel restricted additive Schwarz Preconditioned Jacobi-Davidson algorithm (ASPJD). To validate the ASPJD-based eigensolver, we numerically demonstrate the optimal convergence rate of our discretization scheme and show that ASPJD converges successfully to all target eigenvalues. The extraneous root introduced by the problem reformulation does not cause any observed side effect that produces an undesirable oscillatory convergence behavior. By performing intensive numerical experiments, we identify an efficient correction-equation solver, an effective algorithmic parameter setting, and an optimal mesh partitioning. Furthermore, the numerical results suggest that the ASPJD-based eigensolver with an optimal mesh partitioning results in superlinear scalability on a distributed and parallel computing cluster scaling up to 192 processors.

Optimized Schwarz Methods for Bi-harmonic Differential Equations in Two-Dimensions

Session Schedule Author Index Session Index

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Abstract

We are interested in applying Optimized Schwarz Methods (OSM) techniques to solve bi-harmonic differential equations in two-dimension. The general concept of OSM is based on solving min-max problems to find the optimal parameters that make the corresponding algorithms rapid and efficient. In contrast with the classical Schwarz methods, which exchange only solutions between sub-domains, OSM exchange combinations of solutions and their derivatives between sub-domains. We will investigate the performance of Optimized Schwarz Methods in solving Bi-harmonic differential equations. The methods will be used as iterative and as preconditionners solvers. Numerical experiments will be presented to show the performance of OSM in solving bi-harmonic problem and to confirm the theoretical results.

Robust BDDC Preconditioners for Reissner-Mindlin Plate Problems and MITC Elements

Session Schedule Author Index Session Index

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Abstract

We construct and study some Balancing Domain Decomposition Methods by Constraints (BDDC) for Reissner-Mindlin plate bending problems, discretized with MITC (Mixed Interpolation of Tensorial Components) finite elements. In addition to the standard properties of scalability in the number of subdomains N, quasi-optimality in the ratio H/h of subdomain/element sizes, and robustness with respect to discontinuities of the material properties, our goal here is to obtain robustness also with respect to the additional small parameter t representing the plate thickness. This is a challenging issue since the condition number of plate problems diverges as $O(1/t^2)$ as t tends to zero. The proposed BDDC preconditioners are based on a proper selection of primal continuity constraints, the implicit elimination of the interior degrees of freedom in each subdomain, and the iterative solution of the resulting plate Schur complement by a preconditioned conjugate gradient method. Each preconditioner is built from the solutions of local plate problems on each subdomain with clamping conditions at the primal degrees of freedom and on the solution of a coarse plate problem for the primal degrees of freedom. We can prove that the proposed BDDC algorithm is scalable, quasi-optimal, and, most important, robust with respect to the plate thickness. While this result is due to an underlying mixed formulation of the problem, both the interface plate problem and the preconditioner are positive definite. Numerical results also show that

the proposed algorithm is robust with respect to discontinuities of the plate material properties. Analogous BDDC preconditioners can be extended to Naghdi shell problems discretized with MITC elements.

Contributed Talks C5
Time Dependent Problems

Schedule Author Index Session Index

Date: Wednesday, February 9
Time: 2:45-4:45
Location: B145
Chairman: Pete Kekenes-Huskey

2:45-3:05 : Thu Huyen Dao
A New Approach of Domain Decomposition Methods for Hyperbolic Problems
Abstract

3:05-3:25 : Mikhail Belonosov
Simulation of Elastic Waves by Schwartz Alternations After Application of Laguerre Transform in Time
Abstract

3:25-3:45 : Xiao-Chuan Cai
A Parallel Domain Decomposition Method for Compressible Nonhydrostatic Atmospheric Flows in 2-D
Abstract

3:45-4:05 : Florian Lemarie
Optimized Schwarz Methods in the Context of Ocean-Atmosphere Coupling
Abstract

4:05-4:25 : Martin Neumüller
A Space-Time Domain Decomposition Method
Abstract

4:25-4:45 : Heiko Berninger
Dirichlet-Neumann and Robin Methods for Degenerate Nonlinear Transmission Problems
Abstract

