DD23

International Conference on
Domain Decomposition Methods

23rd International Conference on Domain Decomposition Methods

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July 6-10, 2015

International Convention Center Jeju (ICC-Jeju)
Jeju Island, Korea

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Maps around the ICC Jeju

*** Banquet at Cao Cao (Wednesday, July 8th 2015, 19:00 – 20:50)**

Block Schedule

	Sunday July 05	Monday July 06 (Day 1)	Tuesday July 07 (Day 2)	Wednesday July 08 (Day 3)	Thursday July 09 (Day 4)	Friday July 10 (Day 5)
08:30 - 09:00		Opening Ceremony			Clark Dohrmann (08:30 - 09:15)	
09:00 - 09:30		Panayot Vassilevski (09:00 - 09:45)	Jysoo Lee (09:00 - 09:45)	Felix Kwok (09:00 - 09:45)	Nicole Spillane (09:15 - 10:00)	Parallel Sessions VIII (09:00 – 10:40) MS12, CT-7
09:30 - 10:00						
10:00 - 10:30		Parallel Sessions I (10:15 – 11:55) MS3-1, MS4-1, CT-1	Parallel Sessions III (10:15 – 11:55) MS5-1, CT-3	Parallel Sessions V (10:15 – 11:55) MS6, CT-5	Social Program	
10:30 - 11:00						
11:00 - 11:30						Frédéric Nataf (11:10 - 11:55)
11:30 - 12:00						
12:00 - 12:30		Lunch (11:55 - 14:00)	Lunch (11:55 - 14:00)	Lunch (11:55 - 14:00)		Closing Ceremony
12:30 - 13:00						Lunch (12:10 - 14:00)
13:00 - 13:30						
13:30 – 14:00						
14:00 - 14:30		Yuri Bazilevs (14:00 - 14:45)	Parallel Sessions IV (14:00 – 15:40) MS5-2, MS7-1, CT-4	Sang Joon Shin (14:00 - 14:45)		
14:30 - 15:00		Andrew Wathen (14:45 - 15:30)		Parallel Sessions VI (14:50 – 16:30) MS7-2, MS11-1,MS14		
15:00 - 15:30						
15:30 - 16:00						
16:00 - 16:30		Parallel Sessions II (16:00 – 17:40) MS3-2, MS4-2, CT-2	Lori Badea (16:10 - 16:55)			
16:30 - 17:00			Luca F. Pavarino (16:55 - 17:40)	Parallel SessionsVII (17:00 – 18:40) MS8, MS11-2, CT-6		
17:00 - 17:30						
17:30 - 18:00			Poster Session (18:00 - 19:00)			
18:00 - 18:30					International Scientific Committee Meeting	
18:30 - 19:00						
19:00 - 19:30	Welcome Reception			Banquet (19:00 - 20:50)		
19:30 - 20:00						
20:00 - 20:30					Dinner of ISC and LOC with Invited Speakers	
20:30 - 21:00						

International Scientific Committee

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· **Cai, Xiao-Chuan** (CU Boulder, USA)
· **Gander, Martin** (University of Geneva, Switzerland, CHAIR)
· **Halpern, Laurence** (Paris 13, France)
· **Keyes, David** (KAUST, Saudi Arabia)
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· **Klawonn, Axel** (Universität zu Köln, Germany)
· **Kornhuber, Ralf** (Freie Universität Berlin, Germany)
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· **Park, Eun-Jae** (Yonsei University, Republic of Korea)

Plenary Lectures

PL1 – Element Based Algebraic Coarse Spaces with Applications

Vassilevski, Panayot (Lawrence Livermore National Laboratory, USA)

PL2 – Robust Solution Strategies for Fluid-Structure Interaction Problems with Applications

Bazilevs, Yuri (University of California, San Diego, USA)

PL3 – Preconditioning for Nonsymmetry and Time-dependence

Wathen, Andrew (University of Oxford, United Kingdom)

PL4 – Computational Science Activities in Korea

Lee, Jysoo (KISTI, Republic of Korea)

PL5 – Global Convergence Rates of Some Multilevel Methods for Variational and Quasi-variational Inequalities

Badea, Lori (Institute of Mathematics of the Romanian Academy, Romania)

PL6 – Domain Decomposition Preconditioners for Isogeometric Discretizations

Pavarino, Luca F. (University of Milano, Italy)

PL7 – Schwarz Methods for the Time-Parallel Solution of Parabolic Control Problems

Kwok, Felix (Hong Kong Baptist University, Hong Kong)

PL8 – Development of Nonlinear Structural Analysis using Co-rotational Finite Elements with Improved Domain Decomposition Method

Shin, Sang Joon (Seoul National University, Republic of Korea)

PL9 – BDDC Algorithms for Discontinuous Petrov Galerkin Methods

Dohrmann, Clark (Sandia National Laboratories, USA)

PL10 – Adaptive Coarse Spaces and Multiple Search Directions: Tools for Robust Domain Decomposition Algorithms

Spillane, Nicole (Universidad de Chile, Chile)

PL11 – Recent Advances in Robust Coarse Space Construction

Nataf, Frédéric (Université Paris 6, France)

MS3 - Space-Time Domain Decomposition Methods (MS3-1, MS3-2)

Organizers: Ulrich Langer, Olaf Steinbach

The space-time discretization of transient partial differential equations by using quite general space-time finite and boundary elements in the space-time computational domain allows for an almost optimal, adaptive space-time resolution of wave fronts and moving geometries. The global solution of the resulting systems of algebraic equations can easily be done in parallel, but requires appropriate preconditioning techniques by means of multilevel and domain decomposition methods. This minisymposium presents recent results on general space-time discretizations and parallel solution strategies.

MS4 - Domain Decomposition with Adaptive Coarse Spaces in Finite Element and Isogeometric Applications (MS4-1, MS4-2)

Organizers: Durkbin Cho, Luca F. Pavarino, Olof B. Widlund

The aim of the minisymposium is to bring together researchers in both fields of Finite Elements and Isogeometric Analysis (IGA) to discuss the latest research developments in Domain Decomposition Methods with adaptive coarse spaces. While coarse spaces are essential for the design of scalable algorithms, they can become quite expensive for problems with large number of subdomains, or very irregular coefficients/domains, or for IGA discretizations where the high erregularity of the NURBS basis functions yields large interface and coarse problems. This minisymposium will focus on recently proposed novel adaptive coarse spaces, generalized eigenproblems and primal constraints selection.

MS5 - Domain Decomposition and High Performance Computing (MS5-1, MS5-2)

Organizers: Santiago Badia, Jakub Šístek, Kab Seok Kang

The next generation of supercomputers, able to reach 1 exaflop/s, is expected to reach billions of cores. The success of domain decomposition for large scale scientific computing will be strongly related to the ability to efficiently exploit extreme core counts. This MS is mainly oriented to novel algorithmic and implementation strategies that will boost the scalability of domain decomposition methods, and their application for large scale problems. Since large scale computing is demanded by the most complex applications, generally multiscale, multiphysics, non-linear, and/or transient in nature, tailored algorithms for these types of applications will be particularly relevant.

MS6 - Domain Decomposition Methods and Parallel Computing for Optimal Control and Inverse Problems

Organizers: Huibin Chang, Xue-Cheng Tai, Jun Zou

This mini-symposium will bring together active experts working on domain decomposition methods and parallel computing for large-scale ill-posed problems from image processing, optimal control and inverse problems to discuss and exchange the latest developments in these areas.

MS7 - Efficient Solvers for Electromagnetic Problems (MS7-1, MS7-2)

Organizers: Victorita Dolean, Zhen Peng

In this mini symposium we explore domain decomposition type solvers for electromagnetic wave propagation problems. These problems are very challenging (especially in time harmonic regime where the problem is indefinite in nature and most of the iterative solvers will fail). The mini-symposium will discuss different areas of recent progress as parallel domain decomposition libraries, sweeping preconditioners, iterative methods based on multi-trace formulations, or new results on optimized Schwarz methods.

MS8 - Domain Decomposition Methods for Multiscale PDEs

Organizers: Eric Chung, Hyea Hyun Kim

It is well known that classical ways to construct coarse spaces are not robust and give large condition numbers depending on the heterogeneities and contrasts of the coefficients. Recently, there are increasing interests in constructing domain decomposition methods with enriched coarse spaces or adaptive coarse spaces. The purpose of this minisymposium is to bring together researchers in the area of domain decomposition methods for PDEs with highly oscillatory coefficients, and provide a forum for them to present the latest findings.

MS11 - Birthday Minisymposium Ralf Kornhuber (60th Birthday) (MS11-1, MS11-2)

Organizers: Rolf Krause, Martin Gander

This MS will bring together talks which are related to the scientific work of Ralf Kornhuber. This includes fast numerical methods for variational inequalities, multigrid methods, numerical methods for phase field equations, and biomechanics.

MS12 - Recent Approaches to Nonlinear Domain Decomposition Methods

Organizers: Axel Klawonn, Oliver Rheinbach

For a few decades already, Newton-Krylov algorithms with suitable preconditioners such as domain decomposition (DD) or multigrid (MG) methods (Newton-Krylov-DD or Newton-Krylov-MG) have been the workhorse for the parallel solution of nonlinear implicit problems. The standard Newton-Krylov approaches are based on a global linearization and the efficient parallel solution of the resulting linear (tangent) systems in each linearization step ("first linearize, then decompose"). Increasing local computational work and reducing communication are key ingredients for the efficient use of future exascale machines. In Newton-Krylov-DD/MG methods these aspects can be mainly treated at the level of the solution of the linear systems by the preconditioned Krylov methods. Computational work can be localized and communication can be reduced by a complete reordering of operations: the nonlinear problem is first decomposed and then linearized, leading to nonlinear domain decomposition methods. An early approach in this direction is the ASPIN (Additive Schwarz Preconditioned Inexact Newton) method by Cai and Keyes. Recently, there has been work on nonlinear FETI-DP and BDDC methods by Klawonn, Lanser, and Rheinbach. In this minisymposium, recent approaches to nonlinear domain decomposition methods will be presented.

MS14 - Tutorial for Domain Decomposition on Heterogenous HPC

Organizer: Junard Lee

At this minisymposium, we will have a tutorial sessions. We will cover heterogenous HPC architecture, CUDA programming language, OpenACC directives and how to implement these technology to accelerate PDE solvers specially domain decomposition method.

Contributed Talks

CT-1: Domain Decomposition Methods for Applications

Chair: Panayot Vassilevski

CT-2: Optimized Schwarz Methods

Chair: Felix Kwok

CT-3: Fast Solvers for Nonlinear and Unsteady Problems

Chair: Yuri Bazilevs

CT-4: Domain Decomposition Methods with Lagrange Multipliers

Chair: Luca F. Pavarino

CT-5: Efficient Methods and Solvers for Applications

Chair: Frédéric Nataf

CT-6: Multiphysics Problems

Chair: Sang Joon Shin

CT-7: Coarse Space Selection Strategies

Chair: Nicole Spillane

Schedule Overview

Sunday, July 5th 2015

19:00	Welcome Reception at Ocean View

Monday, July 6th 2015

	Baeknok Hall A	202A	202B
8:30	**Opening Ceremony**		
9:00	PL1 Panayot Vassilevski		
9:45	**Coffee Break**		
10:15	MS4-1 Domain Decomposition with Adaptive Coarse Spaces in Finite Element and Isogeometric Applications	MS3-1 Space-Time Domain Decomposition Methods	CT-1 Domain Decomposition Methods for Applications
11:55	**Lunch at Delizia**		
14:00	PL2 Yuri Bazilevs		
14:45	PL3 Andrew Wathen		
15:30	**Coffee Break**		
16:00	MS4-2 Domain Decomposition with Adaptive Coarse Spaces in Finite Element and Isogeometric Applications	MS3-2 Space-Time Domain Decomposition Methods	CT-2 Optimized Schwarz Methods

Tuesday, July 7th 2015

	Baeknok Hall A	202A	202B
9:00	PL4 Jysoo Lee		
9:45	**Coffee Break**		
10:15		MS5-1 Domain Decomposition and High Performance Computing	CT-3 Fast Solvers for Nonlinear and Unsteady Problems
11:55	**Lunch at Delizia**		
14:00	MS7-1 Efficient Solvers for Electromagnetic Problems	MS5-2 Domain Decomposition and High Performance Computing	CT-4 Domain Decomposition Methods with Lagrange Multipliers
15:40	**Coffee Break**		
16:10	PL5 Lori Badea		
16:55	PL6 Luca F. Pavarino		
17:40	Introduction to Poster Session		
18:00	Poster Session and Apero at 1st Floor Lobby		

Ocean View is located in the fifth floor.
Baeknok Hall is located in the first floor.
Delizia is located in the third floor.

Wednesday, July 8th 2015

	Baeknok Hall A	202A	202B
9:00	PL7 Felix Kwok		
9:45		**Coffee Break**	
10:15	MS6 Domain Decomposition Methods and Parallel Computing for Optimal Control and Inverse Problems		CT-5 Efficient Methods and Solvers for Applications
11:55		**Lunch at Delizia**	
14:00	PL8 Sang Joon Shin		
14:45		**Moving**	
14:50	MS7-2 Efficient Solvers for Electromagnetic Problems	MS14 Tutorial for Domain Decomposition on Heterogenous HPC	MS11-1 Birthday Minisymposium Ralf Kornhuber (60th Birthday)
16:30		**Coffee Break**	
17:00	CT-6 Multiphysics Problems	MS8 Domain Decomposition Methods for Multiscale PDEs	MS11-2 Birthday Minisymposium Ralf Kornhuber (60th Birthday)
18:40		**Moving**	
19:00		**Banquet at Cao Cao**	

Thursday, July 9th 2015

	Baeknok Hall A
8:30	PL9 Clark Dohrmann
9:15	PL10 Nicole Spillane
10:00	**Moving**
10:30	**Social Program**
18:00	International Scientific Committee Meeting
20:00	Dinner of ISC and LOC with invited speakers

Friday, July 10th 2015

	Baeknok Hall A	202A
9:00	MS12 Recent Approaches to Nonlinear Domain Decomposition Methods	CT-7 Coarse Space Selection Strategies
10:40	**Coffee Break**	
11:10	PL11 Frédéric Nataf	
11:55	**Closing Ceremony**	
12:10	**Lunch at Delizia**	

Monday, July 6th 2015

Monday Morning

	Baeknok Hall A	202A	202B
8:30	Opening Ceremony		
9:00	PL1 Panayot Vassilevski		
9:45	Coffee Break		
10:15	MS4-1 Domain Decomposition with Adaptive Coarse Spaces in Finite Element and Isogeometric Applications	MS3-1 Space-Time Domain Decomposition Methods	CT-1 Domain Decomposition Methods for Applications
11:55	Lunch at Delizia		

08:30~09:00 Opening Ceremony

09:00~09:45 PL1 **Baeknok Hall A**

Element Based Algebraic Coarse Spaces with Applications

Panayot Vassilevski

We first provide an overview of the element agglomeration based algebraic multigrid (or AMGe) methodology for generating hierarchy of coarse spaces that form exact de Rham sequences on all coarse levels. The coarse hierarchy can be made as accurate as needed by incorporating enough degrees of freedom into the coarse spaces. This can be achieved by either fitting piecewise polynomials or by using degrees of freedom obtained by the spectral version of the AMGe method. The latter has been recently extended to discretization problems obtained by the mixed finite element method. The constructed coarse spaces can be used for building very robust (with somewhat expensive setup) multilevel solvers, but more importantly, they can be used as discretization tools for deriving accurate coarse (upscaled) models for the entire de Rham sequence with applications to PDEs such as Darcy, Maxwell, and elliptic (scalar or system). Another application of our AMGe-based coarse spaces is in the numerical simulations of multiscale multiphysics phenomena with uncertain input data within a Multilevel Monte Carlo (MLMC) framework. Multilevel Monte Carlo techniques typically rely on geometric hierarchies of computational spaces associated with meshes obtained by successive refinement. With our approach, we can apply MLMC to unstructured meshes by using our constructed hierarchies of coarse spaces since they possess required stability and approximation properties for broad classes of PDEs. An application to subsurface flow simulations in primal and mixed finite element discretization of the SPE10 benchmark illustrates our approach.

