DD22

International Conference on
Domain Decomposition Methods

22nd International Conference on Domain Decomposition Methods

University of Lugano, Switzerland

dd22.ics.usi.ch

Università della Svizzera italiana

Facoltà di scienze informatiche

Institute of Computational Science ICS

Welcome

Dear participants,

It is my great pleasure as chairman of this meeting to welcome you to the 22nd International Conference on Domain Decomposition Methods.

Also on behalf of the Local Organizing/Program Committee, the International Scientific Committee and the Institute of Computational Science, it is a true honor for us to host you here at the Università della Svizzera italiana, in the Italian-speaking part of Switzerland.

With 172 participants from over 24 countries, this conference is part of a long-lasting tradition of internationally oriented meetings on Domain Decomposition Methods. As in previous meetings, it features a well-balanced mixture of established and new topics, such as the manifold theory of Schwarz methods, Isogeometric Analysis, Discontinuous Galerkin methods, exploitation of modern HPC architectures, and industrial applications. From the conference program it is evident that the growing capabilities in terms of theory and available hardware allow for increasingly complex non-linear and multi-physics simulations, confirming the huge potential and flexibility of the domain decomposition idea.

The Institute of Computational Science (ICS) of the Faculty of Informatics at the Università della Svizzera italiana (USI) is delighted to host the 22nd edition of this conference series. The ICS was founded in 2009 towards realizing the vision of USI to become a new scientific and educational node for computational science in Switzerland. It has since then grown into a place with strong competences in mathematical modeling, numerical simulation, and high-performance computing. Research areas range from numerical simulation in science, medicine, and engineering, through computational time series analysis and computational shape analysis, to computational cardiology and the (multi-scale) simulation of physical and biological systems.

We acknowledge our sponsors, first and foremost the Swiss National Science Foundation, the Swiss National Supercomputing Centre, Nvidia, Fondazione Cardiocentro Ticino and the Swiss Mathematical Society for their generous support. In closing, I would like to thank all the participants gathered here in Lugano for their contributions to the scientific success of this conference. We are looking forward to having you with us and hope that the vivid and continuously growing scientific environment at USI, together with the Lago di Lugano, the alpine scenery and of course the scientific and social program of DD22, will turn this week into a memorable experience.

Rolf Krause

Institute of Computational Science
Director


CORPO
CENTRALE

Locations

Lugano

Lugano city is situated on the beautiful Lago di Lugano between Monte San Salvatore and Monte Brè. With its cluster of Italianate piazzas and extensive palm tree-lined promenades, it is the most alluring of the Swiss lake resorts. The city is framed on all sides by wooded, sugar-loaf hills rising from the water, which are popularly called the Rio of the Old World. Lugano is nonetheless an exciting place, full of energy and style, an international city and a melting pot of European culture. The city has been deeply influenced by Italian culture as it is displayed in the language spoken and the food eaten. It is not only Switzerland's third most important financial center but also offers many advantages of a world-class city combined with the cachet of a small town. Lugano is open and welcoming and provides a lot of possibilities typical of a united and constantly open Switzerland, a gate to Europe.

How to get to Lugano

Lugano can be reached from Milan's International airport Malpensa (MXP) by regular shuttle service directly from the arrival terminals (only 27 miles - though one can count on a good hour drive during rush hours). There are flights from MXP to all major US and European destinations. Airport Lugano (LUG) offers direct flights to the main Swiss and European towns (www.lugano-airport.ch). It offers daily connections to: Zurich, Geneva, Rome. Airport in Lugano is 4 miles from the city center. Train from Zurich (www.sbb.ch) is only 2.30 hours and offers one of the best scenic routes in Switzerland.

Local Organizing/Program Committee

- Rolf Krause (USI Lugano; Chair)
- Thomas Dickopf (USI Lugano)
- Martin Gander (U Genève)
- Ralf Hiptmair (ETH Zürich)
- Luca Pavarino (U Milano)
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International Scientific Committee

- Ralf Kornhuber (FU Berlin; Chair)
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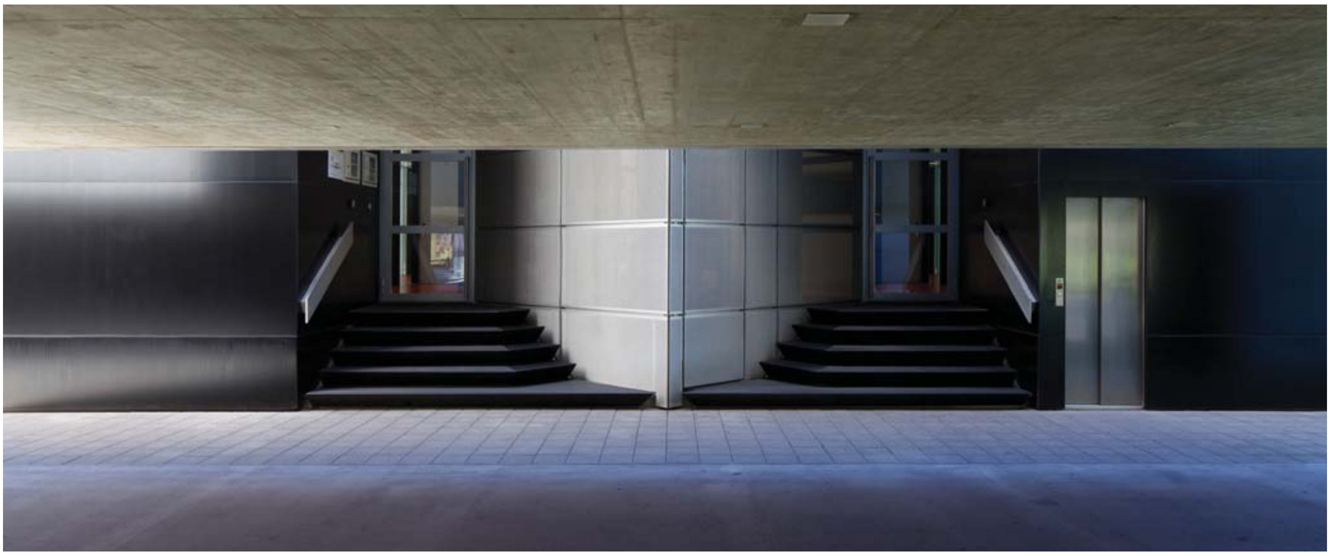


Plenary Lectures (in chronological order)

Nonlinear FETI-DP methods
Oliver Rheinbach (TU Freiberg, Germany)

Domain decomposition methods for high-order discontinuous Galerkin discretizations
Paola F. Antonietti (MOX Milano, Italy)

Numerical treatment of tensors and new discretisation paradigms
Wolfgang Hackbusch (MPI Leipzig, Germany)

Domain decomposition methods in isogeometric analysis
Lourenço Beirão da Veiga (University of Milano, Italy)

Auxiliary space multigrid based on domain decomposition
Johannes Kraus (RICAM Linz, Austria)

Domain decomposition in nonlinear function spaces
Oliver Sander (RWTH Aachen, Germany)

Numerical solution of PDE eigenvalue problems in acoustic field computation
Volker Mehrmann (TU Berlin, Germany)

Applications of the Voronoi implicit interface method to domain decomposition
James A. Sethian (UC Berkeley, USA)

Robin-Neumann explicit schemes in fluid-structure interaction problems
Marina Vidrascu (INRIA Le Chesnay, France)

An assembled inexact Schur-complement preconditioner
Joachim Schöberl (TU Wien, Austria)

Local simplification of Darcy's equations with pressure dependent permeability
Christine Bernardi (LJLL Paris, France)

BDDC deluxe domain decomposition algorithms
Olof B. Widlund (NYU, USA)

Coupling Stokes and Darcy equations: modeling and numerical methods
Marco Discacciati (UPC Barcelona, Spain)

Robust discretization and iterative methods for multi-physics systems
Jinchao Xu (Penn State University, USA)

MS 1 - Advances in FETI-DP and BDDC methods

Organizers: Axel Klawonn, Olof B. Widlund

This minisymposium focuses on recent developments of the closely related families of BDDC and FETI-DP domain decomposition algorithms. These algorithms have proven very effective in a variety of applications. Talks will be offered on applications to nonlinear problems, discontinuous Galerkin methods, mixed finite elements for the Stokes equations with continuous pressures, and on adaptive coarse spaces based on the solution of suitable eigenvalue problems. Recently, there has also been considerable activity in the development of a new variant of BDDC, which is due to Clark Dohrmann. Among the applications of these new ideas are algorithms for H(div) in 3D and for new special discontinuous approximations of H(curl) problems in 2D.

MS 2 - Achieving scalability in domain decomposition methods: advances in coarse spaces and alternatives

Organizers: Felix Kwok, Kevin Santugini

With the increasing availability of massively parallel machines, scalability becomes a crucial factor in the design of domain decomposition algorithms. To be scalable, an iterative algorithm must have a convergence rate that does not depend on the number of subdomains. This precludes methods in which subdomains send information only to their direct neighbors, since they cannot converge in fewer iterations than the diameter of the connectivity graph of the decomposition. A traditional way of introducing long-range communication is to add a coarse space component; there are also other methods inspired by multilevel decompositions and interpolation. Speakers will present their work on either innovative coarse spaces or new alternatives to coarse spaces.

MS 3 - Non-overlapping discretization methods and how to achieve the DDM-paradigm

Organizers: Ismael Herrera, Luis Miguel de La Cruz

The DDM-paradigm is to obtain the global solution by solving local problems exclusively. The introduction of non-overlapping DDMs represented an important step towards achieving this paradigm. However, in non-overlapping DDMs the interface-nodes are shared by two or more subdomains of the coarse-mesh. In this minisymposium we present the non-overlapping discretization methods, which use systems of nodes with the property that each node belongs to one and only one subdomain of the coarse mesh. Then, it is explained how using non-overlapping discretization methods the DDM-paradigm can be achieved.

MS 4 - Solution techniques for discontinuous Galerkin methods

Organizers: Blanca Ayuso de Dios, Susanne Brenner

Based on discontinuous FE spaces, DG methods are extremely versatile and have many attractive features: local conservation properties; flexibility in designing hp-adaptivity strategies and built-in parallelism. DG methods can deal robustly with PDEs of almost any kind. However, their use in many real applications is still limited by the larger number of degrees-of-freedom required compared with other classical discretization methods. The aim of this mini-symposium is to bring together experts in the field to discuss and identify the most relevant aspects of the state of the art for DG methods, including design, theoretical analysis, and issues related to the implementation and applications of the various solution techniques.

MS 5 - Solvers for isogeometric analysis and applications

Organizers: Lourenço Beirão da Veiga, Luca Pavarino, Simone Scacchi

Isogeometric Analysis (IGA) is a novel and fast developing technology for the numerical solution of PDEs, that integrates CAD geometric parametrization and FEA. Since its introduction in 2005 by T.J.R. Hughes and co-workers, IGA is having a strong impact on the engineering and scientific computing community, producing a large amount of journal publications and developing advanced computer codes. In recent years, researchers in this quickly growing field have started to focus on the design and analysis of efficient solvers for IGA discrete systems, and in particular of multilevel domain decomposition methods yielding parallel and scalable preconditioners. The high (global) regularity and polynomial degree of the NURBS spaces employed in IGA discretizations introduce both new difficulties and opportunities for the construction and analysis of novel solution techniques. The aim of the minisymposium is to bring together researchers in both fields of IGA and domain decomposition methods, focusing on the latest developments and on the new research pathways and applications.

MS 6 - Efficient solvers for heterogeneous nonlinear problems

Organizers: Juan Galvis, Lisandro Dalcín, Nathan Collier, Victor Calo

Multiple scales and non-linearities are present in many applications, such as porous media and material sciences. Heterogeneities and disparity in media properties make it difficult to design robust preconditioning techniques and coarse multiscale approximations. Certainly, the presence of non-linearities or many possible (properly parametrized) scenarios make this task even more challenging. In particular, the design and analysis of iterative solvers with good convergence properties with respect to physical parameters and nonlinearities is important for applications. A main interest of this minisymposium is to develop techniques and algorithms to approach efficiently heterogeneous and nonlinear problems such as Richard's equation for heterogeneous porous media and other nonlinear models. In this session, we will bring together experts working on domain decomposition methods for multiscale and nonlinear problems.

MS 7 - Domain decomposition techniques in practical flow applications

Organizers: Menno Genseberger, Mart Borsboom

Last decades domain decomposition techniques have been incorporated in large computer codes for real life applications. By bringing together some of them, this minisymposium aims to - illustrate the importance of domain decomposition (for modeling flexibility, parallel performance, etc.) in the application field, - highlight the applied domain decomposition techniques, to discuss these approaches and, reconsider or further improve them. Application area is restricted to hydrodynamics, to have a good basis for further discussion. The presentations consider domain decomposition techniques in large computer codes being used world wide for shallow water flow in coastal areas, lakes, rivers, ocean flow, and climate modeling.

MS 8 - Domain decomposition methods in implementations

Organizers: Christian Engwer, Guido Kanschat

Domain decomposition and subspace correction methods are tools with potential for high impact on practical applications. They yield efficient solvers for high performance simulations of multi-physics applications or multi-scale problems, way beyond the realm of currently available theoretical analysis. They are in particular suitable for generic implementations in tool boxes and programming libraries, since they replicate structures existing on the whole computational domain on subdomains, and their mathematical structure coincides with parallel implementation. Thus, it is possible to implement these methods in a way, that their optimal performance can be evaluated for the provable problems, but application of the very same code structures to more advanced problems is straightforward.

We bring together experts on the development of software frameworks for high performance computing and on challenging applications to discuss possible approaches for generic implementations as well as demands posed by advanced applications and performance results. By incorporating improved domain decomposition algorithms into high-level frameworks they can be made readily accessible to a wide audience without particular knowledge of their technical details. The talks will focus on different challenges in the context of domain decomposition methods, e.g. multi-physics simulations, construction of preconditioners or generic parallel simulations, and discuss how such topics can be incorporated into a general purpose framework and made available to the application level.

MS 9 - Parallel multigrid methods

Organizers: Karsten Kahl, Matthias Bolten

Modern simulation codes must solve extremely large systems of equations - up to billions of equations. Hence, there is an acute need for scalable parallel linear solvers, i.e., algorithms for which the time to solution (or number of iterations) remains constant as both problem size and number of processors increase. Multigrid (MG), known to be an optimal serial algorithm, is often scalable when implemented on a parallel computer. However, newly emerging many-core architectures present several new challenges that must be addressed if these methods are to be competitive on such computing platforms. Here we discuss new techniques for parallelizing MG solvers for various problems.

MS 10 - Efficient solvers for frequency domain wave problems

Organizers: Victorita Dolean, Martin J. Gander, Ivan Graham

In this minisymposium we explore iterative methods for frequency domain wave problems such as the Helmholtz and Maxwell equations. Driven by important technological applications, considerable recent progress in this topic aims towards obtaining a wavenumber robust efficient scalable solver, accompanied by a rigorous analysis. The minisymposium will discuss several areas of recent progress including sweeping and source transfer preconditioners, techniques based on the principle of limited absorption and new advances in optimised Schwarz methods.

MS 11 - Domain decomposition methods for environmental modeling

Organizers: Florian Lemarié, Antoine Rousseau

Many applications in geophysical fluid dynamics and natural hazards prediction require the development of domain decomposition methods (DDMs) either to optimally use the increasing computational power or to accurately simulate multi-physics phenomena. Due to the complexity of such numerical codes, additional constraints arise in the design of the numerical methods as for example in space-time discretizations, subgrid scale parameterizations, physical/numerical interfaces etc.. In this context, a compromise between efficient numerical methods and their according constraints imposed by the target applications must be found. The aim of this mini-symposium is to bring together theoretical and applied scientists working on realistic environmental simulations. Work presented will explore a range of applications from hydrological, oceanic and atmospheric modeling to earthquake dynamics.

MS 12 - Efficient solvers

Organizers: Sébastien Loisel

Solving large problems is a core interest in domain decomposition. In order to be useful, an algorithm should be efficient -- whether from high parallelization, ease of implementation or low floating point operation counts. One may improve the efficiency of algorithms by carefully choosing artificial interface boundary conditions (Dirichlet, Neumann or Robin); this choice then impacts the design and implementation of algorithms. A further issue is the physical nature of the problem (e.g. elliptic or parabolic, with possible heterogeneities). In this minisymposium, we will discuss algorithms related to the optimized Schwarz and FETI methods and consider especially their performance advantages.

Minisymposia

MS 13 - Space-time parallel methods

Organizers: Daniel Ruprecht, Robert Speck

The number of cores in modern supercomputers increases rapidly, requiring new inherently parallel algorithms in order to actually harness their computational capacities. This fact leads to increasing need for methods that provide levels of concurrency in addition to already ubiquitous spatial parallelization. For time-dependent problems, algorithms that replace classical serial time-stepping with typically iterative approaches more amenable to parallelization have been demonstrated to be promising. The mini symposium features four talks on recent methodological and application-related developments for three different methods: Parareal, revisionist deferred corrections (RIDC) and the parallel full approximation scheme in space and time (PFASST).

