

The Science of Mathematical Modeling, Numerical Computing, Optimization, and Design

A Symposium in Honour of Professor Martin Berggren

Program at a glance

October 14

12:00–13:15	Lunch
13:15–13:30	Intro/Welcome
13:30–14:00	Niels Aage
14:00–14:30	Rainer Picard
14:30–15:00	Dan Henningson
15:00–15:30	Coffee break
15:30–16:00	Stephan Schmidt
16:00–16:30	Juliette Chabassier
16:30–17:00	Anton Evgrafov
19:00–	Dinner

October 15

9:00– 9:30	Jarmo Mallinen
9:30–10:00	Eddie Wadbro
10:00–10:30	Coffee break
10:30–11:00	Ole Sigmund
11:00–11:30	Gunilla Kreiss
11:30–12:00	Dirk Pauly
12:00–	Closing and lunch

Invited speakers

- **Niels Aage**, Department of Civil and Mechanical Engineering, DTU, Technical University of Denmark, Denmark
- **Juliette Chabassier**, Inria Bordeaux Sud Ouest, France
- **Anton Evgrafov**, Department of Mathematical Sciences, Aalborg University, Denmark
- **Dan Henningson**, Department of Mechanics, KTH Royal Institute of Technology, Sweden
- **Gunilla Kreiss**, Department of Information Technology; Division of Scientific Computing, Uppsala University, Sweden
- **Jarmo Malinen**, Department of Mathematics and Systems Analysis, Aalto University, Helsinki
- **Dirk Pauly**, Institute of Analysis, Faculty of Mathematics, Technical University of Dresden, Germany
- **Rainer Picard**, Institute of Analysis, Faculty of Mathematics, Technical University of Dresden, Germany
- **Stephan Schmidt**, Department of Mathematics, Trier University, Germany
- **Ole Sigmund**, Department of Civil and Mechanical Engineering, DTU, Technical University of Denmark, Denmark
- **Eddie Wadbro**, Department of Mathematics and Computer Science, Karlstad University, Sweden

Details on the presentations

Niels Aage — On the enforcement of internal boundary conditions in structural optimization

Abstract

Sufficiently accurate enforcement of internal boundary conditions is a key challenge in structural optimization for coupled multiphysics problems. This talk presents and discusses various recent approaches and advances in mainly density-based topology optimization frameworks, but also and cut-element methods, for applications in vibro-acoustics with viscothermal losses and thermofluidics. Strategies for the robust representation of complex interfaces within the design domain, enabling the optimization of systems with strong field interactions, are discussed. Examples highlight the necessity of such methodologies for addressing challenging multiphysical design problems, and demonstrates that when successful, such methods offers novel insights into complex engineering applications.

Rainer Picard — Evo-Systems as a Recipe for Modeling

Abstract

We recall the concept of evo-systems and illustrate their utility for unifying different fields in mathematical physics and engineering. We shall be discussing various classical systems of differential equations as particular instances of the framework of evo-systems. The Maxwell system and its relatives are a particular topic of interest.

Dan Henningson — Large scale numerical experiments of unsteady aerodynamic flows and the role of laminar-turbulent transition

Abstract

Fluid flows subject to time-dependent external forces or boundary conditions are ubiquitous in aeronautical applications. Whether one considers pitching wings, dynamic stall or the gust response of wind turbines, the flow is unsteady or non-autonomous. We investigate the influence of unsteadiness on the non-linear flow evolution, as well as on the linear response to small disturbances that determines their stability and the subsequent transition to turbulence. The simulations are performed with a high-order spectral-element method (SEM) with the domain discretized by up to several billion grid points. The capabilities of our SEM solvers are presented and two flow cases are studied in more detail. First, a small amplitude pitching wing where the laminar-turbulent interface drastically changes its chordwise location, and subsequently the dynamic stall of an airfoil undergoing a large pitchup motion.

We assess the potential of the optimally time-dependent (OTD) framework for transient linear stability analysis of flows with arbitrary time-dependence using a localized linear/non-linear implementation. This framework is used to track the linear stability of laminar separation bubbles on unsteady wings. For the pitching case the global mode corresponding to an absolute local instability is identified at the rear of the separation bubble, causing its breakdown to turbulence.