A New Approach of Domain Decomposition Methods for Hyperbolic Problems

Session Schedule Author Index Session Index

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Abstract

Domain decomposition methods were first developed for elliptic problems, taking advantage of the strong regularity of their solutions. In the last two decades, many investigations have been devoted to improve the performance of these methods for elliptic and parabolic problems. The situation is less clear for hyperbolic problems with possible singular solutions. In this talk, we will discuss a nonoverlapping domain decomposition method for nonlinear hyperbolic problems. We use the finite volume method and an implicit version of the Roe approximate Riemann solver, and propose a new interface variable inspired from V. Dolean [1]. The new variable makes the Schur complement approach simpler and allows the treatment of diffusion terms. Numerical results for the compressible Navier-Stokes equations in various 2D, 3D configurations such as the Sod shock tube problem or the Lid driven cavity problem show that our method is robust and efficient. Comparisons of performances on parallel computers with up to 512 hundreds of processors are also reported.

References

1. V.Doléan and S.Lanteri. A domain decomposition approach to finite volume solutions of the Euler equations on triangular meshes Int. J. Numer. Meth. Fluids, vol 37-6, p 625-656, 2001

2. B. Després, F. Dubois: Systémes hyperboliques de lois de conservations Les Editions de l'Ecole Polytechnique, 2005

3. E. Godlewski, P.A. Raviart: Numerical Approximation of Hyperbolic Systems of Conservation Laws Springer Verlag, 1996

4. Yousef Saad : Iterative Methods for Sparse Linear Systems Second edition, 2000

5. A. Quarteroni, A. Valli: Domain Decomposition Methods for Partial Differential Equations Clarendon Press 1999

6. A. Toselli, O. Widlund: Domain Decomposition Methods-Algorithms and Theory Springer Vol. 34, 2004

Simulation of Elastic Waves by Schwartz Alternations After Application of Laguerre Transform in Time

Session Schedule Author Index Session Index

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Abstract

We present a method for the simulation of elastic waves in heterogeneous media where domain decomposition and Schwartz alternations play a key role, providing an effective parallelization of the algorithm. Our method starts by applying an integral Laguerre transform to the time variable in the wave equation. Following the transform, we obtain a strictly negative definite elliptic differential operator, which allows stable and fast convergence of Schwartz alternations with overlapping. Decomposition is performed so that computations for each elementary sub-domain fit into single processor elements. Another remarkable feature of the approach is the independence of the wave-equation differential operator on the parameter of separation. Therefore the systems of linear algebraic equations, arising after finite-difference approximations in space are solved by use of LU factorization which is done only once. Finally, we discuss the implementation of the method, and its scalability and performance properties.

A Parallel Domain Decomposition Method for Compressible Nonhydrostatic Atmospheric Flows in 2-D

Session Schedule Author Index Session Index

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Abstract

In this work we study the fully implicit solution of the compressible Euler equations modeling the nonhydrostatic and mesoscale atmosphere. An inexact Newton method is employed to solve the nonlinear system arising at each implicit time step. To solve the Jacobian linear system efficiently on parallel machines with distributed memory, we propose a domain decomposition method as the preconditioner in the GMRES iterative solver. We show by numerical tests in two-spatial dimensions that the fully implicit method is stable for large time steps and the solver is scalable on a supercomputer with thousands of processors.