Contributed Talks

CT-1 Helmholtz equation
Chair: James A. Sethian

CT-2 Implementation strategies
Chair: Oliver Sander

CT-3 Flow and porous media
Chair: Marina Vidrascu

CT-4 Adaptivity in HPC simulations
Chair: William Sawyer

CT-5 Additive Schwarz methods
Chair: Jinchao Xu

CT-6 Optimized Schwarz methods
Chair: Jun Zou

CT-7 Parallelization in time
Chair: Daniel Ruprecht

CT-8 Maxwell's equation
Chair: Laurence Halpern

CT-9 Inverse problems
Chair: Wolfgang Hackbusch

CT-10 Preconditioners and solvers
Chair: Johannes Kraus

CT-11 Non-matching meshes
Chair: Thomas Dickopf

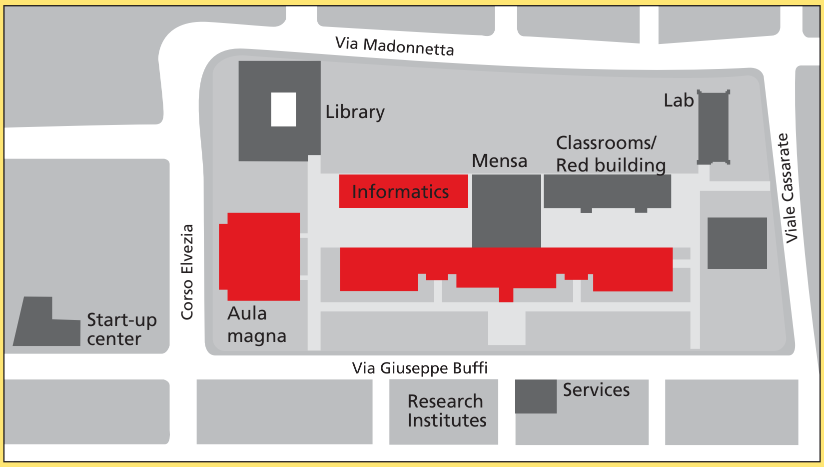
CT-12 Multiphysics problems
Chair: Volker Mehrmann

CT-13 Parallelization in time
Chair: Rolf Krause

CT-14 FETI and BDD methods
Chair: Oliver Rheinbach

Auditorium, Room 351 and Room 402 are located in the Main Building.

Room 15 is located in the Informatics Building.



Schedule Overview

Monday, September 16th 2013

	Auditorium	Room 351	Room 402	Room 15
09:00	**Welcome and Opening**			
09:30	Oliver Rheinbach			
10:15	**Coffee break**			
10:45	MS-1 Advances in FETI-DP and BDDC methods	CT-1 Helmholtz equation	MS-3 Non-overlapping discretization methods and how to achieve the DDM-paradigm	CT-2 Implementation strategies
12:25	**Lunch break**			
14:00	Paola F. Antonietti			
14:45	Wolfgang Hackbusch			
15:30	**Coffee break**			
16:00	MS-1 Advances in FETI-DP and BDDC methods	MS-4 Solution techniques for discontinuous Galerkin methods	MS-2 Achieving scalability in domain decomposition methods: advances in coarse spaces and alter-natives	CT-3 Flow and porous media

Tuesday, September 17th 2013

	Aula Magna	Room 351	Room 402	Room 15
08:30	Lourenço Beirão da Veiga			
09:15	Johannes Kraus			
10:00	**Coffee break**			
10:30	MS-5 Solvers for isogeometric analysis and applications	MS-4 Solution techniques for discontinuous Galerkin methods	CT-4 Adaptivity in HPC simulations	CT-5 Additive Schwarz methods
12:10	**Lunch break**			
13:30	MS-5 Solvers for isogeometric analysis and applications	MS-6 Efficient solvers for heterogeneous nonlinear problems	MS-7 Domain decomposition techniques in practical flow applications	CT-6 Optimized Schwarz methods
15:10	**Coffee break**			
15:40	Oliver Sander			
16:25	Introduction to Poster Session			
17:00	**Poster Session and Apero**			

Auditorium, Room 351 and Room 402 are located in the Main Building.
Room 15 is located in the Informatics Building.

Wednesday, September 18th 2013

	Aula Magna	Room 351	Room 402	Room 15
08:30	Volker Mehrmann			
09:15	James A. Sethian			
10:00	**Coffee break**			
10:30	MS-8 Domain decomposition methods in implementations	MS-6 Efficient solvers for heterogeneous nonlinear problems	MS-9 Parallel multigrid methods	CT-7 Parallelization in time
12:10	**Sandwich lunch break**			
13:00	MS-8 Domain decomposition methods in implementations	MS-6 Efficient solvers for heterogeneous nonlinear problems	CT-8 Maxwell's equation	CT-9 Inverse problems
14:30	**Social program**			

Thursday, September 19th 2013

	Aula Magna	Room 351	Room 402	Room 15
08:30	Marina Vidrascu			
09:15	Joachim Schöberl			
10:00	**Coffee break**			
10:30	MS-10 Efficient solvers for frequency domain wave problems	MS-11 Domain decomposition methods for environmental modeling	CT-10 Preconditioners and solvers	CT-11 Non-matching meshes
12:10	**Lunch break**			
14:00	Christine Bernardi			
14:45	Olof B. Widlund			
15:30	**Coffee break**			
16:00	MS-10 Efficient solvers for frequency domain wave problems	MS-12 Efficient solvers	CT-12 Multiphysics problems	CT-13 Parallelization in time
18:00	**Business Meeting of the International Scientific Committee (Room 4 in the Informatics building)**			
20:00	**Dinner of the International Scientific Committee with the Invited Speakers (Bus from USI)**			

Friday, September 20th 2013

	Aula Magna	Room 351	Room 402
08:30	MS-13 Space-time parallel methods	MS-12 Efficient solvers	CT-14 FETI and BDD methods
10:10	**Coffee break**		
10:40	Marco Discacciati		
11:25	Jinchao Xu		
12:10	Closing		
12:40	**Lunch break**		

Monday, September 16th 2013

Monday Morning

	Auditorium	Room 351	Room 402	Room 15
09:00	**Welcome and Opening**			
09:30	Oliver Rheinbach			
10:15	**Coffee break**			
10:45	MS-1 Advances in FETI-DP and BDDC methods	CT-1 Helmholtz equation	MS-3 Non-overlapping discretization methods and how to achieve the DDM-paradigm	CT-1 Implementation strategies
12:25	**Lunch break**			

09:00-09:30 Welcome and Opening

09:30-10:15 Auditorium

Nonlinear FETI-DP methods

Oliver Rheinbach, Axel Klawonn, Martin Lanser

As a consequence of exploding concurrency it is a challenge to extend the parallel scalability of current domain decomposition (DD) solvers to the scale of future massively parallel computers. DD methods are often used to precondition systems obtained from the linearization of a nonlinear problem. We present new nonlinear, nonoverlapping DD schemes that may help to overcome limitations of current schemes. Nonlinear approaches to domain decomposition are characterized by a geometrical decomposition of the problem before linearization. A well known nonlinear, overlapping DD method is the ASPIN approach by Cai and Keyes. Here, nonlinear FETI-DP and BDDC methods are presented. In these methods, in each iteration, local nonlinear problems are solved on the nonoverlapping subdomains. These new approaches have a potential to reduce communication, especially, but not only, for problems with strong localized nonlinearities.

Chair: Hyea Hyun Kim

10:45-12:25 MS-1 Advances in FETI-DP and BDDC methods Auditorium

On adaptive coarse spaces in FETI-DP methods

Axel Klawonn, Patrick Radtke, Oliver Rheinbach

Adaptive coarse spaces for domain decomposition methods can be used to obtain independence on coefficient jumps for highly heterogeneous problems, even when coefficient jumps inside subdomains are present. In this talk, for FETI-DP methods, we present a new approach to obtain independence of the coefficient jumps by solving certain local eigenvalue problems and enriching the FETI-DP coarse space with eigenvectors.

An adaptive Newton-Krylov FETI-DP method applied to elastoplasticity

Axel Klawonn, Patrick Radtke, Oliver Rheinbach

In this talk, a FETI-DP domain decomposition method in combination with a Newton-Krylov approach is considered for the solution of certain problems in elastoplasticity in two dimensions. A coarse space using vertices and standard edge averages yields bad results. The convergence is improved when the coarse space is enhanced with additional coarse space functions based on the solution of local eigenvalue problems; the latter are chosen as proposed by J. Mandel and B. Sousedík. Numerical results are presented which show the efficiency of this approach.

A BDDC method with deluxe scaling for problems posed in H(div)

Duk-Soon Oh, Olof B. Widlund, Clark Dohrmann

A BDDC method for vector field problems discretized with Raviart-Thomas finite elements is introduced. Our method is based on a new type of weighted average developed to deal with more than one variable coefficient. A bound on the condition number of the preconditioned linear system is provided which is independent of the values and jumps of the coefficients across the interface and depends polylogarithmically on the number of degrees of freedom of the individual subdomains. Numerical experiments, which support the theory and show the effectiveness of our algorithm, are also presented.

A de luxe FETI-DP preconditioner for a staggered discontinuous Galerkin formulation of H(curl) in two dimensions

Hyea Hyun Kim, Eric Chung

A FETI-DP preconditioner with a new weight factor is developed and analyzed for a staggered discontinuous Galerkin formulation of H(curl) in two dimensions. H(curl) problems with two coefficients, curl and mass parts, are considered. The algebraic system is decoupled at the triangle boundaries and then continuity for the decoupled unknowns is enforced by introducing Lagrange multipliers on the edges of each triangle. A FETI-DP type preconditioner with a new weight factor is designed for the resulting algebraic system on the Lagrange multipliers. A scalable condition number bound, which is robust in the coefficients, is obtained. Numerical results are included.

10:45-12:25 CT-1 Helmholtz equation Room 351

Coupling finite and boundary element methods using a localized adaptive radiation condition for Helmholtz's equation

Yassine Boubendir, Abderrahmane Bendali, Nicolas Zerbib

This talk deals with scattering and radiation problems, where the obstacle is composed of a small inhomogeneous dielectric object posed on a large perfectly conducting structure. A numerical method based on combining finite and boundary element methods is proposed. This coupling consists of localizing the adaptive radiation condition only around the dielectric region in contrast with standard radiation condition techniques where the metal and the dielectric are completely enclosed. The resulting formulation is well-posed and allows to solving the dense integral matrix and the sparse finite element one separately.

Local multiple traces formulation for high frequency scattering

Carlos Jerez-Hanckes

We extend the local multiple traces formulation (MTF) to high-frequency problems. The local MTF was introduced by Hiptmair and Jerez-Hanckes (Adv. Comp. Math., 37, 2012) as a boundary integral formulation tackling harmonic wave propagation through scatterers composed of multiple subdomains. The main features of the method are (i) doubling the number of trace unknowns in order to arrive at (ii) a first-kind Fredholm unisolvent formulation amenable to diagonal and Calderón preconditioning. The analysis and numerical results then provided considered only low order h-refinement in two dimensions. In the present work, we show the extension of the method to spectral discretization or p-refinement and observe results at high frequencies.

An optimized Schwarz method for exterior Helmholtz problems

Daisuke Koyama

In DD19, we proposed a parallel Schwarz method for multiple scattering problems. However, its convergence is very slow in numerical experiments. To accelerate the convergence speed of the method, we consider the optimized Schwarz method (OSM) proposed by Gander-Magoulès-Nataf [SIAM J. Sci. Comput. 24 (2002) 38-60]. As a first step, we investigate an OSM for Helmholtz problems in a domain exterior to a disk. We present a procedure to get an optimal parameter in the OSM and some properties of the Bessel functions which we need to establish the procedure.

A coarse space for heterogeneous Helmholtz problems based on the Dirichlet-to-Neumann operator

Lea Conen, Rolf Krause

The discretization of the Helmholtz equation with finite elements results in typically large, difficult to solve linear systems. Domain decomposition methods are suitable for systems of this size, but need a coarse component for good convergence. Here, the Helmholtz equation poses a particular challenge as even slight deviations from the optimal choice can be devastating. We present a coarse space based on local eigenproblems involving the Dirichlet-to-Neumann operator. Our construction is completely automatic and naturally respects local variations in the wave number. The efficiency of the resulting method is demonstrated on 2D homogeneous and heterogeneous numerical examples.

Chair: James A. Sethian

10:45-12:25 MS-3 Non-overlapping discretization methods and how to achieve the DDM-paradigm Room 402

Non-overlapping discretization methods

Ismael Herrera

The DDM-paradigm is to obtain the global solution by solving local problems exclusively. The introduction of non-overlapping DDMs represented an important step forward towards achieving this paradigm. However, in non-overlapping DDMs the interface-nodes are shared by two or more subdomains of the coarse-mesh. In this MS-talk we present the non-overlapping discretization-methods, which use systems of nodes with the property that each node belongs to one and only one subdomain of the coarse mesh. Then, in another talk of this MS it is explained how using non-overlapping discretization-methods the DDM-paradigm is achieved. Afterwards we present applications to non-symmetric and indefinite problems.

Achieving the DDM-paradigm

Luis de La Cruz

The first application of a non-overlapping discretization was to develop the derived-vector-space framework. Such a space possesses a very advantageous algebraic structure that yields a general platform with a natural separation of the concepts and operations, which has permitted us to construct the effective generalized Schur complement formulas presented in another talk in this MS. These formulas are here used to construct codes that achieve the DDM-paradigm and a high level of parallelization, very suitable for efficiently applying the powerful parallel computers to solve PDEs. Details of the generic programming approach used to very effectively address the computational issues are also presented.

Algorithms that achieve the DDM-paradigm for symmetric systems of quations

Iván Germán Contreras Trejo

It should be pointed out that the results of this MS establish procedures for constructing codes (achieving the DDM-paradigm and a high level of parallelization), which are very suitable for efficiently applying the powerful parallel computers available atpresent to any BVP that can be discretized by standard methods (using overlapping nodes). The differential equation may be a symmetric, non-symmetric or indefinite system. In this talk, such codes are constructed for the symmetric positive-definite system of equations of static-elasticity. Conspicuous features of this case are: CGM is applicable and at each node a 3D vector is sought (i.e.,significantly more degrees-of-freedom).

Algorithms that achieve the DDM-paradigm for non-symmetric and indefinite problems

Alberto Rosas-Medina, Antonio Carrillo-Ledesma

Because of its difficulty, much work has been devoted to discretization-procedures of advection-diffusion problems and important progress has been achieved, but the work and progress on their parallel-processing has been considerably less significant. However, the results reported in this MS supply effective methods for parallel-processing present and future advances of discretization procedures. In this talk we illustrate, through specific examples, how to apply non-overlapping discretizations and the DVS-algorithms to advection-diffusion and indefinite (Helmholtz equation) problems. Here, we highlight that the convergence rates observed for the problems treated thus far are similar to those observed for symmetric-positive-definite ones.

10:45-12:25 CT-2 Implementation strategies Room 15

Open-source finite element solver for domain decomposition problems

Christophe Geuzaine, Xavier Antoine, David Colignon, Mohamed El Bouajaji, Bertrand Thierry

The open-source finite element solver GetDP has been recently enriched with a new feature designed to solve domain decomposition problems in parallel. Written with PETSc and MPI, this add-on automatically manages the iterative solver, arising from the DDM, and the communication between subdomains. Coupled with the possibility of solving each subproblem with only one MPI process,this leads to an efficient and relatively easy-to-use parallel domain decomposition solver. As it will be presented, this solver has been tested on 3D large scale problems for time-harmonic wave propagation in acoustics (scalar) and in electromagnetism (vector). Finally, this DDM solver is versatile, e.g. it can consider scalar or vector problems, one-, two- or three-dimensional problems, non-conforming meshes at interfaces and also mixed formulations.

Asynchronous update of the RAS preconditioner for nonlinear CFD problems

Laurent Berenger, Damien Tromeur-Dervout

We propose a numerical strategy to speed up the implicit solution of unsteady nonlinear problems. This strategy consists in a partial update of the restricted additive Schwarz preconditioner used within the Newton-Krylov method that solves the nonlinear problem of each time step. Since there are usually only slight changes between two consecutive Jacobian matrices, it may be relevant to use the same preconditioner for a few Newton iterations or even for a few time steps. Furthermore, it is also possible to update only the parts of the preconditioner associated to certain subdomains. Numerical results for CFD problems are provided.

A balanced accumulation scheme for parallel PDE solvers

Manfred Liebmann

We present a load balancing technique for a boundary data accumulation algorithm for non-overlapping domain decompositions.The technique is used to speed up a parallel conjugate gradient algorithm with an algebraic multigrid preconditioner to solve a potential problem on an unstructured tetrahedral finite element mesh. The optimized accumulation algorithm significantly improvesthe performance of the parallel solver and we show a nearly 50 percent runtime improvement over the standard approach in a benchmark run with 48 MPI processes. The load balancing problem itself is a global optimization problem that is solved approximately by local optimization algorithms in parallel that require no communication during the optimization process.

On some geometric and algebraic aspects of domain decomposition methods

Dmitry Butyugin, Valery Ilin, Danil Perevozkin, Yana Gurieva

Geometric and algebraic aspects of different DDMs are considered in application to parallel solving of very large sparse SLAEs, which arise in approximation of multi-dimension mixed boundary value problems on non-structured grids. DDMs are used with parametrized overlapping of subdomains and different types of boundary conditions at internal boundaries. The algorithm of automatic construction of balancing DD for overlapping matrices is presented. Subdomain SLAEs are solved by direct or iterative preconditioned methods in Krylov subspaces, while external iterations are performed by FGMRES. Experimental analysis of algorithms has been conducted on a set of model and practice problems. The algorithms are implemented using hybrid programming on distributed and shared memory.