The influence of low-amplitude free-stream disturbances on the onset of dynamic stall is also investigated and the onset of intermittent vortex shedding during the bubble bursting is documented. Here the Proper Orthogonal Decomposition framework is extended to include time dependence. This allows for the objective extraction of transient structures from data. Large structures shedding the bubble are identified as precursors of the detachment of the dynamic stall vortex.

Stephan Schmidt — Shape Hessians out of a Unified Discrete-Continuous Sensitivity Analysis Method

Abstract

The talk focuses on how the methodology of “A Unified Discrete-Continuous Sensitivity Analysis Method for Shape Optimization” by M. Berggren can be used to easily and consistently derive a variational formulation for shape Hessians and even higher derivatives for shape optimization problems. In particular, we discuss how a unified finite element formulation for a PDE-constrained shape optimization problem can be derived, which performs Newton-steps to solve the fully coupled problem, i.e., geometry and PDE state. Applications will include Capillary surfaces as generalized Plateau Problems but also inverse problems and CFD.

Juliette Chabassier — Understand and predict acoustic properties of heritage instruments: the case of a Besson trumpet of the Musée de la Musique of Paris

Abstract

Playing historical wind instruments is often incompatible with the policy of conservation and protection of museum collections. Certain musical and acoustic properties of these instruments therefore remain unknown. Theoretical models can predict some of these properties based solely on knowledge of the instrument’s geometry and functioning. A collaboration between the Makutu team at Inria Bordeaux Sud Ouest, the Musée de la Musique - Philharmonie de Paris, the Institut Technologique Européen des Métiers de la Musique (ITEMM) in Le Mans, and the Centre de Recherche et de Restauration des Musées de France (C2RMF) has resulted in a procedure applied to the collection of the Besson Museum, which was one of the leading manufacturers of brass instruments of the early 20th century, and more specifically to several natural trumpets. The geometry of the instruments was measured non-invasively by X-ray tomography at the C2RMF. After extracting their bore (change in internal diameter), their input impedance was calculated. For one specific trumpet (E.0925), the simulated data was compared with the measurements and found to be in excellent agreement. Despite many uncertainties about how these instruments were played, simulated sounds can be calculated. An “acoustically informed” copy of the E.0925 trumpet was made from the X-ray and impedance data and played by a professional trumpet player. This allows the simulated sounds to be compared.

Anton Evgrafov — Nonlocal optimal design and its localization

Abstract

Nonlocal equations and models form an actively developing area of applied mathematics. Their applications include image processing, inverse problems, pattern formation, fractional partial differential equations, and nonlocal characterisation of Sobolev spaces. Our interest in nonlocal modelling stems from its utilization as an alternative description of continuum mechanics, particularly useful in scenarios involving long-range interactions (such as nano-mechanical systems) or where traditional differentiability assumptions fail (such as in the case of crack propagation or cavitation).

Bond-based peridynamics is one of the simplest nonlocal models of continuum mechanics. We study an optimal design problem for a system governed by such a nonlocal, nonlinear model, namely a nonlocal analogue of a p-Laplacian operator. Its objective, stated in the context of heat conduction, is to optimally distribute a limited amount of conductive material in order to minimize the weighted average temperature across the computational domain. We will primarily focus on the limiting behaviour of this problem in the case of the vanishing nonlocal horizon, which necessitates considering instances of rough, heterogeneous diffusion coefficients. Our approach is based on the principle of minimal complementary energy, which we formulate and analyze in the context of nonlinear nonlocal peridynamic diffusion. Through a novel construction of operators relating the local, vectorial fluxes with their nonlocal, two-point counterparts we rigorously establish the local optimal design problem as a Gamma-limit of the corresponding nonlocal optimal design problems.

Jarmo Malinen — Modelling signal propagation for Village radio networks

Co-authors: Jarmo Malinen and Juho Arala

Abstract

Village radio networks are a Finnish grassroots-level communications solution for situations when mobile networks and the internet are unavailable. These networks operate on the license free Finnish RHA68 VHF band near 70 MHz using FM transmissions for speech. The primary propagation mode is line-of-sight but some ground wave propagation is possible, too.