Optimized Schwarz Methods in the Context of Ocean-Atmosphere Coupling

Session Schedule Author Index Session Index

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Abstract

Many applications in coastal and operational oceanography require high resolution local models, for which ocean-atmosphere interactions must be properly taken into account. In order to address the ocean-atmosphere coupling problem in a mathematically consistent way we intend to design an adequate Global-in-Time Schwarz-like domain decomposition method. We first show how the usual ad hoc ocean-atmosphere coupling methods can be described in the formalism of the Schwarz methods. Then we propose a first real-case study (genesis and propagation of a tropical cyclone) with the WRF (Weather Research and Forecasting) and the ROMS (Regional Ocean Modeling System) numerical models. We introduce some numerical results obtained with a non-optimized method. However when one wants to optimize the convergence speed of the corresponding algorithm by looking for a good approximation of the absorbing boundary conditions we face some problem that have been relatively few studied so far : the influence of the presence of turbulent boundary layers on both sides of the interface on the convergence speed. In order to illustrate this point we propose to study an idealized form of the problem: a coupling between two diffusion equations modeling the turbulent mixing in the boundary layers. We consider first the case of coefficients which are discontinuous at the air-sea interface but constant on each subdomain. In this case the optimized transmission conditions are determined analytically. In the more general case with discontinuous and spatially variable coefficients the convergence of the Schwarz algorithm is studied using an ad hoc expansion into eigenfunctions of an associated Sturm-Liouville problem. We finally discuss how to extend those results found on a simplified problem to the full ocean-atmosphere coupling problem.

A Space-Time Domain Decomposition Method

Session Schedule Author Index Session Index

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Abstract

For evolution equations we present a space-time domain decomposition method based on Discontinuous Galerkin finite elements. This results in a large system of linear equations which are handled by a hybrid formulation which also allows the use of parallel solution algorithms. Numerical examples will be given, which show the expected convergence of this approach.

Dirichlet-Neumann and Robin Methods for Degenerate Nonlinear Transmission Problems

Session Schedule Author Index Session Index

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Abstract

A class of transmission problems with quasilinear subproblems and continuity conditions for Dirichlet and flux values across the interface arise naturally in the modelling of coupled hydrological processes. The quasilinear subproblems are usually degenerate in the sense that the nonlinear solution-dependent coefficient functions are not bounded away from zero. By Kirchhoff transformation, these degenerate transmission problems can be regarded as a subclass of transmission problems with semilinear subproblems and nonlinear transmission conditions for Dirichlet and flux values. We derive conditions both for well-posedness of these latter transmission problems and for convergence of DirichletNeumann and Robin methods applied to them. It turns out that these conditions include situations in which the original quasilinear subproblems may indeed degenerate. In case of the Robin method, for instance, this can be seen by applying classical theory on monotone operators by Lions and Mercier [1] and the theorem of Browder and Minty.

References

1. P.L. Lions and B. Mercier. Splitting algorithms for the sum of two nonlinear operators. SIAM J. Numer. Anal., 16:964979, 1979.

Contributed Talks C6
Applications to Flow Problems

Schedule Author Index Session Index

Date: Thursday, February 10
Time: 2:45-5:05
Location: B145
Chairman: Yunrong Zhu

2:45-3:05 : Jyri Leskinen
A New Distributed Optimization Approach for Solving CFD Design Problems Using Nash Games Coalition and Evolutionary Algorithms Implemented on GPUs
Abstract

3:05-3:25 : Veronique Martin
Revisiting the Open Boundary Problem in Computational Fluid Dynamics
Abstract

3:25-3:45 : Rongliang Chen
Parallel One-Shot Lagrange-Newton-Krylov-Schwarz Algorithms for Shape Optimization of Steady Incompressible Flows
Abstract

3:45-4:05 : Eliseo Chacon Vera
A Continuous Approach to FETI-DP Mortar methods: Application to Dirichlet and Stokes Problem
Abstract

4:05-4:25 : Taoufik Sassi
Domain Deconmposition Method for the Stokes Problem with Tresca Friction
Abstract

4:25-4:45 : Hyea Hyun Kim
Domain Decomposition Algorithms for the Stokes Problem Without Primal Pressure Components
Abstract

4:45-5:05 : Beatriz Eguzkitza
An Implicit and Parallel Chimera Method
Abstract

A New Distributed Optimization Approach for Solving CFD Design Problems Using Nash Games Coalition and Evolutionary Algorithms Implemented on GPUs

Session Schedule Author Index Session Index

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Abstract

In this paper, numerical experiments obtained by a new "one shot" innovative new approach that couples the Geometry Decomposition Method (GDM) for the Euler flow analyzer and the Domain Decomposition method (DDM) for the geometry evolutionary optimizer are presented. The efficiency for shape optimization and reconstruction problems can be improved significantly by using a competitive Nash game coalition between GDM and DDM players that avoid synchronization bottleneck introduced when resolving the flow by well known subdomains techniques after each new subdomain based geometry candidate.