Chair: Oliver Sander

Monday Afternoon

	Auditorium	Room 351	Room 402	Room 15
14:00	Paola F. Antonietti			
14:45	Wolfgang Hackbusch			
15:30	**Coffee break**			
16:00	MS-1 Advances in FETI-DP and BDDC methods	MS-4 Solution techniques for discontinuous Galerkin methods	MS-2 Achieving scalability in domain decomposition methods: advances in coarse spaces and alternatives	CT-3 Flow and porous media

14:00-14:45 **Auditorium**

Domain decomposition methods for high-order discontinuous Galerkin discretizations

Paola F. Antonietti

We present and analyse a class of non-overlapping domain decomposition methods for discontinuous Galerkin discretizations. Since subdomains can be handled independently, such methods are very well suited for coarse-grain parallel computers. We will show that the proposed schemes are well suited for both low- order as well as high-order discontinuous Galerkin methods. Numerical experiments to illustrate the performance of the proposed schemes are presented. Finally, a geophysical application in the field of computational seismology is also discussed.

Chair: Susanne Brenner

14:45-15:30 **Auditorium**

Numerical treatment of tensors and new discretisation paradigms

Wolfgang Hackbusch

Tensors may be grid functions on tensor grids, but also the corresponding matrices. It is shown how tensors can be represented and how operations are performed. Under suitable conditions, also sizes like n^d with n=d=1000 can be handled. The possibility to treat large-scale tensors allow us to use regular fine grids. In particular, the overhead of usual adaptive methods can be overcome. Implicitly, the tensor compression yields at least the same efficiency in a black-box manner.

Chair: Susanne Brenner

16:00-17:40 **MS-1 Advances in FETI-DP and BDDC methods** **Auditorium**

BDDC and FETI-DP preconditioners for isogeometric discretizations of saddle point problems

Luca Pavarino, Lourenço Beirão da Veiga, Simone Scacchi, Olof B. Widlund, Stefano Zampini

We will study BDDC and FETI-DP preconditioners for isogeometric discretizations of saddle point problems such as the almost incompressible elasticity system in mixed form and the Stokes system. We will focus on BDDC preconditioners defined by primal continuity constraints associated to subdomain vertices and/or averages or moments over edges or faces of the subdomains, that have a higher multiplicity proportional to the splines regularity. Numerical experiments show that the proposed isogeometric BDDC preconditioners are scalable, quasi-optimal and robust with respect to discontinuities of the material parameters across subdomain boundaries.

A FETI-DP type algorithm for the incompressible Stokes equation in three dimensions

Jing Li, Xuemin Tu

A FETI-DP type algorithm is studied for solving the system of equations arising from the mixed finite element approximation of the three dimensional incompressible Stokes equation. Both continuous and discontinuous pressure spaces can be used, while previous similar type algorithms are valid only for the discretization with discontinuous pressure. This is an extension for our work on a two dimensional problem. Lumped and Dirichlet type preconditioners are analyzed. Numerical experiments also demonstrate the performance of the algorithm.

A FETI-DP preconditioner for DG-FE discretizations of elliptic problems with discontinuous coefficients

Maksymilian Dryja

In the talk a BVP for second order elliptic equations on a 2-D polygonal region is considered. The problem is discretized by a discontinuous Galerkin method on triangular elements with piecewise linear functions. For solving the resulting system a FETI-DP method is designed and analyzed. It is established that the condition number of preconditioned system is bound by $C(1+\log(H/h))^2$ with C independent of H, h and the jumps of the coefficients where H and h are the parameters of coarse and fine triangulations, respectively. The method is very well suited for parallel computations and can be extended to three-dimensional problems. The results are joint work with Marcus Sarkis (WPI, USA).

Boundary element based vertex solver for polygonal subdomains

Dalibor Lukas, Lukas Maly, Jiri Bouchala, Petr Vodstrcil

A boundary-element counterpart of the domain decomposition vertex solver is proposed and tested for a two-dimensional Poisson's equation. While the standard theory has been developed only for triangular or quadrilateral subdomains, where harmonic base functions are available, the practical mesh-partitioners generate complex polygonal subdomains. We aim at bridging this gap. Inspired by Hofreither, Langer, and Pechstein (2010) we construct the coarse solver on general polygonal subdomains so that the local coarse stiffness matrix is approximated by a boundary-element discretization of the Steklov-Poincare operator. The efficiency of our approach is documented by a substructuring into L-shape domains, which is robust with respect to material coefficient jumps.

16:00-17:40 MS-4 Solution techniques for discontinuous Galerkin methods Room 351

A multigrid method for the Darcy system

Li-yeng Sung

We discuss a multigrid algorithm for the saddle point problem resulting from the Raviart-Thomas mixed finite element method for the Darcy system in porous media flows. The smoothing step in this multigrid algorithm involves a fast solver for symmetric interior penalty methods.

Some domain decomposition methods for staggered discontinuous Galerkin methods

Eric Chung, Hyea Hyun Kim, Olof B. Widlund

In this talk, we present some domain decomposition methods for solving linear systems arising from the staggered discontinuous discretization of second order elliptic problems, and related numerical results. The staggered grid DG methods have proved to be useful in preserving the structures of the partial differential equations. For problems arising from large scale applications, one needs a good preconditioner for the linear system. Recently, we have developed and analyzed a BDDC algorithm. On a quite irregular subdomain partition, an optimal condition number bound is proved for two dimensional problems. A less optimal but scalable condition number bound is obtained for three dimensional problems. Moreover, these bounds are shown to be independent of coefficient jumps in the subdomain partition.

A FETI-DP method for a discontinuous Galerkin method

Susanne C. Brenner, Eun-Hee Park, Li-Yeng Sung

In this talk we discuss a non-overlapping domain decomposition method for a DG method for elliptic problems. The formulation is based on the FETI-DP methodology. The key step in our formulation is the localization of the bilinear form of the discrete problem via a change of basis on the interface. Theoretical results on the condition number estimate of the resulting system will be presented along with numerical results.

Schwarz preconditioned DG for all-at-once PDE-constrained optimization problems

Andrew Barker, Martin Stoll

We explore Schwarz in time strategies for preconditioning all-at-once numerical schemes for the solution of time-dependent PDE constrained optimization problems discretized by DG methods. All-at-once schemes aim to solve for all time-steps at once, which has the advantages of preserving physical couplings in the solution, ensuring robustness, and accelerating convergence. However, this approach leads to extremely large linear systems. We outline a parallel preconditioning strategy that uses DG discretizations for the underlying PDE, local Schur complement approximations on each processor, and domain decomposition algorithms in the time domain.

16:00-17:40 MS-2 Achieving scalability in domain decomposition methods: advances in coarse spaces and alternatives **Room 402**

Nonsmooth Newton multigrid solvers for nonsmooth minimization problems

Carsten Gräser

While the extension of classical linear smoothers to nonsmooth convex minimization problems is often straight forward, this is not the case for the construction of coarse grid corrections. Simple multilevel relaxation schemes are in general suboptimal with respect to complexity and performance. We will construct coarse corrections using ideas from nonsmooth analysis leading to Truncated Nonsmooth Newton Multigrid (TNNMG) methods. While the performance is comparable to linear multigrid, they are more flexible and easier to implement than other schemes. Numerical examples from applications in material science, continuum mechanics, and glacier modeling show the flexibility, efficiency, and robustness of this approach.

Coarse grid correction for the Neumann-Neumann waveform relaxation method

Felix Kwok

The Neumann-Neumann waveform relaxation (NNWR) method has been proposed recently by Gander, Kwok and Mandal for the solution of parabolic problems, such as the heat equation. The method has been shown to converge superlinearly for finite time windows; however, as the number of subdomains increases, the number of iterations required for convergence also increases proportionally. We show that by adding a coarse grid correction step, the modified method converges in two iterations for 1D problems, independent of the number of subdomains. We also analyze its convergence behavior for the 2D case when different coarse spaces are used.

A TDNNS-FETI method for compressible and almost incompressible elasticity

Clemens Pechstein, Astrid Pechstein

We consider the hybridized Tangential-Displacement Normal-Normal Stress (TDNNS) discretization of linear elasticity, which is stable with respect to volume locking. We propose a one-level FETI method with a coarse space corresponding simply to the subdomain rigid body modes. Our rigorous analysis for the planar compressible case shows the common condition number bound of $C(1+\log(H/h))^2$. According to numerical experiments, however, the FETI method (with the same coarse space) is also robust when the Poisson ratio tends to 1/2. This is in agreement with symbolic predictions by V. Dolean and coworkers.

Achieving scalability in DDM without coarse spaces: piecewise Krylov methods

Kevin Santugini

The standard way to scalabilize DDMs is to introduce a coarse space. In this presentation, we introduce a new method to achieve scalability in domain decomposition methods: piecewise Krylov/extrapolation methods. In piecewise extrapolation, the extrapolation coefficients are no longer globally constant but only constant in each subdomain. Likewise, in piecewise Krylov methods, the standard Krylov space is replaced by a piecewise Krylov space where linear combinations are considered per subdomain. Krylov methods are mathematically equivalent to extrapolation methods but should be preferred in practice as they behave better numerically.

16:00-17:40 CT-3 Flow and porous media **Room 15**

Mesoscopic and macroscopic mixed variational analysis of two-phase flow in fractured porous media

Gonzalo Alduncin

Mixed variational models of two-phase flow, in fractured porous media, are analyzed at the mesoscopic and macroscopic levels. The mesoscopic models are treated via nonoverlapping domain decompositions, such that the porous rock matrix system and fracture network, interact across rock and fracture interfaces, with flux transmission conditions dualyzed. Alternatively, the models are scaled to a macroscopic level, the fracture network resulting an interface system of one less spatial dimension. The two-phase flow is characterized by a fractional flow mixed model, and augmented two- and three-field variational reformulations are introduced for regularization. Further, proximal-point penalty-duality algorithms are derived for parallel computing.

Coupling conditions for the fluid-solid interaction in fractured porous media

Katja Hanowski

We consider the mechanical and hydrological equilibrium of a saturated, elastic, porous medium with a single fracture. Fluid pressure in the cracks acts on the surrounding matrix by exerting a normal force on the crack boundaries. This surface force induces a change of the fracture width, which in turn influences the fluid flow inside the fracture. We will introduce a model for the coupled processes in which the fracture is represented as hypersurface embedded in the porous medium. Furthermore a numerical solution scheme for the resulting nonlinear system of partial differential equations is presented.

Decoupled schemes for free flow and porous medium systems

Iryna Rybak

Coupled free flow and porous medium flow systems arise in a wide spectrum of environmental settings and industrial applications. In these flow domains, the processes evolve on different scales in space and time that requires an application of different models to each flow system and an accurate treatment of transitions between them at the interface. We propose a multiple time step algorithm for coupled free flow and porous medium flow systems. Several decoupled schemes are considered and compared. Stability estimates and numerical results demonstrating the efficiency of the proposed technique are presented.

Numerical simulations of flows around a full scale wind turbine

Rongliang Chen, Zhengzheng Yan, Yubo Zhao, Xiao-Chuan Cai

In this talk, we discuss numerical simulations of flows passing 3D wind turbines by solving unsteady incompressible Navier-Stokes equations with a realistic Reynolds number on stationary and moving domains. An unstructured stabilized P1-P1 finite element method and a fully implicit scheme are used for the space and temporal discretization. A parallel Newton-Krylov method with a Schwarz type overlapping domain decomposition preconditioner is applied to solve the fully coupled nonlinear algebraic system at each time step. We focus on the performance of the domain decomposition preconditioner, and show numerically that the approach scales well for problems with tens of millions of unknowns on machines with thousands of processors.

Chair: Marina Vidrascu

Tuesday Morning

	Aula Magna	Room 351	Room 402	Room 15
08:30	Lourenço Beirão da Veiga			
09:15	Johannes Kraus			
10:00	**Coffee break**			
10:30	MS-5 Solvers for isogeometric analysis and applications	MS-4 Solution techniques for discontinuous Galerkin methods	CT-4 Adaptivity in HPC simulations	CT-5 Additive Schwarz methods
12:10	**Lunch break**			

08:30-09:15 **Aula Magna**

Domain decomposition methods in isogeometric analysis

Lourenço Beirão da Veiga, Luca Pavarino, Simone Scacchi, Cho Durkbin

Isogeometric analysis (Hughes et al., 2005) is a recent methodology for the discretization of PDE problems that has a direct connection with CAD and thus allows for an exact geometrical description in a very large range of applicative frameworks. Domain decomposition methods are mostly needed in isogemetric analysis, both for parallel implementation and in order to obtain better condition numbers. In the present talk we will investigate some overlapping and non-overlapping domain decomposition methods for IGA, addressing both theory and numerical tests. It turns out that, being based on NURBS rather than standard piecewise polynomial functions, the domain decomposition of IGA schemes poses various interesting new challenges, both at the theoretical and numerical level.

Chair: Petter Bjørstad

09:15-10:00 **Aula Magna**

Auxiliary space multigrid based on domain decomposition

Johannes Kraus

A non-variational multigrid algorithm for general symmetric positive definite problems is introduced. This method is based on exact two-by-two block factorization of local (stiffness) matrices that correspond to a sequence of coverings of the domain by overlapping or non-overlapping subdomains. The coarse-grid matrix is defined via additive Schur complement approximation. Its sparsity can be controlled by the size and overlap of the subdomains. The two-level method is analyzed in the framework of auxiliary space preconditioning. Several applications are addressed, e.g., scalar elliptic problems modeling highly heterogeneous media or locking-free discontinuous Galerkin discretizations of the equations of linear elasticity.

Chair: Petter Bjørstad

10:30-12:10 **MS-5 Solvers for isogeometric analysis and applications** **Aula Magna**

Applications of non-matching domain decomposition methods to isogeometric analysis.

Michel Bercovier

Isogeometric analysis (IGA) is a strong paradigm for the discretization of Partial Differential Equations, based on CAGD functions. It is natural to rely on solid modeling paradigms such as CSG and on local domain refinements. DD methods are natural candidates for the solution of large IGA problems cf. L. Beirão da Veiga, D. Cho, L.F. Pavarino, and S. Scacchi. We advocate the simplest Schwarz Additive DDM for IGA non matching meshes. Examples (computed by, GeoPDEs) illustrate the power of this approach: usage of CGS primitives, zooming, and parallelization. We show that there is no degradation IGA's of advantages when using non matching meshes.

An isogeometric overlapping additive Schwarz preconditioners for bidomain system

Lara Charawi

We develop and analyze an overlapping additive Schwarz preconditioner for the isogeometric discretization of the cardiac bidomain model, consisting of a degenerate system of parabolic-elliptic PDE describing the evolution of the cardiac electrical potentials, coupled with a system of ODEs modeling the ionic membrane currents. The overlapping Schwarz preconditioner is applied with a PCG accelerator to solve the very ill-conditioned linear system arising from the bidomain isogeometric discretization in space and a semi-implicit method in time. The resulting solver is scalable, optimal in the ratio of subdomain/element size, and its convergence rate improves with increasing overlap size.

On full multigrid schemes for isogeometric analysis

Clemens Hofreither

We consider geometric multigrid schemes for the solution of the discretized systems arising in isogeometric analysis. It is known from the literature that V-cycle iteration results in sharply rising iteration numbers as space dimension and spline degree are increased. In this talk, we point out that nested multigrid schemes can result in optimal solvers independently of these parameters over a wide range of tested configurations.

BPX-Preconditioning for isogeometric analysis

Annalisa Buffa, Helmut Harbrecht, Angela Kunoth, Giancarlo Sangalli

We consider elliptic PDEs in the framework of isogeometric analysis, i.e., we treat the physical domain by means of a B-spline or NURBS mapping which we assume to be regular. The numerical solution of the PDE is computed by means of tensor product B-splines mapped onto the physical domain. We construct additive multilevel preconditioners and show that they are asymptotically optimal, i.e., the spectral condition number of the resulting preconditioned stiffness matrix is independent of h. Together with a nested iteration scheme, this enables an iterative solution scheme of optimal linear complexity. The theoretical results are substantiated by numerical examples in two and three space dimensions.

10:30-12:10 MS-4 Solution techniques for discontinuous Galerkin methods Room 351

Preconditioning for high order hybrid discontinuous Galerkin methods

Joachim Schöberl

Discontinuous Galerkin methods provide a lot of freedom for the design of finite element methods, such as upwinding for convection dominated problems, or the choice of stable mixed finite elements. Hybridization of DG methods allows an efficient implementation in terms of matrix entries, and static condensation. We focus on preconditioners for the hybrid-DG method for elliptic problems. We prove a poly-logarithmic condition number in h and p for 2D and 3D. Techniques are p-version extension operators from vertices, edges, and faces with respect to the norm induced by the stabilization term. We show that the Bassi-Rebay method differs essentially from the interior penalty method, in 3D. Numerical results for the model problem as well as more complex problems confirm the theoretical results.

Robust preconditioners for DG-discretizations with hp-refinement

Kolja Brix, Martin Campos Pinto, Claudio Canuto, Wolfgang Dahmen

The enormous flexibility offered by DG methods regarding hp-refinement renders such concepts powerful discretization tools for a variety of problem classes. We propose a new multilevel preconditioner for SIPG discretizations of elliptic boundary value problems. Under mild grading conditions we show that the resulting condition number is uniformly bounded in h and especially also in p. The preconditioner is based on the auxiliary space method in combination with techniques from spectral element methods such as Legendre-Gauss-Lobatto grids. The non-nestedness of Legendre-Gauss-Lobatto grids, which is the main obstruction for hp-refinement, is circumvented by introducing companion dyadic grids. Numerical experiments demonstrate the efficiency of the preconditioner.

Additive Schwarz method for discontinuous Galerkin for elliptic problems on nonconforming meshes

Piotr Krzyzanowski

An additive Schwarz method for DG discretization of a second order elliptic PDE with discontinuous coefficients will be discussed in the case when the underlying triangulation is nonconforming. The Schwarz method presented is essentially without overlap and the subdomains consist of triangulation elements. It will be shown that under mild assumptions the method gives rise to a preconditioned system whose condition number is independent of the jumps of the coefficients. This is a joint work with Max Dryja.