Chair: Xiao-Chuan Cai

10:15~11:55 MS4-1 Domain Decomposition with Adaptive Coarse Spaces in Finite Element and Isogeometric Applications **Baeknok Hall A**

BDDC Algorithms with Adaptive Choices of the Primal Constraints

Olof B. Widlund

In the last few years, considerable and successful efforts have been devoted to the adaptive selection of coarse space components of several domain decomposition algorithms. The focus of this talk will be on BDDC algorithms and their applications to problems posed in H(curl), H(div),and in isogeometric analysis. This is joint work with Beirao da Veiga, Pavarino, Scacchi, and Zampini.

Robust Constraint Selection in BDDC Algorithms for Three-Dimensional Problems

Clark R. Dohrmann*, Clemens Pechstein

In this talk, we discuss different methods to automate the selection of primal constraints in BDDC algorithms for general symmetric positive definite problems in three dimensions. Starting with existing condition number estimates for BDDC, we show how the constraints can be selected to ensure a pre-specified level of performance. Of particular interest in our study is how to keep the number of constraints to a minimum. We find that this problem is fairly straightforward for cases of subdomain faces, but dealing with subdomain edges in three dimensions can be much more challenging. As time permits, a variety of numerical examples will be used to demonstrate the constraint selection methods.

BDDC and FETI-DP Methods with Enriched Coarse Spaces for Elliptic Problems with Oscillatory and High Contrast Coefficients

Hyea Hyun Kim, Eric T. Chung, Junxian Wang*

Enrichment of coarse spaces in BDDC and FETI-DP methods is developed and analyzed for both two and three-dimensional elliptic problems to obtain a robust convergence of the methods for oscillatory and high contrast coefficients. For the enrichment, a carefully designed generalized eigenvalue problem is introduced for each face F and for each edge E. Eigenvectors corresponding to eigenvalues larger than a given τ_{TOL} are selected to enrich the coarse space, which results in robust BDDC and FETI-DP algorithms with their condition numbers depending only on the given τ_{TOL} and the maximum number of neighboring subdomain but independent of the coefficient variation. Various model problems are tested to validate our algorithm and theory. Performance of the algorithm is presented to different choices of scaling matrices in BDDC and FETI-DP methods.

On Three Different Approaches to Adaptive Coarse spaces for FETI-DP Methods

Axel Klawonn, Patrick Radtke, Oliver Rheinbach*

In FETI-DP and BDDC methods, sophisticated scalings, e.g., deluxe scaling, can improve the convergence rate when large coefficient jumps occur. For more general cases, additional information has to be added to the coarse space. One possibility is to enhance the coarse space by local eigenvectors associated with subsets of the interface (edges, faces). Some algorithms directly spud in at the P_D operator and some replace a local extension theorem and local Poincare inequalities. In this talk, we will discuss three different strategies, suggested by different authors, for adapting the coarse space together with suitable scalings, provide proofs, and compare numerical results.

10:15~11:55 MS3-1 Space-Time Domain Decomposition Methods 202A

A Direct Time Parallel Solver for Wave Propagation

Laurence Halpern, Martin J. Gander*

Wave propagation problems are more difficult to parallelize in time than diffusive problems. We present here a variant for wave propagation problems of a direct time parallel method proposed by Maday and Ronquist in 2007 for diffusive problems. It is based on the diagonalization of the time stepping matrix. We study the trade-off between roundoff error and truncation error in this method for the wave equation mathematically and propose an optimization strategy for the choice of the parameters. We also present numerical results which show that indeed substantial speedup for wave propagation problems is possible with this approach.

Geometric Integration and the Parareal Algorithm

Martin Gander

The invention of the parareal algorithm by Lions, Maday and Turinici in 2001 generated a new wave of research efforts for the time parallel solution of evolution problems. If the evolution problem is a small scale system of ordinary differential equations, the time direction is indeed the only direction for large scale parallelization, and several applications require long time integration, for example the simulation of the motion of celestial bodies. In this context, Hamiltonian systems are typical, and the accurate long time integration requires geometric integrators. We show in this presentation the fundamental difficulties for obtaining geometric properties when using the parareal algorithm.

Time Parallel Numerical Solution of Skin Transport and Black Hole Formation

Rolf Krause, Andreas Kreienbuehl, Arne Naegel, Daniel Ruprecht, Robert Speck, Gabriel Wittum*

We present results illustrating the usability of the parallel-in-time integration method Parareal to two structurally different problems, a parabolic and a hyperbolic problem: skin permeation and the formation of black holes. First we investigate parareal for a large scale problem with strongly jumping coefficients in space. We consider the heat equation for the in-silico investigation of diffusion of chemicals through human skin. We applied Parareal to a brick and mortar setup, a precursory problem to skin permeation. Since resolving in full detail all scales involved requires efficient solution methods for large scale problems in space and time, we have combined a C++ library implementing Parareal with the simulation framework ug4, which provided the spatial discretization and a parallel multigrid solver. We discuss the performance of the resulting massively parallel method (in space and time) with respect to convergence and speedup. As a second –and structurally different- test, we apply Parareal to a hyperbolic problem, the Einstein gravity equations describing a collapsing massless scalar field in spherical symmetry. We show that Parareal captures the correct black hole formation event and generates the proper mass scaling law. Moreover, if the computational load is properly balanced in time, Parareal features speedup when compared to the serial two-step Lax-Wendroff Richtmyer scheme. As we took a two-level approach in both space and time, we furthermore talk about the influence of the spatial interpolation. Finally, we discuss the efficiency of different Parareal implementations with respect to energy consumption.

~~**Parallel Space-Time Multigrid Solvers**~~

~~*Martin J. Gander, Martin Neumüller**~~

~~We present and analyze a new space-time parallel multigrid method for parabolic equations. The method is based on arbitrarily high order discontinuous Galerkin discretizations in time, and a finite element discretization in space. The key ingredient of the new algorithm is an inexact block Jacobi smoother. By using local Fourier mode analysis we determine asymptotically optimal smoothing parameters, a precise criterion for semi-coarsening in time or full coarsening, and give an asymptotic two grid contraction factor estimate. We then explain how to implement the new multigrid algorithm in parallel, and show with numerical experiments its excellent strong and weak scalability properties. This space-time multigrid method is also used to solve an optimal control problem, the Stokes and Navier Stokes equations.~~

10:15~11:55 CT-1 Domain Decomposition Methods for Applications 202B

A Domain Decomposition Method for Quasilinear Elliptic PDEs Using Mortar Finite Elements

Matthias Gsell, Olaf Steinbach*

In this talk we consider quasilinear elliptic partial differential equations which allow for an application of the Kirchhoff transformation. Examples are simplified models of the Richards equation, or the stationary heat equation. We assume different nonlinear models within nonoverlapping subdomains. The Kirchhoff transformation then results in linear partial differential equations within the subdomains, but nonlinear transmission conditions. We derive the corresponding variational formulation and discuss unique solvability of the nonlinear systems. For the discretization we consider mortar finite element methods to allow locally different meshes. Finally we present some numerical examples.

Unified Framework for Overlapping and Nonoverlapping Domain Decomposition Methods for the Total Variation Minimization

Changmin Nam, Chang-Ock Lee*

In this talk, we provide a unified framework for overlapping and nonoverlapping domain decomposition methods for the total variation minimization. We decompose the domain into rectangular subdomains, where the local total variation problems are solved with first-order primal-dual algorithm. The convergence of the algorithms is analyzed under certain assumptions and numerical results are to be shown.

Augmented Krylov Iterations in Domain Decomposition Methods

Valery Ilin, Gurieva Yana, Perevozkin Danil*

We consider domain decomposition approaches to solving very large sparse SLAEs resulting from approximations of multi-dimensional boundary value problems on non-structured grids. The main iterative process is based on the additive Schwarz algorithm with overlapping subdomains and FGMRES or semiconjugate residual method. These algorithms are augmented by additional aggregation preconditioners constructed on different coarse grids with various basic interpolation functions. The parallel versions of the algorithms are implemented in Krylov library for solving positive definite and indefinite SLAEs using multiprocessor computers with distributed memory. The efficiency and performance of the software are demonstrated on the representative set of practical problems.

Monday, July 6th 2015

Monday Afternoon

	Baeknok Hall A	202A	202B
14:00	PL2 Yuri Bazilevs		
14:45	PL3 Andrew Wathen		
15:30	**Coffee Break**		
16:00	MS4-2 Domain Decomposition with Adaptive Coarse Spaces in Finite Element and Isogeometric Applications	MS3-2 Space-Time Domain Decomposition Methods	CT-2 Optimized Schwarz Methods

14:00~14:45 PL2 Baeknok Hall A

Robust Solution Strategies for Fluid-Structure Interaction Problems with Applications

Bazilevs, Yuri

The presentation is focused on the computational framework that involves coupling of incompressible flow and large-deformation structural mechanics. The formulation of fluid mechanics on the moving domain is presented, and efficient solution strategies for the underlying linear equation systems are discussed. A framework for computational fluid-structure interaction (FSI) based on the Arbitrary Lagrangian-Eulerian formulation is presented. Basics of Isogeometric Analysis are also shown. The fluid-structure interface discretization is assumed to be nonmatching allowing for the coupling of standard finite-element and isogeometric discretizations for the fluid and structural mechanics parts of the FSI problem, respectively. FSI coupling strategies and their implementation in the high-performance parallel computing environment are also discussed and computational challenges presented. Simulations ranging from cardiovascular fluid mechanics and FSI to full-scale wind-turbine FSI are presented.

Chair: Axel Klawonn

14:45~15:30 PL3 Baeknok Hall A

Preconditioning for Nonsymmetry and Time-dependence

Wathen, Andrew

Preconditioning—whether via domain decomposition of other approaches—is by far more understood for self-adjoint problems, in particular those which are positive definite. In this talk, I will consider preconditioning for certain specifically structured nonsymmetric problems, indicating situations were theoretical guarantees of (fast) convergence of Krylov subspace methods can be established. Some of this work is joint with Jen Pestana and some with Elle McDonald.

Chair: Laurence Halpern

16:00~17:40 MS4-2 Domain Decomposition with Adaptive Coarse Spaces in Finite Element and Isogeometric Applications Baeknok Hall A

Adaptive BDDC Methods for Raviart-Thomas Vector Fields

Stefano Zampini, Clark R. Dorhmann, Duk-Soon Oh, Olof B. Widlund*

An adaptive BDDC method for vector field problems discretized with Raviart-Thomas finite elements is introduced. Our method follows the approach proposed by Dohrmann and Pechstein and it is built on a combination of deluxe scaling and certain eigenvalue problems for each coarse face. In order to reduce the computational costs for large simulations, an effective adaptive 3-level approach is also proposed. Numerical experiments are carried out using state-of-the-art numerical libraries such as PETSc and FENICS. Results for three dimensional problems are presented, which support the theory and show the effectiveness of our algorithm. Large simulations proving scalability and robustness are also provided.

IGA: Some New Developments and Applications

Yuri Bazilevs

In this presentation some recent advances in fundamental developments and applications of Isogeometric Analysis (IGA) are presented. Numerical integration remains a significant challenge in IGA, and, in this work, the ideas from variationally consistent domain integration are employed to develop stable and optimally accurate quadrature rules for IGA. These rules in some cases lead to a formulation that is cost-comparable to a Collocation technique, while preserving a variational structure of IGA. Another largely unaddressed challenge in IGA is volumetric parameterization. In this work, a new technique is proposed where an IGA surface discretization is coupled to a Meshfree discretization of the objectÕs interior. In contrast to prior work on IGA-Meshfree coupling the current methodology provides a coupled IGA-Meshfree discretization that can approximate solutions to partial differential equations with arbitrary order of accuracy. The proposed technique also presents a significant improvement in the accuracy of surface geometry description in Meshfree methods. The presentation concludes with examples that highlight effective uses of IGA in advanced applications, such as fatigue damage and failure prediction in large-scale shell structures, and modeling of floating offshore wind-turbine designs in rough waves.

Overlapping Schwarz Preconditioners for Isogeometric Collocation Methods

L. Beirão da Veiga, D. Cho, L.F. Pavarino, S. Scacchi*

Isogeometric collocation methods are very recent and promising numerical schemes that preserve the advantages of isogeometric analysis but often exhibit better performances than their Galerkin counterparts. In this talk, an additive overlapping Schwarz method for isogeometric collocation discretizations is introduced and studied. The resulting preconditioner, accelerated by GMRES, is shown to be scalable with respect to the number of subdomains and very robust with respect to the isogeometric discretization parameters such as the mesh size and polynomial degree, as well as with respect to the presence of discontinuous elliptic coefficients and domain deformations.

Smoothers for Efficient Multigrid Methods in IGA

Clemens Hofreither, Stefan Takacs, Walter Zulehner*

In this talk, we will discuss how to set up a multigrid method for linear systems arising from the discretization of a partial differential equation with an isogeometric discretization. We will restrict ourselves to maximum smoothness, i.e., to splines of polynomial degree p and smoothness $p-1$. The main focus of this talk is set on the construction of smoothers such that the convergence properties of the multigrid solver do not deteriorate if p is increased. We will provide convergence analysis for this approach based on new approximation error estimates and inverse estimates for splines.

16:00~17:40 MS3-2 Space-Time Domain Decomposition Methods 202A

Space-Time CFOSLS (Constrained First Order System Least Squares) Methods

Martin Neumüller, Panayot S. Vassilevski, Umberto E. Villa*

We consider time-dependent PDEs discretized in combined space-time domains. We first reduce the PDE to a first order system. Very often in practice, one of the equations involves the divergence operator (in space-time). The popular FOSLS (first order system least-squares) method is then applied in a modified form by keeping the divergence equation as a constraint, which we refer to as CFOSLS (constrained FOSLS). Applying finite elements to discretize the CFOSLS problem leads to a saddle-point system. To alleviate the high memory demand of the combined space-time approach (due to the increased dimension), we apply element agglomeration AMG upscaling on space-time elements. This leads to substantially reduced problem sizes with controlled accuracy. Preliminary numerical results for scalar parabolic and hyperbolic model problems, illustrate the potential of the method.