This approach is also well suited for distributed parallelization and it is shown that further cost reduction in the wall-clock time can be gained on GPUs.

Results for shape reconstruction and drag reduction problems for single and multi element airfoils operating at transonic regimes are presented and discussed to illustrate the potential of the distributed optimization methodology.

Revisiting the Open Boundary Problem in Computational Fluid Dynamics

Session Schedule Author Index Session Index

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Abstract

The overall context of this work is the design of efficient open boundary conditions (OBCs) for limited area models of the ocean circulation. In these limited areas, complex systems of equations are solved using a high resolution grid. On the artificial boundaries, boundary conditions with some available external information, must be prescribed. Such external information is generally available from previous simulations of large scale low resolution models. Ideally, the OBC must evacuate the outgoing information reaching the boundary, and must take into account the incoming part of the external information. In this talk, we propose a reformulation of this problem in which the link with absorbing boundary conditions is highlighted. This formulation allows a complete treatment of the problem in simple cases like the 1D Laplace equation, which illustrates in particular the context in which absorbing conditions may be or not efficient OBCs. Moreover some numerical applications for shallow water systems will be given.

Parallel One-Shot Lagrange-Newton-Krylov-Schwarz Algorithms for Shape Optimization of Steady Incompressible Flows

Session Schedule Author Index Session Index

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Abstract

We study parallel one-shot Lagrange-Newton-Krylov-Schwarz algorithms for two dimensional shape optimization problems constrained by steady incompressible Navier-Stokes equations discretized by finite element methods on unstructured meshes. Most algorithms for shape optimization problems solve iteratively the three components of the optimality system: the state equations for the constraints, the adjoint equations for the Lagrange multipliers and the design equations for the shape parameters. There are also several one-shot approaches which solve the three components simultaneously and the main challenges in these approaches are that the system has stronger nonlinearity, the corresponding Jacobian system is more ill-conditioned and very large. Here we investigate a class of Newton-Krylov algorithms preconditioned by one-level additive Schwarz methods for solving such coupled systems. We present some numerical results of our algorithms obtained on supercomputers with hundreds of processors.

A Continuous Approach to FETI-DP Mortar methods: Application to Dirichlet and Stokes Problem

Session Schedule Author Index Session Index

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Abstract

We present a continuous setting for FETI-DP Mortar methods applied to saddle point problems where the elliptic part is enhanced with the introduction of the natural norm of the jumps and the duality at interfaces is replaced by the corresponding Riesz-canonical isometry. As a consequence, the mortaring is performed using the $H^{1/2}_{00}(\Gamma)$ scalar product for each interface Γ and no stabilization is required at the discrete level because the continuous analysis is replicated. In this setting the dual problem has a mesh independent condition number. At each step of this dual problem, a primal problem is solved with a proper preconditioning and the standard optimal condition numbers for convergence show up. Applications to Dirichlet problem and Incompressible Stokes equations are presented. This work follows the ideas recently introduced in [2] and [1].

References

1. C. Bernardi, T. Chacón Rebollo and E. Chacón Vera, A FETI method with a mesh independent condition number for the iteration matrix Computer Methods in Applied Mechanics and Engineering, Vol 197/13-16 pp 1410-1429., 2008.

2. E. Chacón Vera, A continuous framework for FETI-DP with a mesh independent condition number for the dual problem Computer Methods in Applied Mechanics and Engineering, Vol 198, pp 2470-2483., 2009.

Domain Deconmposition Method for the Stokes Problem with Tresca Friction

Session Schedule Author Index Session Index

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Abstract

In this work we propose and study a domain decomposition method for solving the Stokes problem with Tresca-type non-linear boundary conditions [1]. The resulting problem is solved by a parallel version of a bloc relaxation Uzawa algorithm. Optimal error estimate is derived and a numerical validation test is achieved for two subdomains decomposition.

References

1. M. Ayadi, M. K. Gdoura, T. Sassi: Mixed formulation for Stokes prob- lem with Tresca friction, C. R. Acad. Sci. Paris, Ser. I 348 (2010) 1069- 1072.