Multilevel hierarchies and multilevel methods on graphs

Ludmil Zikatanov

Motivated by the increasing importance of large-scale networks, typically modeled by graphs, we study properties associated with the popular graph Laplacian. We exploit its mixed formulation based on its natural factorization as product of two operators. The goal is to construct a coarse version of the mixed graph Laplacian operator with the purpose to construct two-level, and by recursion, a multilevel hierarchy of graphs and associated operators.

10:30-12:10 CT-4 Adaptivity in HPC simulations Room 402

Nearwell local space and time refinement for two phase porous media flows

Walid Kheriji, Roland Masson, Victorita Dolean, Arthur Moncorgé

In reservoir simulations, nearwell regions usually require finer space and time scales compared with the remainder of the reservoir domain. We present a domain decomposition algorithm for a two phase Darcy flow model coupling nearwell regions which are locally refined in space and time with a coarser reservoir discretization. The algorithm is based on an optimized Schwarz method using a full overlap at the coarse level. The main advantage of this approach is the applicability to fully implicit discretizations of general multiphase flow models and that it allows for a simple optimization of the interface conditions based on a single phase flow equation.

Lightweight adaptivity through non-conforming discretization

Thomas Dickopf, Dorian Krause, Rolf Krause, Mark Potse

The reaction-diffusion equations in computational electrocardiology feature solutions that vary strongly in space and time. Appropriate adaptive strategies for the required large-scale parallel computations should come with the smallest possible overhead and a low memory footprint. We present a novel class of lightweight adaptive methods for non-linear parabolic equations. The algorithms are based on locally structured mesh hierarchies glued by a non-conforming mortar discretization. We distinguish (a) the geometrically conforming approach (patch-wise adaptivity) and (b) the geometrically non-conforming case using forests of shallow trees. The effectivity of the methods is demonstrated by numerical studies.

Parallel remeshing unstructured meshes

Cédric Lachat, François Pellegrini, Cécile Dobrzynski

We presents the parallel remeshing capabilities of PaMPA, a middleware library dedicated to the management of unstructured meshes distributed across the processors of a parallel machine. PaMPA performs parallel remeshing by selecting independent subsets of elements that need remeshing, and running a user-provided sequential remesher (e.g. MMG3D) on these subsets. This process is repeated on yet un-remeshed areas until all of the mesh is remeshed. The new mesh is then repartitioned to restore load balance. We present experimental results where we generate high quality, anisotropic tetrahedral meshes comprising several hundred million elements from initial meshes of several million elements.

A probabilistic domain decomposition method for equidistributing meshes

Ronald Haynes, Alexander Bihlo

The solution of many classes of differential equations benefits from the use of non-uniform grids. We are interested in problems which profit from grids that are chosen automatically and globally equidistribute according to some measure of the error. Recently, such grids have been computed in parallel by one of the authors using classical and optimized Schwarz Methods. Here we present an approach for mesh generation using probabilistic domain decomposition. The technique solves for an equidistributing mesh using an elliptic PDE mesh generator. Approximations to the mesh along the subdomain interfaces are computed using Monte Carlo simulations and then provided as boundary conditions for parallel subdomain solves.

Chair: William Sawyer

10:30-11:45 CT-5 Additive Schwarz methods — Room 15

An additive Schwarz method preconditioner for finite volume discretization of elliptic problems in 2D

Leszek Marcinkowski, Talal Rahman

In this talk we discuss an additive Schwarz method (ASM) for a finite volume (FV) discretization of a model second order problem with discontinuous coefficients. In our FV discretization a solution is sought in a standard linear finite element space. The algebraic system of linear equations arising from the FV discretization is nonsymmetric, thus the preconditioned system is solved by GMRES iterative method. The proposed preconditioner is almost optimal, i.e. the convergence rate of GMRES method with our preconditioner depends weakly on the mesh coefficients.

Analysis of two coarse spaces for an additive Schwarz method

Petter Bjørstad, Maksymilian Dryja

In previous work, robust coarse spaces for additive Schwarz methods have been analyzed with respect to their sensitivity to jumps in (material) coefficients. In this presentation, we compare two coarse spaces called the primal and dual respectively, the results can be used as guidance for the design of a method that is competitive with some earlier proposals.

Preconditioning of the restricted Schwarz interface iterations

Francois Pacull, Damien Tromeur-Dervout

We present here a study on the interface iterations associated with the restricted Schwarz method. General sparse unsymmetrical and indefinite matrices with symmetric patterns are considered, within a purely linear algebraic framework. If some given conditions are satisfied, the iterations on the primary unknowns are equivalent to those on the interface unknowns. The restricted Schwarz interface operator can then be explicitly constructed. If the Krylov methods, such as the GMRES algorithm, are often used, it is possible to improve their convergence rates with some direct and indirect preconditioning techniques.

Chair: Jinchao Xu

Tuesday Afternoon

	Aula Magna	Room 351	Room 402	Room 15
13:30	MS-5 Solvers for isogeometric analysis and applications	MS-6 Efficient solvers for heterogeneous nonlinear problems	MS-7 Domain decomposition techniques in practical flow applications	CT-6 Optimized Schwarz Methods
15:10	**Coffee break**			
15:40	Oliver Sander			
16:25	Introduction to Poster Session			
17:00	**Poster Session and Apero**			

13:30-15:10 MS-5 Solvers for isogeometric analysis and applications — Aula Magna

Preconditioning techniques for mass matrices arising from isogeometric analysis

Longfei Gao, Victor Calo

High continuous basis functions are popular within the IGA community for their superior accuracy. However, the broad interaction between these basis functions can also promote the computational cost significantly, if not treated properly. We present three preconditioning techniques focusing on mass matrices arising from IGA. The simplest one uses mass matrices built with the same basis functions but without any geometric information. In terms of number of iteration steps, its numerical performance is independent of basis functions. The other two preconditioning techniques include partial geometric information and obtain even superior performances.

Discontinuous Galerkin isogeometric analysis for elliptic PDEs on surfaces

Ulrich Langer, Stephen E. Moore

Isogeometric analysis uses the same class of basis functions for both, representing the geometry of the computational domain and approximating the solution. In practical applications, geometrical patches are used in order to get flexibility in the geometrical representation. This patch representation corresponds to a domain decomposition. We will present a discontinuous Galerkin (DG) method that allows for discontinuities only along the subdomain (patch) boundaries. The required smoothness is obtained by the DG terms associated with the boundary of the subdomains. The construction and corresponding discretization error analysis of such DG scheme will be presented for Elliptic PDEs in a 2D as well as on open and closed surfaces.

Local refinements for non-standard discretizations in IGA

Francesca Pelosi, Carla Manni, Hendrik Speleers

Adaptive local refinement is one of the key issues in IGA. The original approach of Hughes et al. (2005) employs basis functions generated by tensor product NURBS, both to describe the geometry and to approximate the unknown solutions of differential problems. This allows representing exactly the geometries of interest in engineering problems, but suffers from the drawback of a rectangular topology, which makes a purely local refinement impossible. In order to properly address the problem of local refinements in IGA, several alternative representations have been introduced, such as T-splines, Hierarchical splines, and Powell-Sabin B-splines. In the present talk, we aim to present our recent studies on local refinements obtained with hierarchical representations in the context of IGA.

Isogeometric BDDC preconditioners with deluxe scaling

Stefano Zampini, Lourenço Beirão da Veiga, Luca Pavarino, Simone Scacchi, Olof B. Widlund

A Balancing Domain Decomposition by Constraints (BDDC) preconditioner with deluxe scaling introduced by Dohrmann is extended to isogeometric analysis of scalar elliptic problems. This new scaling turns out to be more powerful than the standard rho- and stiffness scalings considered in previous isogeometric BDDC studies. Our h-analysis shows that the condition number of the resulting deluxe BDDC preconditioner is scalable with a quasi-optimal polylogarithmic bound which is also independent of coefficient discontinuities across subdomain interfaces. Extensive numerical experiments supporting the theory will be given, showing in addition a remarkable improvement over the older scalings for large isogeometric polynomial degree and high regularity.

13:30-15:10 MS-6 Efficient solvers for heterogeneous nonlinear problems Room 351

Error control for heterogeneous multiscale approximations of nonlinear monotone problems

Patrick Henning, Mario Ohlberger

We introduce a heterogeneous multiscale finite element method (HMM) for monotone elliptic operators with rapid oscillations. We first present a macroscopic limit problem for the oscillating nonlinear equations in a general heterogeneous setting and then show the convergence of HMM approximations to the solution of the macroscopic limit equation. On this basis, we derive an optimal a-posteriori error estimate for the L^2-error between the HMM approximation and the solution of the macroscopic limit equation. Applicability of the method and the usage of the a posteriori error estimate for adaptive local mesh refinement is demonstrated in numerical experiments.

Generalized multiscale methods for nonlinear problems

Juan Galvis, Yalchin Efendiev

We review a general approach called Generalized Multiscale Finite Element Method (GMsFEM) for the simulation of complex multiscale problems. The main idea is to construct a small dimensional local solution space that can be used to generate meaningful approximations. We construct an offline space that is used for a systematic enrichment of the coarse solution space in the online stage. The enrichment is performed using spectral decompositions and by choosing important modes information. This local approach that we present here allows us to eliminate unnecessary degrees of freedom on a coarse-grid level. We present various examples.

A multiscale method based on non-overlapping domain decomposition procedure

Victor Ginting, Bradley McCaskill

In this presentation, we develop a non-overlapping iterative domain decomposition technique for solving elliptic boundary value problems. A checkerboard procedure is used to solve the global problem where every iteration only involves exchanging information at the subdomain's interfaces. In the interest of making the whole calculation more efficient, we propose to create a set of multiscale basis functions associated with each subdomain by which the approximate solution are represented. A set of numerical examples are presented to illustrate the performance of the method.

Generalized multiscale finite element methods for wave propagation in heterogeneous media

Eric Chung, Yalchin Efendiev, Wing Tat Leung

Numerical modeling of wave propagation in heterogeneous media is important in many applications. Due to the complex nature of the media, direct numerical simulations on fine grid are prohibitive. It is therefore important to develop efficient and accurate methods that allow the use of coarse grids. We present a multiscale finite element method for the simulations of wave propagation on a coarse grid. The proposed method is based on a Generalized Multiscale Finite Element Method (GMsFEM). To construct multiscale basis functions, we start with a snapshot space in each coarse-grid block. We then use a local spectral problem to identify important modes in the snapshot space. Stability and spectral convergence of our method are rigorously analyzed. Numerical examples are presented to show the performance of our method.

13:30-15:10 MS-7 Domain decomposition techniques in practical flow applications Room 402

Design of an optimized Schwarz domain decomposition method for Navier-Stokes equations

Eric Blayo, David Cherel, Antoine Rousseau

In this work we present optimized interface conditions for the Schwarz domain decomposition algorithm for the Navier-Stokes equations. We start with a presentation of the perfectly absorbing conditions in the linear case. These conditions, which are not tractable in practice, are studied in order to derive some relevant approximations. A family of such approximate conditions are proposed, and their coefficients are optimized in order to minimize the convergence rate of the Schwarz algorithm. These conditions are implemented and validated in a numerical model on the well known test case of the driven cavity.

Response of the Atlantic Ocean circulation to Greenland ice sheet melting

Henk Dijkstra

The sensitivity of the Atlantic Meridional Overturning Circulation (AMOC) to high-latitude freshwater input is believed to be one of the Achilles' heels in climate change. Considering the importance of the AMOC for the climate system, and the vulnerability of the Greenland ice sheet to global warming, assessing this sensitivity is critical for climate change projections. Here we present results from a unique set of computational experiments to investigate the adjustment of the AMOC to enhanced melt water from the Greenland ice sheet. Focus will be on the high-performance computing aspects (numerical algorithms, distributed computing, load balancing, use of GPUs) of the project.

On the optimization of the multi-domain pressure solver in 2D free-surface flow models

Mart Borsboom

The numerical simulation of free-surface flows in environmental problems usually involves solving a symmetric diagonally dominant system of equations per time step for the determination of the (hydrostatic) pressure. Because of the diagonal dominance, solution modes are local. This can be exploited in a domain decomposition solver using a local optimization of the coupling conditions. Convergence can also be improved by a small overlap between the subdomains, at the expense of a small increase in computational time. We will present the optimization of such a DD solver in terms of both coupling conditions and overlap. Optimization of the coupling at subdomain corners will be considered as well.

Parallelization of a shallow-water solver on unstructured meshes (D-Flow FM)

Sander van der Pijl

This presentation elaborates on the parallelization of the D-Flow FM flow solver. D-FLow FM solves the one-, two- and three-dimensional shallow water equations on unstructured meshes. It is used for applications such as flow in rivers and channels (one-dimensional), shallow seas, rivers and overland flow (two-dimensions) and lakes and estuaries (three-dimensional). We will briefly discuss the discretization of the model equations and present the parallelization of the method. We will demonstrate the parallelized method by considering real-life applications and show scaling results.

13:30-15:10 CT-6 Optimized Schwarz methods Room 15

Optimized Schwarz methods for problems with cylindrical interfaces

Christian Vergara, Giacomo Gigante, Matteo Pozzoli

We consider the optimized Schwarz method for 3D problems with cylindrical interfaces between subdomains. We firstly consider the diffusion-reaction problem providing a convergence analysis both for Dirichlet and general interface transmission conditions. This allows to recover, for the latter case, optimal symbols for the interface conditions, which are supposed to work well for geometries with cylindrical interfaces. Starting from these optimal symbols, we propose effective and easily computable constant interface parameters obtained both from a Taylor expansion and an optimization procedure. We present several 3D numerical results aiming at validating the theoretical findings. Finally, we present results of the application of our strategy to the more complex fluid-structure interaction problem.

Optimized Schwarz algorithm with two-sided transmission conditions in an unsymmetric domain decomposition

Yingxiang Xu, Martin J. Gander

Domain decomposition methods are very flexible tools for modelling physical problems with different properties in subregions, and the computational domains are seldom decomposed in a symmetric fashion. In this paper we focus on the optimized Schwarz method with two-sided Robin transmission conditions adapted to unsymmetric domain decompositions. We derive special two-sided transmission conditions for this case, which lead to better performance than the ones reported for symmetric decompositions in [Gander, SINUM, 2006]. To obtain the best performance of the method, we show that the order in which the two-sided transmission conditions should be applied depends on the geometry of the decomposition. We present numerical examples which support our theoretical findings.

Higher order optimized Schwarz algorithms in the framework of DDFV schemes

Florence Hubert, Martin J. Gander, Laurence Halpern, Stella Krell

Over the last five years, classical and optimized Schwarz methods have been developed and analyzed for anisotropic elliptic problems discretized with discrete duality finite volume schemes (DDFV). We will present a new class of DDFV optimized Schwarz methods based on second order transmission conditions. We will prove convergence of the algorithm for a large class of symmetric transmission operators, including the discrete Ventcell operator. We will then show numerical experiments for an anisotropic elliptic operator to illustrate how much faster the convergence is when using Ventcell transmission conditions, compared to Robin transmission conditions or the classical Schwarz method.

Acceleration of algebraic optimized Schwarz methods with GPU computing

Lahcen Laayouni, Omar Soufiane, Daniel Szyld

We investigate the performance of Algebraic Optimized Schwarz Methods (AOSMs) accelerated by GPU computing. To accelerate the preconditioned solvers corresponding to AOSMs, we use the NVIDIA CUDA platform and the CUSP library. We compute the preconditioners associated to AOSMs on CPU memory then we incorporate them on the GPU device to solve the corresponding preconditioned problem. We test the algorithm with different types of matrices and we compare the performance, number of iterations and timing of AOSMs executed on CPU to their performance when they are executed on GPU devices.

Chair: Jun Zou

15:40-16:25 **Aula Magna**

Domain decomposition in nonlinear function spaces

Oliver Sander

We consider partial differential equations for functions with values in a nonlinear Riemannian manifold. These form a fascinating field, with applications in liquid crystal physics, Cosserat materials, ferromagnetic phase fields, and more. Discretization of such equations is difficult, and all previous attempts have only dealt with special cases. We introduce Geodesic Finite Elements, which are a natural covariant generalization of p-th order Lagrangian finite elements to functions with nonlinear codomains. Optimal discretization error bounds have been shown, and can be observed in numerical experiments. Various domain decomposition methods can be generalized to the nonlinear setting, but very little of the existing theory can be reused. We sketch a Steklov-Poincaré-type theory and give a few numerical results.

Chair: Martin Gander

16:25-19:00 **Poster Session**

Multiscale modeling and numerical methods for turbulent fluid mixing

Hyeonseong Jin

Turbulent mixing is a prototypical multiscale problem, with a cascade of length scales generally too broad to be modeled effectively by explicit numerical algorithms. It is neither possible nor desirable to simulate and to understand all fine details accurately. For this reason, governing equations describing multiphase flow behavior effectively and various numerical methods for simulations are studied. 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.

Achieving robustness through coarse space enrichment

Nicole Spillane

Real life or industrial problems can be very challenging for domain decomposition methods. In particular, this is the case when the underlying set of PDEs has heterogeneous coefficients and the heterogeneities are not resolved by the partition into subdomains. Using spectral information to build a coarse space which allows to overcome this problem has been a topical problem for a long time. We present a review of some of these methods and propose a two level FETI method where the coarse space is built on the fly with a guaranteed convergence rate.