Space-Time Finite and Boundary Element Methods

Olaf Steinbach

Although the coupling of finite and boundary element methods via domain decomposition is well established for elliptic partial differential equations, much less is known for time–dependent problems. In this talk we will focus on new space–time finite and boundary element methods and their coupling, i.e. on the stability and error analysis, in the case of the heat equation. As a model problem we consider a free space transmission problem with locally supported initial data, and we apply a Johnson–Nédélec type coupling of finite and boundary elements. The discretization is done by using an admissible finite element mesh in the space–time domain, which allows adaptive refinement strategies simultaneously in space and time, and the related boundary element mesh along the interface. The presentation will close with some numerical results.

~~**Convergence of DNWR and NNWR Methods for Two-dimensional Hyperbolic Problems**~~

~~*Bankim Mandal*~~

~~The Dirichlet-Neumann and Neumann-Neumann Waveform Relaxation (DNWR and NNWR) methods [1] belong to a new class of methods for solving PDEs using space-time domain decomposition algorithms which permit the use of different time steps in different subdomains. In my talk, using Laplace-Fourier transform techniques, I show finite step convergence for both DNWR and NNWR methods for hyperbolic problems in two dimensional spatial domains for an optimal choice of the relaxation parameter. The number of steps depends on the subdomain size and the length of the time interval on which the algorithms are implemented. I illustrate the performance of the algorithms with numerical results, and show a comparison with classical and optimized Schwarz WR methods.~~

~~[1] M. J. Gander, F. Kwok, and B. C. Mandal, Dirichlet-Neumann and Neumann-Neumann Waveform Relaxation Algorithms for Parabolic Problems, submitted (arXiv:1311.2709).~~

16:00~17:40 CT-2 Optimized Schwarz methods 202B

Optimized Schwarz Methods Analyzed by Separation of Variables

Yingxiang Xu

Among the various domain decomposition methods, optimized Schwarz methods (OSMs) have recently attracted a lot of attention because of their advantageous performance in accelerating the convergence of subdomain iterations. OSMs are typically analyzed by Fourier transform which limits the theoretical results to very special situations. In this talk, we show that, instead of Fourier transforms, the technique of separation of variables can be applied in analyzing OSMs, which permits to deal with domain decompositions with certain curved interfaces, and problems with certain variable coefficients.

GetDDM: an Open Framework for Testing Optimized Schwarz Methods for Time-harmonic Wave Problems

Christophe Geuzaine, Xavier Antoine, David Colignon, Mohamed El Bouajaji, Nicolas Marsic, Bertrand Thierry, Alexandre Vion*

This talk presents the parallel domain decomposition solver GetDDM, integrated in the open-source finite element solver GetDP. This add-on has proved to be efficient on large-scale 3D problems, while staying easy to use, by, e.g. managing automatically the iterative solver, arising from the DDM, and the communication between processes. It is moreover versatile, e.g, it can consider scalar or vector problems, one-, two- or three-dimensional problems, mixed formulations and preconditionners. Available with ready-to-use examples for Helmholtz and Maxwell's equations, GetDDM aims to be a framework to test and develop optimized Schwarz methods for time-harmonic wave problems.

Schur Domain Decomposition in Time for Hamiltonian Systems

Tromeur-Dervout Damien

This talk focuses on the first attempt to extend of the Schur domain decomposition in time to a class of nonlinear systems of ordinary differential equations represented by the Hamiltonian systems. In the accepted proceedings of DD21 [1] and DD22 [2] past conferences, we showed how to transform the initial value problem into a boundary values problem in order to have the propagation of the information forward and backward in time. We also showed the importance to preserve some invariants for defining the transmission conditions. When the methodology is applied to a nonlinear ordinary differential equation with initial value , we have a natural invariant in time. None obvious invariants in time exist for general nonlinear differential equation systems . Nevertheless, for Hamiltonian's systems, we have at least the hamiltonian which is invariant in time and possibly Casimir's functions. Keywords: Schur time domain decomposition, Nonlinear transmission conditions, Hamiltonian systems.

References

[1] P. Linel and D. Tromeur-Dervout. Nonlinear Transmission Conditions for time Domain Decomposition Method. In J. Erhel, M. Gander, L. Halpern, G. Pichot, T. Sassi, and O. Widlund, editors, *Domain Decomposition Methods in Science and Engineering XXI, volume 98 of Lecture Notes in Computational Science and Engineering*, pages 807–814. Springer, 2014.

[2] P. Linel and D. Tromeur-Dervout. Dual Schur method in time for nonlinear ODE. In *Domain Decomposition Methods in Science and Engineering XXII, volume . of Lecture Notes in Computational Science and Engineering*, page . Springer, accepted.

Chair: Felix Kwok

Tuesday, July 7th 2015

Tuesday Morning

	Baeknok Hall A	202A	202B
9:00	PL4 Jysoo Lee		
9:45	Coffee Break		
10:15		MS5-1 Domain Decomposition and High Performance Computing	CT-3 Fast Solvers for Nonlinear and Unsteady Problems
11:55	Lunch at Delizia		

09:00~09:45 PL4 Baeknok Hall A

Computational Science Activities in Korea

Lee, Jysoo

An overview of computational science activities in Korea will be presented. Instead of focusing on specific areas, macroscopic view of the national ecosystem of computational science, including infrastructure, research and development, application, and education, will be given. Emphasis will be given to the legislation of the National Supercomputing Promotion Act passed by the National Assembly of Korea in 2011. With the law, increased investment in computational science ecosystem of the nation and coordination among government agencies are expected. The five year master plan of national supercomputing, which was established in 2012, will be described as well as yearly implementation plan. Also discussed are three major projects under development. First is the National Supercomputing Infrastructure Initiative, which is analogous to XSEDE or PRACE. Second is the National Supercomputing Education and Training Framework. Last is SuperKorea 2020, a plan which includes procuring a national leadership computing system, similar to the Tier-0 systems of PRACE, and developing an indigenous Korean supercomputer.

Chair: David Keyes

10:15~11:55 MS5-1 Domain Decomposition and High Performance Computing 202A

Multilevel Balancing Domain Decomposition at Extreme Scales

Santiago Badia, Alberto F. Martín, Javier Principe*

We present a fully-distributed, communicator-aware, recursive, and interlevel overlapped message-passing implementation of the multilevel balancing domain decomposition by constraints (MLBDDC) preconditioner. The implementations highly rely on subcommunicators in order to achieve the desired effect of coarse grain overlapping of computation and communication, and communication and communication among levels in the hierarchy (namely inter-level overlapping). Essentially, the main communicator is split into as many non-overlapping subsets of MPI tasks (i.e., MPI subcommunicators) as levels in the hierarchy. Provided that specialized nodes resources and memory are devoted for each level, a careful re-scheduling and mapping of all the computations and communications in the algorithm lets a high degree of overlapping to be exploited among levels. All subroutines and associated data structures are expressed recursively, and therefore MLBDDC preconditioners with an arbitrary number of levels can be built while re-using significant and recurrent parts of the codes. This approach leads to excellent perfect scalability results as soon as level-1 tasks can mask coarser-levels duties, which can be attained properly choosing coarsening rations and number of levels. We have provided a model to indicate how to choose the number of levels and coarsening ratios between consecutive levels and determine qualitatively the scalability limits for a given choice. We have carried out a comprehensive weak scalability analysis of the proposed implementation for the Laplacian and linear elasticity problems. Excellent weak scalability results have been obtained up to 458,752 processors and 1.8 million MPI tasks.

PermonCube and ESPRESO: Massively Parallel Generator and Hybrid FETI Solver

Lubomír Říha, Alexandros Markopoulos, Tomas Brzobohat*

ESPRESO is a massively parallel implementation of the Hybrid Total Finite Element Tearing and Interconnecting (FETI) method, which is designed to solve extremely large problems using multilevel decomposition. In Hybrid FETI a small number of neighboring subdomains is aggregated into clusters and each cluster is processes by single compute node. When compared to a two level FETI method, it significantly reduces its main bottleneck caused by solving the coarse problem. As of now the solver is able to solve problems larger than 2 billions of unknowns using 350 compute nodes with 64 GB of RAM. In order to test and fine tune the ESPRESO solver a massively parallel problem generator PermonCUBE, with nearly linear scaling, is in parallel developed by our team. Its main capability is generating the mesh with billion of unknowns in parallel over the cubical domain, and also preparing and assembling linear algebra objects, mostly for the problems related to mechanically deformable bodies. Recently a support for Hybrid TFETI has been added which and interface with ESPRESO has been developed. We will show the scalability tests of the PermonCUBE and ESPRESO for both strong and weak scalability as well as on extremely large problems. In addition we will discuss the problems, that arises at this scale.

Algorithmic Aspects of Coarse Space Construction

Pierre Jolivet, Frédéric Nataf, Christophe Prud'homme*

The aim of this talk is to present recent advances in the construction of robust coarse spaces for overlapping and nonoverlapping methods, as well as their implementation inside a C++ open source framework (https://www.github.org/hpddm/hpddm). A broad spectrum of applications will be covered, ranging from a scalar diffusion equation to Helmholtz equation, and including incompressible linear elasticity. Numerical results with hundreds of processes will be provided, clearly showing the effectiveness and the robustness of the proposed approach.

~~**Design and Implementation of Subdomain Local Solvers for Modern Supercomputers**~~

~~*Hiroshi Kawai*, Masao Ogino, Ryuji Shioya, Tomonori Yamada, Shinobu Yoshimura*~~

~~As the hardware architecture of modern supercomputers is getting more and more complicated, it is more and more difficult to achieve high performance in real production-level application codes. In case of DDM solver, one obvious performance bottleneck is the subdomain-wise local FE solver. During the development of open-source CAE system, ADVENTURE, we have been trying to review the design and implementation of DDM subdomain local solver for iterative substructuring. Here in this presentation, performance benchmark of subdomain local solvers of various types, either using direct or iterative solvers, will be provided on modern multi-core scalar based supercomputers, such as RIKEN K Computer.~~

10:15~11:55 CT-3 Fast Solvers for Nonlinear and Unsteady Problems 202B

Comparison of Nonlinear Domain Decomposition Schemes for Coupled Electromechanical Problems

Alexandre Halbach, Christophe Geuzaine*

In this talk we will compare several domain decomposition schemes for nonlinear, coupled electromechanical problems. Both staggered and monolithic electrostatic/elastic formulations are combined with an overlapping domain decomposition method applied either to the uncoupled, linear staggered resolutions or to the monolithic nonlinear system using a multiharmonic approach. The influence of the elastic waves frequency, of the electrostatic potential and of the mesh on the convergence rate is investigated on 2D and 3D models of a vibrating micromembrane array.

Three-level Explicit Schemes for Unsteady Convection-Diffusion Problems

Petr Vabishchevich, Petr Zakharov*

Convection-diffusion problems are fundamental for continuum mechanics. Convective transport can be formulated in various ways, namely, we highlight the divergence (conservative) and non-divergence (characteristic) form. Particular attention should be given to the skew-symmetric form that provides the property of L_2-conservation (the skew-symmetric property for the convective transport operator). In view of parallel computing systems, we use explicit schemes, which are easily parallelized via the domain decomposition method. Standard explicit schemes for parabolic equations demonstrate severe restrictions on the time step in view of stability. The second class of methods is based on splitting the grid elliptic operator of the problem into two triangular operators. Such explicit-implicit schemes are unconditionally stable. Their main disadvantage is that they are conditionally convergent. Recently proposed three-level modifications of the alternating triangular method demonstrate more attractive convergence characteristics. In the present paper, we investigate schemes based on the alternating triangular method for unsteady convection-diffusion problems. Two-level schemes with the explicit approximation of convective transport are constructed. Three-level modifications of such schemes are proposed and investigated. The results of numerical experiments are presented for model time-dependent convection-diffusion problems.

A Preconditioned Inexact Newton Algorithm for Steady State Lattice Boltzmann Equations

*Jizu Huang, Chao Yang, Xiao-Chuan Cai**

Most existing methods for calculating the steady state solution of the lattice Boltzmann equations are based on pseudo time stepping, which often takes a large number of time steps especially for high Reynolds number problems. To avoid the time integration, a preconditioned inexact Newton algorithm is developed to solve the steady state lattice Boltzmann equations directly. In this work, a second-order finite difference scheme is proposed and a two-level inexact Newton algorithm with a local nonlinear elimination preconditioner is employed to solve the nonlinear algebraic system. On the coarse level, an inexact Newton method with Reynolds number continuation is applied to generate the initial guess for the fine level inexact Newton solver. On the fine level, the local high nonlinearity of the system is eliminated by the nonlinear elimination preconditioner before the global Newton update. Some numerical experiments are presented to demonstrate the robustness and efficiency of the algorithm, especially for high Reynolds number.

A Time-Decomposition Approach for the Semilinear Wave Equation

Hyun Lim, Jung-Han Kimn, Matthew Anderson*

A numerical approach based on the space-time finite element method is implemented for the semilinear wave equation in 1(space) + 1(time) dimensions and 2+1 dimensions to explore critical collapse and search for self-similar solutions. Previous work studied this behavior by exploring the threshold of singularity formation using finite difference methods while this work introduces an adaptive time parallel numerical method to the problem. The semilinear wave equation with a $p = 7$ term is examined in spherical symmetry. The impact of mesh refinement and the time additive Schwarz preconditioner in conjunction with Krylov Subspace Methods are examined.

Chair: Yuri Bazilevs

Tuesday, July 7th 2015

Tuesday Afternoon

	Baeknok Hall A	202A	202B
14:00	MS7-1 Efficient Solvers for Electromagnetic Problems	MS5-2 Domain Decomposition and High Performance Computing	CT-4 Domain Decomposition Methods with Lagrange Multipliers
15:40	**Coffee Break**		
16:10	PL5 Lori Badea		
16:55	PL6 Luca F. Pavarino		
17:40	Introduction to Poster Session		
18:00	Poster Session and Apero at 1st Floor Lobby		

14:00~15:40 MS7-1 Efficient Solvers for Electromagnetic Problems — Baeknok Hall A

Computational Advances in Quasi-optimal Domain Decomposition Methods for Time-harmonic Electromagnetic Wave Problems

Nicolas Marsic, Alexandre Vion, Christophe Geuzaine*

In this talk we will present recent advances in the construction of quasi-optimal domain decomposition methods for time-harmonic electromagnetic wave problems. In particular, we will discuss the parallel implementation and computational efficiency of sweeping-type preconditioners, as well as the use of high order finite element discretizations, potentially mixing orders for the volume and interface formulations. Results on several large scale test cases will be analysed.

Schwarz Preconditioning of High Order Edge Elements Type Discretizations for the Time-harmonic Maxwell's Equations

Marcella Bonazzoli, Victorita Dolean, Francesca Rapetti, Richard Pasquetti*

In this work we want to study time-harmonic models of electromagnetic wave propagation in high-frequency regime, and how discretisation methods and solvers can be used efficiently for the solution of Maxwell's equations in heterogeneous, dissipative, and dispersive media. High order edge element methods usually lead to ill-conditioned linear systems, that is why preconditioning is mandatory. The contribution of this work is twofold. First we introduce the high order approximations and second we study numerically the impact of the Schwarz preconditioner for such approximations of Maxwell's equations.

