28TH IFIP TC 7 CONFERENCE
ON SYSTEM MODELLING AND OPTIMIZATION

July 23–27, 2018
Universität Duisburg-Essen, Essen

BOOK OF ABSTRACTS
CONTENTS

PLENARIES 3
MINISYMPOSIA 11
CONTRIBUTED TALKS 89
PARTICIPANTS 97
SPONSORS 112
Shape optimization is indispensable for designing and constructing industrial components. Many problems that arise in application, particularly in structural mechanics and in the optimal control of distributed parameter systems, can be formulated as the minimization of functionals which are defined over a class of admissible domains.

The application of gradient based minimization algorithms involves the shape functionals’ derivative with respect to the domain under consideration. Such derivatives can analytically be computed by means of shape calculus and enable the paradigm first optimize then discretize. Especially, by identifying the sought domain with a parametrization of its boundary, the solution of the shape optimization problem will be equivalent to solving a nonlinear pseudo-differential equation for the unknown parametrization.

The present talk aims at surveying on analytical and numerical methods for shape optimization. In particular, besides several applications of shape optimization, the following items will be addressed:

- first and second order optimality conditions;
- discretization of shapes;
- existence and convergence of approximate shapes;
- efficient numerical techniques to compute the state equation.
Ralf Kornhuber (Freie Universität Berlin)

**Particles in membranes**

The interplay of curvature and particles diffusing in biological membranes is responsible for organizing and shaping the membrane and gives rise to a variety of cellular functions. Hybrid models combining a continuum representation of the membrane with discrete, highly coarse grained descriptions of particles have a long history in physics, while mathematical analysis is still in its infancy. We present a hierarchy of variational formulations of existing hybrid models, where the coupling of particles and membrane is formulated in terms of linear constraints to the minimization of the Canham–Helfrich energy of the membrane. Utilizing concepts from shape calculus, we derive a numerically feasible representation of the derivative of the minimal Canham–Helfrich energy for given particle positions with respect to the particle positions. This representation is applied in numerical investigations of the clustering behavior of BAR domains and paves the way to Langevin dynamics of particles in membranes.

This is joint work of Charles M. Elliott (Warwick), Carsten Gräser (FU Berlin), Tobias Kies (FU Berlin), and Ralf Kornhuber (FU Berlin).
Karl Kunisch (Karl-Franzens Universität Graz & RICAM, Linz)

Monotone and primal-dual algorithms for optimization problems involving $\ell^p$-like functionals with $p \in [0, 1)$

Nonsmooth nonconvex optimization problems involving the $\ell^p$ quasi-norm, $p \in [0, 1)$, are the focus of this talk. Two schemes are presented and analyzed, and their performance in practice is discussed: A monotonically convergent scheme and a primal dual active set scheme. The latter heavily relies on a non-standard formulation of the first order optimality conditions. Numerical tests include an optimal control problem, models from fracture mechanics and microscopy image reconstruction. - We also remark infinite horizon closed loop optimal control problems with $\ell^p$ cost.
Marta Lewicka  (University of Pittsburgh)

*Models for thin prestrained structures*

Variational methods have been extensively used in the past decades to rigorously derive nonlinear models in the description of thin elastic films. They allowed to justify or to improve several classical models, under the hypothesis that rotations minimize the stored energy density at any point. On the other hand, natural growth or differential swelling or shrinking might lead to models where an elastic body aims at reaching a space-dependent metric, which may be not realizable. We will describe the effect of such incompatible prestrain metrics on the singular limits bidimensional models. We will discuss metrics that vary across the specimen in both the midplate and the thin (transversal) directions. We will also cover the case of the oscillatory prestrain and exhibit its relation to the non-oscillatory case via identifying the effective metric, exhibiting the role of the separate entries of the Riemann curvature tensor of the prestrain.
Pierre Cardaliaguet  (Université Paris-Dauphine)

Some aspects of Mean Field Games

Mean Field Games (MFG) is a new and challenging mathematical topic which analyzes the dynamics of a very large number of interacting rational agents. Introduced by Lasry and Lions around 2005, the MFG now appear in many different frameworks: in macroeconomic models, in finance, in crowd motions, in vaccination campaign models, etc. We will first introduce the basic MFG models and discuss their meaning and their well-posedness. We will also discuss why these MFG models are expected to pop up in practice and explain how they can appear as limit of models with finitely many agents.
Carola-Bibiane Schönlieb  (University of Cambridge)

Deep and shallow learning approaches for regularised inversion in imaging

In this talk we discuss the idea of data-driven regularisers, investigating two parametrisation: total variation type regularisers and deep neural networks. This talk is based on joint works with J. C. De Los Reyes, L. Calatroni, C. Chung, T. Valkonen, S. Lunz and O. Oektem.
Tamás Terlaky  *(Lehigh University, Bethlehem, PA, USA)*

A novel approach to discrete truss design problems

Discrete truss sizing problems are challenging to solve due to their combinatorial, non-linear, and non-convex nature. Consequently, truss sizing problems become unsolvable as the size of the truss grows. In this presentation, we focus on modeling and efficiently solving discrete truss sizing problems, where the cross-sectional areas of the bars take only discrete values. We consider various mathematical formulations with the objective to minimize the truss weight. The non-convex Euler buckling constraints and Hooke’s law are also considered. We propose novel Mixed Integer Linear Optimization (MILO) reformulations of the non-convex models. The resulting MILO models, for large real world trusses, are not solvable with existing MILO solvers. We propose a novel solution methodology to solve the MILO models, and present encouraging computational results which demonstrate the power of the novel computational methodology.

Based on joint work with: Mohammad Shahabsafa, Ali Mohammad-Nezhad, Luis Zuluaga Dept. of Industrial and Systems Engineering, Lehigh University, Bethlehem, PA, USA Sicheng He, John T. Hwang, Joaquim R. R. A. Martins Dept. of Aerospace Engineering, University of Michigan, Ann Arbor, MI, USA
Optimal transport and Wasserstein metrics are becoming increasingly popular tools in many applied fields. In particular, they provide a robust and intuitive measure of discrepancy for histograms and mass distributions, which can for instance be exploited in data clustering, data retrieval, image interpolation, deformation analysis, and many more problems. Plain Wasserstein metrics can only compare nonnegative measures of equal mass, which often does not reflect the requirements of applications. For this reason several extensions to so-called unbalanced transport with mass changes have been proposed. I will present recent work with Bernhard Schmitzer, in which we discuss and analyse the special case of unbalanced Wasserstein-1 transport, which is not only computationally efficient, but in which mass change and mass transport also decouple to an extent that allows a comprehensive understanding of this discrepancy measure.
MINISYMPOSIA

MS 01: KREUZER, SMEARS 12
MS 02: GÖTSCHEL, SIEBENBORN 14
MS 03: NEITZEL, WACHSMUTH 17
MS 04: GUGAT, TRÖLTZSCH 18
MS 05: BREITEN, PFEIFFER 22
MS 06: LASIECKA, WEBSTER 25
MS 07: PIETSCHMANN, WOLFRAM 31
MS 08: AVDONIN, MAKSIMOV 34
MS 09: BOTKIN, TUROVA 36
MS 10: FESTA, GÖTTLICH, KNAPP 40
MS 11: HOFMANN, PLATO 44
MS 12: GONG, JIN, LI 48
MS 14: HERZOG, KOSTINA 51
MS 15: SCHMITZER, WIRTH 55
MS 16: AVALOS, GÜVEN GEREDELI 59
MS 17: BERTRAND, BIRK 63
MS 18: PAGANINI, STURM 65
MS 19: BRUNE, SCHLOTTBOM 69
MS 20: STETTNER 72
MS 21: KRÖNER, WINKLER 79
MS 22: KALTENBACHER, WALD 82
MS 23: BETZ, CHRISTOF 85
Convergence of adaptive $C^0$IPG methods for the biharmonic problem.

Alexander Dominicus
TU Dortmund

$C^0$ interior penalty Galerkin ($C^0$IPG) methods for fourth order elliptic problems benefits from simple standard Lagrange finite element spaces which are also used for second order problems. Although a posteriori estimators are available in the literature, due to the non-conformity of the ansatz spaces, a rigorose convergence analysis of adaptive $C^0$IPG methods for elliptic fourth order problems appears to be difficult. In this talk we present a basic convergence analysis for adaptive $C^0$IPG methods for the biharmonic problem which provides convergence without rates. Based on ideas in a recent result from Kreuzer and Georgoulis the theory is accomplished by using several compactness properties of (broken) Sobolev spaces and a new limit space of the adaptively created non-conforming discrete spaces.

Rate optimal adaptivity for non-symmetric/indefinite problems

Michael Feischl
Karlsruhe Institute of Technology (KIT)

We develop a framework which allows us to prove the essential general quasi-orthogonality for non-symmetric and indefinite problems as the stationary Stokes problem or certain transmission problems. General quasi-orthogonality is a necessary ingredient of rate optimality proofs and is the major difficulty on the way to prove rate optimal convergence of adaptive algorithms for many strongly non-symmetric or indefinite problems. The proof exploits a new connection between the general quasi-orthogonality and LU-factorization of infinite matrices.

Numerical approximation of planar oblique derivative problems in nondivergence form

Dietmar Gallistl
University of Twente

A numerical method for approximating a uniformly elliptic oblique derivative problem in two-dimensional simply-connected domains is proposed. The numerical scheme employs a mixed formulation with piecewise affine functions on curved finite element domains. The direct approximation of the gradient of the solution turns the oblique derivative boundary condition into an oblique direction condition. A priori and a posteriori error estimates as well as numerical computations on uniform and adaptive meshes are provided.
A posteriori estimates for optimal control problems

Fernando Gaspoz
Universität Stuttgart

We consider finite element solutions to quadratic optimization problems, where the state depends on the control via an elliptic partial differential equation. Exploiting that a suitably reduced optimality system satisfies a Gårding inequality, we derive a priori and a posteriori error estimates for state, dual and control variables.

Instance optimal adaptive Crouzeix-Raviart FEM

Mira Schedensack
Universität Münster

This talk considers an adaptive algorithm with a modified maximum marking strategy for the Poisson problem and the Stokes equations in two dimensions approximated with P1 nonconforming finite elements, also named after Crouzeix and Raviart. The proof of three properties for the nonconforming approximation allows to extend the results of the proof of instance optimality for the conforming approximation of the Poisson problem to this situation. As a consequence, we obtain instance optimality also for the nonconforming approximation.

A quasi-optimal Crouzeix-Raviart method for linear elasticity

Pietro Zanotti
TU Dortmund

We propose a first-order Crouzeix-Raviart method for the displacement formulation of the linear elasticity system. The method involves a jump penalization to enforce the validity of a discrete Korn’s inequality and is quasi-optimal in the energy norm on shape regular meshes. In the two-dimensional case, we derive a robust error estimate for regular solutions of the problem. We also discuss the behavior of the quasi-optimality constant in the nearly incompressible regime and connect it, if time permits, to some recent advances in the discretization of the Stokes problem.
A low-rank in time approach for the differential Riccati equation

Tobias Breiten
*Karl-Franzens-Universität Graz*

Optimal feedback laws for linear quadratic control problems are intimately connected with the differential Riccati equation (DRE). Due to the curse of dimensionality, an explicit computation of the time-varying matrix valued unknown is infeasible for problems related to partial differential equations. A common remedy is to combine low-rank methods with an ODE integration scheme. While this allows to efficiently compute the solution at each individual time instance, the temporal complexity is still tied to the ODE integration scheme. We propose an alternative procedure that is based on a full space-time discretization of the DRE. For the resulting nonlinear system, we discuss a tensor structured Newton iteration. Based on numerical examples, we evaluate the performance of the method for several PDE constrained control problems.

Parallel-in-time PDE-constrained optimization using PFASST

Sebastian Götschel
*Zuse Institute Berlin*

For the solution of optimal control problems governed by parabolic PDEs, methods working on the reduced objective functional are often employed to avoid a full spatio-temporal discretization. The evaluation of the reduced gradient then requires one solve of the state equation, and one backward-in-time solve of the adjoint equation, making the iterative optimization process computationally very demanding.

One approach to decrease the time-to-solution is to utilize the increasing number of CPU cores available in current computers. In addition to more common spatial parallelization, time-parallel methods are receiving increasing interest in recent years. There, iterative multilevel schemes such as PFASST (Parallel Full Approximation Scheme in Space and Time) are currently state of the art, and achieve a significant parallel efficiency of more than 50%.

In this talk, we investigate approaches to use PFASST for the solution of parabolic optimal control problems. Besides enabling time parallelism, the iterative nature of the temporal integrators within PFASST provides additional flexibility for reducing the cost of solving nonlinear equations, re-using previous solutions in the optimization loop, and adapting the accuracy of state and adjoint solves to the optimization progress. We discuss benefits and difficulties, and present numerical examples.
Real-time optimization of thermal ablation cancer treatments

Martin Grepl
RWTH Aachen University

Percutaneous ablation cancer treatments are performed by inserting a probe directly into or close to the tumor. The probe generates heat and destroys the cancerous tissue. Such treatments are becoming increasingly popular due to their potential to be applied to nonresectable tumors, as well as due to the localized nature of the treatment which minimizes the inflicted damage to surrounding healthy tissue and organs.

The problem can be formulated as a parametrized optimal control problem governed by a partial differential equation, the Pennes bio-heat equation. Our goal is to improve the accuracy and effectiveness of ablation treatments by developing reliable and computationally efficient simulations and optimization routines, which can be used not only preoperative in the planning phase, but also in real-time during the treatment. To this end, we employ the reduced basis method as a surrogate model for the solution of the optimal control problem and develop rigorous and efficiently computable a posteriori error bounds for both the optimal control and the associated optimal cost functional value. We present numerical results to confirm the validity of our approach.

A non-intrusive parallel-in-Time method for simultaneous optimization with unsteady PDEs

Stefanie Günther
TU Kaiserslautern

A non-intrusive framework for reducing the overall runtime of conventional gradient-based optimization algorithms for unsteady PDE-constrained optimization problems will be presented. The new framework applies non-intrusive multigrid iterations to the time-domain of existing unsteady PDE solvers as well as unsteady adjoint sensitivity solvers. The multigrid iterations enable time-parallelism such that workload can be distributed onto multiple processors along the time domain and speedup over conventional time-serial approaches can be achieved through greater concurrency. Additionally, the parallel-in-time multigrid iterations are embedded into a simultaneous optimization framework, namely the One-shot method which incorporates design updates towards optimality after each state and adjoint update. Thus, optimality and feasibility of the design and the PDE solution are reached simultaneously which further reduces the runtime overhead of the optimization algorithm when compared to a pure simulation. Due to the non-intrusiveness of the proposed framework, transitioning from a conventional time-serial optimization algorithm to the time-parallel One-shot method requires only minimal additional coding. The benefit of the new framework will be demonstrated on an advection-dominated model problem which shows significant speedup over a conventional time-serial optimization algorithm.
Pre-dual and splitting algorithms for TVD image reconstruction on surfaces

Stephan Schmidt  
*Julius-Maximilians-Universität Würzburg*

Medical imaging and technical 3D scanning is becoming more and more dominant. Thus, there is an increased interest in image post-processing and edge preserving denoising on surfaces. This edge preservation is often achieved by total variation (TV) denoising. Summarizing the above, several algorithmic difficulties arise. On the one hand, the non-smoothness of the TV-norm needs to be taken into account, while on the other hand, the image on the surface needs to be made accessible within computational methods. To this end, we study the TV-denoising with a splitting type algorithm and an alternative approach based on duality. The image will be represented by finite elements on the surface, with discontinuous Galerkin or Raviart-Thomas elements for the respective primal or dual approaches.

Algorithmic aspects of multigrid methods for optimization in shape spaces

Martin Siebenborn  
*Universität Hamburg*

In many applications, which are modeled by partial differential equations, there is a small number of spatially distributed materials or parameters distinguished by interfaces. In order to identify these parameters, it is often more favorable to treat the shape of the interfaces as a variable instead of the parameter itself. Since the involved materials may form complex contours, high resolutions are required in the underlying finite element discretizations. The challenge is to combine methods from PDE constraint shape optimization with HPC techniques and prepare algorithms for supercomputing.

In this talk we discuss the interaction of multigrid methods and shape optimization in appropriate shape spaces. The aim is a scalable algorithm for application on supercomputers, which can only be achieved by mesh-independent convergence. The impact of discrete approximations of geometrical quantities, like the mean curvature, on a multigrid shape optimization algorithm with quasi-Newton updates is investigated.
Full stability for a class of control problems of semilinear elliptic partial differential equations

Qui Nguyen Thanh  
_Julius-Maximilians-Universität Würzburg_

We investigate full Lipschitzian and full Hölderian stability for a class of control problems governed by semilinear elliptic partial differential equations, where all the cost functional, the state equation, and the admissible control set of the control problems undergo perturbations. We establish explicit characterizations of both Lipschitzian and Hölderian full stability for the class of control problems. We show that for this class of control problems the two full stability properties are equivalent. In particular, the two properties are always equivalent in general when the admissible control set is an arbitrary fixed nonempty, closed, and convex set.

Optimal control problems in non-convex domains with regularity constraint

Johannes Pfefferer  
Technical University of Munich

This talk is concerned with a tracking type optimal control problem subject to the Poisson equation. The control enters the problem on the right hand side of the partial differential equation. As specialty, the underlying domain is assumed to be non-convex. In this case, it is well known that the solution to the Poisson equation, and thus the state of the optimal control problem, does not belong to $H^2(\Omega)$ in general. The lack of regularity is due to the appearance of singular terms in the solution caused by the non-convex corners. However, we are interested in optimal states which nevertheless belong to $H^2(\Omega)$. Thus, we are imposing a regularity constraint on the state. For instance, this can be achieved by considering a closed and convex subset of $L^2(\Omega)$ as control space which only allows for $H^2(\Omega)$-regular states. In the present talk, we discuss existence and uniqueness of solutions to such problems. Moreover, optimality conditions are presented. At the end of the talk, we also state one possible approach to discretize with finite elements the problems under considerations, and show related error estimates.

The subject of this talk is inspired by a paper recently submitted by Jarle Sogn and Walter Zulehner.
**How shape calculus profits from regularity theory: probabilistic lifespan optimization**

Laura Bittner  
*Bergische Universität Wuppertal*

Mechanic devices under cyclic loading are exposed to forces like friction, tension and rotation which cause stress states in the component’s material. These states influence the reliability of the component and can be calculated by the PDE of linear elasticity. Since it is impossible to predict exactly, when and where the components surface will break, it is important to combine a stochastic approach with the common deterministic lifetime calculation.

The resulting objective functional \( J(\Omega, Du(\Omega)) \) determines the failure probability depending on the shape \( \Omega \) and the 1st (or higher) order derivatives of the displacement \( u(\Omega) \). We intend to minimize these failure probabilities by shape calculus methods.

In contrast to common cases, the shape functionals that arise from this strategy are usually not defined on \( H^1(\Omega, \mathbb{R}^n) \) and can't be treated by established methods.

We solve this problem by application of regularity theory for elliptic PDE: We show the existence and uniqueness of higher order differentiable solutions \( u(\Omega) \) and shape derivatives \( u'(\Omega) \). Last but not least, we prove existence of Euler derivatives \( DJ(\Omega) \) and shape gradients \( \nabla J(\Omega) \) for a big class of highly irregular objective functionals.

