# Preface of DD23 Book of Proceedings

The proceedings of the 23rd International Conference on Domain Decomposition Methods contain developments up to 2015 in various aspects of domain decomposition methods bringing together mathematicians, computational scientists, and engineers who are working on numerical analysis, scientific computing, and computational science with industrial applications. The conference was held on Jeju Island, Korea, July 6-10, 2015.

## Background of the Conference Series

The International Conference on Domain Decomposition Methods has been held in fourteen countries throughout Asia, Europe, and North America beginning in Paris in 1987. Held annually for the first fourteen meetings, it has been spaced out since DD15 at roughly 18-month intervals. A complete list of the past meetings appears below. The twenty-third International Conference on Domain Decomposition Methods was the first one held in Korea and it took place on the beautiful Jeju Island.

The main technical content of the DD conference series has always been mathematical, but the principal motivation was and is to make efficient use of distributed memory computers for complex applications arising in science and engineering. As we approach the dawn of exascale computing, where we will command $10^{18}$ floating point operations per second, clearly efficient and mathematically well-founded methods for the solution of large-scale systems become more and more important-as does their sound realization in the framework of modern HPC architectures. In fact, the massive parallelism, which makes exascale computing possible, requires the development of new solutions methods, which are capable of efficiently exploiting this large number of cores as well as the connected hierarchies for memory access. Ongoing developments such as parallelization in time asynchronous iterative methods, or nonlinear domain decomposition methods show that this massive parallelism does not only demand for new solution and discretization methods, but also allows to foster the development of new approaches.

The progress obtained in domain decomposition techniques during the last decades has led to a broadening of the conference program in terms of methods and applications. Multi-physics, nonlinear problems, and space-time decomposition methods are more prominent these days than they have been previously. Domain decomposition has always been an active and vivid field, and this conference series is representing well the highly active and fast advancing scientific community behind it. This is also due to the fact that there is basically no alternative to domain decomposition methods as a general approach for massively parallel simulations at a large scale. Thus, with growing scale and growing hardware capabilities, also the methods can-and have to-improve.

However, even if domain decomposition methods are motivated historically by the need for efficient simulation tools for large scale applications, there are also many interesting aspects of domain decomposition, which are not necessarily motivated by the need for massive parallelism. Examples are the choice of transmission conditions between sub-domains, new coupling strategies, or the principal handling of interface conditions in problem classes such as fluid structure interaction or contact problems in elasticity.

While research in domain decomposition methods is presented at numerous venues, the International Conference on Domain Decomposition Methods is the only regularly occurring international forum dedicated to interdisciplinary technical interactions between theoreticians and practitioners working in the development, analysis, software implementation, and application of domain decomposition methods.

The list of previous Domain Decomposition Conferences is the following:

1. Paris, France, January 7-9, 1987
2. Los Angeles, USA, January 14-16, 1988
3. Houston, USA, March 20-22, 1989
4. Moscow, USSR, May 21-25, 1990
5. Norfolk, USA, May 6-8, 1991
6. Como, Italy, June 15-19, 1992
7. University Park, Pennsylvania, USA, October 27-30, 1993
8. Beijing, China, May 16-19, 1995
9. Ullensvang, Norway, June 3-8, 1996
10. Boulder, USA, August 10-14, 1997
11. Greenwich, UK, July 20-24, 1998
12. Chiba, Japan, October 25-20, 1999
13. Lyon, France, October 9-12, 2000
14. Cocoyoc, Mexico, January 6-11, 2002
15. Berlin, Germany, July 21-25, 2003
16. New York, USA, January 12-15, 2005
17. St. Wolfgang-Strobl, Austria, July 3-7, 2006
18. Jerusalem, Israel, January 12-17, 2008
19. Zhangjiajie, China, August 17-22, 2009
20. San Diego, California, USA, February 7-11, 2011
21. Rennes, France, June 25-29, 2012
22. Lugano, Switzerland, September 16-20, 2013
23. Jeju Island, Korea, July 6-10, 2015

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## About the Twenty-Third Conference

The twenty-third International Conference on Domain Decomposition Methods had 108 participants from over 22 countries. It was the first one to be held in Korea.