A Geometry-aware Integral Equation Domain Decomposition Method for Maxwell's Equations

Zhen Peng, Brian Mackie-Mason*

We investigate a new geometry-aware domain decomposition method for the integral equation based solution of large, complex electromagnetic scattering problems. The electric current continuity across the boundary between adjacent subdomains is attained by a skew-symmetric interior penalty formulation. A non-overlapping additive Schwarz preconditioner is designed and analyzed for the solution of system matrix equation resulted from finite dimensional discretizations. We show that the preconditioned system exhibits a uniformly bounded eigenspectrum with regard to a range of numerical experiments. The convergence of our method scales reasonable well with respect to the discretization size, the operating frequency and problem size. We also test the performance of the proposed method for a range of numerical examples including planar and irregular subdomain boundaries, conformal and non-conformal surface discretizations. The results consistently confirm that the proposed approach provides convergence for all eigenmodes. Moreover, it yields an accurate solution for both smooth targets and targets with sharp edges and corners. The proposed work can be viewed as an effective preconditioning scheme that reduces the condition number of very large systems of equations in challenging electromagnetic scattering problems. The strength and capability of the proposed method will be illustrated by means of several examples of practical interest.

Analysis of Block-Jacobi Preconditionners for Local Multi-trace Formulations

Xavier Claeys, Victorita Dolean, Martin Gander*

Local multi-trace formulations are block-sparse boundary integral equations adapted to elliptic PDEs with piecewise constant coefficients only recently introduced in [Jerez & Hiptmair, 2012] and [Peng, Lim & Lee, 2013]. In these formulations, transmission conditions are enforced by means of local operators, so that only adjacent subdomains communicate. The present talk presents new theoretical and numerical results regarding the spectrum of the iteration operator associated to block-Jacobi preconditionners applied to these formulations.

14:00~15:40 MS5-2 Domain Decomposition and High Performance Computing 202A

Hybridization of FETI Methods

Roberto Molina, François-Xavier Roux*

In this work we develop a new implementation of previous FETI methods, initially the FETI-2LM and the classic FETI. The basic idea is to have a code that can use both methods at the same time by choosing in each interface the most suited method depending on the physics of the problem. By doing this we search to have a faster a more robust code that can work with configurations that usually the previous methods won't handle it optimally by himself. The performance is tested on a linear elasticity benchmark.

Parallel Implementation of BDDC for Mixed-Hybrid Formulation of Flow in Porous Media

Jakub Šístek, Jan Brezina, Bedrich Sousedík*

Balancing Domain Decomposition based on Constraints (BDDC) is extended to saddle point systems arising in solution of flows in fractured porous media by the finite element method. The problem is discretized using Raviart-Thomas finite elements, and the mixed-hybrid formulation is employed. The geologically important fractures within the rock are modelled by lower dimensional elements. A new interface averaging operator is proposed to handle heterogeneous material coefficients and large variations of element sizes within the geoengineering models. The extensions are implemented in our open-source solver of systems of linear equations BDDCML combined with software for subsurface flow simulations *Flow123d*.

Nonlinear Preconditioner for Full-space Lagrange-Newton-Krylov Algorithms with applications in PDE-constrained Optimization Problems

Feng-Nan Hwang, Haijian Yang, Xiao-Chuan Cai*

PDE-constrained optimization problems are important and computationally challenging problems. The full-space Lagrange-Newton algorithms is one of the most popular numerical algorithms for solving the problems, since Newton-type method enjoys fast convergence when the nonlinearities in the system are well balanced. However, in many practical problems such as flow control, if some of the equations are much more nonlinear than the others in the system, the convergence of the method become slow or at worse case the convergence failure happens. The radius of convergence is often constrained by a small number of the variables of equations in the system with the strong nonlinearities. In the talk, we introduce and study a parallel nonlinear elimination preconditioned inexact Newton algorithm for the boundary control of thermally convective flows based on the field variable partition. In this approach, in the standard manner, once the objective function and the PDE constrained problem discretized by some numerical schemes, we convert the constrained optimization problem into unconstrained optimization problem by introducing the augmented Lagrange function, then find the candidate optimal solution by solving the first order necessary condition using an inexact Newton method with backtracking techniques. The key point of new proposed algorithm is that before performing the global Newton update, we first identify the to-be-eliminated components that causes Newton method's into a slow convergence, and then remove the high nonlinearity by using a subspace correction, which can be interpreted the application of nonlinear elimination based preconditioner to the nonlinear system.

Numerical Simulation of the Earth's Core Convection on Many-Core Platforms

Changmao Wu, Fangfang Liu, Chao Yang*

We present our work on designing scalable algorithms for the numerical simulation of the Earth's outer core convection on heterogeneous many-core platforms. A time-split implicit method is used for integrating the incompressible Navier-Stokes equations in a rotating spherical shell. In each implicit time step, the nonlinear PDE system is decoupled into a linear system for the pressure and another linear system for the momentum/energy equations. Krylov subspace iterative methods preconditioned with the restricted additive Schwarz (RAS) algorithm are applied to solve both linear systems. Within each subdomain of the RAS preconditioner, many-core-enabled subdomain solvers are studied. Both the Krylov subspace solver and the RAS preconditioner are implemented and optimized on the Tianhe-2 supercomputer equipped with both Intel Xeon CPUs and Intel Xeon Phi accelerators. Large-scale tests are done on Tianhe-2 to show that the proposed algorithms are scalable to O(10,000) cores.

14:00~15:40 CT-4 Domain Decomposition Methods with Lagrange Multipliers 202B

An Efficient Algorithm for Stokes System Arising from a Regularized Domain Decomposition Method with Lagrange Multiplier

Junxian Wang, Shi Shu, Jie Peng*

In this paper, we are concerned with the non-overlapping domain decomposition method with Lagrange multiplier for Stokes equations with jump coefficient, and obtain a larger saddle point system discretized by $\mathrm{P}_2 - P_0$ element which contain a regularization technique to handle the singularity. We design a multiplicative Schwarz-CG iteration by introducing a diagonal preconditioner $\mathrm{M}_{\mathrm{d}}^{-1}$ and a coarse space W_0 for solving the Schur complement equations corresponding to multiplier variables. Then we establish the spectral equivalence of Schur complement systems between Stokes problem and the vector Possion problem with Lagrange multiplier. Furthermore we construct an efficient preconditioner for Schur complement system of scalar Possion equation discretized by P_2 element in two dimension and prove the condition number of T^*, which also describe the convergence rate of the previous Schwarz-CG iteration, is nearly optimal. The numerical experiments confirm the theoretical results.

A Localized Version of Mortar Method for a Treatment of Dissimilar Interfaces

Yeo-Ul Song, Sung-Kie Youn, K.C. Park*

A localized version of mortar method is proposed for a treatment of nonmatching interfaces. The present method is an update version of a localized Lagrange multipliers method for treating non-matching interfaces. When subdomains have different meshes and the interfaces are curved, a discretized model contains gaps along the curved interface. The gaps in the non-matching interfaces generally carry improper energy injection and dissipation. Therefore many dissimilar interface literatures are highly concerned about linear and angular momentum conservation. The present method provides a balanced treatment of the interface sides using a gap element. We handle the gap elements in the interface without incurring the undesired spurious energy.

Augmented Lagrangian Domain Decomposition Method for a Crack with Friction and Uniform Pressure

Sebastien Court, Olivier Bodart, Valerie Cayol, Jonas Koko*

The reduction of the computational cost of solutions is a key issue to crack identification or crak propagation. One of the solution is to avoid re-meshing the domain when the crack moves. To avoid re-meshing, we propose an approach combining the extended finite element method, the fictitious domain method and the augmented Lagrangian method. We consider a crack with Tresca's friction and uniform pressure. We first extend artificially the crack to split the domain into two subdomains, with prescribed homogeneous displacement jump condition. Using the three-field formulation, we then derive an augmented Lagrangian domain decomposition method.

FETI for Symmetric Saddle-point Problems

Ange Toulougoussou, François-Xavier Roux*

Domain decomposition methods often restrict the discretization of Stokes to discontinuous pressure. The arising system can then be solved by a preconditioned conjugate gradient. The drawback of discontinuous pressure is the large size of the linear system. We have recently combined dual and primal Schur methods to solve Stokes. This combination allows pressure as interface unknowns and leads to a symmetric positive semi-definite interface system that we can solve by a preconditioned conjugate gradient. The purpose of this talk is to extend this method to other saddle-point problems and to complement the theoretical analysis with numerical performance analysis.

Chair: Luca F. Pavarino

16:10~16:55 PL5 Baeknok Hall A

Global Convergence Rates of Some Multilevel Methods for Variational and Quasi-variational inequalities

Badea, Lori

In this talk we introduce some standard multigrid methods, and derive the global convergence rate, for variational inequalities of the first and second kind and for variational inequalities containing a term introduced by a nonlinear operator. Also, we estimate the convergence rate of the one- and two-level methods for variational inequalities of the second kind and of the quasi-variational inequalities. The methods are introduced as subspace correction algorithms in a reflexive Banach space, where general convergence results are derived. These algorithms become multilevel and multigrid methods by introducing the finite element spaces. In this case, the error estimates are written in function of the number of subdomains and the overlapping parameter for the one- and two-level methods, and in function of the number of levels for the multigrid methods. We illustrate the convergence of the introduced methods by numerical experiments. Also, the obtained convergence rates for the multigrid methods are compared with those existing in the literature for the complementarity problems.

Chair: Petter Bjørstad

16:55~17:40 PL6 Baeknok Hall A

Domain Decomposition Preconditioners for Isogeometric Discretizations

Pavarino, Luca F.

Research in isogeometric discretizations of partial differential equations has experienced a tremendous growth in the last decade. The design and analysis of efficient iterative solvers for the resulting discrete systems have started only a few years ago for scalar elliptic problems and they are still challenging research topics for more complex model problems. In this talk, we illustrate some scalable domain decomposition preconditioners for elliptic problems discretized by NURBS-based isogeometric analysis. We consider both overlapping Schwarz and BDDC/FETI-DP preconditioners, showing that scalable convergence rate bounds can be obtained as in the case of hp-finite and spectral element discretizations. We also report on current work extending these preconditioners to: i) almost incompressible linear elasticity and Stokes problems; ii) isogeometric collocation methods, one of the most competitive isogeometric techniques recently proposed; and iii) adaptive selection of primal spaces in dual-primal preconditioners, a critical topic in the isogeometric case due to the proliferation of interface degrees of freedom generated by the high regularity of NURBS discretizations.

Chair: Martin Gander

17:40~18:00 Introduction to Poster Session Baeknok Hall A

Chair: Martin Gander

18:00~19:00 Poster Session 1st Floor Lobby

Improved sweeping preconditioner for the solution of wave problems in non-homogeneous media by domain decomposition methods

Alexandre Vion, Christophe Geuzaine*

Sweeping preconditioners have recently gained interest for the solution of wave propagation problems. They are particularly interesting in the case of a nonhomogeneous medium, when used in combination with PMLs to achieve the transmission condition. However, their sequential nature makes them inadequate for parallel implementation. We propose to improve on that idea by performing smaller range sweeps in parallel. In addition, we suggest to incorporate an inner DDM-like loop to solve the subproblems with detached PMLs. This would limit the impact on memory usage of the increased subproblems size due to the appended PMLs.

Multiscale models for fluid mixing

Hyeonseong Jin

We study governing equations describing multiphase flow behavior effectively and various numerical methods for simulations. The goal of this study is to present multiscale modeling and numerical methods of macro and micro phenomena for turbulent fluid mixing driven by acceleration forces. We propose methods for verification and validation of simulations for chaotic, multiscale flows, specifically for turbulent mixing simulations.

Robotized needle insertion for drug delivery in small animals

Yinoussa Adagolodjo, Hadrien Courtecuisse, Michel De Mathelin, Stéphane Bordas, Raffaella Trivisonne*

Our goal is to develop robotized needle insertion for drug delivery in small animals. We control the robot with a real-time Finite Element simulation that provides accurate models of the deformable environment. To predict the deformations we need to solve a contact problem which is known to be time consuming. To reduce the computational time we use the domain decomposition method: the FE mesh is split in several domains in order to extract parallelism for GPU computing and to concentrate the computation time around the needle.

Weighted Least Squares Method For Poisson Equation In A Polyheral Domain

Seonghee Jeong, Eunjung Lee*

We focus on the difficulties arising from the presence of the singularities in a polyhedron and we describe the main features of the singular solutions near vertices and edges. Our purpose of this work is to show the existence of the unique weak solution to the above Poisson equation and find an approximation by using least squares finite element method in the presence of corner and edge singularities. First we make the equivalent first order system. Then we determine the weighted norm in order to handle the singularities from a corner and edges. After that we define the least squares functional for residual and find associated variational formulation from the minimization problem. We then prove the existence of the unique weak solution and verify theory through numerical computations.

Application of Navier-Stokes equation applying the least-squares method

Ryeongkyung Yoon, Eunjung Lee*

We apply the least-squares method to solve two different nonlinear problems which are derived from the Navier-Stokes equation. Firstly we find an approximation of a solution to the stationary incompressible Newtonian Navier-Stokes equation in 3D. To linearize nonlinear system, we use the Modified Picard method and Newton's method. We prove the well-posedness of minimization problems with respect to each linearlization method. Moreover, we consider the glaciology problem. Since the ice sheets move slowly, we assume that glaciers are incompressible non-Newtonian fluid. In similar way, we establish the minimization problem and prove the existence of a unique solution. After that, this work presents the numerical computations depending on condition of the viscosity

Parallel Domain Decomposition Algorithms for Blood Flows in Patient-Specific Cerebral Arteries

Wen-Shin Shiu, Eric Haujaun Hu, Zhengzheng Yan, Rongliang Chen, Feng-Nan Hwang, Xiao-Chuan Cai*

We develop parallel domain decomposition algorithms to simulate blood flows in the patient-specific cerebral artery using geometric information obtained by standard medical imaging techniques. The complicated patient-specific geometry in the human brain makes the problem challenging. We use a Galerkin/least squares finite element method to discretize the 3D incompressible Navier-Stokes equations, which are employed to model the blood flow, and the resulting large sparse nonlinear system of equations is solved by a Newton-Krylov-Schwarz algorithm. From the computed flow fields, we are able to understand some of the behavior of the blood flow in the dysfunctional territories. We also report the robustness and parallel performance of the domain decomposition based algorithms.

Immersed FEM for Heterogeneous Porous Media

Gwanghyun Jo, Do Y. Kwak*

One of the difficulties in solving the porous media problems is that there are natural variables with discontinuities in porous media. We develop IFEM frameworks to solve two phase immiscible fluids problem in porous media with discontinuous permeability fields. Using the methods of the global pressure (GP) and the total velocity (TV), we solve the problem with implicit pressure and explicit saturation scheme. Q1-Nonconforming element based IFEM functions are used to approximate GP and Raviart-Thomas element are used to approximate TV. Saturation is approximated by Q1-conforming element. Numerical results are provided for the proposed methods.

The role of myosin II in glioma invasion using the immersed boundary method

Wanho Lee, Sookkyung Lim, Yangjin Kim*

Gliomas are malignant tumors that are commonly observed in primary brain cancer. Glioma cells migrate through a dense network of normal cells in microenvironment and spread long distances within brain. In this poster we present a two-dimensional hybrid model in which a glioma cell is surrounded by normal cells and its migration is controlled by cell-mechanical components in the harsh microenvironment via the regulation of myosin II in response to chemoattractants. Our simulations reveal that the myosin II plays a key role in deformation of the cell nucleus as the glioma cell passes through the narrow intercellular space smaller than its nuclear diameter. In addition, our results suggest that in the presence of myosin II the strong signal of chemoattractants may retract invasive glioma cells back to the resection site so that they can be removed completely. This study sheds lights on the understanding of glioma infiltration through the narrow intercellular spaces and a potential approach for the development of anti-cancer invasion strategies.