**Turnpike theory for boundary control problems with hyperbolic systems**

Martin Gugat  
*Friedrich-Alexander-Universität Erlangen-Nürnberg*

Often it is possible to steer the state of a dynamic system rapidly to a static state. If the static state is the solution of a static optimal control problem, this leads to approximate solutions of the corresponding dynamic optimal control problem. In this talk we discuss the relation between the static optimal controls and the dynamic optimal controls. Results of this type are called turnpike results and are well-known since the pioneering work of John von Neumann. In this talk we consider turnpike theory for problems of optimal boundary control of hyperbolic systems. Although for systems governed by ordinary differential equations turnpike theory is well-established, see for example the work of Alexander Zaslavski, in the framework of pde-constrained optimal control problems turnpike results have been developed only recently, see for example "Optimal Neumann control for the 1D wave equation: Finite horizon, infinite horizon, boundary tracking terms and the turnpike property", Gugat M, Trelat E, Zuazua E, Systems & Control Letters 90, 61-70, 2016.
Null-controllability of the heat equation in unbounded domains

Ivica Nakić

University of Zagreb

We adapt a strategy for proving null-controllability of parabolic equations by [Tenenbaum-Tucsnak-2011] to a setting of lower semibounded operators with continuous spectrum. This includes in particular the case of the controlled heat equation in $\mathbb{R}^d$ where the diffusion term $-\Delta$ is replaced by a Schrödinger operator $-\Delta + V$. We lay particular emphasis on explicitly estimating the control cost in terms of all occurring model parameters. This is then combined with recent scale-free unique continuation principles for spectral subspaces of Schrödinger operators and the behaviour of the control cost in certain (homogenization) limits is studied. The talk is based on the joint work with Matthias Täufer, Martin Tautenhahn and Ivan Veselić.

Optimal kernels of Volterra-type integral operators in nonlinear parabolic equations

Mathieu Pascal Rosière

Technische Universität Berlin

In this talk we consider a class of nonlinear parabolic equations where an additional term corresponding to a Volterra-type integral operator is added, whose kernel is used as a control function. We consider first and second order optimality conditions for the optimal control of the aforementioned class of equations with a quadratic objective functional and we investigate stability properties of the associated optimality system that are related to the convergence of an SQP method.

Optimal control of wine fermentation based on partial and ordinary integro-differential equations

Christina Schenk

Carnegie Mellon University

At present many models based on ordinary differential equations already exist to describe the process of wine fermentation. However, the dynamics due to yeast cell growth play an important role in this fermentation process. That is why we take a closer look at the mass structure of yeast cells by introducing a nonlinear partial integro-differential equation for the population balance of yeast and ordinary integro-differential equations for the other substrates such as sugar, nitrogen, oxygen and the product, i.e. ethanol. For this application, a high potential for the conservation of energy exists. Therefore, we study energy-optimal control of the cooling process during wine fermentation where the dynamic process is represented by the described system of integro-differential equations. The reaction behavior is modeled based on a novel model including a death phase for yeast and the influence of oxygen on the process. The derived model is solved numerically using a finite volume scheme for the discretization of the mass domain and a simultaneous approach for the temporal discretization of the resulting system of time dependent ordinary differential equations.
and the control. Efficient optimization techniques are applied to solve the resulting optimal control problem.

**Stationary gas networks with compressor control and random loads: optimization with probabilistic constraints**

Michael Schuster  
*FAU Erlangen Nürnberg*

Stationary Gas Networks with Compressor Control and Random Loads: Optimization with Probabilistic Constraints

We introduce a stationary model for gas flow based on semilinear isothermal Euler equations in a non-cycled pipeline network. Especially the problem of the feasibility of a random load vector is analyzed. Feasibility in this context means the existence of a flow vector meeting these loads, which satisfies the physical conservation laws with box constraints for the pressure.

An important aspect of the model is the support of compressor stations, which counteract the pressure loss caused by friction in the pipes. The network is assumed to have only one influx node, all other nodes are efflux nodes.

With these assumptions the set of feasible loads can be characterized analytically. In addition we show the existence of optimal solutions for some optimization problems with probabilistic constraints. A numerical example based on real data completes this presentation.

**The spatial Ramsey model with endogenous productivity growth – an application of nonlocal PDE-constrained optimization in economics**

Laura Somorowsky  
*IAAEU & Trier University*

The Ramsey model is one of the most popular neoclassical growth models in economics. The primary time-depending model has been extended by a spatial component in the last few years, meaning that capital accumulation is modeled as a process not only in time but in space as well. In a new approach, we consider a Ramsey economy where the value of the capital stock depends not only on the respective location but is influenced by the affluence of the surrounding areas as well. We expand the common spatial Ramsey model by a nonlocal diffusion term. Moreover, we introduce a nonlocal and nonlinear production-productivity operator in order to endogenize the increase of productivity in a location, depending on time and the capital stock in this location and the affluence of the surrounding areas. We consider the resulting optimal control problem under partial integro-differential constraints with a bounded and unbounded spatial domain. We analyze the nonlinear partial integro-differential equation and show the existence of weak solutions. Furthermore, we give conditions under which we can prove the existence of an optimal control. Finally, we discuss the numerical results and interpret them in our new economical setting.
Optimization of time delays in Pyragas type feedback control

Fredi Tröltzsch
Technische Universität Berlin

We consider a semilinear parabolic delay differential equation with finitely many time delays. The delays define a Pyragas type feedback operator and should be optimized such that the associated solution of the partial delay differential equation minimizes the $L^2$-distance to a desired state. Main emphasis is laid on the differentiability of the mapping that associates the solution of the delay equation to the vector of time delays. We improve a result on local differentiability proved by J. K. Hale and L.A.C. Ladeira (1993) for a short time horizon. We are able to prove this for any finite time horizon. Based on our differentiability result, first-order necessary optimality conditions are derived for the optimal vector of delays. Moreover, we present numerical examples.
Optimal control of a 3D heat conductor

Julian Andrej  
*Universität Kiel*

We present an optimal control approach for the linear heat equation in a three dimensional setting, where a model with multiple input and measurement points is considered. Based on a high order finite element discretization we formulate a transient optimal control problem and compute optimal trajectories to reach a desired temperature profile in a given time. The gradient for the optimization problem is computed using the discrete adjoint method of the forward equation.

Using a similar concept we identify parameters of a physical experiment and test the results of the feed-forward trajectory planning to verify the outcome.

Stabilizing flow problems using state-dependent Riccati equations

Peter Benner  
*Max Planck Institute for Dynamics of Complex Technical Systems*

Stabilizing nonlinear systems using the Linearization Principle and Feedback Control has been a successful concept for decades. We will focus here on incompressible flow problems described by the unsteady Navier-Stokes equations as the considered nonlinear system, and on Ricatti-based feedback control. As the setpoint may vary during a flow simulation due to perturbations exceeding the limits of the Linearization Principle, a single Riccati gain may not suffice to keep the flow profile in a laminar regime. This leads then to so-called state-dependent Riccati equations, where the coefficients depend on the current state. We introduce a scheme that avoids to solve a new Riccati equation every time the coefficients change by using incremental updates that only require linear system solves. In closed-form, this scheme leads to a nonlinear feedback controller for incompressible flow problems.

Stabilizing controllers with optimized performance for nonlinear PDEs

Dante Kalise  
*Imperial College London*

We provide a general framework to ensure stability of a Nonlinear Model Predictive Control (NMPC) scheme by an instantaneous control applied to several linear and nonlinear parabolic partial differential equations (PDEs). In general, stability of an NMPC scheme without terminal constraints may result in a long prediction horizon for stabilization. The knowledge of a suboptimal explicit stabilizing
feedback may lead to stability of the NMPC loop with the shortest possible receding horizon. We illustrate our approach with unstable semilinear parabolic PDEs.

**Galerkin approximations for nonlinear optimal control problems and feedback control**

Axel Kroener  
_Humboldt-Universität zu Berlin_

In this talk we formulate a general framework to derive error estimates for the approximation of the value function of nonlinear optimal control problems in Hilbert spaces based on a Galerkin approximation. The framework is applied to optimal control problems of differential delay equations. The numerical approximation of the control in feedback form based on HJB equations is also considered.

**Global stabilization of Burgers’ equation by nonlinear Neumann boundary feedback control and its finite element analysis**

Sudeep Kundu  
_University of Graz_

In this talk, global stabilization results for the Burgers’ equation are established using nonlinear Neumann boundary feedback control law. Then, using \(C^0\)-conforming finite element method, global stabilization results for the semidiscrete solution are shown. Moreover, optimal error estimates for the state variable in \(L^\infty(L^2)\), \(L^\infty(H^1)\) and \(L^\infty(L^\infty)\)-norms are obtained. Further, superconvergence result is derived for the boundary feedback control law. All the results preserve exponential stabilization property. Finally, some numerical experiments are conducted to confirm our theoretical findings.

**POD-Based economic model predictive control for heat-convection phenomena**

Luca Mechelli  
_Universität Konstanz_

We consider an optimal boundary control problem subjected to linear time-dependent convection-diffusion (CD) equation together with bilateral control and pointwise state constraints. Due to the pointwise state constraints, we perform a Lavrentiev regularization and the regularized optimal control problem is solved by a primal-dual active set strategy (PDASS). To speed up the PDASS a reduced-order approach based on proper orthogonal decomposition (POD) is applied and an a-posteriori error analysis ensures that the computed (suboptimal) POD solutions are sufficiently accurate. An Economic Model Predictive Control strategy (EMPC) is considered to treat the long-time horizon and the problem’s parameters’ changes. To improve the model, we combine CD with time-dependent Navier-Stokes equations in the so-called Boussinesq Approximation (BA). Since computing the solution for the optimal control problem subjected to BA can be costly, we solve
BA with an arbitrary control to generate the POD basis for approximating CD, then we apply the POD-based EMPC algorithm to compute the optimal control for CD. According to the a-posteriori error estimator, if the POD approximation is not good anymore, we solve again BA with the optimal feedback control previously computed to generate new POD basis, afterwards we continue to apply the POD-based EMPC algorithm for CD.

**Optimization based feedback control for time varying systems**

Simon Pirkelmann  
*Universität Bayreuth*

In this talk we present a model predictive control (MPC) scheme for time-varying systems. In MPC a feedback law is synthesized from the successive solution of open-loop optimal control problems.

We present conditions under which the resulting solution approximates the solution of a problem on infinite horizon. A particular focus is placed on the convergence of the MPC closed-loop trajectory towards an infinite horizon optimal trajectory. The corresponding infinite horizon optimality criterion is given by the concept of overtaking optimality.

To illustrate the theoretic results we consider a convection-diffusion equation as a model for energy efficient heating, cooling and ventilation.

**Explicit exponential feedback stabilization to trajectories for parabolic equations**

Sergio Rodrigues  
*RICAM*

An explicit feedback controller is proposed for stabilization of linear parabolic equations, with a time-dependent reaction-convection operator. The range of the feedback controller is finite-dimensional, and its dimension depends polynomially on a suitable norm of the reaction-convection operator. A sufficient condition for stabilizability is given, which involves the asymptotic behavior of the eigenvalues of the (time-independent) diffusion operator, the norm of the reaction-convection operator, and the norm of the nonorthogonal projection onto the controller’s range along a suitable infinite dimensional (higher-modes) eigenspace. To construct the explicit feedback, the essential step consists in computing the nonorthogonal projection. Numerical simulations are presented, in 1D and 2D, showing the practicability of the controller and its response to measurement errors.

Under general conditions on the nonlinearity, the same feedback law is able to locally stabilize a semilinear parabolic system to a given (time-dependent) trajectory.
Wellposedness and qualitative analysis of flow-structure PDE models

George Avalos
University of Nebraska-Lincoln

In this talk, we provide results of wellposedness and long time behavior for solutions of compressible and incompressible flow-structure partial differential equation (PDE) models which have recently appeared in the literature, and which have been studied and/or derived outright by Igor Chueshov. For example, we will consider a compressible flow PDE and its associated state equation for the pressure variable – each evolving within a three dimensional domain $O$ – which are coupled to a fourth order plate equation which holds on a flat portion $\Omega$ of the boundary $\partial O$. Moreover, since this coupled PDE model is the result of a linearization of the compressible Navier-Stokes equations about an arbitrary state, the flow system component contains terms which involve a nonzero ambient flow profile $U$. In consequence, this flow-structure PDE system will generally not be dissipative. This talk will represent joint work with Pelin Guven Geredeli (University of Nebraska-Lincoln).

Regularity analysis for the Moore-Gibson-Thompson equation

Francesca Bucci
Universita’ degli Studi di Firenze

In this talk we will report recent results concerning the regularity of solutions to initial/boundary value problems for the Moore-Gibson-Thompson equation (MGT) equation, that is a linearization of a Partial Differential Equation (PDE) model for ultrasonic wave propagation. The embedding of the MGT equation in a class of (linear) wave equations with memory, along with the theory of integro-differential Volterra equations, provides a perspective and method of proof for the derivation of interior as well as trace regularity estimates of its solutions.

(The talk is based on ongoing joint work with Luciano Pandolfi (Politecnico di Torino, Italy).)

On the Moore-Gibson-Thompson equation and its memory relaxation

Filippo Dell’Oro
Politecnico di Milano

We discuss the parallel between the third-order Moore-Gibson-Thompson (MGT) equation arising in acoustics and the equation of linear viscoelasticity with an exponential kernel. We also consider the MGT equation with memory, a model which accounts for additional nonlocal effects due to molecular relaxation, and we investigate its asymptotic properties in the critical regime.
On the boundary controllability of hyperbolic systems

Matthias Eller
Georgetown University

Walter Littman’s approach to boundary controllability in the context of hyperbolic systems of partial differential equations will be reviewed. In the case of constant coefficients a fairly general result is presented, even in the case of characteristics of variable multiplicity. Its proof is based on the knowledge of singularities of the fundamental solutions and on Holmgren’s uniqueness theorem. Extensions of this result to the variable coefficient case will be discussed.

Pullback and uniform attractors for non-autonomous fluid-structure interaction systems.

Tamara Fastovska
V.N. Karazin Kharkiv National University/ Kharkiv National Automobile and Highway University

We consider a non-autonomous fluid-structure interaction system for the fluid velocity field \( \nu = \nu(x, t) = (\nu^1(x, t); \nu^2(x, t); \nu^3(x, t)) \), the pressure \( p(x, t) \), and the transversal displacement of the plate

\[
\begin{align*}
\varepsilon(t) \nu_t - \nu \Delta \nu + \nabla p &= f(x, t) \quad \text{in} \quad O \times (\tau, +\infty), \\
\text{div} \nu &= 0 \quad \text{in} \quad O \times (\tau, +\infty), \\
\delta(t) u_{tt} + \Delta^2 u + F(u) &= p|_{\Omega} + g(x, t) \quad \text{in} \quad \Omega \times (\tau, \infty)
\end{align*}
\]

for any \( \tau \in \mathbb{R} \). Here \( \nu > 0 \), \( O \subset \mathbb{R}^3 \) is a bounded domain representing a vessel filed with viscous incompressible fluid with a smooth boundary \( \partial O = \overline{\Omega} \cup \overline{S} \), where \( \Omega \cap S = \emptyset \). The flat domain \( \Omega \) represents an elastic plate while \( S \) is a rigid wall. Equations (1.1) are supplemented with the boundary

\[
\begin{align*}
\nu &= 0 \quad \text{on} \ S; \quad \nu \equiv (\nu^1; \nu^2; \nu^3) = (0; 0; u_t) \quad \text{on} \ \Omega, \\
u|_{\partial \Omega} &= \frac{\partial u}{\partial n} \bigg|_{\partial \Omega} = 0.
\end{align*}
\]

and initial conditions

\[
\begin{align*}
\nu(x, \tau) &= \nu_{\tau}(x), \quad u(x, \tau) = u^0(x), \quad u_{t}(x, \tau) = u^1_{\tau}(x).
\end{align*}
\]

We prove that problem (1.1)–(1.3) generates a process on a scale of spaces possessing a pullback attractor, in particular if \( \lim_{t \to \infty} \varepsilon(t) = 0 \) and \( \lim_{t \to \infty} \delta(t) = 0 \), under appropriate conditions on the parameters of the problem. Moreover, we show that the fractal dimension of the kernel sections of the process is finite. In case \( \varepsilon, \delta = \text{const} \) we prove the existence of a finite-dimensional uniform attractor.
On the asymptotic behavior of stochastically driven compressible fluid flows

Eduard Feireisl
*Czech Academy of Sciences*

We consider the compressible Navier-Stokes system driven by a stochastic forcing. We discuss the asymptotic behavior of such a system for large time, the existence of stationary and/or time periodic solutions.

Decay properties of compressible fluid structure PDE models

Pelin Güven Geredeli
*Hacettepe University*

In this talk, we present recently derived results of uniform stability for a coupled partial differential equation (PDE) system which models a compressible fluid-structure interaction of current interest within the mathematical literature. The coupled PDE model under discussion will involve a linearized compressible, viscous fluid flow evolving within a 3-D cavity, and a linear elastic plate—in the absence of rotational inertia—which evolves on a portion of the fluid cavity wall. Since the fluid equation component is the result of a careful linearization of the compressible Navier-Stokes equations about an arbitrary state, this interactive PDE component will include a nontrivial ambient flow profile, which tends to complicate the analysis. Moreover, there is an additional coupling PDE which determines the associated pressure variable of the fluid-structure system. Under a suitable assumption on the ambient vector field, and by obtaining an appropriate estimate for the associated fluid-structure generator on the imaginary axis, we provide a result of exponential stability for finite energy solutions of the fluid-structure PDE system.

Weak-strong uniqueness in fluid structure interaction problem

Sarka Necasova
*Czech Academy of Sciences*

Well-posedness and asymptotic properties of solutions to nonlinear PDEs and ODEs in the presence of state-dependent delay

Alexander Rezounenko
Kharkiv University & AS CR

We discuss a general class of non-linear partial differential equations with general type of bounded time delays. We focus on the state-dependent type of delays since the type is the most relevant to real-world applications. Particularly, we are interested in reaction-diffusion equations and systems (in bounded domains) with delays in reaction terms. We investigate the well-posedness in the sense of Hadamard as well as long time asymptotic behaviour of different types of solutions. The Lyapunov stability and the existence of global attractors are discussed. A recent study connected to viral in-host infection models with state-dependent delay is also described. The last includes PDE/ODE infection models with /without CTL and antibody immune responses. This talk is dedicated to the memory of Igor D. Chueshov.

Quasistability method for study of uniform attractors of non-autonomous equations

Iryna Ryzhkova-Gerasymova
V. N. Karazin Kharkiv national university

We generalize quasistability method for using in study of long-time behaviour of non-autonomous equations with translation compact symbols. As a model problem we consider nonlinear wave equation
\[ u_{tt} - \Delta u + \alpha(t)u_t + \beta(t)g(u) = f(t, x). \]
The time-depending coefficient (time symbol) is called translation compact if the completion of \( \{\alpha(t + s), s \in \mathbb{R}\} \) (time symbol space) is compact in an appropriate functional space (e.g. \( C_b(\mathbb{R}) \)).