Preconditioning techniques for heat equations with orthotropic heterogeneous coefficients

Longfei Gao, Victor Calo

Heat equations arise frequently in various application areas or as intermediate states for solving more complicated physical problems. The major numerical difficulty associated is the condition number of the discretized heat equation, which scales as the square of (1/h). Since performances of iterative methods heavily depend on the condition number, a good preconditioner that can remove the h-dependence is needed. We propose a direction splitting technique as our preconditioner for heat equations with orthotropic heterogeneous coefficients. Its origin can date back to the alternating direction implicit method, developed almost 60 years ago.

Domain decomposition in shallow water modelling for practical applications

Mart Borsboom, Arthur van Dam, John Donners, Menno Genseberger, Erik de Goede, Bert Jagers, Herman Kernkamp, Arjen Luijendijk, Adri Mourits, Judith van Os, Sander van der Pijl, Edwin Spee

This poster illustrates the practical application of different shallow water solvers using domain decomposition (for modelling flexibility and/or parallellization) for modelling: the North Sea and a small part of the Atlantic Ocean for operational forecasting of flooding; San Francisco bay and a small part of the Pacific Ocean for prediction of algae concentrations; the new storm surge barrier of Venice for studying morphological effects during the construction phases; Rotterdam harbour with parts of the river Rhine, river Meuse and the North Sea to study the effect of salt intrusion (due to sea level rise) on drinking water.

A comparison of different coarse spaces for the additive Schwarz method

Atle Loneland, Petter Bjørstad, Maksymilian Dryja

Motivated by Nordbotten et al., 2008, we have investigated the use of a new coarse space in the additive Schwarz method. Independently, a somewhat similar coarse space was tested by Graham et al., 2007. Both methods are concerned with the standard elliptic model problem having large (possibly discontinuous) jumps in the (material) coefficients. This talk will report on a comparison of the two methods.

Simulation of cardiac implants using FitzHugh-Nagumo model

Nina Kudryashova

Engineered cardiac implants are believed to play very important role in a regenerative medicine of a heart. In particular, such implant may be based on a specific nanofiber scaffold which provides structural and functional environment for the cardiac tissue grown on it. The cells elongate along the nanofibers and therefore form anisotropic clusters that may perturb propagation of the action potential and serve as the sources of re-entry formation – the most dangerous heart arrhythmia. Computer simulations employed very generic FitzHugh-Nagumo model. Both finite-difference methods and DDM were applied for solving these PDEs on GPU.

Time-space domain decomposition applied to the incompressible Navier-Stokes equations

Oana Alexandra Ciobanu, Laurence Halpern, Juliette Ryan, Xavier Juvigny

On this poster, an explicit time-space domain decomposition method is applied to the Incompressible Navier–Stokes problem discretised with finite volumes method. We use the space-time Schwarz waveform relaxation (SWR) decomposition method to improve convergence of schemes. To accelerate convergence, a multigrid method is used to solve the Poisson equation of pressure. Results, arising from different parallelisation methods: OpenMP, MPI, GPUs are presented on cartesian grids.

Fully implicit two-phase reservoir simulation with the additive Schwarz preconditioned inexact Newton method

Lulu Liu, David Keyes, Shuyu Sun

Implicit approaches are attractive in reservoir simulation for reasons of numerical stability and the avoidance of splitting errors when solving multiphase flow problems. But large nonlinear systems must be solved at each time step, so efficient and robust numerical methods are required to treat the nonlinearity. The ASPIN framework, as outermost solver, handles nonlinearities in the computational fluid dynamics, but is barely explored for the nonlinear models of multiphase flow with capillarity, heterogeneity, and complex geometry. The implicit ASPIN method is demonstrated for a finite volume discretization based on incompressible two-phase reservoir simulators in the presence of capillary forces and gravity. Numerical experiments show that the number of nonlinear iterations is not only scalable with respect to the number of processors, but is also reduced compared with the standard inexact Newton method with backtracking techniques.

A dual-primal domain decomposition method for mixed problems

Ange Toulougoussou, François-Xavier Roux

Saddle-point problems arise in a wide range of applications such as fluid mechanics, linear elasticity, optimization, and optimal control. Stokes is the prototype of such problems and we consider the solution of the linear system arising from the discretization of Stokes system by finite element methods with continuous pressure spaces. We apply FETI for the velocity and BDD for the pressure without decoupling the unknowns. The resulting interface problem is symmetric positive semi-definite and is solved by projected preconditioned conjugate gradient method. We give theoretical analysis of the condition number of the preconditioned system and numerical results.

On the globalization of ASPIN employing trust-region control strategies: convergence analysis and numerical examples

Christian Groß, Rolf Krause

We present a novel solution strategy for large scale nonlinear problems, which is inherently parallel and globally convergent. Each global nonlinear iteration step consists of asynchronous solutions of local nonlinear programming problems followed by a global recombination step. The latter is the solution of a quadratic programming problem and ensures global convergence. The new strategy can be considered a globalized ASPIN method. However, we control the influence of ASPIN's nonlinear preconditioner on the gradient in order to ensure a sufficient decrease condition. Convergence to first-order critical points can be established under standard Trust-Region assumptions. The strategy is investigated along difficult minimization problems arising from nonlinear elasticity in 3D solved on a massively parallel computer with several thousand cores.

Schwarz waveform relaxation method for Schrödinger equation with cross points

Feng Xing

We present our work on the Schwarz waveform relaxation (SWR) method for the two dimensional linear Schrödinger equation with cross points. The 2-Lagrange multiplier like method is used to treat cross points. At the interface between subdomains, several new absorbing boundary operators for Schrödinger equations are used as transmission operators for the Robin transmission condition in the non-overlapping case. Some numerical experiments that compare these different operators and different Krylov methods will also be presented.

Isogeometric analysis with GISMO: some results and implementations

Clemens Hofreither, Bert Jüttler, Ulrich Langer, Angelos Mantzaflaris, Stephen E. Moore, Satyendra Tomar, Walter Zulehner

Isogeometric analysis (IGA) uses the same class of basis functions for both representing the geometry of the computational domain and approximating the solution of problems modeled by PDEs. In practical applications, geometrical patches are used in order to get flexibility in the geometrical representation, i.e. the computational domain is decomposed into sub-domains which are images of the parameter domain by some NURBS map. In this poster, we present an on-going development of a modern open source C++ library for IGA called "Geometry+Simulation Modules" (GISMO). GISMO is a collaborative software project supported by the Austrian Research Fund FWF under the grant NFN S117. We also present results obtained in GISMO and demonstrate the benefits that GISMO yields as a tool for both academic and industrial purposes.

Discrete convergence analysis for optimized Schwarz methods using energy estimates

Martin J. Gander, Felix Kwok, Kevin Santugini

Since their introduction by P.L. Lions, energy estimates are a fundamental tool to prove convergence of domain decomposition methods. They can be used both at the continuous level and at the discrete level. For optimized Schwarz methods however, there are discretizations, like classical finite elements or finite differences, where energy estimates can not be used (Gander, Kwok DD20). In this poster, we present a convergence study of optimized Schwarz methods using energy estimates at the discrete level for cell-centered finite volumes discretizations. We show that the energy estimates of P.L. Lions and B. Després can be adapted for such a discretization scheme, and lead to very general convergence proofs.

A domain decomposition method that converges in two iterations for any subdomain decomposition and PDE

Martin J. Gander, Felix Kwok

All domain decomposition methods are based on a decomposition of the physical domain into many subdomains and an iteration, which uses subdomain solutions only (and maybe a coarse grid), in order to compute an approximate solution of the problem on the entire domain. We show in this poster that it is possible to formulate such an iteration, only based on subdomain solutions, which converges in two steps to the solution of the underlying problem, independently of the number of subdomains and the PDE solved.

Schwarz waveform relaxation algorithms for a class of non-dissipative reaction diffusion equations

Shu-Lin Wu

We study Schwarz waveform relaxation algorithms for non-dissipative problems. For Dirichlet transmission conditions (TCs), we analyze the algorithm for $\partial_t u = \mu\partial_{xx} u + f(u)$ in the case of many subdomains. For Robin TCs, we consider the initial value problem $\partial_t u = \mu\partial_{xx} u + au$ with $a\geq 0$. We focus on optimizing the parameter and analyzing the asymptotic properties of the algorithm with respect to the length of the time interval and the mesh parameters Δt and Δx. The optimization procedure is different from the case $a<0$, which has been thoroughly studied in the literature. For Δx small and $\Delta t=0(\Delta x^r)$ with $r<4/3$, the equioscillation principle which works for $a<0$ does not hold when $a\geq 0$. The optimization procedure is also relevant to other non-dissipative problems, such as advection reaction diffusion problems and reaction diffusion equations with time delay.

A Dirichlet-Neumann waveform relaxation method for many subdomains

Felix Kwok, Bankim C. Mandal

We propose a generalization of the Dirichlet-Neumann Waveform Relaxation method to many subdomains in 1D. This method is based on a non-overlapping spatial domain decomposition, and the iteration involves subdomain solves in space-time with interface conditions of either the Dirichlet or Neumann type, depending on the direction of communication. Using a Laplace transform argument, we show that for a particular relaxation parameter, we get superlinear convergence when we consider finite time windows. We also present numerical experiments comparing the DNWR method to the Schwarz Waveform Relaxation method with overlap for two subdomains.

Optimized Schwarz methods for the Helmholtz equation with discontinuous coefficients

Erwin Veneros, Hui Zhang

We consider the Helmholtz equation with subdomain-wise constant coefficients. We study the non-overlapping optimized Schwarz method with two subdomains and the DD interface aligned with the material interface. We show that the optimized Schwarz methods always converge when used as stationary iterative methods, and if the number of grid points per wavelength is kept constant, then we have convergence independent of the wavenumber. Finally, we present some numerical examples.

Chair: Martin Gander

Wednesday

	Aula Magna	Room 351	Room 402	Room 15
08:30	Volker Mehrmann			
09:15	James A. Sethian			
10:00	**Coffee break**			
10:30	MS-8 Domain decomposition methods in implementations	MS-6 Efficient solvers for heterogeneous nonlinear problems	MS-9 Parallel multigrid methods	CT-7 Parallelization in time
12:10	**Sandwich lunch break**			
13:00	MS-8 Domain decomposition methods in implementations	MS-6 Efficient solvers for heterogeneous nonlinear problems	CT-8 Maxwell's equation	CT-9 Inverse problems
14:30	**Social program**			

08:30-09:15 **Aula Magna**

Numerical solution of PDE eigenvalue problems in acoustic field computation

Volker Mehrmann

We study parametric PDE eigenvalue problems (evps) for problems arising in interior car acoustics. The coustic field is typically modeled in air via the 3D lossless wave equation and in the structure via classical structural engineering discrete finite element modeling. The resulting discrete evp is complex non-hermitian, very large, and is used within an optimization loop. None of the classical adaptive FEM techniques directly applies to this problem and the numerical solution of the associated algebraic evp is a challenge for current solvers as well. We first describe the problem and how it was solved in the industrial context. Then we discuss the difficulties of adaptive FEM methods and suggest an approach via a homotopy method that balances the discretization error, the homotopy error and the error in the iterative eigensolver. This is partially joint work with Christian Schroeder, Carsten Carstensen, Joscha Gedicke, and Agnieszka Miedlar.

Chair: Rolf Krause

09:15-10:00 **Aula Magna**

Applications of the Voronoi implicit interface method to domain decomposition

James A. Sethian

A variety of problems involve multiply-connected regions interacting and moving together, including liquid and solid foams. In such problems, multiple domains share common walls meeting at multiple junctions, and boundaries move under complex physical forces. Voronoi Implicit Interface Methods (VIIM), introduced by Saye and Sethian, are computational techniques to track these multiply-connected multiphase problems. In this talk, we will briefly describe the methods, and discuss their applications, including (1) A multi-scale framework to model dry foam dynamics, linking foam drainage, rupture, and topological rearrangement, to coupled interface-fluid motion. (2) Domain Decompositions of weighted phase regions.

Chair: Rolf Krause

10:30-12:10 **MS-8 Domain decomposition methods in implementations** **Aula Magna**

Generic concepts for domains decomposition with unrelated parallel meshes

Christian Engwer

Domain decomposition methods provide a flexible tool to develop multi-domain/multi-physics simulations and to couple different discretizations methods. In general parallel computations with unrelated meshes pose a big computer-science effort. When working with unrelated parallel meshes, the necessary coupling information are not available locally. We present an abstraction that hides this non-locality and allows the user to implement his domain decomposition strategy in a clear mathematical setting. The mathematical concept allows an easy implementation of a wide range of domain decomposition methods, without the necessity to directly deal with the aspects of parallel computations. We discuss it's incorporation into the DUNE framework.

A locally rescaled radial basis function interpolation for the spatial coupling in FSI problems

Davide Forti, Simone Deparis

Within the context of fluid-structure interaction problems for hemodynamics, we focus our attention on the spatial coupling between fluid-structure meshes that are non-conforming at the interface. We present a modified RBF interpolation that allows for easy parallelization, efficient evaluation, and accuracy of the results. This is based on a local rescaling which recovers the partition of unity. In the context of fully coupled FSI problems, we then apply the interpolation proposed with non-conforming fluid and structure meshes. Numerical examples, obtained using the open source finite element library LifeV, are presented to show the accuracy and efficiency of the coupling strategy.

Modification of the Krylov space methods for parallel FETI

Alexandros Markopoulos, François-Xavier Roux

FETI, a non overlapping domain decomposition method, is an efficient tool for solving large-scale problems on distributed memory machines. We are focusing on the reduction of the cost of data transfer as well as on the improvement of performance for the local forward-backward substitutions during FETI iterations. This can be realized for instance via suitable modification of conjugate gradient method or another Krylov subspace method, by working with several search direction vectors at the same time. Then the solution time can be non-negligibly lesser compared with the standard approach.

Algebraic multigrid for discontinuous Galerkin methods

Christian Engwer, Andreas Nüßing

We present an algebraic multigrid for discontinuous Galerkin methods. Coarser grid levels are created by applying a semi-coarsening approach based on an edge-coloring of the matrix-graph. The grid-transfer uses local basis-transformations between the polynomial bases of neighbouring elements. Along the coarsening process, the implicit block structure of the linear system is preserved. High frequency errors are reduced by applying an overlapping block smoother. The overlapping patches are constructed and locally weighted depending on the problem type. As model problems serve the Poisson and Stokes equations. The multigrid method is implemented in C++ using the DUNE framework.

10:30-12:10 MS-6 Efficient solvers for heterogeneous nonlinear problems — Room 351

Massively parallel balancing domain decomposition finite element fluid solvers based on overlapped coarse-fine correction computations

Santiago Badia, Alberto F. Martín, Javier Principe

Balancing domain decomposition methods have been proved to be optimal preconditioners for elliptic problems. However, the coarse correction harms the weak scalability of these algorithms. For BDDC methods, where the coarse and fine corrections are additive, the coarse correction can be masked by the fine (parallel) component, by means of the overlapped implementation of the algorithm proposed in this work. We start ab initio assuming two types of cores, those with coarse duties, usually one node in the distributed machine and all its cores, and fine duties, the rest of resources. Then, we divide the Krylov iterative solver into three different regions that overlap coarse and fine duties. Numerical experiments showing ideal weak scalability up to 30,000 processors will be presented.

A Three-grid domain decomposition method for a nonlinear eigenvalue problem arising in quantum dot simulations

Xiao-Chuan Cai

A domain decomposition based Jacobi-Davidson algorithm is proposed to compute the interior eigenpairs of some large sparse polynomial eigenvalue problems arising from quantum dot simulations. We apply multilevel domain decomposition methods to improve the convergence of the correction equation, which is the most expensive step in the Jacobi-Davidson algorithm, and also to obtain initial guesses with rich information on the target eigenpairs. Our numerical results show that the proposed approach is effective with good scalability on a supercomputer with thousands of processors. This is a joint work with T. Zhao and F.-N. Hwang.

A variational multiscale method for high-contrast elliptic PDEs

Robert Scheichl, Daniel Peterseim

We discuss the possibility of numerical upscaling for elliptic problems with rough diffusion coefficient at high contrast. Within the general framework of variational multiscale methods, we present a new approach based on novel quasi-interpolation operators with local approximation properties in L^2 independent of the contrast. These quasi-interpolation operators have first been developed in the context and used in the analysis of robust domain decomposition methods. We show that for some relevant classes of high-contrast coefficients, optimal convergence without pre-asymptotic effects caused by microscopic scales or by the high contrast in the coefficient is possible. Classes of coefficients that remain critical are characterized via numerical experiments.

Interface control domain decomposition method for Navier-Stokes/Darcy coupling

Marco Discacciati, Paola Gervasio, Alfio Quarteroni

We present the Interface Control Domain Decomposition (ICDD) method to address Navier-Stokes/Darcy problem modeling the filtration of incompressible fluids through porous media. ICDD is based on overlapping subdomains splittings, the interface controls are unknown functions used as Dirichlet data on the internal boundaries. The main advantage of applying this approach is to avoid sharp interfaces which would require an in-depth knowledge of the physical behavior of the specific sub-problems. We aim at discussing both theoretical and computational aspects of the ICDD method, as well as at comparing it with classic coupling techniques based on the BJS interface conditions.

10:30-12:10 MS-9 Parallel multigrid methods — Room 402

Parallel unsmoothed aggregation algebraic multigrid algorithms on GPUs

James Brannick

In this talk, we design and discuss implementation of a parallel algebraic multigrid method for isotropic graph Laplacian problems on multi-core GPUs. The proposed AMG method is based on the aggregation framework. The setup phase of the algorithm uses a parallel maximal independent set algorithm in forming aggregates and the resulting coarse level hierarchy is then used in a k-cycle iteration solve phase with a l1-Jacobi smoother. Numerical tests of a parallel implementation of the method for graphics processing units are also provided.