A broken P1 nonconforming finite element methods for the elasticity problems with the interface

Daehyeon Kyeong, Doyoung Kwak*

We propose a new scheme for solving linear elasticity problems consisting of heterogeneous materials. Recently, immersed finite element methods (IFEM) are developed for partial differential equation with discontinuous coefficients. IFEM use uniform grids allowing the interface to cut through the elements. To use uniform grids, we develop P1-nonconforming based IFEM functions which satisfy Laplace-Young conditions along the interface. We add stabilizing terms and consistency terms to the bilinear form to improve the results. Optimal rates of convergence are achieved in the numerical results.

Immersed finite element method for eigenvalue problems in elasticity

Seungwoo Lee, Do Y. Kwak, Imbo Sim*

In this poster, we consider the approximation of eigenvalue problems for elasticity equations with the interface. This kind of problems can be efficiently discretized by using immersed finite element method (IFEM) based on Crouzeix-Raviart P1-nonconforming element. By adapting spectral analysis methods for the classical eigenvalue problems, we prove the stability and the optimal convergence of IFEM for solving eigenvalue problems with interface. Moreover, we demonstrate a variety of numerical experiments which corroborate our theoretical results.

~~**Enhancing performance of software by using digraph analysis**~~

~~*Hyoungseok Chu*, Dong-Uk Hwang*~~

~~Parallelization strategies of software have been developed intensively since parallel computation is regarded as the most powerful tool for simulating nature. We propose a strategy of parallelization based on digraph analysis, which emphasize the enhancing performance of software not by investigating a microscopic procedure, but by considering global organization of software. For this purpose, we analyze an open source numerical software GSL (GNU Scientific Library) by exploring their function call-graphs to make a suggestion for parallelization priorities. We set call-graph as directional way to preserve the characteristic of calling functions. In addition, the call-graph has bidirectional links for functions whose arguments are non-constant pointer variables, which implicitly imply changes of variable. We prioritize parallelizable key subroutines based on digraph parameters, and then we calculate cost of each elementary function used in the key subroutine by profiling a test program with variable size of data. To validate our strategy, we perform a benchmark test for matrix decomposition methods.~~

~~**Transition of transient behavior due to exceptional point**~~

~~*Dong-Uk Hwang*, Hyoungseok Chu*~~

~~In the eigenvalue problem of a non-Hermitian matrix, an exceptional point (EP) is a square-root branch point on a two-dimensional parameter space, at which not only eigenvalues but also the associated eigenvectors coalesce. The peculiar feature related to the EP is the exchange of eigenvalues and eigenvectors after a parameter variation encircling the EP once, of which topological structure is same as that of Mobius strip. We studied how EP point cause drastic change in the transient behavior of systems. In the case of coupled damping oscillators, it is shown that there is qualitative difference in transient dynamics exhibiting transition from beating to simple oscillatory damping, and the transient time minimized near EP point. We also investigated the transient dynamics in synchronization between two coupled chaotic oscillators, and observed qualitative changes in transient behavior, which does not come from the stability of synchronization manifold. Based on this general result on EP, we will discuss how an observed data should be analyzed in the presence of noise.~~

Mathematical modeling for the regulation of the T helper cell differentiation and an analysis of a Hopf bifurcation

Jisun Lim, Seongwon Lee, Yangjin Kim*

Airway exposure levels of lipopolysaccharide (LPS) are known to determine type I versus type II T helper cell induced experimental asthma. While low doses of LPS derive Th2 inflammatory responses, high (and/or intermediate) LPS levels induce Th1- or Th17-dominant responses. We develops a mathematical model of the phenotypic switches among three Th phenotypes (Th1, Th2, and Th17) in response to various LPS levels. In the present work, we simplify the complex network of the interactions between cells and regulatory molecules. The model describes the nonlinear cross-talks between the IL-4/Th2 activities and a key regulatory molecule, transforming growth factor β(TGF-β), in response to high, intermediate, and low levels of LPS. The model characterizes development of three phenotypes (Th1, Th2, and Th17) and predicts the onset of a new phenotype, Th17, under the tight control of TGF-β. Analysis of the model illustrates the mono-, bi-, and oneway-switches in the key regulatory parameter sets in the absence or presence of time delays. We show that the system can undergo a Hopf bifurcation at a steady state of the Th17 phenotype for high LPS levels in the presence of time delays. The model also predicts coexistence of those phenotypes and Th1- or Th2-dominant immune responses in a spatial domain under various biochemical and bio-mechanical conditions in the microenvironment.

Numerical Schemes for the Generalized Regularized Long Wave Equation Using a Reproducing Kernel Function

Su-Cheol Yi, Shu-Sen Xie*

Numerical schemes to numerically solve the generalized regularized long wave (GRLW) equation

$$u_t + \alpha u_x + \beta u u_x - \mu u_{xx} - \delta u_{xxt} = 0, \qquad (x,t) \in I \times (0,T]$$

with initial and homogeneous Dirichlet boundary conditions, are proposed and analyzed, where the subscripts t and x denote differentiation and α, β, γ and δ are nonnegative constants. In accordance with the different values of constants α, β, γ and δ, GRLW includes some special equations such as the equal width equation for $\alpha = \mu = 0$, $\beta = 1$ and $\delta \neq 0$ and the regularized long wave equation for $\alpha = 1, \beta \neq 0, \delta \neq 0$ and $\mu = 0$. By using a reproducing kernel function (RKF), the numerical solution at each discrete time step can be obtained by an explicit integral expression although the schemes are truly implicit, and, hence, the computation is fully parallel. Analytic representation of the RKF for a general Hilbert space $(H, <\cdot,\cdot>)$ is usually unknown. The RKF depends on the boundary conditions of functions in H and the inner product $<\cdot,\cdot>$. Let $\{\psi_i\}_1^\infty$ denote the orthogonal basis for H, i.e., $<\psi_i, \psi_j> = \delta_{ij}$ where δ_{ij} is the Kronecker delta. Then the RKF Ry for H can be constructed formally as

$$R^y(x) = \sum_{j=1}^{\infty} \psi_j(x)\psi_j(y)$$

The error estimates for these schemes are given and some numerical experiments are presented.

New way to compute accurate numerical solution for Poisson Equation with Corner Singularities using Stress Intensity Factor

Seokchan Kim

We consider the Poisson equation on a polygonal domain with one re-entrant corner with homogeneous Dirichlet BC. It is well known that the solution u of problem has singular decomposition: $u = w + \lambda\eta s$, with regular part $w \in H_0^1(\Omega) \cap H^2(\Omega)$ and s is a known singular function η is a cut-off function. The coefficient λ is called stress intensity factor and can be computed by the extraction formula. For decades, some numerical approaches was known which tried to compute the regular part w using these facts, then the solution u. Unfortunately, the results were not good enough because in the process the input function f was replaced by $f - \lambda D(\eta s)$, whose L^2-norm is quite large compared to that of f. The talk is to pose new PDE whose solution is in H^2 without increasing the L^2-norm of the input function, from which we get the efficient numerical solution. Some computational results will be given using FreeFEM code.

A modified staggered discontinuous Galerkin method for convection diffusion equations

Lina Zhao, Eun-Jae Park*

In this poster presentation, we design a modified staggered discontinuous Galerkin method for convection-diffusion problems with dominant convection which exhibit solutions with internal layers and boundary layers. A Streamline-Upwind Petrov-Galerkin method combining edge stabilizing jump term is used for the convective term. The theoretical results show that we can obtain optimal convergence rate as in the conforming finite element method. Additionally, to efficiently compute the solution, we apply adaptive finite element method with derived error estimator. The estimator yields a global upper and local lower bounds and the ratio of the upper bound and lower bound only depends on the local mesh-Péclet number. We present various numerical examples to show the performance of the error estimator.

Adaptive mesh refinement for hybrid discontinuous Galerkin methods for elliptic problems

Dong-Wook Shin, Eun-Jae Park*

In this work, we develop fully computable error estimators for hybrid discontinuous Galerkin methods for second order elliptic problems. Two types of a posteriori error estimates are designed by introducing suitable estimators. One is a residual-based estimator. This error estimator is simple, but it is fully computable for even-degree polynomial approximations. Unlike the residual-based estimator, the other estimator exploits the flux reconstruction which provides a guaranteed type estimator for all polynomial approximations. High-order approximations are allowed to compute both estimators, and they help achieve high-order accuracy. Also, both estimators are reliable and efficient. Performances of these estimators are presented using several numerical examples.

High-Order Discontinuous Galerkin method with Lagrange Multiplier for Systems of Conservation Laws

Jaemin Shin, Mi-Young Kim, Eun-Jae Park*

In this poster presentation, we apply a discontinuous Galerkin method with Lagrange multiplier (DGLM) recently introduced by Kim to systems of conservation laws. Lagrange multipliers are introduced on the element boundaries via weak divergence which provides smaller globally coupled problems on the interface. All the computations can be done element by element in parallel. Backward Euler method is used for time integration.
We present several numerical examples including Burgers equations, Euler equations, and Shallow water equations.

An Optimized Schwarz Method for the Biharmonic Equation

*Martin J. Gander, Yongxiang Liu**

We study an Optimized Schwarz method for the biharmonic equation. This problem, which needs two different boundary conditions, is quite different from the classical second order elliptic problem. Through suitable choices of the transmission conditions, as well as their corresponding parameters, we obtain an optimized Schwarz methods with a convergence rate that is exactly the same as for the Laplace equation, and convergence is much better than for the classical Schwarz method applied to the biharmonic equation. We illustrate our theoretical results with numerical experiments.

Analysis of Optimized Schwarz Methods for the Helmholtz Equation

*Martin J. Gander, Hui Zhang**

We analyze optimized Schwarz methods on multi-subdomains, which shows an essential difficulty for the Helmholtz equation that is not seen for the positive definite problems. We also analyze the influence of the boundary conditions equipped in the original problem, which shows a benifit from the radiation conditions.

Wednesday, July 8th 2015

Wednesday Morning

	Baeknok Hall A	202A	202B
9:00	PL7 Felix Kwok		
9:45		**Coffee Break**	
10:15	MS6 Domain Decomposition Methods and Parallel Computing for Optimal Control and Inverse Problems		CT-5 Efficient Methods and Solvers for Applications
11:55		**Lunch at Delizia**	

09:00~09:45 PL7 Baeknok Hall A

Schwarz Methods for the Time-Parallel Solution of Parabolic Control Problems

Kwok, Felix

In optimal control problems, the goal is to find, for a given mechanical or biological system, the forcing function with minimal cost that drives the system to a desired target state. The numerical solution of optimal control problems under PDE constraints has become an active area of research in the past decade, with a growing list of applications that includes the control of fluid flow governed by the Navier-Stokes equations, quantum control and medical applications related to the optimization of radiotherapy administration. When the governing PDE is parabolic, one must solve a coupled system of two PDEs, one forward in time (the state PDE) and another backward in time (the adjoint PDE). The tight coupling between these equations leads to extreme computational and storage requirements, so parallelization is essential. A natural idea is to apply Schwarz preconditioners to the large space-time discretized problem. Because the problem is essentially a two-point boundary value problem in time, it is possible to parallelize in time just as effectively as in space. We present a convergence analysis for a class of Schwarz methods applied to a decomposition of the time horizon into many subintervals. We show that just applying a classical Schwarz method in time already implies better transmission conditions than the ones usually used in the elliptic case, and we propose an even better variant based on optimized Schwarz theory.

Chair: Ralf Kornhuber

10:15~11:55 MS6 Domain Decomposition Methods and Parallel Computing for Optimal Control and Inverse Problems Baeknok Hall A

Parallel Domain Decomposition Based Algorithm for Large-scale Image Denoising

Rongliang Chen, Haiwei Fu, Xiao-Chuan Cai*

Total Variation(TV) methods are very effective for recovering blocky, discontinuous images from noisy data and the solution of the TV model is still challenging because of the ill-conditioning and computational expensive. In this talk, a parallel Newton-Krylov-Schwarz (NKS)-based nonlinear algorithm for the numerical solution of TV problems is proposed. We show numerically that NKS method converges well for image denoising problems. Various numerical experiments and comparisons, including the denosing of color images and 3D images, demonstrate that the proposed method is fast and robust, particularly for images of large size.

Bayesian Approach for an Elliptic Inverse Problem

Xuemin Tu

There are increasing interest in uncertainty quantification for differential equations with uncertain input data. These data can be the initial conditions, boundary conditions, or the parameters in the differential equations. In this talk, we focus on the uncertainty quantification of an elliptic inverse problem, where the uncertain data is the diffusion coefficient. The implicit sampling method is used to sample the posterior density and the BDDC algorithms are used for the forward model simulation.

Block Decomposition Methods for Total Variation by Primal-Dual Stitching

Chang-Ock Lee, Jong Ho Lee, Hyenkyun Woo, Sangwoon Yun*

Due to the advance of image capturing devices, images of huge size are available in our daily life. As a consequence the processing of large scale image data is highly demanded. Since the total variation (TV) is kind of de facto standard in image processing, we consider block decomposition methods for TV based variational models to handle large scale images. Unfortunately, TV is non-separable and non-smooth and it thus is challenging to solve TV based variational models in a block decomposition. In this talk, we introduce a primal-dual stitching (PDS) method to efficiently process the TV based variational models in the block decomposition framework. To characterize TV in the block decomposition framework, we only focus on the proximal map of TV function. Empirically, we have observed that the proposed PDS based block decomposition framework shows better performance than any other methodology such as Bregman operator splitting based approach.

A parallel space-time domain decomposition method for unsteady source inversions

*Qiya Hu, Shi Shu, Jun Zou**

In this talk we discuss a new variational approach for recovering general source profiles in elliptic systems, using measurement data in the interior of physical domains. The inverse source problems are transformed into well-posed direct elliptic problems. The resulting approximate solutions are shown to be stable with respect to the change of the noise in the observation data. The numerical method is computationally cheap, requiring only the solutions of well-posed elliptic problems, which can be well solved by the existing multigrid and domain decomposition methods. Optimal error estimates are derived for the finite element source function. The work of the third author was substantially supported by Hong Kong RGC grants (Projects 14306814 and 404611).

10:15~11:55 CT-5 Efficient Methods and Solvers for Applications 202B

A Locking-free Hybrid DGFEM for Nearly Incompressible Materials

Daisuke Koyama, Fumio Kikuchi, Sho Ihara*

We present a hybrid discontinuous Galerkin finite element method (DGFEM) for static and dynamic problems of elasticity. It has been revealed that many other DGFEMs overcome volume locking for nearly incompressible materials. Our hybrid DGFEM also has such a property. In more detail, if our hybrid DGFEM uses discontinuous numerical traces, and adds a lifting term, which is a kind of stabilization term, then it is free from volume locking. While, if it uses continuous numerical traces, or does not add a lifting term, then volume locking phenomena occur. We show these facts theoretically and numerically in this talk.