We modify quasistability inequality to account for time symbol, so that it’s essential consequences which hold for autonomous equations take place for non-autonomous equations also. We establish asymptotical compactness and improved smoothness of individual trajectories. In the case when time symbol space is of finite fractal or Hausdorff dimension, we find the condition under which a uniform attractor has finite fractal dimension.

Homogenisation with error estimates of attractors for damped semi-linear anisotropic wave equations

Anton Savostianov
Durham University

The talk is devoted to homogenisation of global and exponential attractors for the damped semi-linear anisotropic wave equation on a bounded 3d domain. First we show how to obtain order-sharp
estimates, in a suitable norm weaker than the standard energy norm, between trajectories of the oscillating system and the homogenised one. These estimates are given in terms of the operator-norm difference between resolvents of the corresponding elliptic operators. Based on this, we derive norm-resolvent estimates on the Hausdorff distance between the anisotropic (global and exponential) attractors and their homogenised counter-parts. Furthermore, we obtain first-order correction for the homogenised (global and exponential) attractors suggested by asymptotic expansions. The corrected homogenised attractors, as expected, are close to the anisotropic attractors already in the strong energy norm. The corresponding quantitative estimates on the Hausdorff distance with respect to the energy norm are also obtained. Our results are applied to Dirichlet, Neumann and periodic boundary conditions.

**Thresholds for hanger slackening and cable shortening in the Melan equation for suspension bridges**

Gianmarco Sperone  
*Politecnico di Milano*

The Melan equation for suspension bridges is derived by assuming small displacements of the deck and inextensible hangers. We determine the thresholds for the validity of the Melan equation when the hangers slacken, thereby violating the inextensibility assumption. To this end, we preliminarily study the possible shortening of the cables: it turns out that there is a striking difference between even and odd vibrating modes since the former never shorten the cables. These problems are studied both on beams and plates.

**Genetic algorithm in fluid-structure interactions arising in coupling of elasticity with Navier-Stokes equation**

Katarzyna Szulc  
*Polish Academy of Sciences*

We consider a coupled system of the linearly elastic body immersed in the flowing fluid which is modeled by means of incompressible Navier-Stokes equations. For this system we formulate an optimization problem which amounts to a minimization of a hydro-elastic pressure on the interface between the two environments. The corresponding functional lacks convexity and radial coercivity. The approach taken is based on locating small holes in the elastic domain. These locations are approximated by the genetic algorithm which uses the probability density in random selection for the initial population of single holes, pairs or triples, and also to supplement the population in consecutive generations. The probability density is evaluated based on the values of the topological derivative calculated in the elastic subdomain for a given shape functional defined in the exterior subdomain filled by fluid.
On the periodic Ornstein-Uhlenbeck process

Pierre Vuillermot

*Universidade de Lisboa*

The periodic Ornstein-Uhlenbeck process wandering in Euclidean space is one of the simplest stationary and non-Markovian Gaussian process. In this talk we show that this process may be viewed as a particular Bernstein process which may be associated with a very specific infinite hierarchy of forward-backward systems of decoupled linear deterministic parabolic partial differential equations. Crucial to the definition of this hierarchy is the fact that the spectrum of the so-called Hamiltonian of an isotropic system of quantum harmonic oscillators is an explicitly known pure-point spectrum. The particular Bernstein process we are interested in is generated by a weighted average of signed measures naturally associated with the spectrum in question, and indeed turns out to be identical in law with the periodic Ornstein-Uhlenbeck process.

Inertial manifolds for dissipative PDEs: examples and counterexamples

Sergey Zelik

*University of Surrey*

We will discuss the problem of existence or non-existence of inertial manifolds (IMs) for semilinear parabolic equations. This will include recent results concerning IMs for Cahn-Hilliard and 1D reaction-diffusion-advection problems as well as the explicit examples where the such manifolds do not exist.
Bayesian parameter estimation for macroscopic pedestrian dynamics models

Susana Gomes
*Imperial College London*

The fundamental diagram of pedestrian dynamics relates the experimentally observed density of pedestrians to their average velocity. Although there is a general agreement on its basic shape, its parametrization depends strongly on the measurement and averaging techniques used as well as the experimental setup considered. We aim at developing a systematic approach to identify parameters in nonlinear macroscopic crowd motion models using multiple microscopic trajectories. We assume that each trajectory is a realization of an Ito-McKean process, where the individual velocity depends on the probability density of the process. The probability density satisfies a nonlinear Fokker-Planck equation itself, leading to a coupling between the microscopic SDE and the macroscopic PDE. Motivated by the fundamental diagram we assume that individuals move with a maximum velocity, which decreases linearly as the probability density approaches the maximum crowd density. We are interested in identifying the maximum velocity and the maximum crowd density using multiple trajectories. We discuss Bayesian as well as other derivative free optimization methods to estimate these parameters and present analytic as well as numerical results, which give important insights into the dynamics and challenges of this highly nonlinear inverse problem.

Optimal inflow control of dynamical systems with uncertain demands

Simone Göttlich
*University of Mannheim*

The control problem under consideration consists of a deterministic hyperbolic differential equation used to describe the dynamics of a supply systems (e.g. production, energy) coupled to a stochastic differential equation to model uncertain demands. We are concerned with optimal control strategies to find the optimal system inflow such that the stochastic demands are satisfied. Solution techniques are based on efficient reformulations of the original stochastic control problem and allow for a straightforward numerical treatment.
Proximal methods for Mean Field Games with local couplings

Dante Kalise
Imperial College London

We address the numerical approximation of Mean Field Games with local couplings. For power-like Hamiltonians, we consider both unconstrained and constrained stationary systems with density constraints in order to model hard congestion effects. For finite difference discretizations of the Mean Field Game system, we follow a variational approach. We prove that the aforementioned schemes can be obtained as the optimality system of suitably defined optimization problems. In order to prove the existence of solutions of the scheme with a variational argument, the monotonicity of the coupling term is not used, which allow us to recover general existence results. Next, assuming next that the coupling term is monotone, the variational problem is cast as a convex optimization problem for which we study and compare several proximal type methods. These algorithms have several interesting features, such as global convergence and stability with respect to the viscosity parameter, which can eventually be zero. We assess the performance of the methods via numerical experiments.

On the uniqueness of nonlinear diffusion coefficients

Matthias Schlottbom
University of Twente

We consider the identification of nonlinear diffusion coefficients of the form $a(t, u)$ or $a(u)$ in quasi-linear parabolic and elliptic equations. Uniqueness for this inverse problem is established under very general assumptions using partial knowledge of the Dirichlet-to-Neumann map. The proof of our main result relies on the construction of a series of appropriate Dirichlet data and test functions with a particular singular behavior at the boundary. This allows us to localize the analysis and to separate the principal part of the equation from the remaining terms. We therefore do not require specific knowledge of lower order terms or initial data which allows to apply our results to a variety of applications. If time permits, we will discuss some typical examples.

Relaxation techniques for PDE-constrained optimization

Tristan van Leeuwen
Utrecht University

PDE-constrained optimization problems arise in many applications, including inverse problems and optimal control. As optimization over both the control and state parameters is not feasible for large-scale problems, one often resorts to a reduced formulation by eliminating the constraints. The resulting optimization problem is often highly non-linear, which may cause local descent methods to stall at stationary points away from the global minimizer. Another issue is that it may not even be possible to eliminate the constraints as the PDE may be ill-posed (e.g., due to missing boundary
conditions). In this talk, I will discuss ways to relax the constraints and reduce the problem implicitly. The resulting reduced optimization problem can in some case be much less non-linear than the original reduced problem. I will illustrate the approach with a variety of numerical examples.

**Boltzmann games in heterogeneous consensus dynamics**

Mattia Zanella  
*Politecnico di Torino*

We consider a constrained hierarchical opinion dynamics in the case of leaders’ competition and with complete information among leaders. Each leaders’ group tries to drive the followers’ opinion towards a desired state accordingly to a specific strategy. By using the Boltzmann-type control approach we analyze the best-reply strategy for each leaders’ population. Derivation of the corresponding Fokker-Planck model permits to investigate the asymptotic behaviour of the solution. Heterogeneous followers populations are then considered where the effect of knowledge impacts the leaders’ credibility and modifies the outcome of the leaders’ competition.
Control of time-delay stochastic systems with uncertainties

Boris Ananyev
IMM UB of RAS

Consider a linear controlled uncertain time-delay system with stochastic disturbances and a measured output. The noises in the state and output systems are independent and their matrices contain time-varying parametric uncertainties. The initial condition is assumed to be a zero-mean Gaussian random vector along with some initial function. The procedure of control with final quadratic cost is divided into two parts. For the first one the control equals zero. The first part consists of robust filter design which ends at some random stopping-time $\tau$. We employ hereafter a Riccati equation approach to solve the robust Kalman filtering for time-delay systems. The obtained two-parametric estimator is independent of the delay factor and it reduces to the standard Kalman filtering algorithm in the case of systems without uncertainties and delay. After the first stage we pass to the second one, where the system cannot be observed and the separation principle is used in order to obtain a minimax control on $[\tau, T]$ and a value of the cost. At last we solve an optimal stopping-time problem in order to find optimal $\tau$ and thereby minimize the maximal value of the cost. The work is supported by the Russian Science Foundation, project no. 16-11-10146.

State estimation problem for impulsive control system under uncertainty

Tatiana Filippova
*Krasovskii Institute of Mathematics and Mechanics, Ural Branch of the Russian Academy of Sciences*

The nonlinear dynamical control system with uncertainty in initial states and parameters is studied. It is assumed that the dynamic system has a special structure in which the system nonlinearity is due to the presence of quadratic forms in the system velocities. The case of combined controls is studied here when both classical measurable control functions and also the controls generated by vector measures are allowed. Here we present several theoretical schemes and the related estimating algorithms allowing to find the upper bounds for reachable sets of the studied control system. In our research we use and further develop the basic results and techniques of the ellipsoidal calculus and of the theory of evolution equations for set-valued states of dynamical systems and of related differential inclusions having in their description the uncertainty of set-membership kind. So we enlarge the class of nonlinear control systems for which it is possible to find the upper estimates of their reachable sets. Numerical results of system modeling based on the proposed methods are also included. The research was supported by the Russian Science Foundation (RSF Project No.16-11-10146).
Some problems of feedback control of the distributed systems

Vyacheslav Maksimov
_Krasovskii Institute of Mathematics and Mechanics, Ural Branch of the Russian Academy of Sciences_

In the recent years, a part of mathematical control theory, namely, the theory of control for distributed systems, has been intensively developed. There exists a number of monographs devoted to control problems for distributed systems. In these works, the emphasis is on the problems of open-loop or feedback control in the case when all system’s parameters are precisely specified. But, the investigation of control problems for systems with uncontrollable disturbances (game or robust control problems) is also natural. Similar problems have been insufficiently investigated; in our opinion, this is connected with the fact that the well-known Pontryagin maximum principle is not really suitable for solving such problems. In the early 1970es, N.N. Krasovskii suggested an effective approach to solving guaranteed control problems. This approach is based on the formalism of positional strategies. The goal of this report is to demonstrate the essence and abilities of this approach. Toward this aim, we investigate the problem of tracking an uncontrolled input (a trajectory) by means of feedback laws formalized in the form of positional strategy. In the process, we consider “classical” linear parabolic and hyperbolic equations in the case when the information on their solutions forth comes (with error) at discrete times.
Quick creation of dangerous disturbances for flight systems

Nikolai Botkin
*Technical University of Munich*

This paper addresses a method of constructing repulsive disturbances in linear differential games using a dynamic programming approach. The method constructs, in reverse time, a “repulsive” sequence of polyhedrons such that the enemy player can keep the state vector outside of these polyhedrons if the initial position lies outside of the polyhedron corresponding to the initial time instant. The polyhedrons are stored as unordered systems of linear inequalities, and the computations involve solving a large number of linear programming problems. For this purpose, a fast algorithm for low-dimensional linear programs is used. Several examples of computing dangerous disturbances are presented. This includes a simple linear differential game to demonstrate the main features of the method. Moreover, a linearized model of the longitudinal aircraft motion containing aircraft’s dynamics, servomechanisms, pilot and disturbance inputs, and a controller is considered. Finally, a nonlinear model of aircraft takeoff in windshear conditions is addressed. Simulations showing the efficiency of the method are presented.

This work was supported by the DFG grant TU427/2-1 and HO4190/8-1. Computer resources for this project have been provided by the Gauss Centre for Supercomputing/Leibniz Supercomputing Centre under grant: pr74lu.

Leadership kernels and trajectory control in the presence of windshear

Nikolai Botkin
*Technical University of Munich*

This paper addresses problems of aircraft control in the presence of wind disturbances. It is assumed that the state variables of the model are constrained to define an appropriate flight domain (AFD). The dynamics of the aircraft is considered as a differential game where the first player (pilot) applies control inputs, and the second player (wind) produces the worst wind gusts. The maximal viable subset, viability kernel, of the AFD is computed. This yields a feedback control that keeps trajectories in the viability kernel, and hence in the AFD, for all admissible disturbances. It should be emphasized that the notion of viability kernel is typical for control systems. In the case of differential games, the terms leadership kernel is more suitable. The leadership kernel assumes that the second player (wind) knows current controls of the pilot and uses feedback counter strategies, which is reasonable in context of computing guaranteeing controls.
The paper presents theoretical and numerical aspects of finding leadership kernels for near-to-realistic aircraft models. Nontrivial examples are demonstrated.

This work was supported by the DFG grant TU427/2-1 and HO4190/8-1. Computer resources for this project have been provided by the Gauss Centre for Supercomputing/Leibniz Supercomputing Centre under grant: pr74lu.

Robust trajectory controller and its implementation on a flight simulator

Johannes Diepolder
TU Munich - Campus Garching

We present an approach for the implementation of a robust trajectory control structure based on viability kernel in a realistic flight simulator. This viability kernel is obtained from solving a state constrained differential game between the aircraft control (first player) and a wind disturbance (second player). From the viability kernel solution a state feedback law can be derived which ensures that despite the wind disturbance, the aircraft does not leave the safe set of states. For the numerical solution of the state constrained differential game the associated value function is approximated by a grid function. Due to the curse of dimensionality when using this grid approximation the number of states to be used is restricted (so far we were able to obtain solutions for up to seven states). Therefore, we compute the viability kernel for a lower dimensional model including the translational dynamics and a reference model for the attitude dynamics. The implementation on the flight simulator is then based on a nonlinear dynamic inversion control structure with reference model following control using the same reference model as for the solution of the differential game.

Continuum model of blood circulation in brain

Andrei Kovtaniuk
Technical University of Munich

Numerical modeling of blood circulation in brain is very important for the simulation of possible inuring effects such as critical drop of oxygen in brain tissue or abnormal local pressure concentration. Very often, the capillary network of the brain is considered as a homogenized medium. Thus a domain containing a large number of holes that simulate the ends of arterioles and venules, playing the role of blood inlets and outlets, is considered. The pressure distribution is described by a Poisson equation with the prescribed pressures on the boundaries of holes, which leads to the consideration of the problem in a fine perforated domain. Instead of that, we propose to introduce a linear combination of source terms into the right-hand side of the Poisson equation and to fit the corresponding coefficients in such a way that the boundary conditions would be well approximated. We rigorously formulate this problem and prove its unique solvability. An algorithm for finding the unknown source
intensities and the resulting pressure distribution is proposed. Numerical experiments are discussed.

This work was supported by the Klaus Tschira Stiftung, Buhl-Strohmaier Stiftung, and Würth Stiftung.

Rapid generation of extremal disturbances in linear conflict control problems

Kirill Martynov  
*Technische Universität München*

In this talk, we present a fast method for generation of feedback disturbances for linear conflict control systems. The approach is based on construction of repulsive sets, i.e. domains for which there exists a feedback disturbance producing trajectories violating state constraints. In our method, repulsive sets are approximated by simple geometric objects, parallelotops, which ensure low computational efforts. The method consists in the integration of an ODE system describing centers and matrices of the parallelotops. Such computations can run in real time on a common processor so that high-dimensional linear models can be treated. Nonlinear models can be processed by applying sequential linearization techniques.

Several examples focused on aircraft control are presented. First, a simple low-dimensional linear differential game demonstrates the method. Second, a nonlinear aircraft model with reference to the problem of take-off in wind shear conditions is addressed. Third, generation of disturbances for a highly-nonlinear adaptive aircraft controller is investigated. Simulation results demonstrate the efficiency of disturbances constructed.

This work was supported by the DFG grant TU427/2-1 and HO4190/8-1. Computer resources for this project have been provided by the Gauss Centre for Supercomputing / Leibniz Supercomputing Centre under grant: pr74lu

Mathematical modeling and viability theory-based feedback control of impaired cerebral autoregulation in premature infants

Varvara Turova  
*Technische Universität München*

Cerebral autoregulation is extremely important for keeping cerebral blood flow (CBF) at a constant level. Impaired cerebral autoregulation is a risk factor for cerebral hemorrhages in preterm infants because of sudden fluctuations of CBF, which can damage unstable cerebral blood vessels. The most important factors influencing CBF are arterial carbon dioxide partial pressure (pCO$_2$), mean arterial pressure (MAP), and venous pressure (VP). A mathematical model of impaired cerebral autoregulation accounting for these factors is presented in this paper. An effective heuristic feedback control for keeping deviations of CBF within tolerance limits despite unpredictable disturbances of pCO$_2$, MAP, and VP, is proposed. The efficacy of this feedback control, which can be interpreted as a medication affecting CBF, is proven using viability theory. Simulation results demonstrating
the quality of the feedback control proposed are shown.

This work was supported by the Klaus Tschira Stiftung, Buhl-Strohmaier Stiftung, and Würth Stiftung.
A measure theoretic approach for Vehicular Traffic Control on Networks

Raul De Maio

University of Rome "La Sapienza"

In this talk we present a measure theoretic approach for vehicular traffic problem on networks. In particular, aiming to describe traffic flow on road networks with long-range driver interactions, we show results on existence and uniqueness of solution for nonlinear transport equation defined on an oriented network where the nonlocal velocity fields is assumed. In the same framework, we present examples of control problems such as traffic lights and self-driving cars and advantages offered by this approach.

A semi-Lagrangian scheme for HJ equations on networks

Adriano Festa

INSA Rouen

We present a semi-Lagrangian scheme for the approximation of a class of Hamilton-Jacobi-Bellman equations on networks. The scheme is explicit and stable under large time steps. We discuss a convergence theorem and an error estimate, which is also verified by numerical tests. Finally, we apply the scheme to simulate problems modeling traffic flows.

Non-local conservation laws: A Godunov type scheme and network models

Jan Friedrich

Universität Mannheim

We present a Godunov type numerical scheme for a class of scalar conservation laws with non-local flux arising for example in traffic flow modeling. The considered scheme delivers more accurate solutions than the widely used Lax-Friedrich type scheme. In contrast to existing work, we consider a non-local mean velocity instead of a mean density to adapt it to networks. We provide $L^\infty$ and bounded variation estimates for the sequence of approximate solutions obtained by the proposed scheme. We also demonstrate the well-posedness of the considered class of scalar conservation laws. In addition, we propose an approach to consider the class of scalar conservation laws on a network and provide some numerical examples.
**Discretized feedback control for hyperbolic balance laws**

Stephan Gerster  
*RWTH Aachen University*

Physical systems such as water and gas networks are usually operated in a state of equilibrium and feedback control is employed to damp small perturbations over time. We consider flow problems on networks, described by hyperbolic balance laws, and analyze the stabilization of steady states. Sufficient conditions for exponential stability in the continuous and discretized setting are presented. Computational experiments illustrate the theoretical findings.