Multilevel methods based on domain decomposition in lattice QCD

Karsten Kahl, Matthias Rottmann

In lattice QCD computations a substantial amount of time is spent in solving discretizations of the Dirac equation. Conventional Krylov subspace methods show critical slowing down for large system sizes and physically interesting parameter regions. We present a method that combines ideas of domain decomposition and adaptive algebraic multigrid. Both these approaches have been used seperately in lattice QCD before. We can show in numerical tests conducted with a large-scale parallel implementation that considerable speed-up over conventional Krylov subspace methods, domain decomposition methods and other hierarchical approaches for physically interesting parameter regions can be achieved.

Efficient smoothing in multigrid methods using domain decomposition

Matthias Bolten, Karsten Kahl

Multigrid methods have shown very good scalability even on the largest supercomputers. To improve the efficiency even further, more efficient smoothers can be used. Here, efficiency is the amount of reduction of rough error components per second or per communication step. One option, for more efficient smoothers in this sense, are domain decomposition smoothers that invert small local subdomains. The analysis of these smoothers cannot be done by using the standard local Fourier analysis (LFA). Therefore, we extended the LFA to be applicable to block smoothers. We present the idea, the extension of the LFA and results on GPUs.

A fast parallel Poisson solver for scrape-off-layer

Kab Seok Kang

Fast Poisson solver is a key ingredient of the BIT2 code, which is a code for scrape-off-layer (SOL) simulations in 2D real space and 3D velocity space. For the development of the fast Poisson solver on massively parallel computers, we consider two approaches. One is based on the multigrid method with gathering of the data at a certain coarser level. The other is to star from the physics-based domain decomposition method. Among the many DDM, we consider the FETI-DP method. We also consider the multigrid/FETI-DP hybrid method to get a faster solver on massively parallel computers. The scaling properties of the Poisson solver on machines such as the IFERC-CSC are investigated.

10:30-12:10 CT-7 Parallelization in time — Room 15

Time-space domain decomposition applied to the Navier-Stokes equations

Oana Alexandra Ciobanu

A space-time domain decomposition algorithm for the compressible Navier–Stokes problem has been designed, with the aim of implementing it in three dimensions, in an industrial code. The system is discretised with a second order implicit scheme in time and finite volumes Method in space. To achieve full speedup performance, a Schwarz waveform relaxation method coupled with a Newton procedure is used, as it allows local space and time stepping. The performances of different parallelisation strategies (using OpenMP, MPI and GPUs) are compared in difficult configurations.

Ventcell transmission conditions for mixed formulations of flow and transport problems

Thi-Thao-Phuong Hoang, Caroline Japhet, Michel Kern, Jean E. Roberts

We consider the Optimized Schwarz Waveform Relaxation (OSWR) method with Ventcell (order 2) transmission conditions for flow and transport problems written in mixed form. Lagrange multipliers are introduced on the (space-time) interface to handle the tangential gradient and divergence operators used for the transmission conditions. The well-posedness of the subdomain problems with such multipliers is proved. An interface problem (global in space and in time) is derived so that different iterative solvers can be applied. Numerical results are used to compare the performance of the Ventcell transmission conditions with that of the one-sided and two-sided Robin transmission conditions. The improvement brought by the introduction of Ventcell conditions is pointed out.

Schwarz waveform relaxation method for Schrödinger equation with new transmission operators

Christophe Besse, Pierre Kestener, Feng Xing

We present some of our work on Schwarz waveform relaxation (SWR) method for the linear and semi-linear Schrödinger equation. At the interface between subdomains, the transmission condition plays an important role. Recently, several absorbing boundary operators for Schrödinger equations (1d/2d) have been created, and we use them as transmission operators for the Robin boundary condition in the non-overlapping case. Different theoretical convergence results will be presented, as well as some numerical results which show that these new conditions can make the SWR method convergence fast.

Boundary impedance adaptation for the acceleration of hybrid simulations of power systems

Frederic Plumier, Christophe Geuzaine, Thierry Van Cutsem

Power system time-domain simulation traditionnally makes use of either Fundamental-Frequency (FF) or Electro-Magnetic Transients (EMT) models depending on the dynamics in the phenomena under study and the size of the system. To achieve high accuracy at a reasonable cost, it is helpful to decompose the system into subdomains, each modeled using either FF or EMT, communicating boundary values. In this talk we will show how to accelerate the convergence of the Gauss-Seidel iterative process by adapting the impedance at the boundary to suppress the numerical reflections between subdomains.

Chair: Daniel Ruprecht

13:00-14:15 MS-8 Domain decomposition methods in implementations — Aula Magna

PDELab for domain decomposition problems

Steffen Müthing

PDELab is a simulation toolbox for standard PDE discretization techniques like FEM, FVM and DG built on top of the DUNE grid framework. In this presentation, we investigate how the rich, tree based function space model at the core of PDELab can be used to provide wide-ranging support for multi-physics problems and domain decomposition methods. We demonstrate the ability to automatically reorder DOFs and generate nested matrices from the function space model, as well as a high-level API to compose multi-domain problems. Finally, we show efficiency gains for multi-domain problems using a mesh-decomposing meta grid to represent subdomains.

Domain decomposition for parallel fast marching method

Petr Kotas, Valentina Poletti, Roberto Croce, Rolf Krause, Vit Vondrak

We present our contribution to the parallelization of the fast marching method (FMM). Current attempts to parallelize the FMM algorithm provide either data parallelism or computational parallelism, but not both. The global communication needed by the FMM also poses a problem, since it slows down the computation. To overcome this major drawback, we designed a new domain decomposition scheme for the FMM, which provides parallelism for both data and computation. Furthermore, we introduce our parallel level set library, which implements our algorithm and provides easy to use API to link with other numerical libraries. Finally, we investigate the parallel scalability and efficiency of our algorithm on a series of numerical experiments.

Generic domain decomposition smoothers for finite element cochain complexes

Guido Kanschat

We discuss a class of domain decomposition smoothers for multigrid methods which was introduced by Arnold, Falk, and Winther for the Poisson problem in mixed form. We show how this smoother can be applied to multigrid methods for a variety of problems with solenoidal velocity fields stemming from coupled flow problems and demonstrate the efficiency of these methods. The structure of the smoother does not depend on the actual bilinear forms involved, but only on a cochain complex of finite element spaces. Thus, it can be implemented generically in a finite element library. We discuss how this has been achieved in the deal.II library.

13:00-14:15 MS-6 Efficient solvers for heterogeneous nonlinear problems Room 351

A fully implicit domain decomposition algorithm for the discrete-velocity BGK model of the Boltzmann equation

Jizu Huang, Chao Yang, Xiao-Chuan Cai

Existing approaches for solving the discrete-velocity Bhatnagar-Gross-Krook (BGK) model of the Boltzmann equation are explicit and semi-implicit. Both have stability constraints on the time step size. In this work, a fully implicit second-order finite difference scheme is developed. We focus on a parallel, fully coupled, Newton-Krylov-RAS algorithm for the solution of a large sparse nonlinear system of equations arising at every time step. RAS is a restricted additive Schwarz preconditioner with a first-order discretization. We show numerically that the nonlinear implicit method has no CFL limit, and is scalable on a supercomputer with thousands of processors.

Domain decomposition and parallel direct solvers as an adaptive multiscale strategy for damage simulation in materials

Frank P.X. Everdij, Oriol Lloberas-Valls, Angelo Simone, Daniel J.Rixen, Bert Sluys

We employ domain decomposition to 2D systems representing concrete-like materials by describing the material across multiple scales with different models and meshes. This enables us to perform failure analysis using nonlinear material models such as the gradient-enhanced damage (GD) model. Early results of classical FETI show that heterogeneous materials combined with the GD model necessitates new developments in preconditioners for solving the interface problem iteratively. Alternatively, recent advancements in parallel direct solvers and the ubiquity of computer memory enables solving domain decomposition problems through the fully assembled matrix. Speed and memory usage of various solvers will be discussed.

From core-collapse supernova neutrino transport to fuzzy domain decomposition methods

Jérôme Michaud

In a wide variety of physical problems, the complexity of the physics involved requires to develop approximations. One can then use heterogeneous domain decomposition techniques. But sometimes, information about the domain of validity of the available approximation is missing or incomplete or at least not a priori known. In this talk we consider neutrino transport in core-collapse supernovae. This example is interesting because the IDSA approximation has been developed that couples two relevant approximations avoiding the full model. We interpret IDSA as a new kind of heterogeneous DDM based on Fuzzy Set Theory introduced by Zadeh in 1965. This new kind of method is referred to as Fuzzy Domain Decomposition Method. We apply this technique to simple but relevant problems and show its quality.

13:00-14:15 CT-8 Maxwell's equation Room 402

Optimized Schwarz methods for Maxwell equations with discontinuous coefficients

Erwin German Veneros Alfaro

We study non-overlapping Schwarz methods for solving time-harmonic Maxwell's equations in heterogeneous media. We consider Maxwell's equations in two and three dimensions. We first present the classical Schwarz method. Choosing the interfaces between the subdomains aligned with the discontinuities in the coefficients, we prove convergence for a model problem in two dimensions and divergence in three dimensions. We then define several optimized transmission conditions dependent on the discontinuities of the coefficients. We prove asymptotically that the resulting methods converge in certain cases independently of the mesh parameter, even though the methods are non-overlapping. We illustrate our theoretical results with numerical experiments.

An effective preconditioner for a PML system for the electromagnetic wave scattering problem

Jun Zou

In this talk we will discuss the edge element solution of a perfectly matched layer (PML) system for the electromagnetic wave scattering problem. When the real and imaginary parts of the edge element system are considered independently, the complex algebraic system can be further transformed into a real saddle-point system with some special structure. Based on a crucial observation on its Schur complement, we construct a symmetric and positive definite block diagonal preconditioner for the saddle-point system. Numerical experiments have demonstrated the effectiveness and robustness of the new preconditioner. This is a joint work with Qiya Hu (Chinese Academy of Sciences), Chunmei Liu (Hunan University of Science and Engineering) and Shi Shu (Xiangtan University), supported by Hong Kong RGC grant (Project 405110).

A unified preconditioner construction for engineering problems

Hiroshi Kanayama, Masao Ogino, Shin-Ichiro Sugimoto

An iterative domain decomposition method (DDM) is applied to numerical analysis of 3D engineering problems. The iterative DDM is combined with the preconditioned CG procedure and the hierarchical DDM which is adopted in parallel computing. In this paper, we apply the balancing domain decomposition (BDD) preconditioner to several engineering problems. Namely, heat conduction, elasticity, the viscous incompressible flow and magnetostatic problems are jointly considered. Here, we concentrate our attention on a perturbed problem of the original linear magnetostatic problem for simplicity. The perturbed problem approaches the original one when the perturbation parameter becomes zero and it produces a positive definite coefficient matrix in the approximation process. Therefore, the well-known theory of Mandel (1993) can easily be applied to the perturbed problem.

Chair: Laurence Halpern

13:00-13:50 CT-9 Inverse problems Room 15

A domain decomposition technique for solving the inverse problem in cardiac electrophysiology

Nejib Zemzemi

The mostly used mathematical formulation of the inverse problem in electrocardiography is based on a least squares method using a transfer matrix that maps the electrical potential on the heart to the body surface potential (BSP). Lots of work has been concentrated on the regularization term without thinking of reformulating the problem itself. We propose to solve the inverse problem based on a domain decomposition technique with fictive mirror-like boundary conditions. We conduct BSP simulations to produce synthetic data and use it to evaluate the accuracy of the inverse problem solution.

Sparsity in Bayesian inversion of parametric operator equations

Christoph Schwab, Claudia Schillings

In this talk, we present a novel, deterministic approach to inverse problems for identification of parameters in differential equations from noisy measurements. Based on the parametric deterministic formulation of Bayesian inverse problems with unknown input parameter from infinite dimensional, separable Banach spaces, we develop a practical computational algorithm for the efficient approximation of the infinite-dimensional integrals with respect to the posterior measure. Convergence rates for the quadrature approximation are shown, both theoretically and computationally, to depend only on the sparsity class of the unknown, but are bounded independently of the dimension of the parameter space. This work is supported by the european research council under FP7 grant AdG247277.

Chair: Wolfgang Hackbusch

Thursday Morning

	Aula Magna	Room 351	Room 402	Room 15
08:30	Marina Vidrascu			
09:15	Joachim Schöberl			
10:00	**Coffee break**			
10:30	MS-10 Efficient solvers for frequency domain wave problems	MS-11 Domain decomposition methods for environmen-tal modeling	CT-10 Preconditioners and solvers	CT-11 Non-matching meshes
12:10	**Lunch break**			

08:30-09:15 **Aula Magna**

Robin-Neumann explicit schemes in fluid-structure interaction problems

Marina Vidrascu, Miguel Fernández, Jimmy Mullaert

We are interested in the simulation of incompressible fluid-structure interaction problems. In the framework of domain decomposition, standard explicit coupling schemes can be viewed as one iteration of a Dirichlet-Neumann algorithm with a convenient initial guess. For this class of problems, such coupling schemes are unstable due to the so-called added-mass effect. Implicit and semi-implicit coupling schemes overcome these instabilities but are more computationally time consuming. Explicit Robin-Neumann schemes, recently introduced, guarantee stability and optimal first-order accuracy for a linear Stokes/thin-solid coupled system. In these explicit coupling schemes, the displacement is extrapolated in the fluid sub-step and then it is corrected in the solid. These algorithms will be presented in a fully non-linear framework for the coupling of the Navier-Stokes equations (in ALE form) with a non-linear shell structure or a three dimensional structure. Comparisons in terms of accuracy and efficiency implicit schemes will be discussed.

Chair: Alfio Quarteroni

09:15-10:00 **Aula Magna**

An assembled inexact Schur-complement preconditioner

Joachim Schöberl

We consider the following domain decomposition preconditioner: For each sub-domain, and each closed facet of it, we compute the Schur-complement of the sub-domain stiffness matrix. These Schur-complements are assembled to the global preconditioner matrix. Since now also the interior facet variables can be locally eliminated, the global matrix is comparably cheap to invert. This method requires only algebraic problem-specific input. The computational costs are in the order of other DDM with exact local solves. The advantage is a high robustness with respect to coefficients. Since the condition number depends only on the local approximations, it is independent of jumps across sub-domains. In the case of highly varying local coefficients, bad sub-spaces can be detected locally and fixed by local low-rank corrections. The method shares similarities with the recently proposed BDDC de-luxe variant. One essential difference is that the global coarse system depends on the assembled matrix and thus on domain patches rather than on individual sub-domains. We discuss the extension to hybrid-DG discretizations which involve unknowns on element facets. In this case, the coarse system is of optimal complexity in n dimensions. We show various examples from applications in elasticity, fluid dynamics and electromagnetics.

Chair: Alfio Quarteroni

10:30-12:10 MS-10 Efficient solvers for frequency domain wave problems — Aula Magna

Multigrid for Helmholtz just does not work! Or does it?

Martin J. Gander

It is well known that the multigrid (MG) algorithm does not function properly when applied to a discretized Helmholtz equation. But what happens precisely? Why and how do standard components of a MG algorithm fail? Is it even possible to obtain a convergent algorithm using just the standard components? This talk presents the details on how MG fails for the Helmholtz equation. I explain all the results on a 1D model problem, and show what is needed in 1D in order to obtain a convergent method using only the standard MG components of smoothing and coarse-grid correction. I illustrate the results with numerical experiments, and also discuss the difficulties to extend these results to higher spatial dimensions. The work presented is in collaboration with Oliver Ernst.

Multitrace formulations and Dirichlet-Neumann algorithms

Victorita Dolean, Martin J. Gander

Multi trace formulations (MTF) for boundary integral equations (BIE) have been developed over the last years by Hiptmair et al. for the simulation of problems with piecewise constant media. These formulations seem naturally adapted to the development of new block preconditioners of Schwarz type. The goal of our presentation is to give an elementary introduction to MTFs and their related solvers, and also to establish a natural relation with the more classical Dirichlet-Neumann algorithms. We present a convergence analysis, and also first numerical results to illustrate what one can expect from an iterative solver for MTFs.

Second kind boundary integral equation for scattering at composite objects

Xavier Claeys, Ralf Hiptmair, Elke Spindler

We consider the scattering of time-harmonic acoustic waves at objects made as arbitrary arrangements of homogeneous parts with different material properties. In this context, we will present a new integral formulation of the second kind with the desirable property of being systematically well-conditioned. We will discuss a theoretical analysis of this equation that relies on an adapted functional framework, and show how it can be reformulated in the space of square integrable traces. We will conclude with numerical results.

Sweeping preconditioners and source transfer in the context of domain decomposition

Martin J. Gander, Hui Zhang

The recent work of Ying and Engquist on the sweeping preconditioner for the Helmholtz equation (2011) has caught a lot of attention. The basic idea is to use a block factorization of the block tridiagonal matrix obtained from the discretization, and then to approximate the Schur complements appearing using PDE techniques. In this talk, we establish connections between various sweeping preconditioners, including the optimal Schwarz method of Nataf-Rogier-Sturler (1994), the analytic incomplete LU preconditioner of Gander-Nataf (2000) and the source transfer method of Chen-Xiang (2012). We show both the PDE and matrix formulations, and that in the common framework of optimized Schwarz methods, it is possible to perform a spectral analysis of these preconditioners. We illustrate our results with numerical experiments.