As in previous meetings, DD23 featured a well-balanced mixture of established and new topics, such as space-time domain decomposition methods, isogeometric analysis, exploitation of modern HPC architectures, optimal control and inverse problems, and electromagnetic problems. From the conference program, it is evident that the growing capabilities in terms of theory and available hardware allow for increasingly

complex nonlinear and multi-scale simulations, confirming the huge potential and flexibility of the domain decomposition idea. The conference, which was organized over an entire week, featured presentations of three different types: The conference contained

- 11 invited presentations, fostering also younger scientists and their scientific development, selected by the International Scientific Committee,
- a poster session, which also gave rise to intense discussions with the mostly younger presenting scientists,
- 9 minisymposia, arranged around a special topic,
- 7 sessions of contributed talks

The present proceedings volume contains a selection of 42 papers, split into 8 plenary papers, 21 minisymposia papers, and 13 contributed papers and posters.

### *Sponsoring Organizations*

- KAIST Mathematics Research Station
- National Institute for Mathematical Sciences
- The Korean Federation of Science and Technology Societies
- KISTI Supercomputing Center
- A3 Foresight Program
- NVIDIA
- Jeju Convention & Visitors Bureau

The organizing committee would like to thank the sponsors for the financial support.

### *Local Organizing/Program Committee Members*

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## Research Activity in Domain Decomposition According to DD23 and its Proceedings

The conference and the proceedings contain three parts: the plenary presentations, the minisymposia presentation, and the contributed talks and posters.

### *Plenary Presentations*

The plenary presentations of the conference have been dealing with established topics in Domain Decomposition as well as with new approaches.

- Global convergence rates of some multilevel methods for variational and quasi-variational inequalities, Lori Badea (Institute of Mathematics of the Romanian Academy, Romania)
- Robust solution strategies for fluid-structure interaction problems with applications, Yuri Bazilevs (University of California, San Diego, USA)
- BDDC algorithms for discontinuous Petrov Galerkin methods, Clark Dohrmann (Sandia National Laboratories, USA)

- Schwarz methods for the time-parallel solution of parabolic control problems, Felix Kwok (Hong Kong Baptist University, Hong Kong)
- Computational science activities in Korea, Jysoo Lee (KISTI, Korea)
- Recent advances in robust coarse space construction, Frédéric Nataf (Université Paris 6, France)
- Domain decomposition preconditioners for isogeometric discretizations, Luca F. Pavarino (University of Milano, Italy)
- Development of nonlinear structural analysis using co-rotational finite elements with improved domain decomposition method, Sang Joon Shin (Seoul National University, Korea)
- Adaptive coarse spaces and multiple search directions: Tools for robust domain decomposition algorithms, Nicole Spillane (Universidad de Chile, Chile)
- Element based algebraic coarse spaces with applications, Panayot Vassilevski (Lawrence Livermore National Laboratory, USA)
- Preconditioning for nonsymmetry and time-dependence, Andrew Wathen (University of Oxford, United Kingdom)

## *Minisymposia*

There are 9 minisymposia organized within DD23:

1. Space-time domain decomposition methods (Ulrich Langer, Olaf Steinbach)

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

2. Domain decomposition with adaptive coarse spaces in finite element and isogeometric applications (Durkbin Cho, Luca F. Pavarino, Olof B. Widlund)

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

3. Domain decomposition and high performance computing (Santiago Badia, Jakub Šístek, Kab Seok Kang)

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

4. Domain decomposition methods and parallel computing for optimal control and inverse problems (Huibin Chang, Xue-Cheng Tai, Jun Zou)

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

5. Efficient solvers for electromagnetic problems (Victorita Dolean, Zhen Peng)

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

6. Domain decomposition methods for multiscale PDEs (Eric Chung, Hyea Hyun Kim)

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

7. Birthday minisymposium Ralf Kornhuber (60th Birthday) (Rolf Krause, Martin Gander)

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

8. Recent approaches to nonlinear domain decomposition methods (Axel Klawonn, Oliver Rheinbach)

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

9. Tutorial for domain decomposition on heterogenous HPC (Junard Lee)

   At this minisymposium, we will have a tutorial session. We will cover heterogeneous HPC architecture, CUDA programming language, Open ACC directives and how to implement these technologies to accelerate PDE solvers specially domain decomposition method.


### *Contributed Presentations and Posters*

The contributed talks have been distributed over 7 different sessions:

1. Domain Decomposition Methods for Applications

2. Optimized Schwarz Methods
3. Fast Solvers for Nonlinear and Unsteady Problems
4. Domain Decomposition Methods with Lagrange Multipliers
5. Efficient Methods and Solvers for Applications
6. Multiphysics Problems
7. Coarse Space Selection Strategies

The proceedings part with poster presentations is also a real treasure trove for new ideas in domain decomposition methods.

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