**Dynamic boundary control game with a star of vibrating strings**

Martin Gugat  
*Friedrich-Alexander-Universität Erlangen-Nürnberg*

Consider a star-shaped network of vibrating strings. Each string is governed by the wave equation. At the central node, the states are coupled by algebraic node conditions in such a way that the energy is conserved. At each boundary node of the network there is a player that performs Dirichlet boundary control action and in this way influences the system state. We consider the corresponding antagonistic game, where each player minimizes her quadratic objective function that is the sum of a control cost and a tracking term for the final state. We show that under suitable assumptions a unique Nash equilibrium exists and give an explicit representation of the equilibrium strategies.

M. Gugat, S. Steffensen: Dynamic boundary control games with networks of strings, *ESAIM: COCV*, DOI: https://doi.org/10.1051/cocv/2017082

**Production network models with stochastic capacities: semi-Markov and load-dependent approaches**

Stephan Knapp  
*University of Mannheim*

We focus on production network models based on coupled ordinary and partial differential equations combined with time-dependent random capacity functions. The partial differential equations are scalar conservation laws and of hyperbolic type coupled with ordinary differential equations at the boundaries.

In a first step, the random capacity function of every processor is an external given stochastic process, a semi-Markov process that allows intermediate capacity states in the range of total breakdown to full capacity. The operating and down times can be arbitrarily distributed, provided they keep positive.

In general, the assumption that capacity drop probabilities are independent of the production and external given by a stochastic process is too restrictive. This motivates to introduce an influence from
the production to the capacity process as well and we obtain a bidirectional relation between the pro-
duction and the random capacity process. For this purpose, we embed the stochastic load-dependent
production network model into the theory of piecewise deterministic Markov processes.

We present solution concepts for both stochastic production network models and show the well-
posedness. Caused by the complexity of the model, we state suitable simulation methods and
performance measures to evaluate and interpret the results.

Crowd dynamics in domains with boundaries

Elena Rossi

*Inria Sophia Antipolis - Méditerranée*

In this talk, we present a new approach to the macroscopic modelling of moving crowds, based on a
class of conservation laws able to describe non local interactions and taking into consideration the
presence of boundaries. The apparent conflict between boundaries and non locality is solved through
the introduction of an ad hoc operator, aware of walls and obstacles, describing the interactions
among individuals at different positions. Besides the well posedness of this class of non local
initial boundary value problems, in any space dimensions, see [2], we develop an ad hoc numerical
algorithm to compute the solutions to these equations, see [1]. We provide convergence tests and
evaluate the behaviour of the model in realistic crowd dynamics situations. References [1] R. M.

On a degenerate parabolic model for gas transport in pipeline networks

Lucas Schoebel-Kroehn

*TU Darmstadt*

As a model for gas transport in pipeline networks on practically relevant length and time scales, we
consider a degenerate parabolic system of partial differential algebraic equations which describe
the conservation of mass and the dissipation of energy due to friction at the pipe walls. Based on
variational arguments, we establish existence of weak solutions and we discuss the discretization by
finite elements and an implicit time stepping scheme. Numerical tests are presented for illustration
of the theoretical results.

A comparison of different models coupled by gas turbines for power generation

Aleksey Sikstel

*RWTH Aachen University*

A gas flow through a turbine generating electrical power is modeled by coupled $p$-systems and Euler
equations respectively. The $p$-systems are equipped with isentropic and isothermal pressure laws
while the Euler equations with an ideal gas law. The validity of the simpler $p$-system is investigated quantitatively for typical scenarios. The gas turbine is modeled as coupling conditions. Explicit coupling conditions for the in and outflow, which rely on the solution of a nonlinear equation, are derived and validated.

**Control strategies for road risk mitigation in kinetic and hydrodynamic traffic modelling**

Mattia Zanella  
*Politecnico di Torino*

We present a Boltzmann–type kinetic approach to the modelling of road traffic dynamics, which includes control strategies at the level of microscopic binary interactions aimed at the mitigation of speed-dependent road risk factors. Such a description is meant to mimic a system of driver–assist vehicles, which by responding locally to the actions of their drivers can impact on the large–scale traffic dynamics, including those related to the collective road risk and safety. Furthermore, we present the derivation of the corresponding hydrodynamic equations for the conserved quantities of the kinetic model, where the derived control term results embedded in the definition of a constrained flux function. Suitable numerical methods are necessary to observe the described hierarchy of scales.
Adaptive discretization for the problem of identification of laser beam quality parameters

Teresa Reginska
Institute of Mathematics PAS

The problem of identification of laser beam quality parameters can be reduced to finding the waist of the axial profile defined by the radii of the beam. The regularized solutions of the Cauchy problem for the Helmholtz equation can be employed to approximate the axial profile at some points. So we look for an approximate minimum of a function describing the axial profile given on a discrete set of points where its values are given with some errors. Presented is a new method for finding an approximate minimum of a real function $f$. The initial problem is replaced by that of finding parameters $v \in \mathbb{R}^d$ such that $F(v, \cdot)$ approximates $f(\cdot)$. Here $F$ is appropriately chosen and $F(v, \cdot)$ are functions whose minima can easily be calculated. A modification of the iterative Tikhonov regularization is applied in which the set of points (where noisy value of $f$ are taken) changes at every step of iteration; The convergence of the method is proved but the rate of convergence is still an open problem.

On the characterization of unstable ultra-short laser pulse trains with D-SCAN

Daniel Gerth
TU Chemnitz

Since the reaction time of electronics spans several cycles of a modern high-end pulse laser, such pulses cannot be measured directly and indirect methods are averaged over an unknown number of individual pulses. If there are differences from one pulse to another we speak of an unstable pulse train. A problem that is known in the literature but only recently gained more attention is that unstable pulse trains may lead to incorrect reconstructions and thus misinterpretation of the results.

It is impossible to recover individual pulses in an unstable pulse train. Instead, one is interested in key quantities such as the average duration of each pulse. In this talk we explain these technicalities in more details and show how the model for D-SCAN for stable pulses is used to estimate the average lengths of pulses in an unstable pulse train. The key to this is treating an in practice known quantity as unknown and comparing its reconstruction with the data from the measurement setup. Mathematically, the problem corresponds to the solution of a complex-valued autoconvolution equation with nontrivial unknown kernel function where additionally only the absolute values of the right-hand side are known and the phase information is missing.
On ill-posedness concepts, stable solvability and saturation

Bernd Hofmann  
*Technische Universität Chemnitz*

We consider different concepts of well-posedness and ill-posedness and their relations for solving nonlinear and linear operator equations in Hilbert spaces. First, the concepts of Hadamard and Nashed are recalled which are appropriate for linear operator equations. For nonlinear operator equations, stable respective unstable solvability is considered, and the properties of local well-posedness and ill-posedness are investigated. Those two concepts consider stability in image space and solution space, respectively, and both seem to be appropriate concepts for nonlinear operators which are not onto and/or not, locally or globally, injective. Several example situations for nonlinear problems are considered, including the prominent autoconvolution problems and other quadratic equations in Hilbert spaces. It turns out that for linear operator equations, well-posedness and ill-posedness are global properties valid for all possible solutions, respectively. The special role of the nullspace is pointed out in this case. Finally, non-injectivity also causes differences in the saturation behavior of Tikhonov and Lavrentiev regularization of linear ill-posed equations. This is examined at the end of this study. This talk presents joint work with Robert Plato (University of Siegen). Research is partially supported by the Deutsche Forschungsgemeinschaft (DFG) under grant HO 1454/10-1.

New convergence rates for variational Lavrentiev regularization of nonlinear monotone ill-posed problems

Robert Plato  
*Universität Siegen*

We consider nonlinear ill-posed equations $Fu = f$ in Hilbert spaces $\mathcal{H}$, where $F : \mathcal{H} \to \mathcal{H}$ is monotone on a closed convex subset $\mathcal{M} \subseteq \mathcal{H}$. For given data $f^\delta \in \mathcal{H}$, $\|f^\delta - f\| \leq \delta$, a standard approach is Lavrentiev regularization $Fv^\delta + \alpha v^\delta = f^\delta$, with $\alpha > 0$ small. In practical applications like parameter estimation problems, the considered operator is monotone on $\mathcal{M} \subseteq \mathcal{H}$ only. Since the regularized equation may not have a solution in $\mathcal{M}$ then, we replace this equation by the regularized variational inequality and consider $u^\delta_\alpha \in \mathcal{M}$ satisfying

$$\langle Fu^\delta_\alpha + \alpha u^\delta_\alpha - f^\delta, w - u^\delta_\alpha \rangle \geq 0 \quad \text{for each } w \in \mathcal{M}.$$ 

In this talk we present new estimates of the error $u^\delta_\alpha - u_*$ for suitable choices of $\alpha = \alpha(\delta)$, if the solution $u_* \in \mathcal{M}$ of $Fu = f$ is source-representable. This is joint work with B. Hofmann (TU Chemnitz).
IRGNM Ivanov type method with a posteriori choice of regularization parameter under a tangential cone condition in Banach space

Mario Luiz Previatti de Souza
Alpen-Adria-Universität Klagenfurt

This talk deals with a combined analysis of regularization and discretization of inverse problems in Banach spaces with partial differential equations (PDEs). The quantities - parameters and states - have to be discretized, e.g., by the finite element method, and the error due to this discretization has to be estimated and controlled by error estimators and mesh refinement. A challenge is to take into account the interplay between mesh size, regularization parameter and data noise level. The PDEs setting is relevant to the adaptive discretization of the regularized problems. I will show convergence result and an algorithm of the Iteratively Regularized Gauss Newton Method (IRGNM) in its Ivanov version with a posteriori choice of regularization parameter under a tangential cone condition in Banach space setting. I will present how to obtain the a posteriori estimates and to achieve the accuracy by adaptive discretization using goal oriented error estimators. This is illustrated for an inverse source problem for a nonlinear elliptic boundary value problem with $L^\infty$ source. There are numerous applications with the Banach space setting assigned by the regularity of the sought coefficients and features like sparsity, e.g., medical imaging.

The Arnoldi process for ill-posed problems

Lothar Reichel
Kent State University

The Arnoldi process is the basis for the GMRES method, which is one of the most popular iterative methods for the solution of large linear systems of algebraic equations that stem from the discretization of a linear well-posed problem. The Arnoldi process and GMRES also can be applied to the solution of ill-posed problems. This talk discusses properties of Tikhonov regularization and iterative methods, that are based on the Arnoldi process, for the solution of linear ill-posed problems.

Variational method for multiple parameter identification in elliptic PDEs

Nhan Tam Quyen Tran
University of Hamburg

In this talk I present the inverse problem of identifying simultaneously the diffusion matrix $Q \in L^\infty(\Omega)^{d\times d}$, source term $f \in L^2(\Omega)$ and boundary condition $g \in L^2(\partial \Omega)$ in the Neumann boundary value problem for an elliptic partial differential equation (PDE)

$$
-\nabla \cdot (Q \nabla \Phi) = f \text{ in } \Omega \subset \mathbb{R}^d,
Q \nabla \Phi \cdot \vec{n} = g \text{ on } \partial \Omega
$$
from a measurement \( z_\delta \in L^2(\Omega) \) of the solution \( \Phi \in H^1(\Omega) \), where \( \vec{n} \) is the unit outward normal on the boundary \( \partial \Omega \) of the open bounded connected domain \( \Omega \) in the Euclidean space \( \mathbb{R}^d \). A variational method based on energy functions with Tikhonov regularization is here proposed to treat the identification problem. We discretize the PDE with the finite element method and prove the convergence as well as analyze error bounds of this approach. To illustrate the theoretical results, a numerical case study is presented which supports our analytical findings.
Organizers: W. Gong, B. Jin, B. Li

**Optimal control of instationary gas transport**

Herbert Egger  
_TU Darmstadt_

We consider the optimal control of instationary gas transport in a pipeline network. The well-posedness of the governing system of partial differential-algebraic equations is discussed and the existence of minimizers is established. For the numerical solution, we consider a Galerkin approximation of the state equation by mixed finite elements, we establish well-posedness of this discretization, and prove the existence of minimizers for the corresponding discretized optimal control problem. We further discuss the efficient numerical minimization via projected Newton-type algorithms and present computational test to illustrate the performance of the proposed algorithms and to demonstrate their viability for online control of typical situations arising during intraday operation of a gas network.

**Convergence of adaptive finite element method for PDE-constrained optimal control problems**

Wei Gong  
_Academy of Mathematics and Systems Science, Chinese Academy of Sciences_

In this talk we present our recent results on convergencne of adaptive finite element method for PDE-constrained optimal control problems. The study of adaptive finite element method for optimal control problems started from the end of last century but the convergence analysis is rather recent. We use variational discretization for the control variable, thus the study of the first order optimality system reduces to the study of the state and adjoint state equations. Then the well-established convergence analysis of AFEM for single PDE can be adapted to prove the convergence and optimality of the state and adjoint state of optimal control problems. The control variable in the convergence analysis is eliminated based on a duality argument which gives higher order a priori bound for L2 norm error than the energy norm error, this introduces an assumption on the smallness of initial mesh. The convergence of the control variable is thus a direct consequence of above results. To prove the optimality of the control variable we can use L2-norm based AFEM, so we have to assume H2 regularity of the governing state equation.
Error estimates of an optimal control problem for fractional diffusion

Bangti Jin
*University College London*

Fractional diffusion has received immense attention in recent years. However, the related optimal control problems are scarcely studied. In this talk, I present a complete numerical analysis for a distributed optimal control problem for fractional diffusion, with box constraint on the control. The fully discrete scheme is obtained by applying the conforming linear Galerkin finite element method in space, L1 scheme/backward Euler convolution quadrature in time, and the control variable by a variational type discretization. I shall give sharp convergence rates for the numerical solutions of the optimal control problem. Numerical experiments are provided to support the theoretical results. This is a joint work with Buyang Li and Zhi Zhou.

Integration based profile likelihood calculation for parameter estimation in PDEs

Barbara Kaltenbacher
*Alpen-Adria-Universität Klagenfurt*

PDE models are widely used in engineering and natural sciences to describe spatio-temporal processes. The parameters of the considered processes are often unknown and have to be estimated from experimental data. Uncertainty in the estimates due to partial observations and measurement noise, can be assessed using profile likelihoods, a reliable but computationally intensive approach. In this talk, we present the integration based approach for profile likelihood calculation developed by Chen and Jennrich, 2002, and adapt it to inverse problems with PDE constraints. While existing methods for profile likelihood calculation in parameter estimation problems with PDE constraints rely on repeated optimization, the proposed approach exploits a dynamical system evolving along the likelihood profile. We derive the dynamical system for the unreduced estimation problem, prove convergence and study the properties of the integration based approach for the PDE case. To evaluate the proposed method, we compare it with state-of-the-art algorithms for an application in systems biology. We observe a good accuracy of the method as well as a significant speed up as compared to established methods. Joint work with Romana Boiger, Alpen-Adria-Universität Klagenfurt, as well as Jan Hasenauer and Sabrina Hroß, Helmholtz Zentrum München.

Improved error estimates for finite element solutions of parabolic dirichlet boundary control problems

Buyang Li
*Hong Kong Polytechnic University*

The parabolic Dirichlet boundary control problem and its finite element discretization are considered in convex polygonal and polyhedral domains. We improve the existing results on the regularity of the solutions by establishing and utilizing the maximal $L^p$-regularity of parabolic equations under
inhomogeneous Dirichlet boundary conditions. Based on the proved regularity of the solutions, we prove $O(h^{1-1/q-\varepsilon})$ convergence for the semi-discrete finite element solutions for some $q > 2$, with $q$ depending on the maximal interior angle at the corners and edges of the domain and $\varepsilon$ being a positive number that can be arbitrarily small.

**Second-order analysis and numerical approximation for bang-bang bilinear control problems**

Daniel Wachsmuth  
*Institut für Mathematik*

We consider bilinear optimal control problems, whose objective functionals do not depend on the controls. Hence, bang-bang solutions will appear. We investigate sufficient second-order conditions for bang-bang controls, which guarantee local quadratic growth of the objective functional in $L^1$. In addition, we prove that for controls that are not bang-bang, no such growth can be expected. Finally, we study the finite-element discretization, and prove error estimates of bang-bang controls in $L^1$-norms.
Optimal sensor placement for detection and localization of seismic sources

Christian Boehm
*ETH Zürich*

Earthquakes, landslides and nuclear explosions excite waves that can be measured in form of seismograms at remote receiver locations. The waveform data contains information about both the internal structure of the Earth, and the characteristics of the source. Seismic source inversion infers the location, origin time, source-time function and source mechanism from the measured seismograms. This can be stated as an inverse problem governed by the elastic wave equation.

We present strategies for experimental design to determine the optimal locations of seismic stations that minimize the uncertainty in the inferred source parameters. To this end, we consider a probability density function characterizing the likelihood of a source location, and apply A-optimal experimental design using the expected value of the trace of the posterior covariance to select an optimal subset of seismic stations.

Assuming a-priori knowledge of complex 3D Earth structure, and exploiting reciprocity allows us to solve the forward problem for arbitrary source locations without significant computational cost. Furthermore, we compare sequential optimal experimental design approaches and sparsifying constraints to determine a suitable number of seismic stations.

Numerical examples illustrate several important applications, such as improving earthquake hazard management and Tsunami early warning systems, or monitoring nuclear explosions.

An OED problem for interface identification

Roland Herzog
*TU Chemnitz*

Interface identification refers to a class of parameter estimation problems where the unknown is the location of an interface, e.g., between two values of a material parameter, which may appear as a coefficient in a partial differential equation. Compared to classical parameter estimation problems, the unknown is therefore not a point in a finite dimensional vector space, but can be considered an element of an infinite dimensional manifold of shapes. Its tangent space, which contains potential directions of parameter variations, can be conceived as a space of velocity fields acting on the shape boundary.

The proper formulation and numerical solution of OED problems for interface identification, which we will address in this talk, therefore imposes a number of challenges compared to classical OED problems in vector spaces.
The use of the population Fisher information matrix for parameter estimation of nonlinear mixed-effects models

Felix Jost
*Universität Magdeburg*

Parameter estimation for nonlinear mixed-effects models is widely used in pharmaceutical and biomedical research and population pharmacokinetic and pharmacodynamic analysis. In clinical studies measurements from a population of patients or healthy volunteers are collected and used to personalize a suited mathematical model via parameter estimation. In comparison to point estimators (least squares problems), in which one set of parameters is estimated, in mixed-effects modelling the population shares the same model but each patient has an set of parameters depending on individual and population parameters. In this talk we give an introduction to estimation methods and the population Fisher information matrix (FIM) for nonlinear mixed-effects models. Additionally, we propose a Gauss-Newton algorithm for parameter estimation of this kind of models in which the Hessian of the objective function is approximated by the population FIM. The algorithm is implemented as an prototype in CasADi.