Domain Decomposition Algorithms for the Stokes Problem Without Primal Pressure Components

Session Schedule Author Index Session Index

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Abstract

Domain decomposition algorithms for the Stokes problem are developed. Using only the primal velocity unknowns in the construction of the coarse problem, a smaller and symmetric positive definite coarse problem matrix is obtained compared to the previous approaches for the Stokes problem. This new approach provides dual and primal algorithms for solving the Stokes problem with a good scalability and allows the use of continuous pressure finite elements. Numerical results will be presented.

An Implicit and Parallel Chimera Method

Session Schedule Author Index Session Index

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Abstract

The Chimera method was first envisaged as a tool for simplifying the mesh generation. Independent meshes are generated for each component of the computational domain, enabling a flexibility on the choice of the type of element as well as on their orientation that could not be possible when meshing complex three dimensional geometries. The Chimera method is very useful when these components are moving or when they can take different locations for optimization purpose. In this paper we will present a parallel implementation of an implicit Chimera method for fixed subdomains. It is implicit in the sense that the transmission conditions are assembled in the matrix and the method does not involve one additional coupling loop (like iteration-by-subdomain methods). The examples of applications are the Incompressible Navier-Stokes equations, electrophysiology and free surface flows.

Poster Session

Schedule Author Index Session Index

Date: Monday, February 7
Time: 5:15-6:30
Location: SDSC Auditorium
Chairman: TBA

5:00-6:30 : Josselyn Touzeau
Arlequin Method and Domain Decomposition-Solver Applied to the Simulation of Multiscale Mechanical Problems
Abstract

5:00-6:30 : Tomáš Brzobohatý
MatSol - an Efficient Way to Solve Large Problems of Contact Mechanics
Abstract

5:00-6:30 : Laslo Diosady
A Unified Analysis of Balancing Domain Decomposition by Constraints for Higher-order Discontinuous Galerkin Discretizations
Abstract

5:00-6:30 : Feng-Nan Hwang
Parallel Newton-Krylov-Schwarz Algorithms for the Three-dimensional Poisson-Boltzmann Equation in NumericalSimulation of Colloidal Particle Interactions
Abstract

5:00-6:30 : Christian Waluga
Hybrid Discontinuous Galerkin Methods for Incompressible Flow
Abstract

Arlequin Method and Domain Decomposition-Solver Applied to the Simulation of Multiscale Mechanical Problems

Session Schedule Author Index Session Index

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Abstract

In this work efficient solution strategies are sought in the context of the Arlequin multiscale method. This approach allows to connect patches using complex physical models to a simpler global model. The coupling is realized on a so-called gluing zone, on which an energy distribution is set between each model, and by a Hù scalar product based operator involving a Lagrange multiplier field. Such an approach produces a non-positive operator whose factorization contains a dense block of the size of the multiplier unknowns. Thus, a Krylov-based domain decomposition solver is preferred to a direct one in order to treat problems with millions degrees of freedom. Our contribution delivers a new way to deal with rigid body motions that allows better performances. Various comparisons between different kinds of preconditionners in the simulation of mechanical problems with conform and non-conform interfaces have been carried out.

MatSol - an Efficient Way to Solve Large Problems of Contact Mechanics

Session Schedule Author Index Session Index

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Abstract

MatSol library allows to override standard solvers in commercial and noncomercial finite element packages and substitute them by parallelly and numerically scalable algorithms implemented in MatSol. This gives a very useful alternative to users of commercial packages and great tool to test the new methods on the realistic problem.

A Unified Analysis of Balancing Domain Decomposition by Constraints for Higher-order Discontinuous Galerkin Discretizations

Session Schedule Author Index Session Index

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Abstract

We extend the BDDC algorithm to a large class of discontinuous Galerkin (DG) discretizations of second order elliptic problems. An estimate of $C(1 + \log(H/h))^2$ is obtained for the condition number of the preconditioned system where C is a constant independent of h or H or the coefficients of the problem. Numerical simulations are presented which confirm the theoretical results. A key component for the development and analysis of the BDDC algorithm is a novel perspective presenting the DG discretization as the sum of element-wise "local" bilinear forms. The element-wise perspective allows for a simple unified analysis of a variety of DG methods and leads naturally to the appropriate choice for the subdomain-wise local bilinear forms. Additionally, this new perspective enables a connection to be drawn between the DG discretization and a related continuous finite element discretization to simplify the analysis of the BDDC algorithm.