Shape Design Problem of Waveguide by Controlling Resonance Poles

Takashi Kako

We develop a numerical method to design the acoustic waveguide shape which has the filtering property to reduce the amplitude of frequency response in a given target bandwidth. The basic mathematical modeling is given by the acoustic wave equation and the related Helmholtz equation, and we compute complex resonant poles of the wave guide by finite element method with Dirichlet-to-Neumann mapping imposed on the domain boundary between bounded and unbounded domains. We adopt the gradient method to design the desired domain shape using the variational formula for complex resonant eigenvalues with respect to the shape modification of the domain.

Application of the BDDC Method for Incompressible Navier-Stokes Equations

Martin Hanek, Jakub Šístek, Pavel Burda*

We deal with numerical simulation of incompressible flows using Balancing Domain Decomposition by Constraints (BDDC). Scalability of the BDDC method is explored for nonsymmetric problems arising from linearization of incompressible Navier-Stokes equations. Picard iteration is employed for the linearization, and the arising linear systems with nonsymmetric matrix are solved by the BiCGstab method using one step of BDDC as the preconditioner. Results for the problem of 3-D lid-driven cavity are presented.

A Minimax Control Strategy for Domain Decomposition of Parabolic Equations

Mykhaylo Zayats, Emanuele Ragnoli, Sergiy Zhuk, Michael Hartnett*

In this work a novel strategy for Domain Decomposition (DD) that combines Differential Algebraic Equations (DAE), Optimal Control and Minimax Estimation is presented. It is based on the concepts of interface control and minimization of worst-case state estimation error. Some of the advantages of the method are, among others: no knowledge is required about specific interface conditions, making the local sub-problems completely independent; robustness of the method using various DD configurations through the accounting of transmission conditions in the algebraic equations and not in the local sub-problems. In this work the method is illustrated with non-stationary advection diffusion processes.

Chair: Frédéric Nataf

Wednesday, July 8th 2015

Wednesday Afternoon

	Baeknok Hall A	202A	202B
14:00	PL8 Sang Joon Shin		
14:45		**Moving**	
14:50	MS7-2 Efficient Solvers for Electromagnetic Problems	MS14 Tutorial for Domain Decomposition on Heterogenous HPC	MS11-1 Birthday Minisymposium Ralf Kornhuber (60th Birthday)
16:30		**Coffee Break**	
17:00	CT-6 Multiphysics Problems	MS8 Domain Decomposition Methods for Multiscale PDEs	MS11-2 Birthday Minisymposium Ralf Kornhuber (60th Birthday)
18:40		**Moving**	
19:00		**Banquet at Cao Cao**	

14:00~14:45 PL8 Baeknok Hall A

Development of Nonlinear Structural Analysis using Co-rotational Finite Elements with Improved Domain Decomposition Method

Shin, Sang Joon

This paper presents an all-direct domain decomposition approach for large-scale nonlinear structural analysis. In the proposed approach, compatibility of the displacement field across the sub-domain boundaries is enforced via local Lagrange multipliers. The augmented Lagrangian formulation (ALF) is applied to achieve computational robustness and efficiency. The improved algorithm for nonlinear problem will be demonstrated. And, then the numerical results and the performance for two dimensional nonlinear problem will be compared with those obtained by the other existing commercial software.

Chair: Jun Zou

14:50~16:30 MS7-2 Efficient Solvers for Electromagnetic Problems Baeknok Hall A

Optimized Schwarz Methods for Heterogeneous Helmholtz and Maxwell's Equations

Marcella Bonazzoli, Victorita Dolean, Martin J. Gander, Erwin Veneros*

It is nowadays widely recognized that like for the Helmholtz equation, also for the high frequency time-harmonic Maxwell's equations domain decomposition methods are currently the most promising solution techniques. We wish to develop optimized versions for the cases of dissipative and conductive media with strongly heterogeneous coefficients. In this sense, all the standard analysis performed previously has to be revisited. We present results that establish a link between the use of such conditions in the case of Helmholtz and MaxwellâĂŽ s equations, and show preliminary numerical results for two-dimensional configurations.

From Surface Equivalence Principle to Modular Domain Decomposition

Florian Muth, Hermann Schneider*

For the simulation of complex models and complete systems whose components involve different electromagnetic scales and properties, it is often appropriate to apply domain decomposition methods.
Based on the surface equivalence principle, the aim of the presented project is to develop a modular, black box framework for domain decomposition which is capable of assigning any formulation and numerical method to a certain subdomain. In this approach, equivalent surface currents act as interface between the subdomains exchanging boundary data.
Here, the focus is on coupling finite element and boundary element frequency domain methods driven by application examples like antenna placement. First results and encountered challenges will be presented.

Parallel Implementation of FETI-2LM for Large Problems with Many Right-hand-sides in Computational Electromagnetics

Francois-Xavier Roux

The numerical simulation of large antenna arrays is extremely expensive since the mesh must be fine enough to represent the complex inner structure of each element of the antenna which features thousands of them. Furthermore, the characterization of the antenna requires multiple solutions for each frequency for various incoming waves. This talk deals with the 2-level parallel implementation of the FETI-2LM method for such problems, with an efficient block ORTHODIR strategy to deal with several right-hand sides at the same time. This methodology is very efficient when mixing multi-threading on one multi-core for each subdomain and MPI for the global FETI-2LM iterations. Performance results with models with up to 400 millions degrees of freedom and hundreds of right-hand-sides will be presented.

Efficient Domain Decomposition Techniques Using Pade Approximants for the Helmholtz Equation

Yassine Boubendir

Our presentation is concerned with the recently proposed non-overlapping domain decomposition algorithm for the Helmholtz equation based on the use of Padé approximants, and whose effective convergence is quasi-optimal. This algorithm combined appropriate choice of transmission conditions with a suitable approximation of the Dirichlet to Neumann operator. In this talk, we proposed to modify this approach in order to reduce the CPU time of the iterative procedure.

14:50~16:30 MS14 Tutorial for Domain Decomposition on Heterogenous HPC 202A

Heterogenous HPC Architecture & Trends

Junard Lee

In this talk, we will introduce heterogenous HPC architectures. GPU acceleratedComputing is suitable for massively parallel computing jobs. we will show which areas researchers use this technology.

OpenACC Programming

Hyungon Ryu

In this talk, we will introduce OpenACC directives which you can easily accelerate your in-house code app with GPU. OpenACC directives are easier than openMP but more powerful method. at this talk we will cover C/C++ and Fortran directives.

CUDA Programming

Hyungon Ryu

At this talk ,we will introduce CUDA programming language and how to accelerate your in-house code with unified memory configuration. CUDA programming platform support C/C++ , fortran, python and JAVA languages.

Accelerate Example

Hyungon Ryu

We will illustrate how to accelerated explicit code for laplace equation and bio heat transfer equation step by step. we also show how to accelerated your app with cuBLAS/cuSolver/cuFFT libraries.

14:50~16:30 MS11-1 Birthday Minisymposium Ralf Kornhuber (60th Birthday) 202B

Multiscale Discretization by Subspace Decomposition

Ralf Kornhuber, Harry Yserentant*

We present a novel approach to the finite element discretization of elliptic problems with oscillating coefficients based on basic concepts of frequency spitting and subspace decomposition. In this framework, we derive and analyze a class of new discretization schemes and contribute to the analysis of existing methods as described, e.e., Efendiev & Hou [1] or Malquist & Peterseim [2].

[1] Y. Efendiev & T. Hou: Multiscale Finite Elements, Springer, 2009.
[2] A. Malquist & D. Peterseim: Localization of Elliptic Multiscale Problems. Math. Comp. 83, p. 2583-2603, 2014.

Nonsmooth Schur Newton Methods for Nonsmooth Saddle-point Problems

Carsten Gräser, Uli Sack, Ralf Kornhuber*

Discretization of multicomponent Cahn–Hilliard systems leads to large scale nonlinear saddle point problems with singular or nonsmooth terms that cannot be solved by classical Newton methods. We present nonsmooth Schur-Newton methods for nonsmooth saddle point problems based on a dual formulation of such problems. By relying on convexity rather than smoothness the presented methods are robust with respect to the nonlinearity and exhibit mesh independence and global convergence. Efficiency and robustness are illustrated for multicomponent Cahn–Hilliard equations with logarithmic and obstacle potentials.

Extreme Scale Solvers for Coupled Systems

Gabriel Wittum

Projected from today, exascale computers are characterized by billion way parallelism. Computing on such extreme scale needs methods with perfect scaling and optimal complexity. The solver itself must be of optimal numerical complexity – a requirement becoming more and more severe with increasing problem size – and scale efficiently on extreme scales of parallelism. We will present a multigrid approach scaling efficiently unto the full size of the largest computers available and looks promising for even larger scales. We further show that robustness can be maintained during the scaling process for relevant application problems while still maintaining optimal complexity.

Fast Elliptic Solvers for Extreme Computing

David Keyes

Emerging architectures invite additions to the library of optimal elliptic solvers and preconditioners methods that take advantage of the flooding of cores within shared memory domains and that tolerate less global synchronization. Accelerated Cyclic Reduction is a fast direct solver for variable-coefficient rank- compressible block tridiagonal linear systems with $O(N\log^2 N)$arithmetic complexity and $O(N\log N)$memory footprint. Algebraic Fast Multipole builds the low-rank machinery of H^2 hierarchical matrices on the tree-based data structures of FMM to generalize the architecturally ideal properties of $O(N)$FMM to variable coefficients. FMM can also be employed as a spectrally equivalent preconditioner for mildly variable coefficients, providing an $O(N)$ solver with potentially better strong scaling in distributed memory than multigrid. Numerical experiments demonstrate the scaling and convergence properties of these methods on a collection of elliptic PDEs with an increasing complexity in their coefficient structure and compare them various forms of multigrid. [joint with Gustavo Chavez, Huda Ibeid, Hatem Ltaief, GeorgeTurkkiyah, and Rio Yokota]

17:00~18:40 CT-6 Multiphysics Problems Baeknok Hall A

Domain-Decomposition-Based Fluid Structure Interaction Methods using Nonlinear Anisotropic Arterial Wall Models

Alexander Heinlein, Daniel Balzani, Simone Deparis, Simon Fausten, Davide Forti, Axel Klawonn, Alfio Quarteroni, Oliver Rheinbach, Jörg Schröder*

Stress distributions in walls of in vivo arteries (transmural stresses) are a major factor driving, e.g., arteriosclerosis and arteriogenesis. We focus on fluid-structure interaction using sophisticated nonlinear structural models. Such models have been developed and adapted to experiments in the past. We use an anisotropic, polyconvex hyperelastic structural model. Our coupled problems are solved using a monolithic approach based on domain decomposition, i.e., Overlapping Schwarz and Dirichlet-Neumann. Our solver environment combines the FEM software packages FEAP, the library LifeV, and parallel domain decomposition preconditioners using nonlinear models for the fluid and a nonlinear, polyconvex, anisotropic model for the structure.

A Domain Decomposition Method for Large Scale Simulation of Two-phase Flows with Moving Contact Lines

Li Luo, Qian Zhang, Xiao-Ping Wang, Xiao-Chuan Cai*

Moving contact line (MCL) problems, where the fluid-fluid interface intersects with the solid wall, can be described by a phase field model consists of the coupled Cahn-Hilliard and Navier-Stokes equations with the generalized Navier boundary condition. We designed an efficient numerical method based on convex splitting and projection method. Accurate simulations for the MCL problem require very fine meshes, and the computation in 3D is challenging because of the complex computational domain and the boundary condition. Thus the use of high performance computers and scalable parallel algorithms are indispensable. Based on the technique of domain decomposition, we apply a geometrical additive Schwarz preconditioned GMRES iterative method to solve the disceretized systems in parallel. Numerical experiments show that the algorithm is efficient and scalable on a supercomputer with a large number of processors.

Chair: Sang Joon Shin

17:00~18:40 MS8 Domain Decomposition Methods for Multiscale PDEs 202A

BDDC Preconditioners for Nonlinear Cardiac Mechanics

Luca Pavarino, Simone Scacchi, Stefano Zampini*

We present a BDDC solver for the nonlinear elasticity system modeling the mechanical deformation of cardiac tissue, modeled as a nearly-incompressible hyperelastic material. The cardiac electromechanical model is discretized with finite elements in space and semi-implicit finite difference schemes in time, yielding at each time step the solution of large-scale linear and nonlinear systems. We propose a PETSc based Newton-Krylov-BDDC mechanical solver. 3D parallel numerical tests show that this solver is scalable in the number of subdomains, quasi-optimal in the ratio of subdomain to mesh sizes, and robust with respect to tissue anisotropy.

Two-level Methods for Multiscale Time-Dependent Problems

Felix Kwok

The design of two-level domain decomposition algorithms for time-dependent parabolic problems has received much interest recently. This is because by subdividing both the spatial and temporal domain into multiple subdomains, one can introduce additional parallelism in the time direction, which is not possible with traditional methods that solve the problem one time step at a time. In this talk, we consider the design of coarse spaces for parabolic PDEs with highly oscillatory spatial coefficients. In particular, we will compare the performance of the two-level algorithm with a coarse space derived from homogenization theory with its performance using standard coarse spaces.

BDDC domain decomposition for Weak Galerkin Methods

Xuemin Tu, Bin Wang*

A Balancing domain decomposition by constraints (BDDC) algorithm is studied for solutions of large sparse linear algebraic systems arising from weak Galerkin discretization of second order elliptic boundary value problems. The condition number for the preconditioned system is estimated and numerical results are provided to confirm the results.

17:00~18:40 MS11-2 Birthday Minisymposium Ralf Kornhuber (60th Birthday) 202B

Linear and Non-Linear Preconditioning

Martin Gander, Victorita Dolean, Walid Kheriji, Felix Kwok, Roland Masson*

Preconditioning iterative methods for the solution of linear systems goes back to Jacobi (1845), and has become a major field of research over the past decades. Much less is known about the preconditioning of non-linear systems of equations. An important contribution is Additive Schwarz Preconditioned Inexact Newton (ASPIN) by Cai and Keyes (2002). Using the relation between stationary iterative methods and preconditioning for linear systems, we show in this presentation how one can systematically obtain a non-linear preconditioner from classical domain decomposition iterations, and present a new two level non-linear preconditioner called RASPEN (Restricted Additive Schwarz Preconditioned Exact Newton).

Globally Convergent Multigrid Approaches for Nonlinear Problems

Rolf Krause

Multigrid methods are well established as optimal solution methods for linear problems. Although multigrid ideas can also be applied to non-linear problems, the convergence theory for non-linear multilevel methods is much less developed. However, if the sought solution can be characterised as minimizer of an appropriate energy, different ways of proving the convergence of multilevel methods for non-linear problems are available. In this talk, we discuss two different approaches for proving convergence of multilevel methods for non-linear problems. We start with the Monotone Multigrid Methods, as introduced by R. Kornhuber, which is designed for convex and constrained minimization problems. We then consider non-convex minimization problems and discuss Recursive Multilevel Trust Region Methods. We discuss the similarities and differences between the two approaches as well as their parallelisation and illustrate their respective performance with numerical examples.