Optimum experimental design based on a second-order analysis of parameter estimates

Ekaterina Kostina
*Heidelberg University*

A successful application of model-based simulation and optimization of dynamic processes requires an exact calibration of the underlying mathematical models. Here, fundamental tasks are the estimation of unknown model coefficients by means of real observations and design of optimal experiments. The goal of the design of optimal experiments is the identification of those measurement times and experimental conditions, which allow a parameter estimate with a maximized statistical accuracy. The design of optimal experiments problem can be formulated as an optimization problem, where the objective function is given by a suitable quality criterion based on the sensitivity analysis of the parameter estimation problem. In this talk we present a new objective function, called the Q-optimality function, which is based on a second order sensitivity analysis of parameter estimates. The robustness properties of the new objective function in terms of parameter uncertainties is investigated and compared to a worst-case formulation of the design of optimal experiments problem. Numerical experiments show that the design of experiments based on Q-optimality leads to a drastic improve of the Gauss-Newton convergence rate for the underlying parameter estimation problems. The talk is based on the joint work with M. Nattermann.
First-order methods for regularized optimal experimental design problems

Eric Legler
TU Chemnitz

The task of parameter identification of a certain model by carrying out experiments is closely connected to the question of finding the most valuable experimental conditions. The identification of these experiments leads to so-called Optimal Experimental Design problems. Among other formulations, it is possible to cast these problems in the form \( \min F(\Lambda(w)) + G(w) \) with a measure \( w \in C^*(X) \), where \( F \) and \( G \) are convex and \( \Lambda \) is a linear operator. Therefore this problem is convex but nonsmooth since \( G \) and in some cases also \( F \) are not differentiable. In order to reformulate this problem in Hilbert space, we regularize the problem by an additional term and solve a problem with a density \( w \in L^2(X) \) instead. After discretization we compare various first-order methods.

Experimental design for ill-posed problems

Marta Sauter
Universität Heidelberg

Experimental design for parameter estimation is based on the minimization of an appropriate function of the covariance matrix subject to constraints on experimental conditions. The covariance matrix is implicitly defined by a generalized inverse of the Jacobian of the underlying parameter estimation problem under condition that the Jacobian has full rank. In this case the parameters can be identified using experimental data. Here we consider the situation when the Jacobian does not have full rank, hence the covariance matrix can be computed, and experimental design methods cannot be applied directly. In order to compute optimal experiments for such ill-posed parameter estimation problems we first suggest to apply the Tikhonov regularization to estimate the biased parameters. The regularized parameter estimation problem can be solved with generalized Gauss-Newton methods. A statistical analysis of the solution yields the mean square error which is taken as a new criterion for experimental design. Numerical results for the Diels-Adler reaction show that this approach allows to exploit the information from regularized problem for parameter estimates without regularization and to take into account existing correlations between parameters. Moreover, the local identifiability of parameters can be re-established with the new design criterion without using correlations of these parameters.

Sensitivity analysis and approximation of sparse sensor placement problems

Daniel Walter
Technische Universität München

We consider the estimation of an unknown parameter \( q \) entering a partial differential equation. In practice, \( q \) can not be inferred directly but only through finitely many noisy measurements of the
associated state $y$. We propose to determine a suitable measurement setup by solving a sparse sensor placement problem

$$\min_{\omega \in M^*(\Omega_o)} \Psi(I(\omega) + I_0) + \beta \|\omega\|_M. \quad (P)$$

Here, the distribution of the measurement sensors in the observation domain $\Omega_o$ is described by a positive Borel-measure $\omega$. By $\Psi$ we denote a suitable optimal design criterion which assesses the quality of a design measure $\omega$ through properties of the associated Fisher-information matrix $I(\omega)$. The matrix $I_0$ represents possible a priori knowledge on the unknown parameter and $\| \cdot \|_M$ is the canonical total variation norm.

In this talk, we consider the stability and sensitivity of minimizers to $P$ with respect to the problem data. In an appropriate sense, we show the existence of first-order derivatives of the optimal design measure with respect to perturbations of the optimal design criterion and discuss their numerical computation. Furthermore we propose a suitable discretization for $P$ and present several convergence results. The results are illustrated by numerical examples.
**MS 15: OPTIMAL TRANSPORT AND APPLICATIONS**

Organizers: B. Schmitzer, B. Wirth

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**Error estimates for numerical approximations of optimal transport**

Soeren Bartels  
*Albert-Ludwigs-Universität Freiburg im Breisgau*

Numerical schemes for two instances of optimal transportation problems are devised and analyzed. The first one concerns linear transportation costs and the discretization and iterative solution of the corresponding Monge-Kantorovich problem. The approximation error for the optimal cost is controlled by a discrete primal-dual gap which leads to a priori and a posteriori error estimates. A splitting algorithm is used to solve the nondifferentiable primal and dual problems. For transportation problems with superlinear cost function we consider the numerical approximation of transport plans within suitable spaces of measures and devise an active set strategy for its efficient numerical solution.

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**Gradient flows that converge to global minimizers in the many-particle limit**

Lénaïc Chizat  
*Inria*

We consider the problem of minimizing a loss function on a Hilbert space, the latter being parametrized in a non-linear way through sums of "particles". This non-convex problem is very common in statistics and signal processing (e.g., neural networks with one hidden layer, low-rank semidefinite programming, gridless spikes deconvolution). To shed light on "when" and "why" we can expect gradient descent-based algorithms to succeed on these problems, we suggest to study the gradient flow when the number of particles grows to infinity. We prove that, in some important cases, when initialized with sufficient variety, this many-particle gradient flow converges to a global minimizer, whenever it converges.

This work is at the crossroads of non-convex optimization, variational problems on measures for statistics, and Wasserstein gradient flows (a by-product of optimal transport theory). This is joint work with Francis Bach.

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**On Entropy-transport problems and the Hellinger-Kantorovich distance**

Matthias Liero  
*Weierstrass Institute for Applied Analysis and Stochastics (WIAS)*

In this talk, we will present a general class of variational problems involving entropy-transport minimization with respect to a couple of given finite measures with possibly unequal total mass.
These optimal entropy-transport problems can be regarded as a natural generalization of classical optimal transportation problems. With an appropriate choice of the entropy/cost functionals they provide a distance between measures that exhibits interesting geometric features. We call this distance Hellinger-Kantorovich distance as it can be seen as an interpolation between the Hellinger and the Kantorovich-Wasserstein distance. The link to the entropy-transport minimization problems relies on convex duality in a surprising way. Moreover, a dynamic Benamou-Brenier characterization also shows the role of these distances in dynamic processes involving creation or annihilation of masses. Finally, we will give a characterization of geodesic curves and of convex functionals and discuss other geometric properties. This is joint work with Vaios Laschos (TU Berlin), Alexander Mielke (WIAS Berlin and HU Berlin) and Giuseppe Savaré (U Pavia).

**Statistics for optimal transport: Inference, algorithms and applications**

Axel Munk  
*Georg-August-Universität Göttingen*

We discuss some recent statistical laws for empirical optimal transport distances on discrete spaces and its consequences for statistical inference. These laws are given as dual optimal transport problems in a multidimensional normal variable. Our proofs are based on a combination of sensitivity analysis from optimization and discrete empirical process theory. We discuss several strategies, e.g., resampling, to overcome the computational burden to simulate such laws. In particular, we examine empirically an upper bound for such limiting distributions on discrete spaces based on a spanning tree approximation which can be computed explicitly. This can be used for generating new randomized computational schemes for the computation of optimal transport itself and we give precise error bounds on such schemes. Our results are illustrated in computer experiments and on biological data from super-resolution cell microscopy.

This is joint work with Jörn Schrieber, Max Sommerfeld and Carla Tameling.

**Adaptive grid methods for branched transportation networks**

Carolin Roßmanith  
*Applied Mathematics Münster, Westfälische Wilhelms-Universität Münster*

Transportation problems and the need of finding an optimal network to transport mass appear in several fields of application. Here, we consider a branched transport model which aims at finding an optimal path between a given initial and final distribution of mass to the lowest possible costs, where mass is preferentially transported in bulks. Unfortunately, the non-convexity of the cost functional causes the task of performing realistic numerical simulations to be challenging in many cases. The problem can be reformulated as a Mumford-Shah-type optimisation problem and therefore admits a convex relaxation via so-called functional lifting, which as a penalty comes along with an increased dimensionality and a large number of constraints. We provide an efficient adaptive grid
discretisation method for the variational model which is capable of dealing with the above-mentioned disadvantages and perform some numerical simulations.

Unbalanced optimal transport

Bernhard Schmitzer
WWU Münster

Optimal transport induces a geometrically intuitive metric on the space of probability measures and is a powerful tool for image and data analysis. With the evolution of efficient numerical methods it is becoming increasingly popular. However, in many models the assumption that all measures have unit mass and that mass is exactly preserved locally are too restrictive, for instance in biochemical growth processes. Hence, in recent years, ‘unbalanced’ transport problems, that allow creation or annihilation of mass during transport, have received increased attention. In this talk we present several formulations for such problems, efficient numerical methods and illustrate applications and advantages of unbalanced metrics.

This is joint work with Lénaïc Chizat, Gabriel Peyré, François-Xavier Vialard and Benedikt Wirth.

Compressed motion sensing

Christoph Schnörr
Heidelberg University

We study the recovery of a sparse time-varying signal from linear measurements of a single static sensor, that are taken at two different points of time. This set-up can be modelled as observing a single signal using two different sensors – a real one and a virtual one induced by signal motion. We examine the recovery properties of the resulting combined sensor. Assuming the sensor matrix to be in general position, we impose a weak a condition of sufficient change of the signal, besides the usual sparsity assumption, under which not only the signal can be uniquely recovered with overwhelming probability by linear programming, but also the correspondence of signal values (signal motion) can be established between the two points of time. In particular, we show that in our scenario the performance of an undersampling static sensor is doubled or, equivalently, that the sufficient number of measurements of a static sensor can be halved.

Applications of optimal transport in spatial statistics

Dominic Schuhmacher
Universität Göttingen

In spatial statistics data in $\mathbb{R}^d$ is modelled by suitable random structures, such as point patterns, maps, or unions of convex bodies. Often such structures exhibit spatial dependence which decays as a function of the distance in space. Amenable data comes from plant ecology (positions of plants...
form point patterns), disease mapping (risk maps for rare diseases), materials science (meso-scale structure of porous material), and many other fields.

In this talk I give a brief introduction to spatial statistics and present some theory and applications of optimal transport in this context.
Exponential stability of partially damped plate equations

Robert Denk
Universität Konstanz

We consider the transmission problem for a coupled system of undamped and structurally damped plate equations in two sufficiently smooth and bounded subdomains. It is shown that, independently of the size of the damped part, the damping is strong enough to produce uniform exponential decay of the energy of the coupled system.

Viscoelastic wave equations with supercritical nonlinearities

Yanqiu Guo
Florida International University

The talk presents a study of the history value problem of a viscoelastic wave equation which features a fading memory term as well as a supercritical source term and a frictional damping term. Well-posedness, asymptotic behavior, as well as singularity formulation are discussed for the model. The special features of the model lie in that the source term has a supercritical growth rate and the memory term accounts for the full past history that goes back to negative infinity.

Exact locally distributed controllability of string bounding a linear potential fluid

Scott Hansen
Iowa State University

A variable coefficient string or beam equation is used to model the flexible portion of the boundary of the domain of a two dimensional linear potential fluid.

Exact controllability is proved when control is applied either at an end point or over an open interval of positive length. The method of proof is based on application of Ingham's inequality together with mini-max estimates of eigenvalues. Related results wherein the fluid surrounds a string or membrane are described.

Feedback control of the acoustic pressure in HIFU propagation.

Irena Lasiecka
Institute of Systems Research, Polish Academy of Sciences
This talk will discuss boundary feedback control associated with PDE models arising in HIFU modles – which are PDEs of third order in time. This leads to a notion of a non-standard Riccati equations which provide suitable gain operators for the feedback control. Singularity of the control action compromises the usual regularity of the associated Riccati operators making the analysis challenging particularly in the case of boundary controls. In this latter case, the loss of regularity is “double” – due to singularity caused by the appearance if time derivatives in control function and also due to the intrinsic loss associated with unbounded and un-closeable trace operators. In order to construct a viable theory one needs to develop suitable regularity theory within the framework of non-smooth optimization. It will be shown how the propagation of hidden trace regularity in hyperbolic dynamics allows to build suitable concepts. This talk is based on joint work with Francesca Bucci from Universita di Firenze.

A generalization of the Aubin-Lions-Simon compactness Lemma for problems on moving domains

Boris Muha

Faculty of Science, University of Zagreb

This work addresses an extension of the Aubin-Lions-Simon compactness result to generalized Bochner spaces \( L^2(0, T; H(t)) \), where \( H(t) \) is a family of Hilbert spaces, parameterized by \( t \). A compactness result of this type is needed, e.g., in the study of the existence of weak solutions to a class of nonlinear evolution problems governed by partial differential equations defined on moving domains. We identify the conditions on the regularity of the domain motion in time, i.e., on the dependence of the functions spaces on time, under which our extension of the Aubin-Lions-Simon compactness result holds. Concrete examples of the application of the new compactness theorem are presented. They include a classical problem for the incompressible, Navier-Stokes equations defined on a given non-cylindrical domain, and a class of fluid-structure interaction problems for the incompressible, Navier-Stokes equations, coupled to the elastodynamics of a Koiter shell. Both the no-slip coupling condition, and the Navier slip coupling condition, are discussed. The compactness result presented in this talk is crucial in obtaining constructive existence proofs to nonlinear, moving boundary problems, using Rothe’s method.

Poro-visco-elasticity in biomechanics

Marcella Noorman

NC State University

Modeling of fluid flows through porous deformable media is relevant for many applications in biology, medicine and bioengineering, including tissue perfusion and fluid flow inside cartilages and bones. These fluid-structure mixtures are described mathematically by nonlinear poro-visco-elastic systems, driven by mixed boundary conditions. We investigate the well-posedness of solution, as well as sensitivity analysis with respect to data, as precursor to control problems subject to these coupled
systems. Our theoretical results and numerical analysis provide a novel hypothesis concerning the causes of damage in biological tissues. I will discuss our results and their applications to ocular perfusion and confined compression tests for biological tissues.

**Pseudo-backstepping and stabilization of higher order PDEs**

Turker Ozsari  
*Izmir Institute of Technology*

We consider the boundary feedback stabilization problem for higher order PDEs such as KdV, Kawahara, and fourth order Schrödinger equations on a finite interval. A well-known technique for stabilizing PDEs from the boundary is constructing a backstepping controller which is obtained from an integral transformation involving a specially constructed kernel. However, this method fails as the order of the PDE gets higher, and there are serious mathematical challenges in finding the right kernel. The purpose of this talk is to introduce "pseudo-backstepping," a technique using only an imperfect kernel, which is obtained by relaxing some of the conditions enforced in the standard backstepping method. We prove that the boundary controllers constructed via these imperfect kernels still exponentially stabilize the system with the cost of a slower rate of decay. Finally, this method allows us to answer some open problems in the stabilization theory for higher order PDEs.

This research has been supported by TÜBİTAK 1001 Grant #117F449 and IZTECH BAP Grant #2017IYTE14.

**Decay estimates for a Korteweg-de-Vries-Burgers equation with time delay**

Cristina Pignotti  
*University of L’Aquila*

We consider a KdV-Burgers equation with indefinite damping and time delay in the whole real line. Under appropriate conditions on the damping mechanism and the time delay feedback, global well-posedness and exponential decay estimates are established for the linearized equation and the nonlinear model. Joint work with Vilmos Komornik (Université de Strasbourg).

**Flow-induced instability of a cantilever in axial flow**

Justin Webster  
*University of Maryland Baltimore County*

Flow-induced instability of a flexible object is of great interest in engineering—both the onset (flutter), as well as the qualitative properties of post-flutter dynamics. In particular, the case of a cantilever in axial flow (flag-like) has been vigorously researched in the last 15 years. Yet, there have been very few rigorous analyses of the appropriate fluid-structure interaction. This is largely due to the challenging nature of the flow boundary conditions (at the elastic interface and in the wake), which are mixed
and dynamic in nature; moreover, structural nonlinearity is required to capture the post-flutter dynamics, and the appropriate inextensible beam is highly nonlinear and nonlocal.

Here, we present three approaches to analyzing these flow-structure dynamics. We first invoke a simplifying flow assumption (piston theory) and demonstrate that the corresponding nonlinear, non-dissipative beam dynamics are semigroup well-posed with a compact global attractor. Following this, we consider the full linear flow-beam system and discuss its well-posedness in the context of recent flow-structure work addressing the Kutta-Joukowsky condition (near the free end of the beam). Time-permitting, we will discuss a heuristic way of studying the system which rewrites the effect of the flow acting on the structure via an integral (memory) term.
MS 17: SELECTED ASPECTS OF MODELLING THERMALLY INDUCED DAMAGE AND FRACTURE

Organizers: F. Bertrand, C. Birk

A priori und a posteriori Fehleranalyse der SBFEM

Fleurianne Bertrand
*Universität Duisburg-Essen*

In this talk, we study the treatment of Linear Elastic Fracture Mechanics with the Scaled Boundary Finite Element Method (SBFEM). First, a priori estimates are developed using standard FEM techniques. Then, an a posteriori error estimator using a stress reconstruction is presented.

Optimal control of a damage model with penalty

Livia Betz
*Universität Duisburg-Essen*

The talk is concerned with a damage model including two damage variables, a local and a non-local one, which are coupled through a penalty term in the free energy functional. After introducing the precise model, we prove existence and uniqueness for the viscous regularization thereof. We then introduce the optimal control problem and establish that the control-to-state operator is Hadamard directionally differentiable, but not Gateaux differentiable. Hence, standard adjoint calculus is not applicable. However, it turns out that, under additional assumptions, an optimality system of strong stationary type can be derived.

Thermal stress analysis using the scaled boundary finite element method

Carolin Birk
*Universität Duisburg-Essen*

Sudden temperature changes lead to thermally induced stresses that cause fracture and damage in brittle materials such as ceramics. Here, complex networks of cracks may develop rapidly. The simulation of crack propagation processes requires numerical methods that can represent stress singularities accurately and efficiently, such as the SBFEM. The SBFEM is a semi-analytical technique which combines a numerical solution in the circumferential directions with an analytical solution in the radial direction of the considered domain. It facilitates the derivation of generalized polygon elements and thus provides great flexibility in meshing. In a crack propagation simulation, polygon meshes based on SBFEM require minimal re-meshing in the vicinity of crack tips. The principles of the SBFEM towards nonlinear problems will also be addressed.
Numerical simulation of mechanical damage processes and associated optimal control problems

Marita Holtmannspötter
Universität Duisburg-Essen

In this talk a numerical solution method for an optimal control problem of a specific viscous two-field gradient damage model will be presented. The mechanical damage model features two damage variables which are coupled by a penalty term in the gradient enhanced free energy functional. The minimization of the free energy as well as the consideration of the evolution of the damage in time result in state equations which are nonlinear and nonsmooth in general. Therefore necessary optimality conditions are difficult to obtain. Under certain assumptions it is possible to derive an approximate gradient which is used to apply a gradient based optimization algorithm. We focus on solving the discretized problem and present supporting test results.