10:30-12:10 MS-11 Domain decomposition methods for environmental modeling — Room 351

A domain decomposition method for coupling CFD and GFD models to simulate coastal ocean flows

Han-song Tang, Ke Qu, Xiu-guang Wu

We propose to combine geophysics fluid dynamics (GFD) models with computational fluid dynamics (CFD) models to simulate multiphysics coastal processes. In particular, the unstructured grid model FVCOM is coupled with a structured grid CFD model; the former is used to simulate large-scale coastal flows, and the latter is employed to capture local, small-scale processes. In order to demonstrate its feasibility and performance, modeling for typical flow problems has been made, which shows that the proposed approach is promising in simulation of multiscale and multiphysics coastal ocean flows that are beyond the reach of conventional coastal ocean models.

Schwarz waveform relaxation for heterogeneous cluster computing: Application to numerical weather prediction

Laurent Debreu

This presentation deals with the numerical simulation of partial differential equations on highly heterogeneous computing platforms both in terms of computing power and speed of communication. These difficulties are even stronger when the initial problem is not easily decomposable into independent tasks, and when other issues such as fault tolerance come into play. We show that the Schwarz waveform relaxation methods may prove to be the right tool to address all these issues. After explaining the benefits of these methods on a simple 2D advection equation, we present preliminary results of running the weather research and forecasting (WRF) model on the Amazon EC2 computing platform. The main open problems are finally outlined.

Schwarz method for slip weakening friction with applications to earthquake source dynamics

Ioan Ionescu, Lori Badea, Sylvie Wolf

The dynamic faulting under slip-dependent friction in a linear elastic domain is considered. The use of an implicit time-stepping scheme (Newmark method) allows much larger values of the time step than the critical CFL time step, and higher physical consistency with respect to the friction law. The finite element form of the quasi-variational inequality is solved by a Schwarz domain decomposition method, by separating the inner nodes of the domain from the nodes on the fault. Numerical experiments are performed to illustrate convergence in time and space, instability capturing, energy dissipation and the influence of normal stress variations.

Domain decomposition in shallow lake modelling for practical applications

Menno Genseberger

For lake IJssel and lake Marken, the two big shallow lakes in the Netherlands, various societal aspects are of importance: 1) safety assessment of the dikes, 2) operational forecasting of flooding, 2) improving water quality and ecology, 3) salt intrusion and drinkwater quality (lake IJssel only), and 4) maintenance of the navigation channels. Despite the diversity of aspects, all underlying physical and biological processes are related to the hydrodynamics. With several illustrative real-life applications it will be shown how domain decomposition is used in the hydrodynamic modelling of the lakes for flexibility and/or parallel performance.

10:30-12:10 CT-10 Preconditioners and solvers Room 402

Comparison of different parallel solvers of linear systems based on domain decomposition

David Horak, Vaclav Hapla, Vit Vondrak

Large sparse linear systems of equations can be solved by means of direct, iterative or hybrid solvers, which can be also categorized into primal, mixed or dual methods. The presentation deals with the applications of non-overlapping DD techniques for the iterative solution using conjugate gradients (CG) and their comparison. The resulting problem can be solved by CG in primal variables or after transformation by CG in dual variables (FETI). Grouping of the nodes based on DD can be even used to generate the subspace for deflated CG (DCG) applied to the undecomposed problem. Numerical experiments illustrate the efficiency of various methods on several architectures.

Block H-LU preconditioners for higher-order FEM

Sabine Le Borne

The finite element discretization of partial differential equations requires the selection of suitable finite element spaces. While higher order finite elements lead to solutions of higher accuracy, their associated discrete linear systems of equations are often more difficult to solve than those of lower order elements. Here, we present efficient preconditioners for these types of linear systems of equations. More specifically, we will use hierarchical (H-) matrices to build block H-LU preconditioners. We distinguish between blackbox H-LU preconditioners which factor the entire stiffness matrix and hybrid methods in which only certain subblocks of the matrix are factored. We conclude with numerical results.

Optimal solver for Morley element problem for biharmonic equation on shape-regular grids

Shuo Zhang

In this joint work with Jinchao Xu and Chunsheng Feng we report on an optimal solver for the Morley element problem for the Dirichlet boundary value problem of the biharmonic equation by decomposing it into several subproblems, and solving these subproblems optimally. The optimality of our proposed method is mathematically proved for general shape-regular grids. An interesting observation is introduced that a ``bad" discretization/discrete problem may be used to precondition a ``good" discretization/discrete problem.

Global convergent multigrid method for variational inequalities with a nonlinear term

Lori Badea

We introduce a multigrid method for variational inequalities having, beside a term arising from the derivation of a convex functional, a non differentiable term. We first introduce the method as a subspace correction algorithm in a general reflexive Banach space and prove its global convergence and estimte the convergence rate in function of the number of levels. In finite element spaces, the algorithm becomes multigrid V-cycles for two-obstacle problems, but the results hold for other iteration types, the W-cycle iterations, for instance. In particular, the proposed method supplies a multigrid method for semilinear or quasi-linear inequalities.

Chair: Johannes Kraus

10:30-12:10 CT-11 Non-matching meshes Room 15

Mortar methods with optimized transmission conditions for advection-diffusion problems

Caroline Japhet, Yvon Maday, Frederic Nataf

For many applications in fluid dynamics, one needs to use different discretizations in different regions of the computational domain to match with the physical scales. The New Interface Cement Equilibrated Mortar (NICEM) method enables the use of nonconforming grids and allows for the use of Robin or Ventcell interface conditions which greatly enhance the information exchange between subdomains. We present the NICEM method for advection-diffusion problems. We prove well-posedness of the nonconforming domain decomposition method and convergence of the iterative algorithm. Error analysis is performed. Then we present numerical results that illustrate the method.

A domain decomposition method for solving flow in stochastic discrete fracture networks on non-conforming mesh

Géraldine Pichot, Baptiste Poirriez, Jocelyne Erhel, Jean-Raynald de Dreuzy

The use of non-conforming meshes in discrete fracture networks (DFN) simplifies mesh adaptivity which is useful as the flow is mostly localized. The matrix shape of the linear system encourages the use of DD methods. We use the BDD Mortar method proposed in (Pencheva and Yotov, 2003), (Poirriez, 2011). The coarse level is defined following (Tang et al., 2009). Balancing is implemented as a preconditioning matrix (Erhel and Guyomarc'h, 2000). The algorithm is implemented in the parallel software SIDNUR (Poirriez, 2011). We present the decomposition of the linear system in local matrices and apply the BDD Mortar method to networks satisfying some hypotheses on the mesh.

Space-time domain decomposition with finite volumes for porous media applications

Paul-Marie Berthe, Pascal Omnes, Caroline Japhet

We consider the optimized Schwarz waveform relaxation (OSWR) method for flow and transport problems with widely varying coefficients, discretized with the discrete duality finite volume (DDFV) method extended to time dependent convection-diffusion problems and Robin transmission conditions. We analyzed the method in a presentation at DD21, whereas in this presentation, we show 2D numerical results on highly nonconforming meshes, adapted to heterogeneities, that are easily dealt with by the DDFV scheme. We compare the one-sided and two-sided Robin conditions and present simulations in the context of nuclear waste repositories.

The HERMESH method: a coupling method for non-matching, overlapping and disjoint meshes

Beatriz Eguzkitza, Guillaume Houzeaux

We present a geometrical domain decomposition method to couple the solutions of PDE's obtained on independent meshes. The meshes can be overlapping, separated or disjoint, in relative motion or fixed, and of different sizes. The technique consists in extending each subdomain towards the others through the addition of new elements, referred to as extension elements, which connect the nodes of the interfaces to the interior nodes of the adjacent subdomains, in a non-conforming way. The technique is applied to the Chimera method and to glue disjoint meshes to solve different physical problems.

Chair: Thomas Dickopf

Thursday Afternoon

	Aula Magna	Room 351	Room 402	Room 15
14:00	Christine Bernardi			
14:45	Olof B. Widlund			
15:30	**Coffee break**			
16:00	MS-10 Efficient solvers for frequency domain wave problems	MS-12 Efficient solvers	CT-12 Multiphysics problems	CT-13 Parallelization in time
18:00	**Business Meeting of the International Scientific Committee (Room 4 in the Informatics building)**			
20:00	**Dinner of the International Scientific Committee with the Invited Speakers (Bus from USI)**			

14:00-14:45 **Aula Magna**

Local simplification of Darcy’s equations with pressure dependent permeability

Christine Bernardi

We consider the flow of a viscous incompressible fluid in a rigid homogeneous porous medium provided with mixed boundary conditions. Since the boundary pressure can present high variations, the permeability of the medium also depends on the pressure, so that the model is nonlinear. A posteriori estimates allow us to omit this dependence where the pressure does not vary too much. We perform the numerical analysis of a spectral element discretization of the simplified model. Finally we propose a strategy which leads to an automatic identification of the part of the domain where the simplified model can be used without increasing significantly the error.

Chair: David Keyes

14:45-15:30 **Aula Magna**

BDDC deluxe domain decomposition algorithms

Olof B. Widlund

The BDDC algorithms, first developed by Clark Dohrmann, have proven to be very successful domain decomposition algorithms for a variety of elliptic problems. For any particular application, the success of such an algorithm depends on the choice of a set of primal constraints and the choice of an averaging operator, which is used to restore the continuity of certain intermediate vectors in each iteration. In the deluxe version, a new averaging procedure is used; it was first developed in joint work with Dohrmann on H(curl) problems. A theory will be outlined and a variety of successful applications will be discussed.

Chair: David Keyes

16:00-17:40 **MS-10 Efficient solvers for frequency domain wave problems** **Aula Magna**

A new theory of domain decomposition for the Helmholtz equation

Ivan Graham, Euan Spence, Eero Vainikko

We consider the iterative solution of the (generally non-normal) complex linear systems which arise from finite element approximation of the Helmholtz equation with first order absorbing boundary conditions. We analyse preconditioners for these systems using classical two level additive Schwarz techniques applied to the corresponding Helmholtz problem with absorption added. Using the coercivity of the problem with absorption and stability and regularity estimates (which are explicit in wave number and absorption parameter) we are able to prove estimates on the number of GMRES iterations for the problem with absorption, leading to an efficient solver for the original problem.

Multigrid for the Helmholtz equation: choice of the coarse scale perator

Chris Stolk

We study the convergence of multigrid schemes for the Helmholtz equation, focussing on the choice of coarse scale operators. Assuming that coarse scale solutions approximate the true solutions, the coarsest level grid must have a minimum number of points per wavelength, call this G. Theoretically, G>2, but in practice the requirement is more like G≥8. We show that by choosing new, optimized, coarse scale operators this can be reduced to G≥4. In 3-D this implies that the number of unknowns in the coarsest scale linear system is reduced by an order of magnitude.

A source transfer domain decomposition method for Helmholtz equations in unbounded domains

Zhiming Chen, Xueshuang Xiang

We propose and study a domain decomposition method for solving the truncated perfectly matched layer (PML) approximation in bounded domain of Helmholtz scattering problems. The method is based on the decomposition of the domain into non-overlapping layers and the idea of source transfer which transfers the sources equivalently layer by layer. The solution in the final layer is solved using a PML method defined locally outside the last two layers using transferred sources. The convergence of the method is proved for the case of constant wave number based on the analysis of the fundamental solution of the PML equation. The method can be used as an efficient preconditioner in the preconditioned GMRES method for solving discrete Helmholtz equations with constant and heterogeneous wave numbers. Numerical examples are included.

Double sweep preconditioner for Schwarz methods applied to the Helmholtz equation

Christophe Geuzaine, Alexandre Vion

Observing that the optimized Schwarz algorithm is equivalent to the solution of a linear system, we design a new preconditioner as an approximate inverse of the iteration operator, in the particular case of a layered decomposition. We show that it can be rewritten as two independent sequences of subproblem solves (forward and backward), hence the name 'double sweep'. The whole algorithm is implemented as a matrix-free GMRES iteration, that requires no more additional preprocessing than the original algorithm. Numerical experiments indicate that the convergence rate is independent of the wavenumber and number of subdomains when good approximations of the DtN maps are used, in both homogeneous and non-homogeneous cases.

16:00-17:40 MS-12 Efficient solvers — Room 351

Comparing multigrid and domain decomposition methods

Sébastien Loisel

Many preconditioners are available for elliptic problems, including multigrid and domain decomposition methods. In a domain decomposition method, one must further choose how the subdomain problems are solved; a natural choice is to use a multigrid solver for each subdomain. This gives rise to an ``inner iteration" in the preconditioner and one must decide how many iterations to use in the inner iteration. Using more iterations in the inner iteration can improve the condition number, thus reducing the number of outer iterations. We will discuss how these choices affect the performance of the solver.

An optimal preconditioner for parallel adaptive finite elements

Hieu Nguyen, Sébastien Loisel

An approach for combining domain decomposition and adaptivity is to build local meshes of the whole domain. These meshes are fine in their associated subdomains but much coarser elsewhere. We will present a Schwarz-type preconditioner formulated based on these meshes. We prove that the convergence rate of the corresponding PCG algorithm depends only on the effective condition number, which is the ratio of the second largest eigenvalue to the smallest eigenvalue. Our estimates show the preconditioner is optimal, as the effective condition number is bounded independently of the mesh sizes and the number of subdomains.

Frugal FETI

Nicole Spillane, Pierre Jolivet, Frédéric Nataf

We introduce a new two level variant of the FETI algorithm which is robust with respect to heterogenous media and automatic partitions. The second level is built on the fly within the conjugate gradient iterations (in the spirit of adaptive or boostrap multigrid). Convergence is guaranteed by a theoretical result and illustrated numerically. We have called the algorithm frugal (this means economical in a good way) because the idea is to make full use of all the quantities that are computed within the FETI iterations and in particular each local contribution to the preconditioner.

A unified framework for Schwarz and Schur methods

Pierre Jolivet, Frederic Nataf, Christophe Prud'Homme

Domain decomposition methods are often referred to as scalable methods, meaning that they are supposed to perform well with an increasing number of subdomains. While a lot of work has been carried out to provide such scalable preconditioners in theory, there are not many ways to try and to compare them from a computational standpoint. In this talk, we will present a massively parallel lightweight implementation that can be used for both overlapping and non-overlapping methods to solve problems with a few billion unknowns for various elliptic PDEs, using thousands of subdomains.

16:00-17:40 CT-12 Multiphysics problems Room 402

Scalable multilevel preconditioners for the cardiac electro-mechanical coupling

Simone Scacchi, Piero Colli Franzone, Luca Pavarino

We develop a parallel solver for cardiac electro-mechanical coupling, a system of two parabolic PDEs that model the electrical activity (Bidomain model) and mechanical contraction (non-linear elastic model) of the myocardium. The discretization in space and time yields at each time step the solution of a large ill-conditioned linear system and a non-linear system, derived from the Bidomain and finite elasticity models, respectively. We solve the linear system with the Conjugate Gradient method, preconditioned by Multilevel Additive Schwarz preconditioners, and the non-linear system with a Newton-Krylov-Algebraic Multigrid method. Parallel numerical tests show that the solver is scalable and robust with respect to the domain deformations due to cardiac contraction.

Partitioned time-stepping solvers for coupled multi-physics problems

Christian Waluga, Barbara Wohlmuth

Coupled problems, involving multiple scales and/or physics, arise in many applications. An important question in such problems is the choice of flexible, stable, physically meaningful and well-approximating interface couplings. Moreover, the coupling should allow the efficient treatment of different scales of the problem. We propose a non-iterative domain decomposition scheme for a parabolic model problem based on a hybridized Nitsche-type discretization technique. The scheme allows for multi-scale couplings across possibly non-matching interfaces while ensuring the conservation of physical quantities. The algorithm consists of an explicit predictor step for the discrete trace, fully decoupled implicit solves on the subdomains and a corrector step involving communication of interface quantities. We discuss the stability and convergence theory and illustrate our theoretical results by numerical examples.

Augmented Lagrangian domain decomposition methods for bonded structures

Jonas Koko, Taoufik Sassi

A bonded structure consists of elastic bodies bonded by a thin adhesive layer. Bonded structures are increasing alternatives to mechanical joints in engineering applications. Optimization based domain decomposition methods, for bonded structures, exist. However, these methods cannot handle problems for which the geometry allows rigid body motions. We propose augmented Lagrangian based domain decomposition methods for bonded structures with any number of adherents. The mass terms provided by the penalization functional prevent the rigid body motions. The methods proposed are based on Uzawa block relaxation methods. In every iteration, uncoupled linear elastic subproblems are solved.

Resonance eigenvalues for structure-structure interaction through soil foundation

Takashi Kako

Using the perfectly matching layer for elastic soil foundation, we study the resonance phenomena of structures which reside on the soil. For this purpose, we formulate the problem consisting of infinite half space soil foundation and several structures on it. The resonance phenomena are very important for the response of structures to the incident input seismic vibration source. We discretize the governing PDE by FEM and compute the complex resonant eigenvalues for the time harmonic equation.

Chair: Volker Mehrmann

16:00-17:40 CT-13 Parallelization in time Room 15

A time parallel algorithm for linear inhomogeneous parabolic equations

Achim Schädle

A highly parallel algorithm for the numerical solution of inhomogeneous parabolic differential equation is presented. The algorithm requires the solution of $O(\log(1/h)\log(1/\epsilon))$ linear systems in parallel, where h is the time step size required to resolve the inhomogeneity and ϵ is the required accuracy. Additionally the solution of $O(N \log(1/h)\log(1/\epsilon))$ scalar linear inhomogeneous differential equations is needed. The basic ingredients of the algorithm are the variation of constants formula, the Cauchy integral representation for the approximation of the operator exponential and the discretization of contour integrals using $O(\log(1/h))$ contours with $O(\log(1/\epsilon))$ quadrature points each.

Fast and robust tensor-product solvers

Thuy Tran Thi Bich, Laurence Halpern

Fast tensor-product solvers have been proposed by Maday and Ronquist in 2007. The parallelization in time relies on a block-diagonalization. In that process, the choice of the time steps is crucial, as it can deteriorate both the precision and the condition number of the linear system. We propose an optimization strategy for the choice of these parameters, and apply it to various discretization in time of the heat equation.