The Method of Subspace Correction and Beyond

Jinchao Xu

In this talk, I will make a few observations on the method of subspace corrections and related topics (such as singular problems, XZ identity, auxiliary spaces, algebraic multigrid and conjugate gradient). In particular, I will emphasis the importance on the correct use of dual spaces in the theory of iterative methods.

Thursday, July 9th 2015

	Baeknok Hall A
8:30	PL9 Clark Dohrmann
9:15	PL10 Nicole Spillane
10:00	**Moving**
10:30	**Social Program**
18:00	International Scientific Committee Meeting
20:00	Dinner of ISC and LOC with invited speakers

08:30~09:15 PL9 Baeknok Hall A

BDDC Algorithms for Discontinuous Petrov Galerkin Methods

Dohrmann, Clark

In this talk, we discuss the application of BDDC algorithms to a variety of problems discretized using discontinuous Petrov Galerkin (DPG) methods. One attractive feature of DPG methods is that they result in symmetric positive semidefinite subdomain matrices. Consequently, the rich theory and understanding of BDDC algorithms can be brought to bear on a wide variety of problem types. Specific areas covered in the talk include scalar elliptic, elasticity, convection-diffusion, and Helmholtz problems. An efficient preconditioning strategy for higher-order formulations is also discussed. Finally, we show how recent work on adaptive constraint selection for BDDC algorithms can help guide the design of effective coarse spaces for DPG methods.

Chair: Susanne Brenner

09:15~10:00 PL10 Baeknok Hall A

Adaptive Coarse Spaces and Multiple Search Directions: Tools for Robust Domain Decomposition Algorithms

Spillane, Nicole

I will present two families of methods that aim at achieving robustness. This is an important topic since we want to solve industrial problems with heterogeneous materials, bad aspect ratios, automatic partitions into subdomains...

The first family of methods (called GenEO) relies on a generalized eigenvalue problem per subdomain to isolate all the modes responsible for the possible slow convergence of FETI and BDD.

The second family of algorithms aims at generating the same information with no preprocessing step. This is achieved by taking advantage of the block structure of FETI and BDD as well as some properties of Krylov methods. In short, by allowing one search direction per subdomain we identify the space of vectors responsible for slow convergence within the conjugate gradient iterations.

Finally, I will discuss how to combine these two ideas into an adaptive algorithm which is both robust and efficient.

Chair: Olof Widlund

Thursday, July 9th 2015

10:30~18:00 Social Program

The excursion includes the following:

·Admission fee
·Lunch
·Transportation

Jeju Folk Village Museum

Jeju Folk Village Museum exhibits a comprehensive collection of traditional folk articles from the island, which were mostly prevalent around the 1890's. More than 100 traditional houses were moved from their original locations where the islanders had actually resided - even along with a piece of stone and pole. Over 8,000 pieces of folk articles are also displayed. It is expected that great attention and wholehearted support will be paid to the center for cultures, Jeju Folk Village, where the island's cultures have been kept alive and species of native trees and flowers can be seen. As the focal point for Jeju Island traditional cultural assets, the Jeju Folk Village intends to find, preserve, and develop the heritage with hopes that the Folk Village will remain a stimulus for further cultural development.

Seongsan Ilchulbong

Seongsan Ilchulbong Tuff Cone was created by hydrovolcanic eruptions 100,000 years ago. The peak was once an island, but it is now connected to Jeju Island, due to the sand and gravel washed ashore from Shinyang Beach. Farmers used to grow crops on it. About 200 varieties of plants and animals live on it. Udo Island is to the north and Seopjikoji is to the south. The peak is a prime spot from which to view the sunrise. It was designated as a natural monument on July 19, 2000; a UNESCO World Natural Heritage site on July 2, 2007; a Global Geopark on October 1, 2010; and one of the New 7 Wonders of Nature on November 12th, 2011.

Friday, July 10th 2015

	Baeknok Hall A	202A
9:00	MS12 Recent Approaches to Nonlinear Domain Decomposition Methods	CT-7 Coarse Space Selection Strategies
10:40	Coffee Break	
11:10	PL11 Frédéric Nataf	
11:55	Closing Ceremony	
12:10	Lunch at Delizia	

09:00~10:40 MS12 Recent Approaches to Nonlinear Domain Decomposition Methods Baeknok Hall A

Domain Decomposition Methods for Nonlinear Fluid-structure Interaction Problems

Xiao-Chuan Cai

In this talk, we discuss some recent progress in the development of scalable domain decomposition methods for solving fluid-structure interaction problems in 3D. A fully coupled approach is introduced for the nonlinear incompressible Navier-Stokes equations and a nonlinear elasticity equation. The parallel scalability of the method is determined mostly by the multilevel overlapping Schwarz preconditioner which is the main concern of the talk. This is a joint work with Fande Kong.

Domain Decomposition Methods in Computational Scale Bridging for Extreme Scale Computations

*Martin Lanser, Axel Klawonn, Oliver Rheinbach**

We use the FE^2 computational micro-macro scale bridging approach well known in engineering to directly incorporate micromechanics in macroscopic simulations of multiphase steels. In this approach, a microscopic boundary value problem based on the definition of a representative volume element (RVE) is solved at each macroscopic Gauß integration point. We are applying linear or nonlinear nonoverlapping domain decomposition methods of the FETI-DP type to solve nonlinear hyperelasticity or plasticity problems on the RVEs. We show parallel scalability to millions of MPI ranks and up to 40 billion d.o.f.

Nonlinear Schwarz Preconditioning

David Keyes

The multiplicative Schwarz preconditioned inexact Newton (MSPIN) algorithm is presented as a complement to additive Schwarz preconditioned inexact Newton (ASPIN, 2002). At an algebraic level, ASPIN and MSPIN are variants of the same strategy to improve the convergence of systems with unbalanced nonlinearities; however, they are complementary in practice. MSPIN is naturally based on partitioning of degrees of freedom in a nonlinear PDE system by field type rather than by subdomain, where a modest factor of concurrency can be sacrificed for physically motivated convergence robustness. ASPIN, as originally introduced for decompositions into subdomains, is natural for high concurrency and reduction of global synchronization. We consider both types of inexact Newton algorithms in the field-split context, and we augment the classical convergence theory of ASPIN for the multiplicative case. Numerical experiments show that MSPIN can be significantly more robust than Newton methods based on global linearizations, and that MSPIN can be more robust than ASPIN, and maintain fast convergence even for challenging problems, such as high-Reynolds number Navier-Stokes. [joint with Lulu Liu]

Nonlinear FETI-DP and BDDC Methods - Towards Computing on the Extreme Scale

Axel Klawonn, Martin Lanser, Oliver Rheinbach*

For a few decades already, Newton-Krylov algorithms with suitable preconditioners such as domain decomposition (DD) or multigrid (MG) methods (Newton-Krylov-DD or Newton-Krylov-MG) have been the workhorse for the parallel solution of nonlinear implicit problems. In these methods the nonlinear problem is first linearized and then decomposed. By changing the order of these operations, new algorithms with increased locality and reduced communication are obtained. Computational results combining domain decomposition with multigrid methods on several hundred thousand BG/Q cores will be shown.

09:00~10:40 CT-7 Coarse Space Selection Strategies 202A

A New Enriched Multiscale Coarse Space for Average Additive Schwarz Method

Leszek Marcinkowski, Talal Rahman*

In our talk we present an extension of the average Additive Schwarz Method for the second order elliptic problem in two dimensions with highly varying coefficients. In our method we proposed larger enriched coarse space which allows us to obtain the same bounds on condition number of the parallel average Schwarz preconditioner as in the classical average additive Schwarz method which was proposed by Bjørstad, Dryja, Vainikko in 1990s. In our approach we propose a simple procedure which enables us to enrich the coarse space of the average ASM by the local spaces spanned by eigenfunctions of specially defined local problems.

A New Harmonically Enriched Multiscale Coarse Space for Domain Decomposition Methods

Atle Loneland, Martin J. Gander, Talal Rahman*

In this talk we propose a new multiscale coarse space for domain decomposition methods, that is naturally enriched with harmonic functions. For a coercive model problem, we show how to enrich the coarse space so that the method is robust against any variations and discontinuities in the problem parameters both inside subdomains and across and along subdomain boundaries. We prove our results for an enrichment strategy based on solving simple and lower dimensional eigenvalue problems on the interfaces between subdomains, as well as, give a variant which performs equally well in practice, and does not require the solve of eigenvalue problems. Our enrichment process naturally reaches the optimal coarse space represented by the full discrete harmonic space, which enable us to turn the method into a direct solver. We illustrate our findings with several numerical experiments.

Relaxing the Role of Corners in BDDC with Perturbed Formulation

Hieu Nguyen, Santiago Badia*

In BDDC, corners not only contribute to the construction of the coarse space but also need to ensure the invertibility of the local subdomain problems and the global coarse problem. Algorithms for finding such corners exist, but can be expensive. In addition, corner constraints are not as efficient as constraints on averages on edges or faces functions in term of convergence. In this talk, we introduce a perturbed formulation of BDDC, where the invertibility is guaranteed and corners can be omitted. The new preconditioner has the same polylogarithmic bounds for the precondition number. Computational experiments confirm the theory.

DD Methods on Irregular Subdomains

Erik Eikeland

For domain decomposition methods analyzed by the Schwarz framework, it is often for simplicity assumed that the subdomains are regular, i.e. a finite union of coarse elements. This assumption is not always desirable, and for domain specific reasons, it could be impractical. Also a mesh partitioner would in general not give this kind of setup. The topic of irregular subdomains has been treated in previous works for domain decomposition methods with coarse spaces consisting of energy minimizing functions under the assumption that the subdomains are John domain or Uniform domain. In this talk we show, under the same assumptions, that DD method with alternative coarse spaces may be treated in the same manor as the energy-minimizing coarse spaces for irregular grids. In addition we show that these coarse spaces maintain the same robust behavior for problems with high contrast in the material coefficient.

Chair: Nicole Spillane

11:10~11:55 PL11 Baeknok Hall A

Recent Advances in Robust Coarse Space Construction

Nataf, Frédéric

Optimized Schwarz methods (OSM) are very popular methods which were introduced by P.L. Lions for elliptic problems and by B. Despres for propagative wave phenomena. One drawback was the lack of theoretical results for variable coefficients problems and overlapping decompositions. We build here a coarse space for which the convergence rate of the two-level method is guaranteed regardless of the regularity of the coefficients. We do this by introducing a symmetrized variant of the ORAS (Optimized Restricted Additive Schwarz) algorithm A. St Cyr et al. and by identifying the problematic modes using two different generalized eigenvalue problems instead of only one as for the ASM (Additive Schwarz method), BDD (balancing domain decomposition) or FETI (finite element tearing and interconnection methods.

Chair: Jinchao Xu

List of Participants

Adagolodjo, Yinoussa (Strasbourg University, France)	Poster*
Badea, Lori (Institute of Mathematics of the Romanian Academy, Romania)	PL5*
Badia, Santiago (Universitat Politècnica de Catalunya, Spain)	MS5-1*, CT-7
Bazilevs, Yuri (University of California, San Diego, USA)	PL2*, MS4-2*
Bjørstad, Petter (University of Bergen, Norway)	
Bonazzoli, Marcella (University Nice Sophia Antipolis, France)	MS7-1*, MS7-2
Boubendir, Yassine (New Jersey Institute of Technology, USA)	MS7-2*
Brenner, Susanne (Louisiana State University, USA)	
Cai, Xiao-Chuan (University of Colorado Boulder, USA)	MS5-2, MS6, MS12*, CT-3*, CT-6, Poster
~~**Chang, Huibin** (Tianjin Normal Univerisity, China)~~	~~MS6-1*~~
Chen, Rongliang (Chinese Academy of Sciences, China)	MS6*, Poster
Cho, Durkbin (Dongguk University, Republic of Korea)	MS4-2*
~~**Chu, Hyoungseok** (National Institute for Mathematical Sciences, Republic of Korea)~~	~~Poster*~~
Claeys, Xavier (Univ. Paris 6/ INRIA Alpines, France)	MS7-1*
Court, Sebastien (Universite Clermont II, France)	CT-4*
Courtecuisse, Hadrien (CNRS , France)	Poster
Damien, Tromeur-Dervout (U. Lyon1 / Institut Camille Jordan, France)	CT-2*
Dohrmann, Clark (Sandia National Laboratories, U.S.A.)	PL9*, MS4-2*
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Eikeland, Erik (Bergen University College, Norway)	CT-7*
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Halbach, Alexandre (University of Liège, Belgium)	CT-3*
Halpern, Laurence (LAGA Université Paris 13, FRANCE)	MS3-1*
Hanek, Martin (Czech Technical University in Prague, Czech Republic)	CT-5*
Heinlein, Alexander (Universität zu Köln, Germany)	CT-6*
~~**Huang, Jizu** (Institute of Computational Mathematics and Scientific/Engineering Comp, China)~~	~~CT-3*~~
~~**Hwang, Dong-Uk** (National Institute for Mathematical Sciences, Republic of Korea)~~	~~Poster*~~
Hwang, Feng-Nan (National Central University, Taiwan)	MS5-2*, Poster
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Jeong, Seonghee (Yonsei University, Republic of Korea)	Poster*
Jin, Hyeonseong (Jeju National University, Republic of Korea)	Poster*
Jo, Gwanghyun (KAIST, Republic of Korea)	Poster*
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Kako, Takashi (University of Electro-Communications, Japan)	CT-5
Kang, Kab Seok (IPP, Germany)	
~~**Kawai, Hiroshi** (Tokyo University of Science-Suwa, Japan)~~	~~CT5-1*~~
Keyes, David (King Abdullah University of Science and Technology, Saudi Arabia)	MS11-1*, MS12*
Kim, Hyea Hyun (Kyung Hee University, Republic of Korea)	MS4-1*
Kim, SeokChan (Changwon National University, Republic of Korea)	Poster*
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Kornhuber, Ralf (Freie Universität Berlin, Germany)	MS11-1*
Koyama, Daisuke (University of Electro-Communications, Japan)	CT-5*
Krause, Rolf (USI Lugano, Switzerland)	MS3-1*, MS11-2*
Kwak, Do Young (KAIST, Republic of Korea)	Poster
Kwok, Felix (Hong Kong Baptist University, Hong Kong)	PL7*, MS8*, MS11-2
Kwon, Kiwoon (Dongguk University, Republic of Korea)	
Kyeong, Daehyeon (KAIST, Republic of Korea)	Poster*
Lee, Chang-Ock (KAIST, Republic of Korea)	MS6, CT-1
Lee, Junard (NVIDIA Korea, Republic of Korea)	MS14*
Lee, Jysoo (KISTI, Republic of Korea)	PL4*
Lee, Seongwon (NIMS, Republic of Korea)	Poster*
Lee, Seungwoo (KAIST, Republic of Korea)	Poster*
Lee, Wanho (NIMS, Republic of Korea)	Poster*