Weakly symmetric stress reconstruction and a posteriori error estimation for elasticity

Marcel Moldenhauer
Universität Duisburg-Essen

We present an a posteriori error estimator for the conforming finite element method of the linear and nonlinear elasticity problem based on a nonsymmetric H(div)-conforming approximation of the stress tensor. We derive an a posteriori error estimator which gives us a completely computable upper bound of the error. First we want to show results for linear elasticity in the compressible and incompressible limit. Afterwards we extend this idea to hyperelastic material models.
Optimal design of the shape of a column against buckling revisited

Michel Delfour
*Université de Montréal*

Lagrange considered the design of vertical columns that can accommodate the largest vertical load before buckling. This problem was generalized to a family indexed by \( p > 0 \) (solid \( p = 2 \), hollow \( p = 1 \)). Cox and Overton (SIAM J. Math. 1992) proved existence of a maximizing profile for profiles bounded below and above by strictly positive constants. For the hollow column their numerical results indicated the possibility that the cross sectional area of the column might be zero in two points. Their a priori hypothesis was challenged by Egorov (J. Math. Phys. 2003). In this paper we revisit the clamped clamped circular column. We first provide numerical computations that indicate that for \( 0 \)

Multimaterial topology optimization based on the topological derivative

Peter Gangl
*Graz University of Technology*

The majority of shape and topology optimization algorithms considers the optimization with respect to two different states (e.g. material and void). In many engineering applications, however, one is interested in finding an optimal material distribution consisting of three or more different materials. We present an extension of the level-set algorithm introduced by Amstutz and Andrae in 2006, which is based on the topological derivative, to the case of three and more materials. We show numerical results obtained by applying the algorithm to the optimization of an electric motor where the task is to find the optimal distribution of ferromagnetic material, air and permanent magnets.

Homogenization-based topology optimization for high-resolution microstructures

Jeroen Groen
*Technical University of Denmark*

We present a projection method to obtain high-resolution manufacturable structures from coarse-scale, homogenization-based topology optimization results[1]. The focus of this work is on compliance minimization of linear-elasticity problems, for which the optimal solution is in the space of layered materials. Pantz and Trabelsi introduced a method to project the microstructures from homogenization-based topology optimization[2]. The microstructures are oriented along the directions of lamination such that a well-connected design is achieved. This approach paves the way for
coarse-scale topology optimization where the projection can be performed on a high-resolution mesh, without a need for cumbersome and expensive multi-scale formulations. In a recent work we have simplified the projection procedure, and introduced procedures for controlling the shape of the projected design [1]. This allowed for high-resolution (1 million elements in 2D), near-optimal and manufacturable designs, obtained within a few minutes on a standard PC. In the current work we will demonstrate extensions of the method into 3D, and discuss the potential of the method over standard topology optimization.


Topology optimization in Navier–Stokes flow with the phase field approach

Christian Kahle
TU München

We investigate the problem of finding optimal topologies of fluid domains. In a given domain $\Omega$ we search for a topology of a fluid domain, such that an objective is minimized that might depend on the velocity field and the pressure field inside the domain and that depends on the topology. In addition we use integral constraints on the optimizing topology. The problem class especially contains the problem of minimizing the drag of an obstacle in free flow.

Using the phase field approach, we describe the distribution of the fluid and non-fluid domain by a phase field variable $\phi \in H^1(\Omega) \cap L^\infty(\Omega)$ that encodes the fluid domain by $\phi(x) = 1$ and the non-fluid domain by $\phi(x) = -1$.

Additionally we use a porosity approach to extend the Navier–Stokes equation from the fluid domain to the non-fluid domain by assuming a material with high density inside and adding a Darcy term in the Navier–Stokes equation, that are now stated on the whole domain $\Omega$.

Due to the regularity of the optimization variable $\phi$, we apply the variable metric projection type method proposed in [L. Blank and C. Rupprecht, SICON 2017, 55(3)].

Applications of the distributed shape derivative in shape optimization

Antoine Laurain
University of São Paulo

The concept of shape derivative is fundamental in shape optimization, and used as the basis of many numerical algorithms. In view of Zolésio’s structure theorem, the shape derivative is usually written as a boundary integral depending on the normal perturbations of the boundary, if the boundary is sufficiently smooth. Alternatively, the shape derivative can be written as a domain integral, in which case it is called distributed shape derivative. This representation is actually more convenient
than the boundary expression for handling shapes with low regularity. In this talk we will discuss some interesting theoretical features of the distributed shape derivative, and compare it with the boundary expression. We will also show numerical applications and results, in particular for level set methods.

**Second order directional shape derivatives of integrals on submanifolds**

Anton Schiela
*Universität Bayreuth*

We compute first and second order shape sensitivities of integrals on smooth submanifolds using a variant of shape differentiation. The result is a quadratic form in terms of one perturbation vector field that yields a second order quadratic model of the perturbed functional. We discuss the structure of this derivative, derive domain expressions and Hadamard forms in a general geometric framework, and give a geometric interpretation of the arising terms.

**Weak shape Hessians in applications**

Stephan Schmidt
*Julius-Maximilians-Universität Würzburg*

Many PDE constrained optimization problems fall into the category of shape optimization, meaning the geometry of the domain is the unknown to be found. Most natural applications are drag minimization in fluid dynamics, but many tomography and image reconstruction problems also fall into this category.

The talk introduces shape optimization as a special sub-class of PDE constraint optimization problems. The main focus here will be on generating Newton-like methods for large scale applications. The key for this endeavor is the derivation of the shape Hessian, that is the second directional derivative of a cost functional with respect to geometry changes in a weak form based on material derivatives instead of classical local shape derivatives. To avoid human errors, a computer aided derivation system is also introduced.

The methodologies are tested on problem from fluid dynamics and geometric inverse problems.

**Second-order shape derivatives along normal trajectories, and approximation methods**

Jean-Léopold Vié
*École Nationale des Ponts et Chaussées*

Computing derivatives with respect to a shape is essential for shape optimization. Following the work of Zolesio and co-workers a perturbation of a shape can be defined by the maximal flow of a regular vector field. In this context, the structure of the second order shape derivatives is well described [3,4].
The goal of this work is to derive along time trajectories - similarly to this approach - in the case of the level-set method [1], when the vector field is aligned with the outer normal of the shape.

The present work focuses on the shape derivatives in this particular framework, with the help of the bicharacteristic method for solving the Hamilton-Jacobi equation [2,5]. At the end, this leads to a second order derivative which has a different structure from those of the derivatives obtained in the previous contexts.

In a second time we focus on computing the second-order derivative of the compliance, which is well known in shape optimization. Computing the second-order shape derivative of this criteria basically requires to invert the stiffness matrix, which make it computationally expensive. This is the reason why we then consider different methods for approximating the second-order shape derivative of this criteria.

**Shape optimisation with nearly conformal mappings**

Florian Wechsung  
*University of Oxford*

In shape optimisation the shapes are often discretised using meshes. When updating the shape, we want to move the initial mesh instead of generating a new mesh, as the process of remeshing is costly.

In two dimensions conformal mappings are good candidates for mesh deformations as they keep angles constant and can easily be characterised by the Cauchy-Riemann equations. We propose a method that augments the inner-product and norm on a function space in a way that deformations that lead to stretched mesh elements are penalized. We can make use of this new inner-product both in first order methods (steepest descent, L-BFGS) as well as in second order methods (Newton) to obtain fast optimisation methods that automatically choose mesh updates that retain the mesh quality of the initial mesh.

We present an analytical result stating that in a certain limit the chosen mesh updates are conformal. Furthermore we show several numerical examples that illustrate the performance of the resulting optimisation methods for simple toy problems as well as classical problems in aerodynamic shape optimisation.
Model parameter learning for quantitative photoacoustic tomography reconstruction

Yoeri Boink
*University of Twente*

Photoacoustic tomography (PAT) is a hybrid biomedical imaging technique that combines high optical tissue contrast with high ultrasound resolution. The goal of quantitative PAT is to retrieve the image of optical absorption that gives contrast between blood vessels and surrounding tissue.

Many PAT systems require calibration measurements in order to enhance accuracy of reconstructions. Moreover, the inverse problem is based on physical models that require input of parameters such as sound speed and transducer sensitivity in the acoustic reconstruction. Also, the physical model is sometimes simplified to speed-up the reconstruction process, for instance when diffusion approximation of the radiative transfer equation is used for the optical reconstruction.

In this talk, we will explore a data-driven approach to learn model parameters involved in quantitative photoacoustic reconstruction. An easy learning procedure involves fitting a linear convolution kernel to enhance acoustic reconstruction. More involved procedures account for parameters that have a nonlinear effect in the forward model.

Bounded variation regularization: convergence analysis in higher dimensions

Miguel del Alamo
*University of Goettingen*

In inverse problems, variational methods based on bounded variation (BV) penalties are well-known for yielding edge-preserving reconstructions, which is a desirable feature in many applications. Despite its practical success, the theory behind BV-regularization is poorly understood: hereby we mean in particular convergence guarantees.

In this talk we present a variational estimator that combines a BV penalty and a multiscale constraint, and prove that it converges to the truth at the optimal rate. Our theoretical analysis relies on a proper statistical modeling of noise in the inverse problem, as well as on refined interpolation inequalities between function spaces. We also illustrate the performance of these variational estimators in Monte Carlo simulations.
Tests for qualitative features in the random coefficients model

Konstantin Eckle
Leiden University

The random coefficients model is an extension of the linear regression model that allows for unobserved heterogeneity in the population by modeling the regression coefficients as random variables. Given data from this model, the statistical challenge is to recover information about the joint density of the random coefficients which is a multivariate and ill-posed problem. Because of the curse of dimensionality and the ill-posedness, pointwise nonparametric estimation of the joint density is difficult and suffers from slow convergence rates. Larger features, such as an increase of the density along some direction or a well-accentuated mode can, however, be much easier detected from data by means of statistical tests. In this article, we follow this strategy and construct tests and confidence statements for qualitative features of the joint density, such as increases, decreases and modes. We propose a multiple testing approach based on aggregating single tests which are designed to extract shape information on fixed scales and directions. Using recent tools for Gaussian approximations of multivariate empirical processes, we derive expressions for the critical value. We apply our method to simulated and real data.

On Tikhonov regularization under conditional stability

Herbert Egger
TU Darmstadt

We consider the stable solution of nonlinear ill-posed problems by Tikhonov regularization in Hilbert scales. Order optimal convergence rates are established for a-priori and a-posteriori parameter choice strategies under a conditional stability assumption for the inverse problem. The role of a hidden source condition is investigated and the relation to previous results for regularization in Hilbert scales is elaborated. The applicability of the results is discussed for some model problems, and the theoretical results are illustrated by numerical tests.

New aspects of L1-regularization

Daniel Gerth
TU Chemnitz

In the last decade, sparsity-regularization became an important method in theory and practice of Inverse and Ill-posed problems. Its most prominent example, the L1-regularization, leads to linear convergence rates if the true solution is sparse. Convergence rates without assuming sparsity of the true solution have been shown provided that the standard basis elements of L1 are in the range of the adjoint of the forward operator. In the talk, we review modifications of this range inclusion that have been proposed recently and show that, if the forward operator is injective and the image space is reflexive, one can derive convergence rates whenever L1-regularized solutions exist. While
generally impossible to give these rates explicitly, we show that using the discrepancy principle one can always achieve these rates. We extend these results also to the case that the image space is non-reflexive. Furthermore, we show that $l_1$-regularization is even applicable when the true solution does not belong to $l_1$, but lies in $l_2\|$. In particular, $l_1$-regularization does not saturate as is the case for classical Tikhonov regularization. Our theoretical results are supported by numerical experiments.

**Imaging subsurface saltbodies – a geometric inverse problem**

Tristan van Leeuwen  
*Utrecht University*

Detailed images of the subsurface can be obtained from seismic data by solving an inverse problem. As usual, there are not sufficient measurements to recover the parameters of interest uniquely and hence regularization is needed. In simple geological settings one may settle for recovering the global trends of the properties by imposing a smoothness constraint. In the presence of large impedance contrasts, such a smoothing is no longer suitable and other regularization is required (e.g. Total Variation). Of special interest are subsurface salt bodies which have constant (known) impedance and can thus be characterized by their shape alone. The inverse problem now consists of recovering this shape. In this talk I will discuss the application of a parametric level-set method for this geometric inverse problem in seismic imaging. As an extension we consider joint recovery of both the shape of the salt body and the parameters of the surrounding sediments.
Optimal control of partially observable Piecewise Deterministic Markov Processes

Nicole Bäuerle
Karlsruher Institut für Technologie (KIT)

In this talk we consider a control problem for a partially observable Piecewise Deterministic Markov Process of the following type: After the jump of the process the controller receives a noisy signal about the state and the aim is to control the process continuously in time in such a way that the expected discounted cost of the system is minimized. We solve this optimization problem by reducing it to a discrete-time Markov Decision Process. This includes the derivation of a filter for the unobservable state. Imposing sufficient continuity and compactness assumptions we are able to prove the existence of optimal policies and show that the value function satisfies a fixed point equation. A generic application is given to illustrate the results.

Non-smooth verification for impulse control problems

Christoph Belak
University of Trier

Stochastic impulse control problems are continuous-time optimization problems in which a stochastic system is controlled through finitely many impulses causing a discontinuous displacement of the state process. The objective is to choose the impulses optimally so as to maximize or minimize a reward or cost functional of the state process. This type of optimization problem arises in many branches of applied probability and economics such as optimal portfolio management under transaction costs, optimal forest harvesting, inventory control, and real options analysis.

In this talk, I will give an introduction to optimal impulse control and discuss classical solution techniques. I will then introduce a new method to solve impulse control problems based on super-harmonic functions and a stochastic analogue of Perron's method, which allows to construct optimal impulse controls under a very general set of assumptions. Finally, I will show how the general results can be applied to a problem of optimal investment in the presence of constant and proportional transaction costs.

Linear-Quadratic control for stochastic equations driven by Rosenblatt processes

Tyrone E. Duncan
University of Kansas
For some modeling problems it is not reasonable to assume that the noise processes are Gaussian. However a limited amount of results are available for stochastic analysis for non-Gaussian processes. The Rosenblatt processes are a natural generalization from Gaussian processes and some applications have been noted. A control problem for a linear system driven by a Rosenblatt process is considered to determine optimal controls.

**Nonlinear factor analysis for identifying features of epileptogenesis after traumatic brain injury**

Dominique Duncan  
*University of Southern California*

Most people with epilepsy have acquired forms of the disorder, and the development of antiepileptogenic interventions could potentially prevent or cure epilepsy in many of them. We investigate the development of post-traumatic epilepsy (PTE) following traumatic brain injury (TBI), because this condition offers the best opportunity to know the time of onset of epileptogenesis in patients. Epileptogenesis is common after TBI, and because much is known about the physical history of PTE, it represents a near-ideal human model in which to study the process of developing seizures. A fundamental challenge in discovering biomarkers of epileptogenesis is that this process is likely multifactorial, crossing multiple modalities. Investigators must have access to numerous high quality, well-curated data points and study subjects for biomarker signals to be detectable above the noise inherent in complex phenomena, such as epileptogenesis and TBI. We have developed and applied analytic tools for denoising, spike detection, dimensionality reduction, and pattern classification of the EEG using nonlinear factor analysis, particularly, power spectrum analysis, Diffusion Maps, and Unsupervised Diffusion Component Analysis. Based on heterogeneous biomarkers, we describe novel analytic tools designed to study epileptogenesis after TBI with the goal of tracking the probability of developing epilepsy over time.

**Asymptotic stability of Boltzmann-type equations on convex sets**

Henryk Gacki  
*University of Silesia in Katowice*

(Joint work with Prof. Łukasz Stettner, Polish Academy of Sciences)

Some problems of the mathematical physics can be written as differential equations for functions with values in the space of measures.

We will discuss a equation drawn from the kinetic theory of gases. This equation was stimulated by the problem of the stability of solutions of the following version of the Boltzmann equation (see [1])

\[
\frac{d\psi}{dt} + \psi = \sum_{n=1}^{n} c_n P_n \psi
\]
where \( \psi : \mathbb{R}_+ \to \mathcal{M}_{\text{sig}}(\mathbb{R}_+) \) is an unknown function, \( c_1, \ldots, c_n \) is a finite sequence of real summings up to one and \( P_1, \ldots, P_N \) are operators acting on the space of probability measures. \( P_k \) for \( k \geq 2 \) describes the simultaneous collision of \( k \) particles and \( P_1 \) the influence of external forces.

It will be a generalized version of (1.4) (see [2]) with an infinite sum of the right hand side. This corresponds to the situation in which the number of colliding particles is not bounded.


**Invariance formulas for stopping times of squared Bessel process**

Jacek Jakubowski  
*University of Warsaw*

We present the invariance formulas for stopping times of a squared Bessel process \( R \) with positive index. For a stopping time \( \tau \) satisfying some relatively mild assumptions and every positive Borel function \( f \) we have the invariance formula

\[
\mathbb{E} f(\tau + R(\tau)\zeta^{(\mu)}(\tau))(\zeta^{(\mu)}(\tau))^{2\mu} 1_{\{\tau < \infty\}} = \mathbb{E} f(\zeta^{(\mu)})(\zeta^{(\mu)})^{2\mu},
\]

where \( \zeta^{(\mu)} = \frac{1}{\sqrt{f(\mu)}} \) and \( \gamma_{\mu} \) is a gamma random variable independent of \( \sigma(\tau, R(\tau)) \). The applications of invariance formulas are presented. Hence new results on the distribution of a killed squared Bessel process, a conditional inverse local time and the first hitting time of a graph by a squared Bessel process are delivered.

**Optimal uniform approximation of Lévy processes on Banach spaces with finite variation processes**

Rafal Lochowski  
*Warsaw School of Economics*

Let \( X_t, t \geq 0, \) be a càdlag Lévy process on a Banach space \( V \) (i.e. a process with a.s. càdlag paths and independent and stationary increments), and let \( \mathcal{A}_X \) be the family of \( V \)-valued processes \( Y_t, t \geq 0, \) adapted to the natural filtration of \( X \). By \(|.|\) we denote the norm in \( V \). For \( T > 0 \) and two processes \( Y, Z : \Omega \times \mathcal{T} \to B, \) where \( \mathcal{T} \) is an index set such that \([0, T] \subset \mathcal{T}, \) we denote

\[
\|Y - Z\|_{\infty,[0,T]} := \sup_{0 \leq t \leq T} |Y_t - Z_t|
\]
and

\[ TV(Y, [0, T]) := \sup_{n} \sup_{0 \leq t_{0} < \cdots < t_{n} \leq T} \sum_{i=1}^{n} |Y_{t_{i}} - Y_{t_{i-1}}|. \]

In this talk we will deal with the following optimisation problem. For given non-decreasing function \( \psi : [0, +\infty) \rightarrow [0, +\infty) \) and \( T, \theta > 0 \), calculate (or at least estimate up to universal constants)

\[
V_{X}(\psi, \theta, T) := \mathbb{E} \inf_{Y \in \mathcal{A}_{X}} \left\{ \psi \left( \| X - Y \|_{\infty, [0, T]} \right) + \theta \cdot TV(Y, [0, T]) \right\}. \tag{1.5}
\]

To make the problem non-trivial we assume that \( \mathbb{E} |X_{1}| < +\infty \). Such problems arise for example in financial mathematics when the process \( X \) denotes optimal hedging strategy while \( Y \) denotes approximation of this strategy in the presence of (proportional) transaction costs. We will present formulas for \( V_{X}(\psi, \theta, T) \) expressed in terms of simpler functionals of \( X \) and apply them to a standard Brownian motion on \( \mathbb{R}^{n} \) or a symmetric \( \alpha \)-stable process on \( \mathbb{R} \).