Tools for radio network planning are implemented, utilising terrain elevation data from public sources. The algorithms use geometric “ray tracing” models to evaluate the feasibility of the radio connections between fixed locations. Quality numbers for connections are calculated for pairs of node locations that are typically village houses, public and private spaces, etc., that are deemed suitable for village radio stations. The proposed models only require terrain elevations on straight lines between the nodes whereas a direct computational EM approach would require an unreasonable amount of terrain/conductivity data as well as excessive computing power.

This study presents three kinds of quality numbers for connections:

1. Mast number equals the smallest total height of two mast needed to establish a line-of-sight connection between two locations.
2. Curvature number equals the smallest curvature that allows circular arc between two nodes to cross terrain obstacles.
3. Hybrid number is a combination where mast numbers are augmented with properly scaled curvature information.

Inspired by the physical attenuation of signal, the quality numbers are refined by introducing distance penalisation.

The quality numbers are used in network optimisation by using them as weights of the connections between the node locations and calculating the lowest cost minimum spanning trees of the networks. In stability evaluation, some nodes are randomly removed from the networks in order to find the connections that appear robustly on several partial network variations. This simulation is carried out many times, and the connections that appear most often in the minimum spanning trees are regarded relevant for the network planning.

Eddie Wadbro — Design optimization for Newtonian cooling heat sink

Abstract

We consider the problem of optimizing heat sink design. A computationally attractive alternative to modeling the coupled thermal-fluid system is to use the Poisson equation with Newtonian cooling boundary conditions. To enable efficient simulation on a fixed computational domain, we adopt a fictitious domain formulation with a weak material approximation: the conductivity is set to one in the solid subdomain Ω_s and to a small positive parameter ϵ in the surrounding fictitious region. We derive a priori error estimates showing that the solution restricted to Ω_s converges to the true solution with an $O(\epsilon)$ error in the $H^1(\Omega_s)$ norm. From a design perspective, we augment the objective function with a term from the standard thermal compliance problem for a plate with constant heating. Numerical experiments demonstrate that the proposed approach improves both thermal performance and computational efficiency compared to standard methods.

Ole Sigmund — Topology Optimization with uncertainties

Abstract

Free optimization may lead to extreme structures that only work for perfect realizations. Thus it is important include manufacturing variations in the optimization scheme. We discuss the SOTA and recent developments within inclusion of random variations in topology optimization and show examples of its importance within structural and wave propagation optimization problems.

Gunilla Kreiss — Stability and accuracy for initial-boundary value problems revisited

Abstract

Stability and accuracy for a numerical method approximating an initial boundary value problem are inherently linked together. Stability means that perturbations of data have a bounded effect on the discrete solution, and is usually characterized by a precise estimate, which links the perturbations of data to perturbations of the solution. Such an estimate can be directly used to quantify the accuracy of the method. A very convenient and common way to investigate stability, and hence accuracy, is to use the energy method. If this approach fails one may instead attempt to get results by Laplace transforming in time. Such analysis is usually more involved, but sharper results may follow. In this talk we will discuss the two basic approaches, both in continuous and discrete settings. We will also show two examples where, even though the energy method is applicable, it is rewarding to consider the problem in the Laplace domain. In the first case we get sharper accuracy results, and in the second case we get sharper temporal bounds.

Dirk Pauly — Traces for Hilbert Complexes

Joint work with Ralf Hiptmair and Erick Schulz, ETH Zürich

Abstract

We study a new notion of trace operators and trace spaces for abstract Hilbert complexes. We introduce trace spaces as quotient spaces/annihilators. We characterize the kernels and images of the related trace operators and discuss duality relationships between trace spaces. We elaborate that many properties of the classical boundary traces associated with the Euclidean de Rham complex on bounded Lipschitz domains are rooted in the general structure of Hilbert complexes. We arrive at abstract trace Hilbert complexes that can be formulated using quotient spaces/annihilators. We show that, if a Hilbert complex admits stable “regular decompositions” with compact lifting operators, then the associated trace Hilbert complex is Fredholm. Incarnations of abstract concepts and results in the concrete case of the de Rham complex in three-dimensional Euclidean space will be discussed throughout. References

[1] R. Hiptmair and D. Pauly and E. Schulz, Traces for Hilbert complexes, *Journal of Functional Analysis* 284(10) (2023), 50 pp.