Parallel Newton-Krylov-Schwarz Algorithms for the Three-dimensional Poisson-Boltzmann Equation in NumericalSimulation of Colloidal Particle Interactions

Session Schedule Author Index Session Index

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Abstract

We investigate fully parallel Newton-Krylov-Schwarz (NKS) algorithms for solving the large sparse nonlinear systems of equations arising from the finite element discretization of the three-dimensional Poisson-Boltzmann equation (PBE), which is often used to describe the colloidal phenomena of an electric double layer around charged objects in colloidal and interfacial science. The NKS algorithm employs an inexact Newton method with backtracking (INB) as the nonlinear solver in conjunction with a Krylov subspace method as the linear solver for the corresponding Jacobian system. An overlapping Schwarz method as a preconditioner to accelerate the convergence of the linear solver. Two test cases including two isolated charged particles and two colloidal particles in a cylindrical pore are used as benchmark problems to validate the correctness of our parallel NKS-based PBE solver. In addition, a truly three-dimensional case, which models the interaction between two charged spherical particles within a rough charged micro-capillary, is simulated to demonstrate the applicability of our PBE solver to handle a problem with complex geometry. Finally, based on the result obtained from a PC cluster of parallel machines, we show numerically that NKS is quite suitable for the numerical simulation of interaction between colloidal particles, since NKS is robust in the sense that INB is able to converge within a small number of iterations regardless of the geometry, the mesh size, the number of processors. With help of an additive preconditioned Krylov subspace method NKS achieves parallel efficiency of 71for a 3D problem with 5 million unknowns.

Hybrid Discontinuous Galerkin Methods for Incompressible Flow

Session Schedule Author Index Session Index

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Abstract

We present a hybrid discontinuous Galerkin mortar method that can be used for coupling incompressible flow problems on partitioned and possibly non-matching meshes. The proposed method is motivated by Nitsche-type mortaring methods, but relaxes the (unnatural) coupling across the interface through hybridization, thus making it a feasible discretization method for domain decomposition algorithms. A nice feature of this method is that stability can be shown under rather weak assumptions on the hybrid multiplier space. We also comment on further results for the finest partitioning case, yielding a hybrid discontinuous Galerkin finite element method.

Short Course

Introduction to the Design and Theory of Domain Decomposition Algorithms

Schedule Author Index Session Index

Date: Sunday, February 6
Time: 9:00-5:00
Location: Applied Physics and Math 2402
Chairman: Olof Widlund

Abstract

The goal of this tutorial is to give a survey of domain decomposition algorithms and their analysis for linear elliptic equations discretized by finite element methods. Emphasis will be given on a relatively small set of mathematical tools which can be used in the analysis of several families of algorithms and which also can help guide the design of competitive iterative solvers.

Variational formulation and piece-wise linear finite element approximations of Poisson's problem. Dirichlet and Neumann boundary conditions and Poincaré's and Friedrichs's inequalities. Linear elasticity and Korn's inequality. Condition numbers of finite element matrices and the preconditioned conjugate gradient method.

Domains and subdomains. Subdomain matrices as building blocks for domain decomposition methods and the related Schur complements. The two-subdomain case: the Neumann–Dirichlet and Schwarz alternating algorithms placed in a unified framework and written in terms of Schur complements.

Extension to the case of many subdomains; coloring, the problems of singular subdomain matrices, and the need to use a coarse, global problem. Three assumptions and the basic result on the condition number of additive Schwarz algorithms. Some alternative Schwarz methods.

Classical and more recent two-level additive Schwarz methods. Remarks on the effect of irregular subdomains. Extensions to elasticity problems including the almost incompressible case.

Modern iterative substructuring methods: FETI–DP and BDDC. An introduction

in terms of block-Cholesky for problems only partially assembled. The equivalence of the spectra. Results on elasticity and the incompressible Stokes problem.

Author Index