**BSDEs on random horizon – applications to quadratic hedging**

Mariusz Niewegłowski  
*Warsaw University of Technology*

We consider BSDE’s on random interval driven by general martingale of the form

\[
Y_{t} = \eta + \int_{t}^{\sigma} (a(Y_{u})dN_{u} + g(Y_{u})d\langle M \rangle_{u}) + \int_{t}^{\sigma} \psi_{u}dM_{u} + L_{\sigma} - L_{t}
\]

where \( N \) is a bounded counting process, \( M \) is a martingale and \( L \) is a martingale orthogonal with \( M \). We prove existence and uniqueness of solutions for such BSDE’s. We show that one can construct solution by solving corresponding recursive system of BSDE on random intervals and piecing them together appropriately. This generalizes BSDE’s considered by Carbone et.al and El Karoui and Huang. Then we prove that under some Markovianity assumption solution of the above BSDE are associated with system of Cauchy problems. This results are then applied to quadratic hedging problems i.e. risk-minimization of claims described by general dividend process.

**Monte Carlo algorithm for optimal control of Markov processes**

Jan Palczewski  
*University of Leeds*

We develop two Regression Monte Carlo algorithms (value and performance iteration) to solve general problems of optimal stochastic control of discrete-time Markov processes. We formulate our method within an innovative framework that allow us to prove the speed of convergence of our numerical schemes. We rely on the Regress Later approach unlike other attempts which employ the Regress Now technique. We exploit error bounds obtained in our proofs, along with numerical experiments, to investigate differences between the value and performance iteration approaches.
Introduced in Tsitsiklis and VanRoy [2001] and Longstaff and Schwartz [2001] respectively, their characteristics have gone largely unnoticed in the literature; we show however that their differences are paramount in practical solution of stochastic control problems. Finally, we provide some guidelines for the tuning of our algorithms.

**Linear-quadratic control for bilinear evolution equations with Gauss-Volterra processes**

Bozenna Pasik-Duncan  
*University of Kansas*

Some control problems are explicitly solved for bilinear evolution equations where the noise is a Gauss-Volterra process. The controls are chosen from the family of linear feedback gains. The optimal gain is different from the control problem for a linear equation with a quadratic cost functional. Some examples are given.

**Risk-sensitive portfolio optimisation: weighted approach**

Marcin Pitera  
*Jagiellonian University*

In this talk we discuss the long-run risk sensitive optimisation in discrete-time. Using the span-contraction framework we show how to deal with the associated Bellman equation (MPE) and discuss it's intricacies. In particular, we show how to extend the classical bounded and uniformly ergodic framework by considering appropriate Lyapunov weight functions, and how to link solution to Bellman equation to various portfolio optimisation problems.

The talk is based on a join work with prof. L. Stettner.

**Dual characterization of super-replication prices in uncertain volatility models with friction**

Agnieszka Rygiel  
*Cracow University of Economics*

We study the problem of super-replication of contingent claims in a discrete time financial market model with transaction costs and volatility uncertainty, considering a general multi asset market. The distribution of stocks prices is not assumed to be (completely) known a priori. Our sole assumption on each stock price dynamic is that the absolute value of the log-returns is bounded from below and above. We show that the pricing of European options with convex payoff can be reduced to study pricing of suitable multinomial model. Using classical convex optimization results we obtain a dual representation of the super-replication cost for a basket option. The results generalize papers [1] and [2]. References [1] Bank, P., Dolinsky, Y., Gökay, S.: Super-replication with nonlinear transaction costs and volatility uncertainty. The Annals of Applied Probability 26 (3), 1968-1726, (2016). [2] Dolinsky, Y.,

Optimal consumption and investment for a large investor: an intensity-based control framework

Frank Seifried
University of Trier

We introduce a stochastic control framework where in addition to controlling the local coefficients of a jump-diffusion process, it is also possible to control the intensity of switching from one state to the other. Building upon this framework, we investigate optimal consumption and investment of a large investor as a benchmark example.

Long run control with degenerate observation

Łukasz Stettner
Institute of Mathematics PAS

We assume that a given discrete time controlled Markov process \((x_n)\) is observed using degenerate observation \(y_n = h(x_n)\), where \(h\) not necessarily invertible function. The behaviour of such system is described using so called filtering process, which is a measure valued process \(\pi_n\) such that \(\pi_n(B) = P [x_n \in B | Y^n]\), where \(Y^n\) is a sigma field of available observations till time \(n\). The state process is controlled basing on available observation. When the observation space is at most denumerable we can get an explicit recursive formula for \(\pi_n\) and consequently \(\pi_n\) forms a controlled Markov process. Using suitable limit procedure we can show that it is also true for general observation space however we don't have explicite formulae. Our problem is to maximize long run average cost per unit time functional. For this purpose we adapt resulta of [1] concerning nondegenerate problem and obtain first existence of solutions to suitable Belman equation for at most denumerable observation case. Then using limit procedure is solve the problem in the case of general observation space. The problem is closely related to ergodicity of filtering process.

References:


Bilateral incomplete information stopping problem

Krzysztof Szajowski
Wroclaw University of Science and Technology

This paper treats decision problem related to the observation of a Markov process by two decision makers. Admissible strategies are stopping moments. The receiving payment decision makers are
defined by stopped and accepted state of the process. The players’ decision to stop has a variable effect which depends on the type of the decision makers (players). The type $\beta$ player’s stopping decision assign the state of the process with chance $\beta$ and it gives the state to the opponent with probability $1 - \beta$. It is a random mechanism which decides the type of the player. The knowledge about the type of the players is not public and by this way, the players have also different information. The details of the description allow formulating the problem as a Bayesian game with sets of strategies based on the stopping times. It is an extension of the Dynkin’s game related to the observation of a Markov process with random assignment mechanism of states to the players. Some example related to the best choice problem is analyzed.
Global minima for semilinear optimal control problems

Ahmad Ahmad Ali  
*University of Hamburg*

We consider an optimal control problem subject to a semilinear elliptic PDE together with its variational discretization. We provide a condition which allows to decide whether a solution of the necessary first order conditions is a global minimum. This condition can be explicitly evaluated at the discrete level. Furthermore, we prove that if the above condition holds uniformly with respect to the discretization parameter the sequence of discrete solutions converges to a global solution of the corresponding limit problem. Numerical examples with unique global solutions are presented.

An algorithmic approach for time-optimal control problems with bang-bang controls

Lucas Bonifacius  
*Technische Universität München*

We consider time-optimal control problems subject to linear parabolic equations. Due to the state constraint and the absence of a regularization term in the objective, it is in general difficult to solve these problems algorithmically. We propose an equivalent reformulation leading to a bilevel optimization problem: In the outer loop we have to determine the root of a certain value function and in the inner loop we need to solve convex optimal control problems subject to control constraints, only. Different methods will be discussed for the solution of both loops. For the classical case that the terminal set is given as the $L^2$ ball centred at some desired state, we can employ a Newton method for the outer loop that typically requires just a few iterations to reach machine precision.

In numerical examples we see that this approach is capable of solving the time-optimal control problem up to high precision in short time. Moreover, our approach is at least competitive with a regularization strategy for the original problem.

Optimization with abs-linearization for non-smooth PDE problems

Olga Ebel  
*University Paderborn*

We present a new algorithmic approach for solving optimal control problems constrained by non-smooth PDEs where the non-smoothness is assumed to be given by combinations of the piecewise non-differentiable functions abs(), min() and max(). The key idea of the presented optimization method is to locate stationary points by appropriate decomposition of the original problem into
several smooth branch problems, which can be solved by classical means. Suitable optimality conditions and subsequent exploitation of information given by the respective dual variables lead to the next branch and thus to successive reduction of the function value. A discussion of numerical results for selected model problems is also involved.

Optimal control of a critical semilinear wave equation in 3d

Hannes Meinlschmidt

RICAM

We consider optimal control problems subject to a defocusing $H^1$ critical semilinear wave equation on a domain in three spatial dimensions. The prototype of such an equation is given by

$$y''(t) - \nabla y(t) - y^5 = u, \quad y(0) = y_0, \quad y'(0) = y_1$$

with homogeneous Dirichlet- or Neumann boundary data and the control $u$. The critical exponent $5$ makes global analysis for the equation under consideration very difficult, and global existence for $u = 0$ has been shown only recently. In this talk, we explore what we can achieve in an optimal control setting for this equation.

Discretization error estimates for normal derivatives on boundary concentrated meshes

Johannes Pfefferer

Technical University of Munich

This talk is concerned with finite element error estimates for the solution of linear elliptic equations. More precisely, we focus on approximations and related discretization error estimates for the normal derivative of the solution. In order to illustrate the ideas, we consider the Poisson equation with homogeneous Dirichlet boundary conditions and use standard linear finite elements for its discretization. The underlying domain is assumed to be polygonal but not necessarily convex. Approximations of the normal derivatives are introduced in a standard way as well as in a variational sense. On quasi-uniform meshes, one can show that these approximate normal derivatives possess a convergence rate close to one in $L^2(\partial\Omega)$ as long as the singularities due to the corners are mild enough. Using boundary concentrated meshes, we show that the order of convergence can even be doubled in terms of the mesh parameter.

As an application, we use these results for the numerical analysis of Dirichlet boundary control problems, where the control variable corresponds to the normal derivative of some adjoint variable. Finally, the predicted convergence rates are confirmed by numerical examples.
Shape optimization for a viscous Eikonal equation with applications in electrophysiology

Philip Trautmann
KFU Graz

This talk is concerned with a shape optimization problem involving a viscous Eikonal equation as the state equation. This problem is motivated by an inverse problem from cardiac electrophysiology. The viscous Eikonal equation under consideration is a semilinear elliptic equation. Its solution models the arrival time of an electromagnetic wave in the heart which is initiated at several activation sites. The heart is modeled by a domain and the activation sites are given by small domains inside the heart. The state equation is posed on the heart without the activation sites and thus has Dirichlet boundary conditions on the surface of the activation sites. Given measurements on the surface of the heart the locations of the activation sites are sought-after. This constitutes a shape optimization problem. First the wellposedness of the state and adjoint state equation is discussed. Then shape derivative of the involved cost functional is derived. Based on this derivative a perturbation field is calculated which is used to translate the activation sites. The talk is concluded with two numerical experiments in 2D and on a realistic geometry of a heart in 3D.
Optical flow regularization for dynamic inverse problems

Marta Betcke  
*University College London*

In dynamic inverse problems the data acquisition speed dictates the temporal resolution of the imaging system. More frequently than not, the underlying dynamics happens at a rate much higher than the data acquisition resulting in a severely subsampled data per time frame. To compensate for the missing information, the reconstruction problem is usually formulated in a variational framework and regularization is included. The choice of the latter is paramount to the quality of the final dynamic image reconstruction. In this talk we are going to discuss a particular choice of spatio-temporal regularization for motion dominated dynamics based on optical flow. We discuss different solvers for the resulting non-convex optimisation problem and present results for applications in X-ray and Photoacoustic imaging.

Modelling and algorithms in dynamic imaging

Bernadette Hahn  
*Universität Würzburg*

Motion compensation represents an important time-dependent problem in tomography. Most modalities record the data sequentially, including computerized tomography, magnetic resonance imaging, etc. Therefore, temporal changes of the object lead to undersampled and/or inconsistent measurements. Consequently, suitable models and algorithms have to be developed in order to provide artefact free reconstructions. In particular, they have to incorporate some prior information about the dynamic behavior. This talk presents recent advances concerning modelling and algorithms in dynamic imaging.

Spatio-temporal concentration estimation in magnetic particle imaging using a priori motion information

Tobias Kluth  
*Universität Bremen*

Magnetic particle imaging (MPI) is a new imaging modality to determine the concentration of nanoparticles from their nonlinear magnetization behavior. Highly dynamic applied magnetic fields allow a rapid data acquisition in 3D. The applied magnetic fields are characterized by a field free point (FFP) moving along a predefined trajectory which mainly defines the field of view. Due to
safety limitations the size of this field of view is limited. To overcome this issue, homogeneous offset fields (focus fields) were introduced to shift the measured region in space to increase the total field of view. This can be realized with an increased measurement time in a patch by patch strategy or continuously in time. Despite the fact that data is acquired rapidly, temporal changes of the particle concentration can already be relevant in single cycles of the FFP. As a result the dynamics are not negligible when increasing the field of view by using multiple FFP cycles. In this talk we discuss the dynamic MPI problem with time-dependent particle concentration and the incorporation of suitable motion constraints in the concentration reconstruction which is illustrated by initial numerical results.

**All-at-once versus reduced version of Landweber-Kaczmarz for parameter identification in time dependent problems**

Tram Nguyen
*Alpen-Adria-Universität Klagenfurt*

A large number of inverse problems in applications ranging from engineering via economics to systems biology can be formulated as a state space system with a finite or infinite dimensional parameter that is supposed to be identified from additional continuous or discrete observations. In this talk we will compare reduced and all-at-once versions of Landweber-Kaczmarz iteration for a reformulation of the problem as a system resulting from splitting the time line into subintervals.

**Modeling the system function in MPI**

Anne Wald
*Saarland University*

Magnetic particle imaging is a novel fast, dynamic medical imaging technique for, e.g., blood flow visualization. Magnetic nanoparticles are injected into the blood stream and the main objective is to reconstruct their concentration. The particles respond to an applied dynamic magnetic field and the response is measured in the shape of induced currents in a set of receive coils. The forward operator in MPI is given by an integral equation of the first kind. The integration kernel is called the system function, which describes the potential of magnetic particles to induce a signal in the receive coils by a change in their magnetization. The particles’ change in their magnetization depends on the applied magnetic field. A simple approach is the equilibrium model, which states that the mean magnetization only depends on the absolute value of the applied field. However, our aim is to include the dynamic behavior of the magnetization (leading in particular to relaxation effects), which can be done by using the Landau-Lifshitz-Gilbert equation in combination with an uncertainty approach in the model to reduce its complexity.
Coefficient inverse problems for Kelvin-Voigt viscoelasticity

Masahiro Yamamoto
The University of Tokio

We consider the Kelvin-Voigt viscoelasticity equation in a bounded smooth domain, which is a non-stationary Lame system with memory term. For suitable subboundary $\Gamma$, we discuss Coefficient inverse problems: Determine spatially varying coefficients by extra data of solution on $\Gamma \times (0, T)$.

We prove Lipschitz conditional stability estimates for the inverse problems provided that we can choose a finite number of suitable initial values and boundary values. The key is a Carleman estimate for the parabolic system with time-integral term.

The work is based on the joint work with Professor Oleg Yu. Imanuvilov (Colorado State University).
MS 23: VARIATIONAL INEQUALITIES AND NONSMOOTH PDE-CONSTRAINED OPTIMIZATION

Organizers: L. Betz, C. Christof

Bouligand-Landweber iteration for a non-smooth ill-posed problem

Christian Clason
University Duisburg-Essen

We consider an inverse source problem for an elliptic partial differential equation with a non-differentiable non-linearity. The corresponding solution mapping is merely directionally but not Gâteaux differentiable, which makes standard regularization methods inapplicable. We present a novel iterative regularization method of Landweber type that makes use of specific elements in the Bouligand subdifferential in place of the non-existent Fréchet derivative and show its convergence in the noise-free setting and its regularization property if the iteration is stopped according to the discrepancy principle. Numerical examples illustrate the behavior of the proposed method.

Optimal control of a non-smooth evolution equation with viscous regularization

Tobias Geiger
Julius-Maximilians-Universität Würzburg

We study the optimal control of an evolution equation with non-smooth dissipation. The solution mapping of this system is non-smooth and hence the analysis is quite challenging. Our aim is to find an optimality system and we present two approaches to get such a system. The first one is to regularize the dissipation via approximation by a smooth function. The second one is a time discretization of the state equation. In both cases we get optimality systems for an approximation of the optimal control problem. By passing to the limit we obtain optimality conditions for the original non-smooth problem. Finally, we compare the systems that were derived by the different approaches and show some numerical examples.

Solving inverse optimal control problems to global optimality

Felix Harder
BTU Cottbus-Senftenberg

We consider a class of bilevel optimization problems which can be interpreted as inverse optimal control problems. The lower-level problem is an optimal control problem and it has a convex and parametrized objective function. The upper-level problem is used to identify the parameters of the lower-level problem. We reformulate the inverse optimal control problem using the value function of the lower-level problem. The feasible set of this reformulation is relaxed by using piecewise affine approximations of the value function. This allows us to compute global optimal solutions of the
original non-smooth and non-convex inverse optimal control problem. The global convergence of our algorithm can be shown rigorously. Finally, the theory is illustrated by means of some numerical examples.

**A non-smooth trust-region method for optimal control of variational inequalities**

Christian Meyer  
*TU Dortmund*

We present a new trust-region approach for the optimization of non-smooth objectives. It is in particular designed to optimize composite functions consisting of a smooth outer objective and a non-smooth control-to-state operator as it appears in the implicit programming approach for optimal control of variational inequalities (VIs). The construction of the trust-region sub problems is based on a distinction of cases depending on the trust-region radius and employs the Bouligand-subdifferential once the trust-region radius becomes small. For the example of a particular VI of the second kind, we demonstrate how to compute the Bouligand subdifferential and to solve the associated trust-region subproblems. We show that accumulation points of the sequence of iterates are Clarke-stationary.

**Subgradient calculus for the obstacle problem**

Anne-Therese Rauls  
*TU Darmstadt*

The obstacle problem is an important prototype of an elliptic variational inequality which appears in the mathematical formulation of applications from physics, finance and other fields. The main difficulty to handle when dealing with constraints of obstacle type in optimization problems is the nondifferentiability of the solution operator.

In this talk we investigate how specific elements of the Bouligand subdifferential respective to the solution operator of the obstacle problem can be computed. Using density of Gâteaux differentiability points for Lipschitz functions, we construct an abstract sequence of differentiability points whose derivatives converge to a subgradient. In order to show this convergence, a precise analysis of the relevant set-valued mappings connected to the Gâteaux derivatives is necessary. The limit and thus the subgradient itself is determined by the solution operator of a Dirichlet problem on a quasi-open domain and it is independent of the approximating sequence.