Nonlinear Schur complement for time domain decomposition method

Patrice Linel, Damien Tromeur-Dervout

We developed a parallel-in-time DDM to solve systems of linear ODEs that claim the transformation of the initial value problem into a boundary value problem in time. When systems of nonlinear ODEs are under consideration, we have shown (DD21 proceeding) that a nonlinear boundary condition preserving the invariants of the solution must be imposed at the end of the time slices. This talk will focus on the special care to design the Schur complement method where the nonlinear boundary conditions are integrated in the local nonlinear time slice problem.

Domain decomposition methods with overlapping subdomains for the time-dependent problems

Petr Vabishchevich, Petr Zakharov

Domain decomposition methods for solving time-dependent problems can be classified by (i) the method of domain decomposition used, (ii) the choice of decomposition operators (exchange of boundary conditions), and (iii) the splitting scheme employed. To construct homogeneous numerical algorithms, overlapping subdomain methods are preferable. The domain decomposition is associated with the corresponding additive representation of the problem operator. To solve time-dependent problems with the DD splitting, various operator-splitting schemes are used. Various variants of decomposition operators differ by distinct types of data exchanges on interfaces. They ensure the convergence of the approximate solution in various spaces of grid functions.

Chair: Rolf Krause

Friday

	Aula Magna	Room 351	Room 402
08:30	MS-13 Space-time parallel methods	MS-12 Efficient solvers	CT-14 FETI and BDD methods
10:10	**Coffee break**		
10:40	Marco Discacciati		
11:25	Jinchao Xu		
12:10	Closing		
12:45	**Lunch break**		

08:30-10:10 MS-13 Space-time parallel methods — Aula Magna

Convergence of Parareal for diffusion problems with non-constant coefficients

Daniel Ruprecht, Robert Speck, Rolf Krause

For the time-parallel Parareal method, there exists both numerical and analytical proof that it converges very well for diffusive problems like the heat equation. Many applications, however, do not lead to simple homogeneous diffusive problems but feature strongly inhomogeneous and possibly anisotropic coefficients. In the talk, we will present results from a numerical study of how non-constant coefficients in a diffusion problem influence the convergence behaviour of Parareal. Further, the effect of different parameters like e.g. temporal and spatial resolution and geometry is explored.

Application of the parareal algorithm to burning plasma scenarios characterized by events

Debasmita Samaddar, Thomas A. Casper, Sunhee Kim, Lee A. Berry, Wael R. Elwasif, Donald B. Batchelor, Wayne A. Houlberg

The parareal algorithm (Lions, Maday, Turincini 2001) has been applied to achieve computational speedup in scenario studies in burning plasma experiments. With the construction of the ITER project well under way, these simulations demand reduced wall clock time calculations in order to achieve goals concerning both construction and analysis. The CORSICA code (Casper et al. 2010, Crotinger et al. 1997) has been used as a test case. Scenario studies typically involve plasma in a steady state interrupted by events introduced by MHD activity, pellet injection or ELMs. The presence of these sudden events makes the parareal application particularly challenging. This work explores different coarse solvers and their effects on the parareal convergence.

Optimized RIDC - DD methods for time dependent PDEs

Ronald Haynes, Benjamin Ong

Recently we have proposed a parallel space-time approach for time dependent partial differential equations by coupling the Revisionist Integral Deferred Correction (RIDC) parallel in time approach with domain decomposition in space. It has been shown to be a relatively easy way to add small scale parallelism (in time) to an existing parallel in space method. The DD in space was provided by a simple (and inefficient) classical Schwarz method. Here we extend the technique by coupling RIDC with optimized Schwarz methods in space. This results in a truly parallel space-time method for PDEs suitable for hybrid OpenMP/MPI implementation. Examples will demonstrate the viability of the approach.

Convergence studies for multilevel spectral deferred corrections and PFASST

Robert Speck, Daniel Ruprecht, Matthew Emmett

With the parallelization of multilevel spectral deferred corrections (MLSDC), concurrent integration in time is possible in a novel, multigrid-fashioned way. In order to maximize parallel efficiency, the "parallel full approximation scheme in space and time" (PFASST) is able to apply multiple coarsening strategies in space and time. Here, careful balancing between aggressive coarsening and fast convergence is necessary. Going from plain spectral deferred corrections to MLSDC and PFASST, the talk presents first steps towards a characterization of this delicate interdependency.

08:30-10:10 MS-12 Efficient solvers Room 351

Two-level Schwarz preconditioner for the stochastic finite element method

Waad Subber, Sébastien Loisel

Increasingly the spectral stochastic finite element method (SSFEM) has become a popular computational tool for uncertainty quantification in numerous practical engineering problems. For large-scale problems however, the computational cost associated with solving the arising linear system in the SSFEM still poses a significant challenge. The development of efficient and robust preconditioners for the SSFEM linear system therefore, is of paramount importance for uncertainty quantification of large-scale industrially relevant problems. To exploit the available high performance computing platforms, these preconditioners must be parallel and scalable. To this end, a two-level Schwarz preconditioner is described for the iterative solution of the SSFEM linear system.

A massively parallel implementation of the 2-Lagrange multiplier method

Anastasios Karangelis, Sébastien Loisel

The optimized Schwarz method enhances the rate of convergence of the classical Schwarz method by replacing the Dirichlet boundary condition at the artificial interface with a Robin boundary condition, where the Robin parameter is then tuned to optimize the convergence of the algorithm. In this talk we will discuss a massively parallel implementation of the 2-Lagrange multiplier method, which is dual to the OSM.

Substructuring waveform relaxation methods for the wave equation

Bankim Mandal

We present a Waveform Relaxation (WR) version of the Dirichlet-Neumann and Neumann-Neumann algorithms for the wave equation in space time. Each method is based on a non-overlapping spatial domain decomposition, and the iteration involves subdomain solves in space time with corresponding interface condition, followed by a correction step. Using a Laplace transform argument, for a particular relaxation parameter, we prove convergence of both algorithms in a finite number of steps for finite time intervals. The number of steps depends on the size of the subdomains and the time window length on which the algorithms are employed. We illustrate the performance of the algorithms with numerical results, and also show a comparison with classical and optimized Schwarz WR methods.

How DG discretizations influence the convergence of block Jacobi preconditioning

Soheil Hajian, Martin J. Gander

For discretizations of elliptic partial differential equations, it has been shown recently that block Jacobi methods for some Discontinuous Galerkin (DG) discretizations can be viewed as non-overlapping Schwarz methods with Robin transmission conditions. The convergence of the block Jacobi methods for DG discretizations therefore depend directly on the penalty parameter of the DG method. The convergence analysis of non-overlapping Schwarz methods suggest that the usual choice for this parameter will result in slow convergence of block Jacobi iterations. We show how to locally modify the Jacobi blocks in order to obtain faster convergence, while preserving the approximation properties of the DG method.

08:30-10:10 CT-14 FETI and BDD methods Room 402

A domain decomposition method based on augmented Lagrangian with an optimized penalty parameter

Chang-Ock Lee, Eun-Hee Park

A domain decomposition method as a variant of the FETI-DP method was introduced in the previous works by the authors. The proposed method imposes the continuity on the interface not only by using Lagrange multipliers but also by adding a penalty term which consists of a positive penalty parameter and a measure of the jump across the interface. Due to the penalty term, the resulting dual problem has a constant condition number bound. In this talk, we will discuss a further study for the domain decomposition method with an optimized penalty parameter in terms of its convergence analysis and practical efficiency.

Hybrid total FETI

Marta Jarosova, Martin Mensik, Alexandros Markopoulos, Tomas Brzobohaty

We propose a hybrid FETI method based on our variant of the FETI type domain decomposition method called Total FETI. Our hybrid method was developed in an effort to overcome the bottleneck of classical FETI methods, namely the bound on the dimension of the coarse space due to memory requirements. We first decompose the domain into relatively large clusters that are completely separated, and then we decompose each cluster into smaller subdomains that are joined partly by Lagrange multipliers. The continuity in the rest of the interface and the Dirichlet condition are enforced also by Lagrange multipliers. This decomposition leads to the algorithm, where TFETI is used on two levels.

The efficient reconstruction formula for the amplitudes of the rigid body modes in FETI for contact problems

David Horak, Vaclav Hapla

The presentation deals with the relation of the vector of amplitudes of rigid body modes in FETI methods and multipliers generated by the SMALSE algorithm for the solution of nonlinear problems. Once the dual solution is computed, to get the primal solution it is necessary to exclude rows in the constraint matrix with inequalities corresponding to zero Lagrange multipliers, compute a new coarse space matrix and solve a new coarse problem. We present our new formula for computing this vector using data being at disposal in each step and one forward solve applied to the SMALSE multipliers and illustrate the scalability improvement.

Balancing domain decomposition method for semi-definite problems

Ange Toulougoussou, François-Xavier Roux

Singular linear systems arise in many engineering applications and numerical algorithms. The null space of such problems is not trivial and the right-hand side must be orthogonal to the kernel to ensure the existence of a solution. Additional constraint on the solution is necessary to recover uniqueness. Most of iterative methods dont address the compuation of the kernel of singular problems. The issue of computing the null space of semi-definite problems in FETI has been successfully tackled. We introduce a technique to reconstruct global rigid body modes when solving irregular problems with BDD. Numerical results confirm the theory we have developed.

Chair: Oliver Rheinbach

10:40-11:25 **Aula Magna**

Coupling Stokes and Darcy equations: modeling and numerical methods

Marco Discacciati

We present two possible methods to compute the finite-elements approximation of a Stokes/Darcy problem to model filtration of incompressible fluids through porous media. On one hand, using suitable continuity conditions, we transform the coupled problem into an equivalent one defined on the interface separating the fluid from the porous medium, and we present possible numerical methods to solve effectively such interface problem (Discacciati, 2013). On the other hand, we propose to adopt an optimal-control approach that allows to couple the two sub-problems avoiding relying on any specific interface conditions (Discacciati, Gervasio, Quarteroni 2013, Discacciati, Gervasio, Quarteroni 2012). We compare these approaches theoretically and we present some test cases of physical relevance.

Chair: Ralf Kornhuber

11:25-12:10 **Aula Magna**

Robust discretization and iterative methods for multi-physics systems

Jinchao Xu

In this talk, I will present some recent works on discretization and preconditioning techniques for coupled multi-physics systems. Examples include Navier-Stokes equations, magnetohydrodynamics, complex fluids, Darcy-Stokes coupling and multi-phase flow in porous media. Both conforming and DGM will be discussed. Particular technical issues to be addressed include the treatment of the divergence-free condition and the strongly discontinuous coefficients in the design of both discretization and preconditioning methods.

Chair: Ralf Kornhuber

List of Participants

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Zhang, Hui (Universite de Genève, Switzerland)
Zikatanov, Ludmil (Penn State, USA, USA)
Zou, Jun (Chinese University of Hong Kong, Hong Kong SAR China)

Social Events

Sunday evening - Welcome reception at Parco Ciani

The DD22 Welcome reception will be held at the Ristorante Parco Ciani from 19:00 to 21:00.

Wednesday afternoon - Visit at CSCS

Bus from USI to CSCS

14:45 - 14:55	CSCS Welcome
15:00 - 15:45	1st group visit
15:00 - 15:45	2nd group introduction of CSCS
15:50 - 16:35	2nd group visit
15:50 - 16:35	1st group introduction of CSCS
~16:45	End of the tour

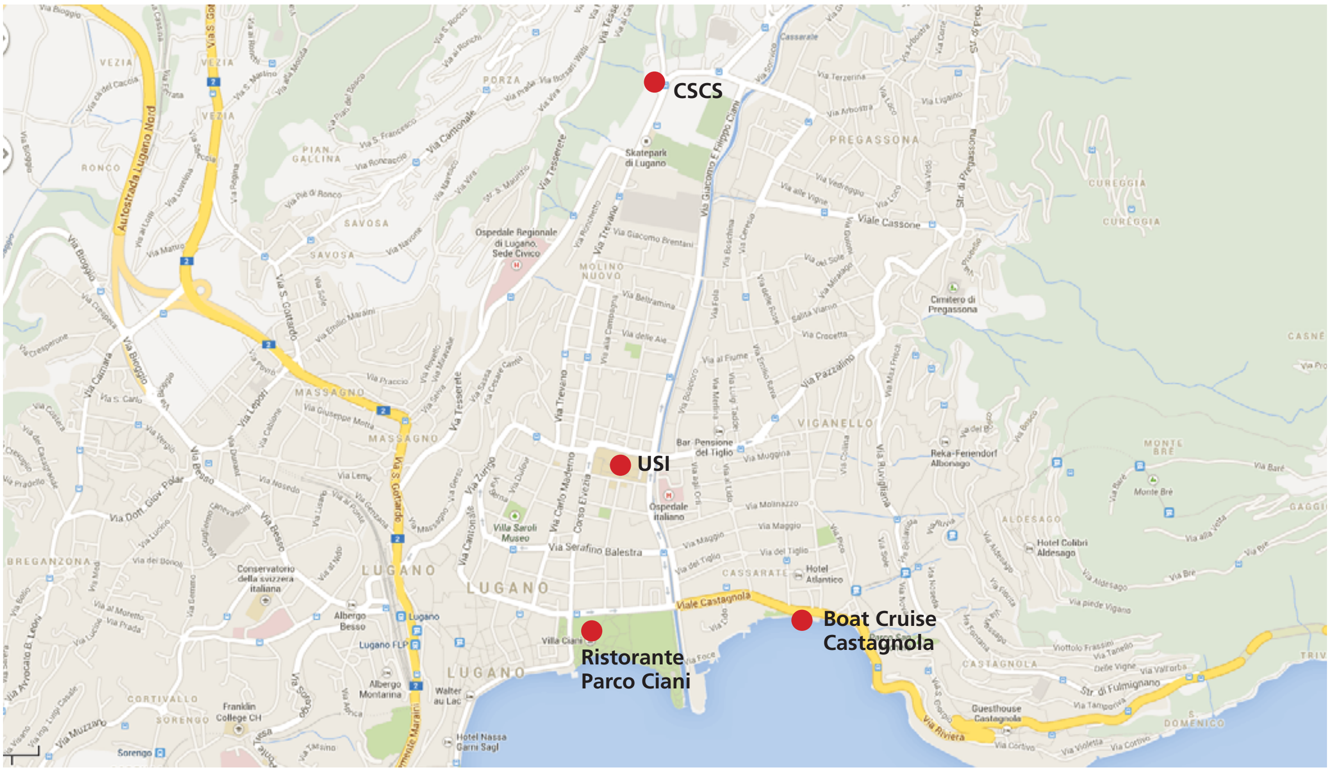
Bus to the pier

Wednesday evening - Boat Cruise and Banquet

The social event programme will begin with a Boat Cruise on the Lugano lake and a stop in Morcote.
The boat leaves at 18:00 from Castagnola. The pier is located in Via Castagnola 12 within the shipyards of the Lugano Lake Navigation company and is reachable from the University with a 15 minute walk along the river. Participants of the CSCS tour will be brought to the pier by bus.

The Conference Banquet will be held on the boat.

Return to the main pier in Lugano around 21:00.


CSCS
USI
Ristorante
Parco Ciani
Boat Cruise
Castagnola

Useful Information

Contact and venue address

Institute of Computational Science
Via G. Buffi 13
6900 Lugano
Switzerland
dd22@usi.ch
dd22.ics.usi.ch

Internet access

Conference delegates have access to a dedicated wi-fi network.
SSID: dd22
Password: Lugano2013

Lunch

Lunch will be served in the foyer of the Aula Magna at the following times: Monday 12:30, Tuesday 12:15, Wednesday 12:15, Thursday 12:15, Friday 12:45.

Registration desk

The registration desk will be open as follows:
- Monday: from 08:00 Foyer of the main building
- Tuesday: from 08:00 Foyer Aula Magna

Guest tickets

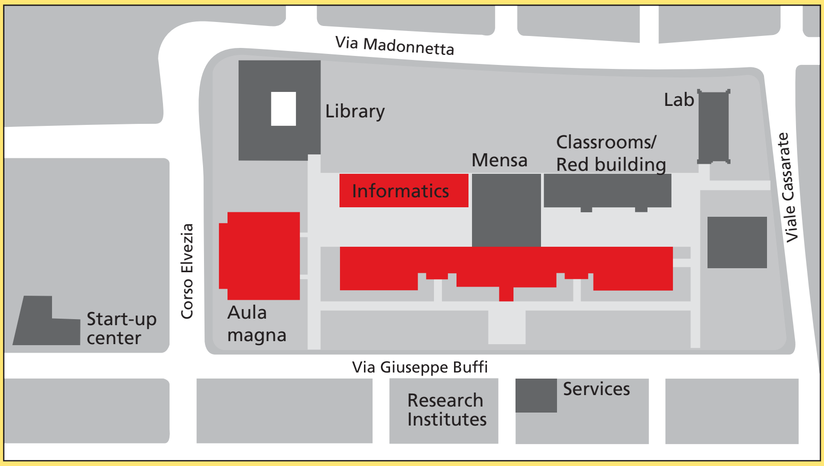
Subject to availability additional tickets for the Conference Banquet can be purchased for CHF 100 (students CHF 75) at the Registration Desk until Tuesday 10:30.

Emergency numbers

DD22: +41 58 666 46 90
USI Campus Security (17:00-07:00): +41 58 666 4730
Ambulance: 144
Police: 117

Auditorium, Room 351 and Room 402 are located in the Main Building.

Room 15 is located in the Informatics Building.



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