Lim, Hyun (South Dakota State University, USA) CT-3*
Liu, Yongxiang (University of Geneva, Switzerland) Poster*
Loneland, Atle (University of Bergen, Norway) CT-7*
Luo, Li (Hong Kong University of Science &Technology, Hong Kong) CT-6*
~~**Mandal, Bankim** (Michigan Technological University, United States)~~ ~~MS3-2*~~
Marcinkowski, Leszek (University of Warsaw, Poland) CT-7*
Markopoulos, Alexandros (IT4Innovations, Czech Republic) MS5-1
Marsic, Nicolas (University of Liège, Belgium) MS7-1*, CT-2
Molina, Roberto (Paris 6, France) MS5-2*
Muth, Florian (Computer Simulation Technology, Germany) MS7-2*
Nam, Changmin (KAIST, Republic of Korea) CT-1*
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~~**Neumüller, Martin** (Johannes Kepler University Linz, Austria)~~ ~~MS3-1*~~
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Oh, Duk-Soon (Rutgers University, USA) MS4-2
Park, Eun-Hee (Kangwon National University, Republic of Korea)
Park, Eun-Jae (Yonsei University, Republic of Korea) Poster
Pavarino, Luca F. (University of Milan, Italy) PL6*, MS4-1, MS4-2, MS8*
Peng, Zhen (University of New Mexico, USA) MS7-1*
Rheinbach, Oliver (Technische Universität Bergakademie Freiberg, Germany) MS4-1, MS12*, CT-6
Riha, Lubomir (IT4Innovations, Czech Republic)
Roux, Francois-Xavier (ONERA, FRANCE) MS5-2, MS7-2*, CT-4
Ryu, Hyungon (NVIDIA Korea, Republic of Korea) MS14*
Shin, Dong-wook (Yonsei University, Republic of Korea) Poster*
Shin, Jaemin (Yonsei University, Republic of Korea) Poster*
Shin, Sangjoon (Seoul National University, Republic of Korea) PL8*
Shiu, Wen-Shin (Chinese Academy of Science, China) Poster*
Šistek, Jakub (Institute of Mathematics of the Academy of Sciences of the Czech Repub, Czech Republic) MS5-2*, CT-5
Song, Yeo-Ul (KAIST, Republic of korea) CT-4*
Spillane, Nicole (Universidad de Chile, Chile) PL10
Steinbach, Olaf (TU Graz, Austria) MS3-2*, CT-1
Sung, Li-yeng (Louisiana State University, USA)
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Toulougoussou, Ange (INRIA Alpines/Université Pierre et Marie Curie Paris 6, France) CT-4*
Tu, Xuemin (University of Kansas, USA) MS6*, MS8*
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Vion, Alexandre (University of Liege, Belgium) MS7-1, CT-2, Poster*
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Wathen, Andy (Oxford University, UK) PL3*
Widlund, Olof B. (Courant Institute, USA) MS4-1*, MS4-2
Wittum, Gabriel (G-CSC, University of Frankfurt, Germany) MS3-1, MS11-1*
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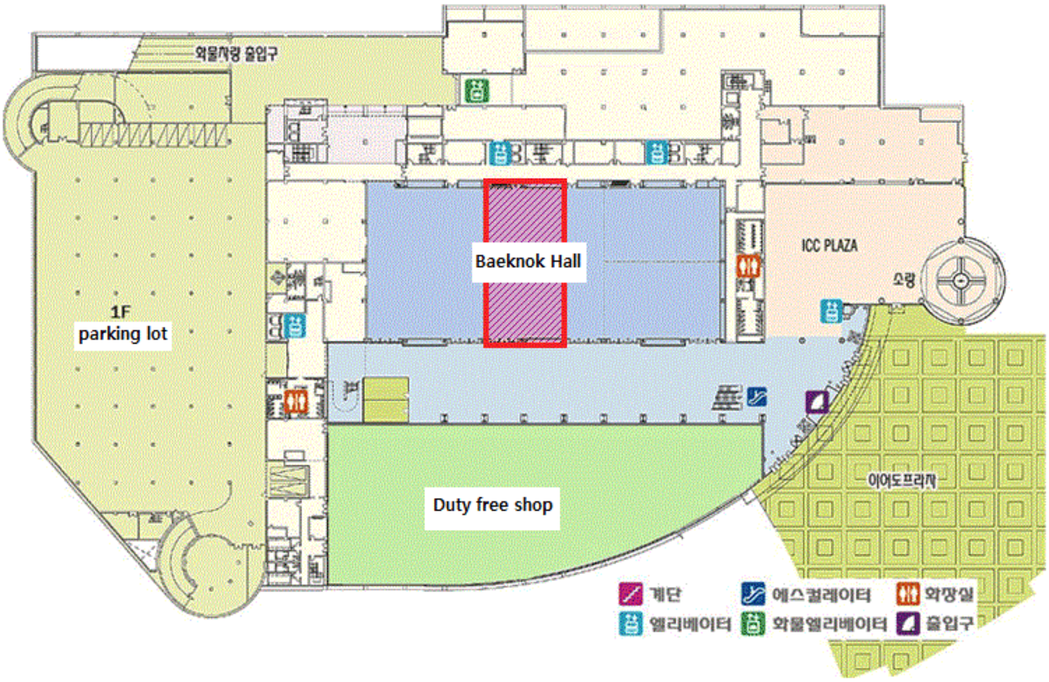
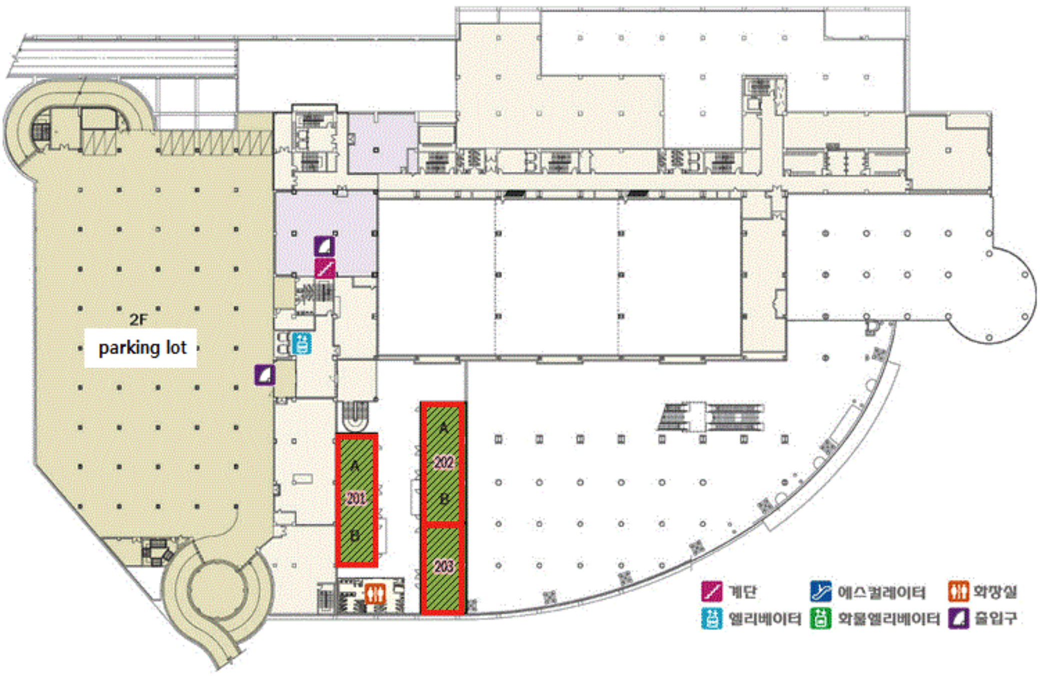
Yi, Su-Cheol (Changwon National University, Republic of Korea) Poster*
Yoon, Ryeongkyung (Yonsei University, Republic of Korea) Poster*
Zampini, Stefano (KAUST, Arabia Saudita) MS4-2*, MS8
Zayats, Mykhaylo (NUI Galway, Ireland) CT-5*
Zhang, Hui (University of Geneva, Switzerland) Poster*
Zhao, Lina (Yonsei University, Republic of Korea) Poster*
Zou, Jun (The Chinese University of Hong Kong, Hong Kong SAR, China) MS6*

*Speaker

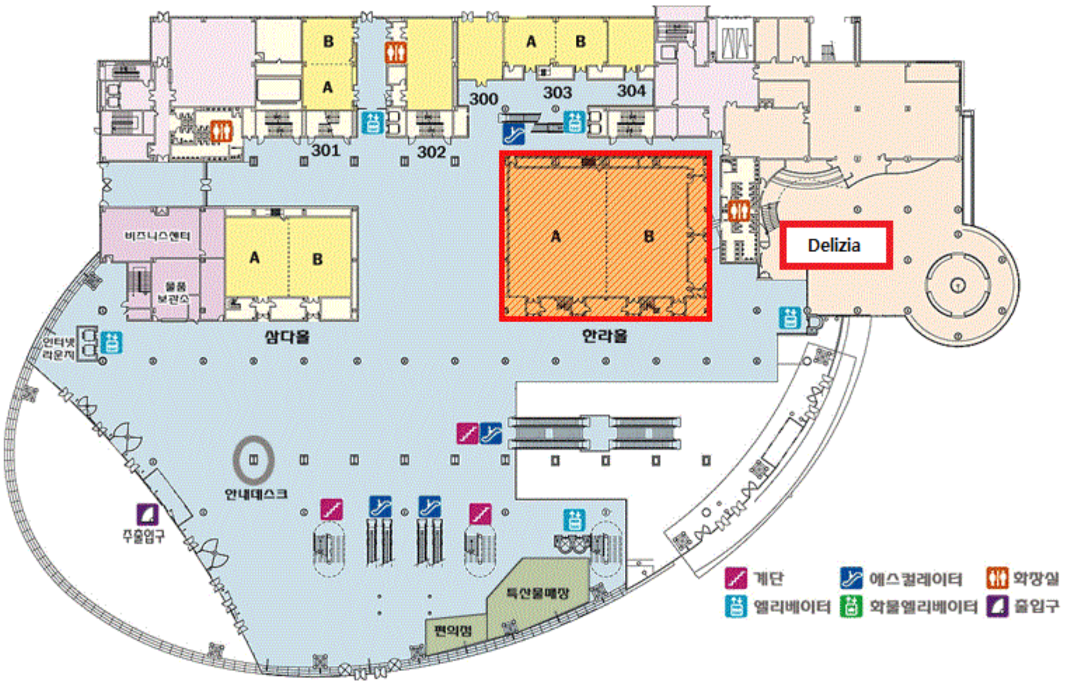
DD23 Maps



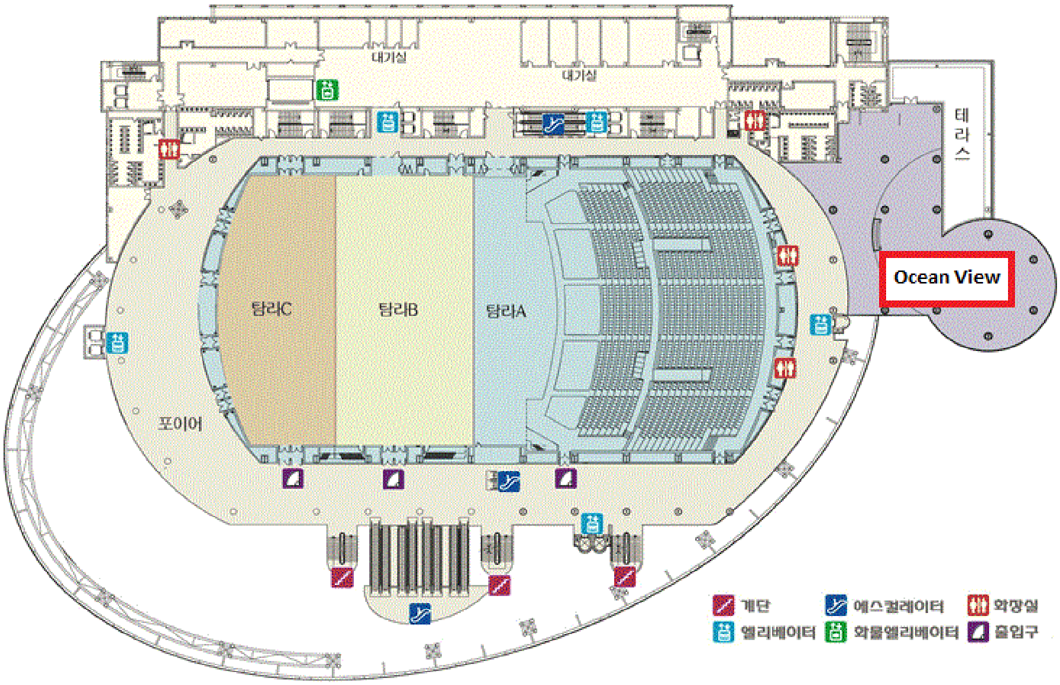
Baeknok Hall is located in the first floor.



202A, 202B are located in the second floor.



Delizia is located in the third floor.



Ocean View is located in the fifth floor.

Useful Information

Bus Schedule

Name of bus stations for each hotel:

Suite Hotel Jeju	Suite Hotel Bus Stop
The Port Avenue Hotel & The Familia Hotel	Walk 3 mins to the Jungmun Daepohang Bus Stop
The Hidden Hotel	Walk 8 mins to the Yakcheonsa Bus Stop
Hotel Hana	Hana Hotel Bus Stop
Booyoung Resort	ICC Jeju Bus Stop

Schedule for Airport limousine buses No.600:

	Yakcheonsa	Jungmun Daepohang	ICC Jeju	Suite Hotel	Hana Hotel	Jeju Airport		Yakcheonsa	Jungmun Daepohang	ICC Jeju	Suite Hotel	Hana Hotel	Jeju Airport
1	6:39	6:41	6:43	6:51	6:52	7:40	28	14:49	14:51	14:53	15:01	15:02	15:50
2	6:59	7:01	7:03	7:11	7:12	8:00	29	15:07	15:09	15:11	15:19	15:20	16:08
3	7:19	7:21	7:23	7:31	7:32	8:20	30	15:25	15:27	15:29	15:37	15:38	16:26
4	7:37	7:39	7:41	7:49	7:50	8:38	31	15:43	15:45	15:47	15:55	15:56	16:44
5	7:55	7:57	7:59	8:07	8:08	8:56	32	16:01	16:03	16:05	16:13	16:14	17:02
6	8:13	8:15	8:17	8:25	8:26	9:14	33	16:19	16:21	16:23	16:31	16:32	17:20
7	8:31	8:33	8:35	8:43	8:44	9:32	34	16:37	16:39	16:41	16:49	16:50	17:38
8	8:49	8:51	8:53	9:01	9:02	9:50	35	16:55	16:57	16:59	17:07	17:08	17:56
9	9:07	9:09	9:11	9:19	9:20	10:08	36	17:13	17:15	17:17	17:25	17:26	18:14
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26	14:13	14:15	14:17	14:25	14:26	15:14	53	21:53	21:55	21:57	22:05	22:06	22:54
27	14:31	14:33	14:35	14:43	14:44	15:32	54	22:09	22:11	22:13	22:21	22:22	23:10

NOTE: The bus may come earlier than the above schedule.

Contact

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Homepage: dd23.kaist.ac.kr

Tickets for Excursion and Banquet

Subjects to availability additional tickets for the **Conference Banquet** and the **Excursion** can be purchased for **USD 30 (KRW 33,000)** and **USD 70 (KRW 77,000)**, respectively, at the Registration Desk.

Emergency numbers

DD23: 010-8718-7633 (Lee, Chang-Ock)
Ambulance: 119
Police: 112