Based on these theoretic results, we discuss strategies for obtaining inexact subgradients resulting from discretization and approximation schemes.
Optimal control of static contact in finite strain elasticity
Matthias Stoecklein
Universität Bayreuth

Nonlinear elastic problems usually appear in modeling the deformations of nonlinear materials in classical mechanics. These deformations can be described as minimizers of an respective energy functional. Solving such problems is already a highly challenging task owing to the nonlinearity and nonconvexity of elastic energy functionals. Extending this to contact problems and an optimal control approach results in a nonsmooth, nonconvex, nonlinear and constrained optimization problem. To address these kinds of problems we have to apply suitable regularization and optimization methods in function space. The talk will therefore deal with the theoretical foundations of static contact problems in nonlinear elasticity and corresponding optimal control problems. The focus here will lie on theoretical results we have achieved so far such as existence theory and convergence results for the regularized problem. Also, a short discussion about suitable algorithms to solve such problems numerically will be given.

Optimal control of thermoviscoelasticity
Ailyn Stötzer
TU Chemnitz

Elastoplastic deformations play a tremendous role in industrial forming. Many of these processes happen at non-isothermal conditions. Therefore, the optimization of such problems is of interest not only mathematically but also for applications.

In this talk we will present the analysis of the existence of a global solution of an optimal control problem governed by a thermovisco(elasto)plastic model. We will point out the difficulties arising from the nonlinear coupling of the heat equation with the mechanical part of the model. Finally, we will discuss some numerical results.

Fixed domain approaches in variational inequalities and free boundary problems
Dan Tiba
Romanian Academy

We report on recent results concerning the numerical approximation of certain variational inequalities and free boundary problems. The main point is to avoid the geometric difficulties related to the tracking of the unknown free boundary. From this point of view, one may compare free boundary problems with shape optimization problems. The proposed methods have a fixed domain character and are based on the fictitious domain approach. The applications concern elliptic and parabolic variational inequalities, as well as solid- fluid interface problems. The results are relevant both from the computational and the theoretical points of view.
Hyperbolic quasi-variational inequality of Maxwell type for high-temperature superconductors

Irwin Yousept

University of Duisburg Essen

Bean's critical-state model describes the irreversible physical phenomena of penetration and exit of magnetic flux in type-II superconductors. The model postulates a nonlinear and nonsmooth constitutive relation between the current density and the electric field through the so-called critical current. By the nature of superconductivity, confirmed by experimental measurements, the critical current depends not only on the magnetic field but also on the temperature distribution, which makes the corresponding mathematical analysis intricate. In this talk, we discuss the well-posedness of an evolutionary Maxwell system governed by the Bean critical-state law with a nonlinear temperature and magnetic field dependence in the critical current. As a final result, a well-posed hyperbolic quasi-variational inequality is presented and shown to be equivalent to the evolutionary Maxwell system.
Optimum brain cooling to reduce TBI damages using inverse heat transfer method

Ali Abbas Nejad  
*Shahrood University of Technology*

The brain is one of the most important organs in a biological body. With the interruption of cardiopulmonary circulation in many cardiac surgical procedures or accidental events leading to cerebral circulation arrest, an imbalance between energy production and consumption will occur. Meanwhile, the cooling function of the blood flow on the hot tissue will be stopped, while metabolic heat generation in the tissues still keeps running for a while. Under such adverse situations, the potential for cerebral protection through hypothermia has been intensively investigated in clinics by lowering brain temperature to restrain the cerebral oxygen demands. In this paper, the conjugate gradient method, coupled with an adjoint equation approach, is used to solve the inverse heat conduction problem using Pennes bioheat equation in the axisymmetric coordinate system and estimate the time-dependent heat flux using temperature distribution at a point brain to achieve the temperature reduction about 5 degrees within 30 minutes. Two cases containing one-layer and three-layer, are considered. To solve this problem the general coordinate method is used. The obtained results for few selected examples show the good accuracy of the presented method. Also the solutions have good stability even if the input data includes noise.

Bregman iterated variational regularization for nested primal-dual algorithms: with the application for an atmospheric tomography problem

Erdem Altuntac  
*Universite Libre de Bruxelles*

The problem of minimization of the least squares functional with Bregman distance associated with the non-smooth total variation (TV) penalizer, and an indicator function is considered to be solved iteratively by some nested primal-dual algorithm.

It is assumed that the exact solution of the linear inverse ill-posed problem satisfies a variational source condition (VSC). The regularization parameter obeying Morozov’s discrepancy principle provides tight convergence rates of the regularized solution of the minimization problem against the exact solution in terms some concave, positive definite index function. Convergence of the regularized solution of the minimization problem to the exact solution of the inverse problem, and convergence of the iteratively regularized solution to the exact solution are both analyzed separately.

Theoretical development is applied for an atmospheric tomography problem named as *GPS-Tomography*. GPS-tomography involves the reconstruction of some quantity (e.g. humidity), pointwise within a volume, from geodesic X-ray measurements transmitted by nonuniformly distributed transducers.
(satellites). These measurements are sparse and fluctuate randomly with receiver availability. The task here is the reconstruction of the 3-dimensional spatially varying index of refraction of the atmosphere, from a set of line integrals which are fan-beam projections.

**Shape gradients for three-dimensional contact problems with Tresca friction**

Bastien Chaudet  
*Université Laval*

Part of an ongoing research on shape optimization for hyperelastic contact problems, this presentation deals with three dimensional elastic bodies in contact with given friction (Tresca model). The proposed method is based on shape gradients combined with a level set representation of the shape. Due to the irregularity (non-linearity, non-differentiability) of the boundary conditions, the computation of shape gradients requires a specific treatment. Indeed, since the solution of the contact problem is non-differentiable with respect to the shape, we introduce a regularized Lagrange multiplier approach. The main advantages of this approach are its variational formulation, which takes the form of a non-linear variational equality, and the shape-differentiability of the regularized solution obtained.

After proving the convergence of the regularized solutions to the original one, we express the shape gradient of a general functional for the regularized problem, and try to establish sufficient conditions for those regularized shape gradients to converge.

Numerical experiments, based on the finite element method for the augmented Lagrangian formulation and finite differences for the advection of the level set, will be presented. The method benefits from an original mesh cutting algorithm allowing sharp representation of the boundary at each iteration of the optimization process.

**Magnetic induction tomography in 3D using a shape optimization approach**

Oliver Dorn  
*The University of Manchester*

There exists a large variety of problems in industry and technology where the goal is to noninvasively detect and identify objects or structural imperfections hidden inside conductive materials. Magnetic Induction Tomography has been discussed lately as a promising tool for addressing this task. However, due to the conductive nature of the material, very low frequencies need to be used in order to achieve sufficient penetration depths. This makes the corresponding inverse problem highly ill-posed. Often, classical regularization schemes do not seem appropriate in these applications due to their inherent oversmoothing property which makes it difficult to identify and correctly characterize the sought objects. As an alternative approach, we propose here a novel 3D shape optimization scheme for detecting and characterizing shapes of inhomogeneities buried in conductive box-like domains at various scales. A level set technique in 3D, combined with an efficient forward
solver for Maxwell's equations in frequency domain, is applied for practically performing the shape optimization driven by a reduction of a given data misfit functional. An efficient line search strategy is proposed for each individual step which avoids the need of an excessive number of additional forward solves for finding appropriate step-sizes.

**Stochastic optimization of fluid flow simulation in porous media by incorporating controlled source electromagnetics data**

Oliver Dorn  
*The University of Manchester*

The forecasting of production and injection in active reservoirs is an important component of modern production technologies adopted by oil companies. The modeling of the underlying multiphase flow in porous media requires the estimation of various distributed system parameters over the entire production cycle. As data for these estimations usually well-logs, water and hydrocarbon pressure and production data, and time-lapse seismic data are employed. Additional modalities such as controlled source electromagnetics have also been discussed recently which can help improving the estimation of those system parameters that are correlated with electromagnetic properties of the reservoir, in particular the unknown water saturation. In the talk we propose a modified ensemble Kalman filter approach for incorporating such additional electromagnetic data into the time-dependent estimation approach. It relates water saturation inside the 3D reservoir to electromagnetic measurements at the surface by solving an additional inverse problem for Maxwell’s equations. Numerical results are presented which demonstrate that the incorporation of such additional electromagnetic data significantly improves the estimation of reservoir properties and the final match of production data.

**Cut-sharing in stochastic dual dynamic programming**

Christian Füllner  
*Karlsruhe Institut of Technology*

Stochastic Dual Dynamic Programming (SDDP) is a widely used method to solve multi-stage stochastic linear programming problems, introducing sampling to the Benders decomposition method and, hence, allowing to deal with a large number of scenarios and stages. Yet, in its classical form SDDP relies on interstage independent random vectors so that Benders cuts can be shared among different scenario subproblems at the same stage. Recently, techniques have been developed to enable cut sharing also for some types of interstage dependency, mainly assuming uncertainty in the right-hand side of the problem modelled by affine linear or at least convex interstage dependent stochastic processes. We build upon this work and further generalize the cut sharing methodology to a broader class of uncertainty models. A real-life power system example is examined to illustrate the effectiveness of the proposed techniques.
An optimal control problem governed by a parabolic obstacle problem

Dominik Hafemeyer
Technische Universität München

We consider an optimal control problem with an parabolic obstacle problem as constraint. Given a time intervall $I$ and a sufficiently regular domain $\Omega \subset \mathbb{R}^N$ with $N \in \{2, 3\}$ it has the form

$$\begin{cases}
0 \leq y - \Psi \perp \partial_t y - \Delta y + f(y) - u & \geq 0 \text{ in } I \times \Omega, \\
y|_{I \times \partial \Omega} = 0, \ y(0) = y_0.
\end{cases} \quad \text{(VI)}$$

Here $\Psi$ is a sufficiently regular obstacle, $u \in L^\infty(I \times \Omega)$ and $f$ is a “nice” nonlinearity. The optimal control problem has the form

$$\min_{(y, u)} \frac{1}{2} \|y - y_Q\|^2_{L^2(I \times \Omega)} + \frac{\alpha}{2} \|u\|^2_{L^2(I \times \Omega)} \text{ such that } (y, u) \text{ satisfy (VI)}. \quad \text{(P)}$$

We regularize (VI) by a family of appropriate semilinear parabolic differential equations. We discretize those equations by a $dG(0)cG(1)$ scheme. We deduce a sharp $L^\infty$ discretization error estimate, which is independent of the regularization parameter. We can now combine this discretization error estimate for (VI) with an regularization error estimate to give a complete a priori error estimate between the solution of the variational inequality and the regularized, discretized solution. We then transfer those results to the optimal control problem (P) to obtain estimates.

Maximal discrete sparsity in parabolic optimal control with measures

Evelyn Herberg
Universität Hamburg

We consider a parabolic optimal control problem governed by space-time measure controls. Two approaches to discretize this problem will be compared. The first approach has been considered by Eduardo Casas and Karl Kunisch and employs a discontinuous Galerkin method for the state discretization where controls are discretized piecewise constant in time and by Dirac measures concentrated in the finite element nodes in space. In the second approach we use variational discretization of the control problem utilizing a Petrov-Galerkin approximation of the state which induces controls that are composed of Dirac measures in space and time, i.e. variational discrete controls that are Dirac measures concentrated in finite element nodes with respect to space, and concentrated on the grid points of the time integration scheme with respect to time. The latter approach then yields maximal sparsity in space-time on the discrete level. Numerical experiments show the differences of the two approaches.
An inexact bundle algorithm for nonconvex nondifferentiable functions in Hilbert space

Lukas Hertlein
Technische Universität München

Motivated by optimal control problems for elliptic variational inequalities we develop an inexact bundle method for nonsmooth nonconvex optimization subject to general convex constraints. The proposed method requires only approximate (i.e., inexact) evaluations of the cost function and of an element of Clarke's subdifferential. The algorithm allows for incorporating curvature information while aggregation techniques ensure that the piecewise quadratic subproblem can be solved efficiently. A global convergence theory in a suitable infinite-dimensional Hilbert space setting is presented. We discuss the application of our framework to optimal control of the obstacle problem and present preliminary numerical results.

A Lagrange multiplier method for semilinear elliptic state constrained optimal control problems

Veronika Karl
Julius-Maximilians-Universität Würtzburg

In this paper we apply an augmented Lagrange method to a class of non-convex optimal control problems with pointwise state constraints. These control problems are non-convex due to the nonlinearity of the state equation. We show strong convergence on subsequences of the primal variables to a KKT point of the original problem as well as weak convergence of the adjoint states and weak* convergence of the multipliers associated to the state constraint. Under second order conditions, we reach convergence towards local solutions. Further we are able to show that for every iteration of our algorithm there exist KKT points of the arising augmented Lagrange sub-problem in arbitrary small neighborhoods of local solutions of the original problem, provided that the penalty parameter of the applied augmented Lagrange term is sufficiently large. We present some numerical examples to illustrate our results.

External polyhedral estimates of reachable sets of discrete-time systems with integral bounds on additive terms

Elena K. Kostousova
Krasovskii Institute of Mathematics and Mechanics, Ural Branch of the Russian Academy of Sciences

The reachability problem is one of the fundamental problems of the mathematical control theory. Since exact construction of reachable sets is usually a very complicated problem, different numerical methods were devised for approximations. In particular, different techniques were developed for estimating reachable sets by domains of some fixed shape such as ellipsoids, parallelepipeds and some others. Most of the results in this direction were obtained for linear systems with hard
CONTRIBUTED TALKS

bounds on additive input terms. Here we study linear and bilinear discrete-time systems for the case when additive input terms are restricted by integral nonquadratic constraints and initial states are restricted by parallelepiped-valued constraints. We consider such a class of bilinear systems where hard interval bounds on the coefficients (in other terms, on the matrices) of the system are imposed. The main attention is paid to time-invariant systems. We construct external parallelepiped-valued (shorter, polyhedral) estimates of reachable sets of the considered systems. First, algorithms for constructing families of touching external estimates with constant orientation matrices for reachable sets of linear time-invariant systems are developed. Then techniques for constructing polyhedral estimates for the case of bilinear systems are proposed. The research is supported by RFBR, Project 18-01-00544a.

Generalized solution concepts to the Ericksen–Leslie equations modeling liquid crystal flow

Robert Lasarzik
WIAS Berlin

This talk focuses on a system of nonlinear partial differential equations, the so-called Ericksen–Leslie equations, describing the flow of liquid crystals. Whether solutions to such a system exist, is a challenging question by itself. Different partial answers are presented in the form of different solvability concepts. The plethora of different solution concepts ranges from strong over weak and measure-valued solutions to dissipative solutions. These concepts are introduced and important properties are reviewed. Additionally, the numerical approximation is discussed and ideas for an optimal control scheme for the Ericksen–Leslie system are presented.

Regularity assumptions for partial outer convexification of semilinear-constrained MIOCPs

Paul Manns
TU Braunschweig

Mixed-Integer-Optimal-Control-Problems (MIOCPs) being constrained by time-dependent differential equations can be relaxed by continuous OCPs by means of partial outer convexification. Then, so-called Sum-Up-Rounding algorithms can be used to approximate feasible points of the relaxed, convexified continuous problems with binary ones that are feasible up to some arbitrarily small constant. This approximation property of the relaxed problem has been known to hold for ODEs and a class of semilinear PDEs with its linear part being the generator of a strongly continuous semigroup under some uniform estimates on the derivative of a term arising in the variation of constants formula giving mild (and classical) solutions of the inhomogeneous abstract Cauchy problem. We are going to show that one can relax these requirements from differentiability to uniform continuity for both cases.
**Limit analysis shape optimization for von Mises criterion**

Aymeric Maury  
*Université Laval*

Considering a structure made of a perfectly plastic material it is known that the stress problem is well posed as long as an admissible stress exists for the given loads $F$. The goal of limit analysis is to compute $\lambda > 0$ such that $\lambda F$ is the threshold load between the existence and the non-existence of a stress field.

From a mathematical point of view, the problem takes the form of a saddle point with respect to displacement $u$ and stress. For the von Mises yield function it is possible to write this problem as an infimum problem with respect to $u$ taken in $BD$ since it can present surface discontinuities.

Our goal is to perform a sensitivity analysis of $\lambda$ and compute the shape gradient. The non-uniqueness of $u$ and its intrinsic lack of smoothness urge the use of a regularization. We choose the Norton-Hoff-Friaa regularisation which admits a unique solution $u_p \in W^{1,p}(\Omega)^d$. We discuss the convergence of this model as $p \to 1$. Then, reformulating the problem with respect to $u_p$ into a saddle point problem, we compute the shape derivative and present some numerical experiments.

**Exploring sparsity in image and data domains in photoacoustic tomography**

Bolin Pan  
*UCL*

In photoacoustic tomography, the acoustic propagation time across the specimen is the ultimate limit on sequential sampling frequency. Any further speed-up can only be obtained by parallel acquisition and subsampling/compressed sensing. In this talk, we consider the photoacoustic reconstruction problem from compressed/subsampled measurements utilizing the sparsity of photoacoustic data or photoacoustic image in the Curvelet frame. We discuss the relative merits of the two approaches and demonstrate the results on 3D simulated and real data.

**On finding of initial conditions of equations of flexural-torsional vibrations of a bar**

Aysel Ramazanova  
*Uni Duisburg-Essen*

The problem of finding the initial conditions in the boundary-value problem for the system of flexural-torsional vibrations of a bar with additional conditions on the straight line is brought to the optimal control problem and is studied by the methods of optimal control theory. We show that the functional (10) is differentiable. The gradient of the functional is calculated and using the gradient expression a necessary and sufficient optimality condition were proved.
Uniform boundary observability with Legendre-Galerkin formulations of the 1-D wave equation

Jose Urquiza
Université Laval

For a Legendre-Galerkin semi-discretization of the 1-D wave equation, the high frequency components of the numerical solution prevent us from obtaining the boundary observability (inequality), uniformly with regard to the discretization parameter. A classical Fourier filtering that filters out the high frequencies is sufficient to recover the uniform observability. Unfortunately, this remedy needs to compute all the frequencies of the underlying system. We will present several cheaper alternative remedies. Among them: a spectral filtering technique, a mixed formulation of the 1-D wave equation, and Nitsche’s method to append Dirichlet type boundary conditions. Numerical results will be presented in order to show the effectiveness of these remedies. This is a joint work with Ludovick Gagnon (Université de Nice Sophia-Antipolis).

Fully discrete scheme for Bean’s critical-state model with temperature effects in superconductivity

Malte Winckler
Universität Duisburg-Essen

This talk is devoted to the electromagnetic phenomenon in type-II superconductivity, which occurs in many technological applications nowadays. Focusing on the original formulation of Maxwell together with Bean’s critical-state constitutive law, we obtain a non-smooth hyperbolic Maxwell system. After deriving a suitable formulation, we address the numerical analysis of hyperbolic mixed variational inequalities of the second kind for the governing evolutionary Maxwell’s equations. At first, we propose a fully discrete scheme based on the implicit Euler in time and a mixed FEM in space consisting of Nédélec’s edge elements for the electric field and piecewise constant elements for the magnetic induction. As a main result, we prove strong convergence for the fully discrete scheme under physically reasonable regularity assumptions on the initial data. In particular, this result yields a solution to the variational inequality satisfying the physical Gauss law. After presenting a priori error estimates, we close our talk by demonstrating some numerical results, which confirm not only our theoretical findings but also the physical effects in type-II superconductivity.
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WE GRATEFULLY ACKNOWLEDGE SUPPORT FROM

International Federation for Information Processing

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